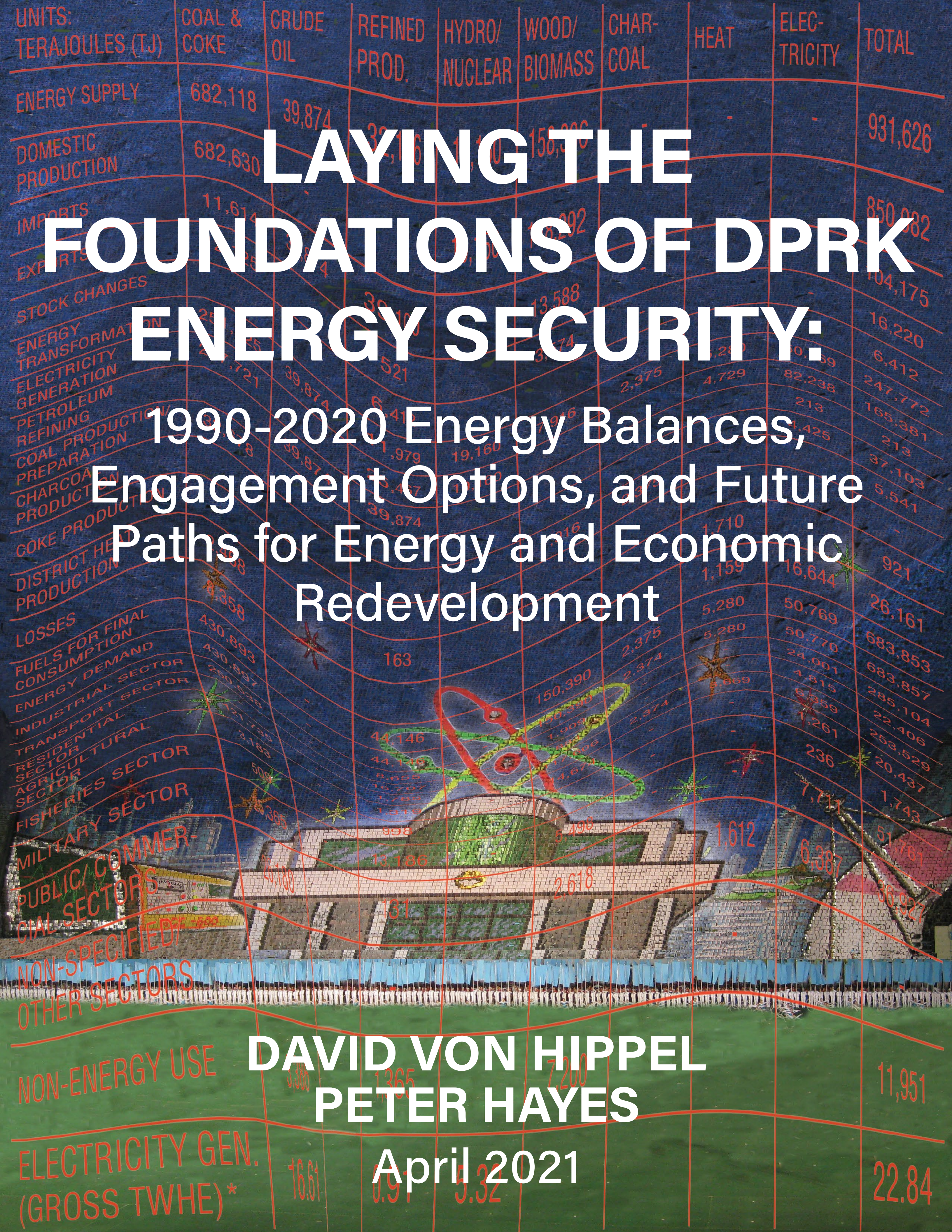

LAYING THE FOUNDATIONS OF DPRK ENERGY SECURITY:

1990-2020 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment

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The Nautilus Institute

for Security and Sustainability

LAYING THE FOUNDATIONS OF DPRK ENERGY SECURITY:

1990-2020 ENERGY BALANCES, ENGAGEMENT OPTIONS, AND FUTURE PATHS FOR ENERGY AND ECONOMIC REDEVELOPMENT

REPORT PREPARED BY THE NAUTILUS INSTITUTE FOR SECURITY AND SUSTAINABILITY

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Executive Summary

The purpose of this report is to provide policymakers and other interested parties with an overview of the evolution of demand for and supply of energy in the Democratic Peoples' Republic of Korea (DPRK) over the last three decades. This report provides estimates of demand and supply for 14 individual years during that span, namely:

- **1990**, just before much of the DPRK's economic and technical support from the Soviet Union was withdrawn;
- **1996**, possibly when the DPRK hit its lowest economic point in the 1990s;
- **2000**, a year that has been perceived by some observers as a period of modest economic "recovery" in the DPRK, and just before (October 2002) the nuclear confrontation re-erupted between the DPRK, the United States, and it neighbors in Northeast Asia over the DPRK's nuclear weapons development program;
- **2005**, when observers noted an upward trend in some aspects of the DPRK economy, as well as the most recent year for which any published estimates on the DPRK's energy sector and economy are available;
- **2008 through 2010**, starting with the last year in which the DPRK received heavy fuel oil from its negotiating partners in the Six-Party talks; and
- **2014-2019**, recent historical years during which the DPRK economy began to grow with expanded coal exports to China, imports of consumer goods, and adoption of some additional aspects of a market economy, followed by several years during which the DPRK has been under United Nations Security Council sanctions affecting its energy trading (oil imports and coal exports) in particular, and marked by on-again, off-again interludes of engagement and conflict with the international community.
- **2020,** the year of the coronavirus-19 pandemic, which has affected the economy and energy sector of every country on the map, including the DPRK.

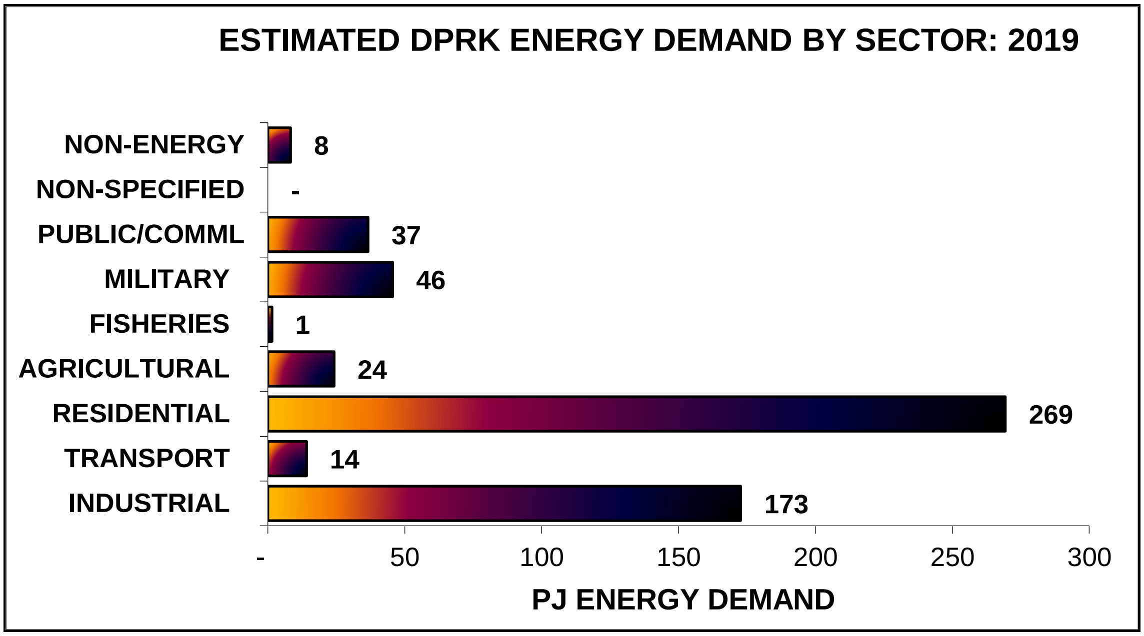
Building on previous energy balances prepared for 1990, 1996, 2000, and 2005, 2008 through 2010, and 2014, the authors assembled information from as many data sources as possible to update our earlier work and to provide estimates of recent-year energy supply and demand in the DPRK. Somewhat revised results of the 1990, and 1996 energy balances, which provide the underpinnings of our updated DPRK energy sector analysis, as well as a detailed description of input parameters and assumptions used in the analytical process, are presented in Chapter 2 of the Report that follows.

The estimates of year 2000 and on energy demand and supply presented here are typically somewhat lower than some estimates assembled by others, including international statistical resources and ROK estimates. The estimates described in Chapter 3 of this report include overall year 2000 through 2020 gross electricity generation varying somewhat by year within the range of 13 to 18 terawatt-hours (TWh, or billion kilowatt-hours) annually, reflecting somewhat improved electricity sector performance in some recent years. Overall coal production between 2000 and 2020 peaked in 2016 at about over 1 million terajoules (TJ), or about 35 million tonnes of coal equivalent, of which more than half was exported, almost all to China. Crude oil imports in 2020 were an estimated 750,000 tonnes, somewhat higher than in previous years, and net refined products imports were 6.6 million GJ, or about 150,000 tonnes, a considerable decline from previous years caused, we estimate, but the combination of United Nations Security Council sanctions and the impacts of COVID-19. The electricity and coal output, and oil imports, estimates for even 2019 are on the order of one third of the levels of output and imports of these fuels as of 1990, and outputs in 2020 were lower due to COVID-19 restrictions on cross-border travel and activity within the DPRK imposed by the DPRK government to try to halt (or limit) the spread of the pandemic. The use of wood and biomass has to some extent, particularly in households in rural areas, made up for the lack of commercial fuels, and in-country observers and forestry experts alike note the negative impact of increased wood harvesting for energy on the DPRK's forest resources and, in some areas, on soil fertility.

One major refinery continues to run in the DPRK as of 2020, and likely operated at a higher rate than in 2000 or through most of the 2010s, but at a lower level even than in 1996. A minor refinery also apparently operated periodically in 2000, and we assume that has continued to do so through 2020, though we have no direct recent evidence regarding this facility. Much of the electricity generation infrastructure in the DPRK continues to be in poor condition, though some rehabilitation of power plants has apparently taken place, thus our estimate is that thermal and hydroelectric power plant operable capacity (and output) are slightly higher than in 2000. Hydroelectric plants continue to be in somewhat better condition than thermal power plants, but remain at the mercy of water availability, and thus operate with relatively low capacity factors. Coal mines continue to be plagued with equipment and transport problems and, most importantly, by lack of electricity to operate mining machinery, lights, air supply, water pumps, and other crucial infrastructure, though selected coal mines have been upgraded in the 2010s to produce coal for export to China. The coal seams currently mined in many locations are becoming lower-yielding, or yield coal of lower quality, as the better deposits are mined and new seams are not opened up. In addition, many coal galleries are reportedly flooded—and may in some cases take years to pump out.

Industrial output is estimated to have declined, even by 2019 (with further declines in 2020), to 9 to 60 percent of 1990 levels, varying substantially by subsector—with export-oriented subsectors such as mining and metals showing the greatest activity relative to 1990 levels. As a consequence of this decline, the share of overall energy demand contributed by the industrial sector is now second to that of the residential sector, as shown in figure ES-1, though residential demand continues to include a substantial amount of wood and other biomass estimated to be used as "substitute" fuels in the absence of sufficient or consistent supplies of coal and electricity.

Figure ES-1:



In Chapters 4 and 7 of this report, we review what is known about the DPRK's natural resource base, with Chapter 4 focusing on fossil fuels and renewable resources including forests, and Chapter 7 providing more detail on other minerals, including existing mining infrastucture and institutions in the DPRK, along with a summary of some of the key challenges facing the minerals sector. The resources described in these Chapters, plus the productive capacity of the North Korean people, provides the base on which future economic and energy development in the DPRK will be built, and must be considered in any plan for DPRK energy sector assistance. Chapter 4 also provides updated results of our illustrative analysis of the "energy efficiency" resource in the DPRK, in which we estimate the potential cost and resource savings from the application of several key energy efficiency options for the DPRK energy demand and supply sectors. Chapters 5 and 6 of this report present, respectively, additional detail on the electricity and refined products supply sectors, including a review of resources available for use in generating power, and existing infrastructure, and oil refining infrastructure and oil product supply and demand.

Chapter 8 presents sketches and analysis of several future pathways for the DPRK economy and energy sector, including a "Redevelopment" pathway, and describes some of the preconditions for and impacts on the energy sector of different paths—including the relative costs and benefits of different DPRK energy futures, as well as their relative impacts on the DPRK's energy security. Also described in Chapter 8 is a list of institutional changes—ranging from training to establishment of energy pricing practices to strengthening of regulatory agencies to setting out clear and consistent rules for commerce with foreign companies—that the DPRK should adopt and be assisted with in order to work toward rebuilding its energy sector.

Following on from the quantitative exploration of different DPRK energy futures in Chapter 8, in Chapter 9 we address the implications of a possible collapse of the DPRK's government Although we continue to emphasize that in our view, even as the DPRK transitions to a new young leader, such a collapse is **not** likely, considering the possible implications of such a collapse provides insights into which policies by the international community are likely to be helpful in any kind of DPRK transition, whether abrupt or gradual and managed.

Chapter 10 provides suggestions on a number of areas for international cooperation, including providing technical and institutional assistance in implementing energy efficiency measures, promoting better understanding of the North Korean situation in the ROK, working to open opportunities for independent power companies to work in the DPRK, and cooperation on technology transfer for energy efficiency and renewable energy. Key and attractive energy sector technologies and processes for energy sector redevelopment in the DPRK are identified, including rebuilding of the electricity transmission and distribution system, rehabilitation of power plants and other coal-using infrastructure, rehabilitation of coal supply and coal transport systems, development of alternative sources of small-scale energy and implementation of energy-efficiency measures, rehabilitation of rural infrastructure, advanced investigation of regional electricity grid interconnections, and gas supply and demand infrastructure development. Referring to another recent report by the authors, Chapter 10 also includes a brief description of a potential cooperative threat reduction "plus" approach led by a non-governmental consortium of international actors and focused on building energy efficiency, renewable energy, and microgrid measures, all of which DPRK representatives have consistently shown a keen interest in. Also discussed, in response to the DPRK's announcement of its construction and operation of a uranium enrichment facility and ongoing construction of a small experimental light water nuclear reactor, are possibilities for international cooperation with the DPRK on peaceful activities in the nuclear energy arena.

This document is intended to provide a best estimate, given available data, of an internally consistent energy supply/demand balance for the DPRK for the most recent year that our analysis covers, 2020, as well as balances for previous years prepared with similar methodologies. In so doing, we have tried to assemble what is known, and assess what is not known, about the DPRK energy sector. As with previous reports, this analysis is intended to be revised as more and better data are available, and the authors welcome reader comments and input on the material presented here. For example, much of the analysis for energy supply and demand in the DPRK for the year 2020 presented here was prepared before 2020 was over, and given recent news reports (still almost all anecdotal) of energy shortages in the DPRK during 2020, we would say that our estimates of energy use, and particularly electricity use, might in fact be a bit higher than actual values in 2020, to the extent that they could or can be known.

As this report is being finalized, a new administration in Washington D.C is just entering its second month in office. How the administration of President Biden will approach the possibility of discussions with Chairman Kim Jong Un's regime on the DPRK's nuclear weapons program and other issues is not yet fully evident, although President Biden seems likely to take a much more collaborative approach, at least with regard to coordination with the Republic of Korea and Japan than did his predecessor. Ultimately, however, the DPRK, the United States, and the DPRK's neighbors, and other parties will need to return to the bargaining table, and at that point, as in past negotiations, provision of energy security will continue to be a critical element of a successful and robust resolution to the nuclear confrontation between the DPRK and the international community.

Foreword

As this Report is released, prospects for engagement of the international community with the DPRK on its nuclear weapons program and a variety of related issues seem indeterminate. This state of affairs has not been unusual over the past 30 years, with opportunities for diplomacy waxing and waning as leadership of the countries involved changed, as the DPRK's rhetoric toward the ROK and the US, in particular, has oscillated from strident to conciliatory and back (often with matching rhetoric on the other side), as conditions inside the DPRK have changed, and as politicians in all of the countries involved have adjusted their approaches to engagement to, in part, address domestic political needs. Still, a new administration in Washington, an ROK administration with a generally favorable attitude to engagement, and signals from the DPRK that, while decidedly mixed, appear to offer hope for at least sitting down for discussions, suggest that there may be an opportunity for progress in addressing concerns related to the DPRK. Given the deep reservoir of distrust that has built up between the DPRK and those who would seek to engage it in discussions, any such engagement must be considered a long-term effort, one in which any given day, month, or even year may see steps back, but in which steady progress must be the goal.

Since the early 1990s, we have contended that one of the core (though not only) reasons that the DPRK has pursued development of nuclear weapons and related delivery systems has been energy insecurity—namely the lack of adequate fuel supplies and energy conversion systems—particularly electricity generation systems—to support a reasonable rate of economic development. Starting with the publication, in 1995, of our first report related to analysis of the DPRK energy sector, and its prospects for evolution in the future, we have worked to provide those who study the DPRK, and particularly those whose jobs are to figure out ways to engage the DPRK, with analysis of what is known, what can be inferred or estimated, and what isn't known about the DPRK energy sector, because we see an understanding of the DPRK's energy systems and energy needs as crucial for the international community to be able to develop meaningful energy sector engagement with the DPRK. And, as shown in many of the agreements forged (if later abandoned) with the DPRK over the years, energy sector measures are crucial to providing the DPRK with incentives to engage.

The cover of this report is a composite of two different images. The grid of red text and lines represents an estimated "energy balance"—a common tabular representation of the supply and demand of the different forms of energy used in an economy—for the DPRK, in this case, for the year 1996. Energy balances like this one summarize where an economy has been, with regard to energy supply and demand, where it is currently, and where it might be going (balances for future years). The underlying image, showing a nuclear power plant and other infrastructure of the modern age, shows the DPRK's vision of where it saw its energy sector and broader economy going, at least as of 2009. This image (provided below) was presented by a cast of many thousands of North Koreans in a large stadium in Pyongyang at the fall "Arirang" festival in late September, witnessed in person by one of us (von Hippel). It represents a message relaying the country's leadership's aspirations to the international audience in attendance and, just as crucially, to the DPRK people. As such, it represents a marker for what the DPRK may most value out of any engagement with the international community, and should be taken into account by those in the US, ROK, and elsewhere who are working to prepare diplomatic initiatives to engage the DPRK. *–David von Hippel and Peter Hayes*

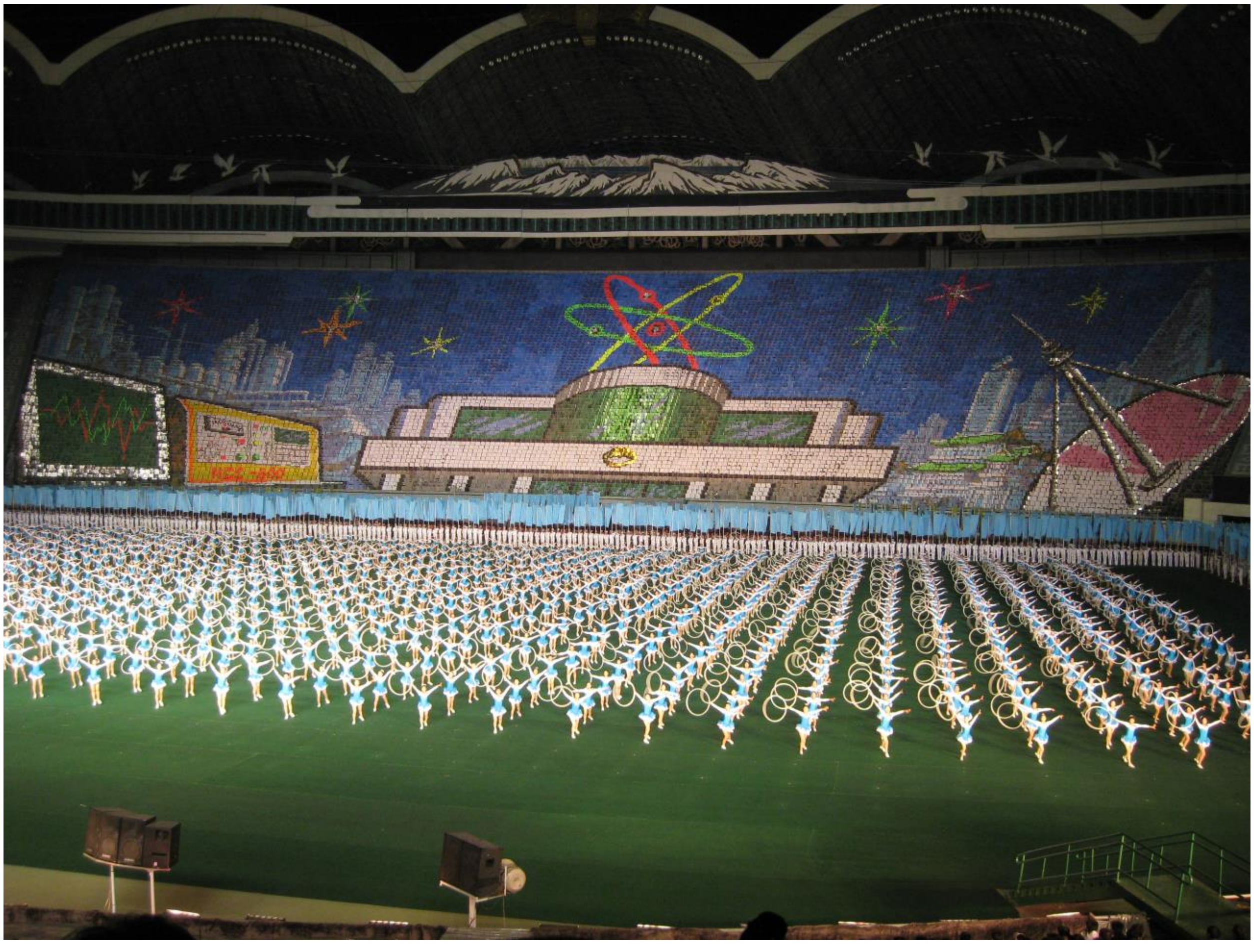


Photo of performance at “Arirang” festival in Pyongyang, September 2009. The background image of a nuclear reactor and other technologies is composed of cards held up by thousands of DPRK performers seated in the steeply-pitched area on the other side of the stadium from where the photo was taken. Photo by D. von Hippel.

Acknowledgments

The authors acknowledge the financial support of the MacArthur Foundation for the preparation of this report as a part of Nautilus Institute's 2018-2020 Regional Energy Security (RES) project, as well as the support of the United States Department of Energy, the Korea Energy Economics Institute (KEEI), the Korea Foundation, the Ploughshares Foundation, the MacArthur Foundation, the Iara Lee and George Gund III Foundation, and the New Land Foundation, which have funded earlier, recent, and in some cases current Nautilus research efforts related to the DPRK, and the Korean Institute for Energy Research and the Korea Development Cooperation Institute, which previously funded work related to this study. We would also gratefully acknowledge the many colleagues who have provided their time and invaluable insights to assist us and guide us in the preparation of this analysis, including the participants in the 2006 and 2008 DPRK Energy Experts Working Group (EEWG) Meeting and the 2010 Energy and Minerals Experts Working Group Meeting. Some of those colleagues' names and work are cited in the pages that follow, but there are many who are not cited but who have made key contributions nonetheless. We are indebted to the Preventive Defense Project for their support of the 2006 DPRK EEWG Meeting, which was held at Stanford University: see https://nautilus.org/projects/by-name/dprk-energy/2006-meeting, and to KEEI for co-sponsoring the 2010 Meeting; see http://www.nautilus.org/projects/dprk-energy/dprk-energy-and-minerals-working-group-2010/dprk-energy-and-minerals-working-group-meeting.

We would also like to acknowledge the input of Nautilus colleagues past and present in the research that underlies this report. Ms. Lea Prince, Dr. Jungmin Kang, and Ms. Eun Kyung Park helped to assemble data used in earlier versions of this report, and Mr. Tim Savage provided materials for and was involved in the preparation of earlier versions of this Report. Ms. Joan Diamond was instrumental in organizing and facilitating workshops that hosted DPRK delegations and informed our DPRK analysis work. Mr. Steve Freedkin provided relevant news articles and ably administered the Nautilus Regional Energy Security project as a whole. Thanks also to Mr. Roger Cavazos, for a review of an earlier version of this Report, to Mr. Liam Tasa, who assisted with research on oil storage in the DPRK and helped to assemble the workpapers volumes attached to this report, and Ms. Sophia Mauro, who prepared the cover art for this volume. We also thank the many DPRK experts and counterparts in our regional energy, regional grid, and in-DPRK training projects, including our colleagues from the DPRK, for their assistance and guidance on country-specific energy matters that are analyzed in this report. Finally, our special thanks go to our Korean colleagues at KEEI and in many other institutions in the Republic of Korea for their continuing support and friendship through more than 25 years of collaboration.

As always, any errors of fact or analysis in this report are by the authors, not those with whom we have been fortunate to work with over the previous twenty-plus years of energy and environmental engagement and cooperation with the DPRK.

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ACRONYMS AND ABBREVIATIONS

APLN	Asia Pacific Leadership Network
BOE	Barrell of Oil Equivalent
CDM	Clean Development Mechanisms
CFL	Compact Fluorescent Lighting
CH_4	Methane
CO_2	Carbon Dioxide
CO	Carbon Monoxide
DMZ	Demilitarized Zone between the ROK and DPRK
DPRK	Democratic People's Republic of Korea
EU	European Union
EUR	Euro
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GJ	Gigajoule (10^9 Joules)
GW	Gigawatt (one billion Watts)
GW	Gigawatt (one billion Watts) of electric power
GWh	Gigawatt-hour
ha	Hectares (land area)
HH	Household
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
KEDO	Korean Peninsula Economic Development Organization
KEEI	Korea Energy Economics Institute
KFRI	Korea Forest Research Institute
kg	Kilogram
kJ	Kilojoules (thousand Joules)
kV	kilovolts (1000 Volts)
kW	kilowatt (one thousand Watts)
kWh	Kilowatt-hour
kWp	Peak kilowatts (power output)

LED	Light-emitting Diode
LWR	Light Water Reactor
Mha	Million Hectares (land area)
MJ	Megajoule (million Joules)
NPT	Nuclear Weapons Non-Proliferation Treaty
MVA	Megavolt-Amp (million volt-amps)
MW	Megawatt (one million Watts)
MWh	Megawatt-hour
N_2O	Nitrous Oxide
NOx	Oxides of Nitrogen
Pass-km	Passenger-kilometer (a unit of transportation service)
PCBs	Polychlorinated Biphenyls
PJ	Petajoule (10^{15} Joules)
PPP	Purchasing Power Parity
PRC	People's Republic of China
PWR	Pressurized Water Reactor
RFE	Russian Far East
ROK	Republic of Korea
SOx	Oxides of Sulfur
T&D	Transmission and Distribution
TCE	Tonnes of Coal Equivalent
TJ	Terajoule (10^{12} Joules)
TOE	Tonne of Oil Equivalent
Tonne-km	Tonne-kilometer (a unit of transportation service)
TWh	Terawatt-hour
UNDP	United Nations Development Programme
UNSC	United Nations Security Council
US	United States
USD	United States Dollar
USSR	Union of Soviet Socialist Republics
WFP	United Nations World Food Programme
UN FAO	United Nations Food and Agriculture Organization

1. Introduction and Background: The DPRK Energy Sector

1.1. Purpose and Goal of Report

During the decade of the 1990s and continuing through the second decade and now into the third decade of the 21st century, a number of issues have focused international attention on the Democratic People's Republic of Korea (the DPRK). Most of these issues—including nuclear weapons proliferation, military transgressions, provocations, and posturing, economic collapse, transboundary air pollution, food shortages, floods, droughts, tidal waves, the death of North Korean leader Kim Jong Il and the passing of the DPRK leadership mantle to the third generation of the Kim dynasty in Chairman Kim Jong Un, increasingly stringent United Nations Security Council (UNSC) sanctions on the DPRK economy, and the summits over the last two years involving Chairman Kim, Republic of Korea President Moon Jae-in, and former United States President Donald Trump—have their roots in a complex mixture of Korean and Northeast Asian history, global economic power shifts, environmental events, and internal structural dilemmas in the DPRK economy. Energy demand and supply in general—and, arguably, demand for and supply of electricity in particular—have played a key role in many of these high-profile issues involving the DPRK and have played and will play (and are playing, as of February 2021) a central role in the resolution of the ongoing confrontation between the DPRK and much of the international community over the DPRK nuclear weapons program. It was unclear as when this Report was finalized whether international engagement on addressing DPRK nuclear weapons and related issues, a process that has seen many periods of optimism, and even more of pessimism, over the past decades, will be successfully initiated in the coming year. It may well take some time for the new United States Administration of President Joe Biden to form a DPRK policy team and to develop and pursue a DPRK engagement strategy.

If a multilateral engagement strategy comes to fruition, it will likely involve many or all of the same actors (and perhaps others) that participated in the Six-Party Talks process of the 2000s. What is clear, however, is that DPRK energy sector issues will continue to be a key to the resolution of the nuclear weapons issues that are the major (if by no means the only) disputes preventing the DPRK from working with its neighbors and others in the international community to redevelop its economy. At such times as the DPRK and the international community sit down to address DPRK nuclear weapons and related issues (such as missile development), it is certain that options for energy and economic assistance to the DPRK will be discussed, as they have been during negotiations dating back at least to the 1994 Agreed Framework. Understanding the DPRK energy sector, to the extent that it is possible for an outsider to do so, is and will be crucial to developing useful, effective, and appropriate energy and economic inducements to bring the DPRK to the negotiating table and keep them engaged through what will inevitably be a long process of stepwise improvements in relations.

The purpose of this Report is to provide policymakers and other interested parties with an overview of the demand for and supply of the various forms of energy used in the DPRK in a number of years during the last three decades:

- **1990**, the year before much of the DPRK's economic and technical support from the Soviet Union was withdrawn;

- **1996**, thought by some to be one of the most meager years of the difficult economic 1990s in the DPRK; and
- **2000**, a year that has been perceived by some observers as a period of modest economic "recovery" in the DPRK, as well as a marker of the period before the start, in late 2002, of a period of renewed political conflict between the DPRK, the United States, and it neighbors in Northeast Asia over the DPRK's nuclear weapons development program; and
- **2005**, also a year in which observers have again noted an upward trend in some aspects of the DPRK economy, as well as the most recent year for which any published estimates on the DPRK's energy sector and economy are available.
- **2008**, the last year in which the DPRK received heavy fuel oil from its negotiating partners in the Six-Party talks;
- **2009 and 2010**, years marked by a notable lack of engagement between the DPRK and the international community, but also by events such as a second nuclear weapons test by the DPRK and the unveiling of an operating uranium enrichment facility.[1]
- **2014 through 2020**, the most recent years for which we have analyzed the DPRK's energy sector, and years spanning a period of economic growth and expanded imports and exports for the DPRK, followed by the application of a series of United Nations Security Council (UNSC) sanctions on the DPRK's energy and other imports and exports, on-and-off discussions with the ROK and the US, additional DPRK tests of nuclear weapons and missiles, and other events, capped in 2020 by the global, regional, and national DPRK response to the COVID-19 (coronavirus disease 2019) pandemic.

Requirements for fuels to provide people with energy services—and the ways in which fuels, including electricity, coal, oil, and biomass, are supplied—are tightly linked to social, political, and economic conditions, and to the demand for industrial commodities. To analyze the status of and prospects for changes in electricity demand and supply in the DPRK, we have developed internally-consistent estimated energy balances for 1990, 1996, 2000, 2005, 2008 through 2010, and 2014 through 2020 for the whole of the DPRK economy on a sector-by-sector basis. This method allows a review of the energy situation in a broader context, and illuminates some of the key issues, options, and uncertainties that must be included in the consideration of energy—including electricity, coal, oil, and biomass fuels—supply and demand, present and future, in the DPRK. We conclude with a discussion of what can be done to improve the energy situation in the DPRK, and of the role of international cooperation in assisting the DPRK with addressing energy-sector issues—issues that very often have ramifications beyond its national borders.

This analysis described in this report updates Nautilus studies of the energy situation in the DPRK that have been ongoing since 1994.[2] As a consequence, the estimates presented here are

[1] See, for example, CNN (2020), "North Korea Nuclear Timeline Fast Facts", CNN Editorial Research, updated June 21, 2020, and available as https://www.cnn.com/2013/10/29/world/asia/north-korea-nuclear-timeline---fast-facts/index.html.

[2] Nautilus experience drawn upon in preparing this study includes analyses of Korean security issues from 1980 on, and more recently: Several consulting missions to the DPRK, on energy sector and environmental issues, undertaken in the early 1990s, for the United Nations Development Programme (UNDP); an analysis of the DPRK's energy situation as of 1990, and an assessment of the degree to which energy efficiency measures could result in improved performance of the DPRK energy sector (Von Hippel, D. F., and P. Hayes, *The Prospects For Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*. Nautilus Institute Report, December, 1995); a review of the demand for and supply of heavy fuel oil in the DPRK as of 1996, with demand pathways for the year 2000, prepared for the Korean Peninsula Energy

in many cases based on earlier work, revised to take into account new information and new insights from colleagues with knowledge of and experience in DPRK energy sector issues. Some of the new information and insights used in previous updates were gleaned from the papers and discussions presented at the "DPRK Energy Experts Working Group Meeting", held June 26th and 27th in Palo Alto, California, USA, a second meeting of the same name held in Beijing, China, in March of 2008, and a "DPRK Energy and Minerals Experts Working Group Meeting" held also in Beijing, in September of 2010. See http://www.nautilus.org/projects/dprk-energy for information on and papers and presentations from these Meetings.

The discussions and text provided here are in many cases modified versions of discussions in earlier reports, but, particularly for this report, estimates of energy sector activity in earlier years (1990, 1996, 2000, 2005, and 2008 through 2010) have been revised as information from colleagues and the literature have changed our understanding of both the present and the history of the DPRK energy sector. The goal of this work is to provide, to the extent that time allows, quantitative estimates of annual "snapshots" of the evolution of the DPRK energy situation over the past three decades. This update endeavors to take into account as much recent and current information as possible, despite the considerable difficulties inherent in obtaining reliable information about the DPRK.

1.2. Summary and History of the Current Economic Situation in the DPRK

The DPRK energy system exists to serve the DPRK economy. As such, we present a very brief review of the recent and not-so-recent history of the economy in the DPRK, and of the forces that have helped to shape and change the economy.

Development Organization (KEDO); research focusing on the DPRK electricity system, updating our estimate of the status of the DPRK energy sector to 1996, and elaborating and evaluating energy pathways for the DPRK to 2005 (D.F. Von Hippel, and P. Hayes, *Demand and Supply of Electricity and Other Fuels in the Democratic People's Republic of Korea (DPRK)*, Nautilus Institute (prepared for Northeast Asia Economic Forum), 1997); a discussion of the rural energy crisis in the DPRK, and of measures that might be taken to rebuild rural energy and agricultural infrastructure in the country (J. Williams, D.F. Von Hippel, and P. Hayes, *Fuel and Famine, Rural Energy Policy Options in the DPRK*, Nautilus Institute, March 2000); and a long-term project, which to date has included three missions by U.S. engineers to the DPRK, to provide wind-powered electricity generation, electricity storage, efficient electric end-use equipment, and water pumping windmills to a flood-affected village in a rural area of the DPRK. In the latter project, Nautilus engineers worked (and played) side-by-side with North Korean counterparts to construct facilities in the village. The project has also included what is to our knowledge the first systematic survey of rural energy use ever carried out in the DPRK. (J. Williams et al, "The Wind Farm in the Cabbage Patch", *Bulletin of the Atomic Scientists*, May/June 1999). The two most recent versions of Nautilus' DPRK energy sector analyses, and the starting points for the preparation of this document (and the analysis that underlies it), were D. Von Hippel, P. Hayes, and T. Savage, March, 2003, *The DPRK Energy Sector: Estimated Year 2000 Energy Balance and Suggested Approaches to Sectoral Redevelopment*, available as http://nautilus.org/wp-content/uploads/2011/12/DPRK_Energy_20001.pdf. D. von Hippel and P. Hayes, June 2007 *Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths*, available as http://nautilus.org/wp-content/uploads/2011/12/07042DPRKEnergyBalance.pdf, , and the most recent (prior to the current volume) published full version of Nautilus' DPRK energy sector analysis, David von Hippel and Peter Hayes (2012) *Foundations of Energy Security for the DPRK: 1990-2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment*", NAPSNet Special Reports, dated December 18, 2012, available at https://nautilus.org/napsnet/napsnet-special-reports/foundations-of-energy-security-for-the-dprk-1990-2009-energy-balances-engagement-options-and-future-paths-for-energy-and-economic-redevelopment, from which PDF versions of both the Main Report and its Attachments volume can be downloaded. A partial update to the latter report is available as David F. von Hippel and Peter Hayes (2014), *An Updated Summary of Energy Supply and Demand in the Democratic People's Republic Of Korea (DPRK)*, NAPSNet Special Reports, April 15, 2014, https://nautilus.org/napsnet/napsnet-special-reports/an-updated-summary-of-energy-supply-and-demand-in-the-democratic-peoples-republic-of-korea-dprk/. A large number of more recent (2000 through 2020) Nautilus DPRK-related publications are referenced later in this Report.

1.2.1. Brief history of the evolution of the DPRK economy following WWII, and status as of 1990

Although the affirmation of a unified and independent Korean state was agreed upon by the major powers in discussions during 1943 to 1945, the Yalta Conference at the end of World War II resulted in the partitioning of Korea.[3] The boundary created thereby was altered slightly by the 1953 armistice that suspended hostilities in the Korean War. Since then, the Korean Peninsula has been politically and economically divided. "North Korea" (the DPRK), backed politically by the Soviet Union and the People's Republic of China, was formed in the area south of Russia and China (bordered by the Amnok and Tumen rivers) and roughly north of the 38th parallel, while the portion of the peninsula south of the 38th parallel became the Republic of Korea (ROK), backed politically and militarily by a host of Western nations, prominently including the United States. The two Korean states went on to rebuild their shattered economic infrastructure and pursue development in very different ways, aided by their different economic and political partners. The DPRK's economic rise from the ashes of war was impressive, particularly given its political isolation from the Western world. In the three decades since 1990, however, the effective end of the Cold War and the substantial withdrawal of economic aid from the former Soviet Bloc, together with other world and regional events, have set the DPRK's economy in what most observers agree is either a downward spiral or (at best) stagnation, with years of modest improvement interspersed with years in which economic conditions worsened.

The DPRK is a nation of, depending on the source of the information, somewhat under 20 million to over 24 million people (as of 2010—and probably close to 25 million in 2020), with approximately 60 percent[4] of the population living in urban areas. The population growth rate for the nation had been estimated near 1.8 percent per year as of 1990, but the DPRK population in fact probably decreased, overall, in the decade of the 1990s, with perhaps some modest growth in population since.[5] DPRK population centers, as well as the bulk of industry and agriculture, are concentrated in the coastal plains on both the east and particularly west coasts of the peninsula. The interior of the peninsula is generally rugged and mountainous. Political/infrastructure and topographic maps of the DPRK are provided as Figure 1-1 and Figure 1-2.

[3] Embassy of the Republic of Korea (1997), "Historical Background of the Division of the Korean Peninsula". Part of "The Unification Policy of Korea", presented at the time as part of the ROK Embassy (Washington, DC) World-wide Web site, http://korea.emb.washington.dc.us/korea/Division.html, although no longer available, at least in the same format.

[4] Anecdotal reports in the years around 2000 suggested movement of population from some urban areas to the countryside, in part to help provide labor to bring in crops, and in part for improved access to food. Official statistics, however (see next footnote) do not reflect a significant urban-rural movement.

[5] Census data from the DPRK are notoriously unreliable, when available. An official DPRK census for the year 2008 (*DPR Korea National Population Census*, 2008, Central Bureau of Statistics, Pyongyang, 2009, available as https://dataspace.princeton.edu/bitstream/88435/dsp01hx11xh65b/1/DSDPRKoreacensus2008.pdf) was completed under United Nations auspices in 2009, and was the first such official data made available in many years. Though comprehensive and generally accepted by researchers working on DPRK issues (in part due to a lack of better alternatives), its estimate of a total DPRK population of over 24 million in 2008 seemed overstated to many, including the authors, though we have provisionally used this value and other data from the 2008 census in preparing the energy balances described in this report.

Figure 1-1: Political Map of the DPRK[6]

Map No. 4163 UNITED NATIONS
March 2001

Department of Public Information
Cartographic Section

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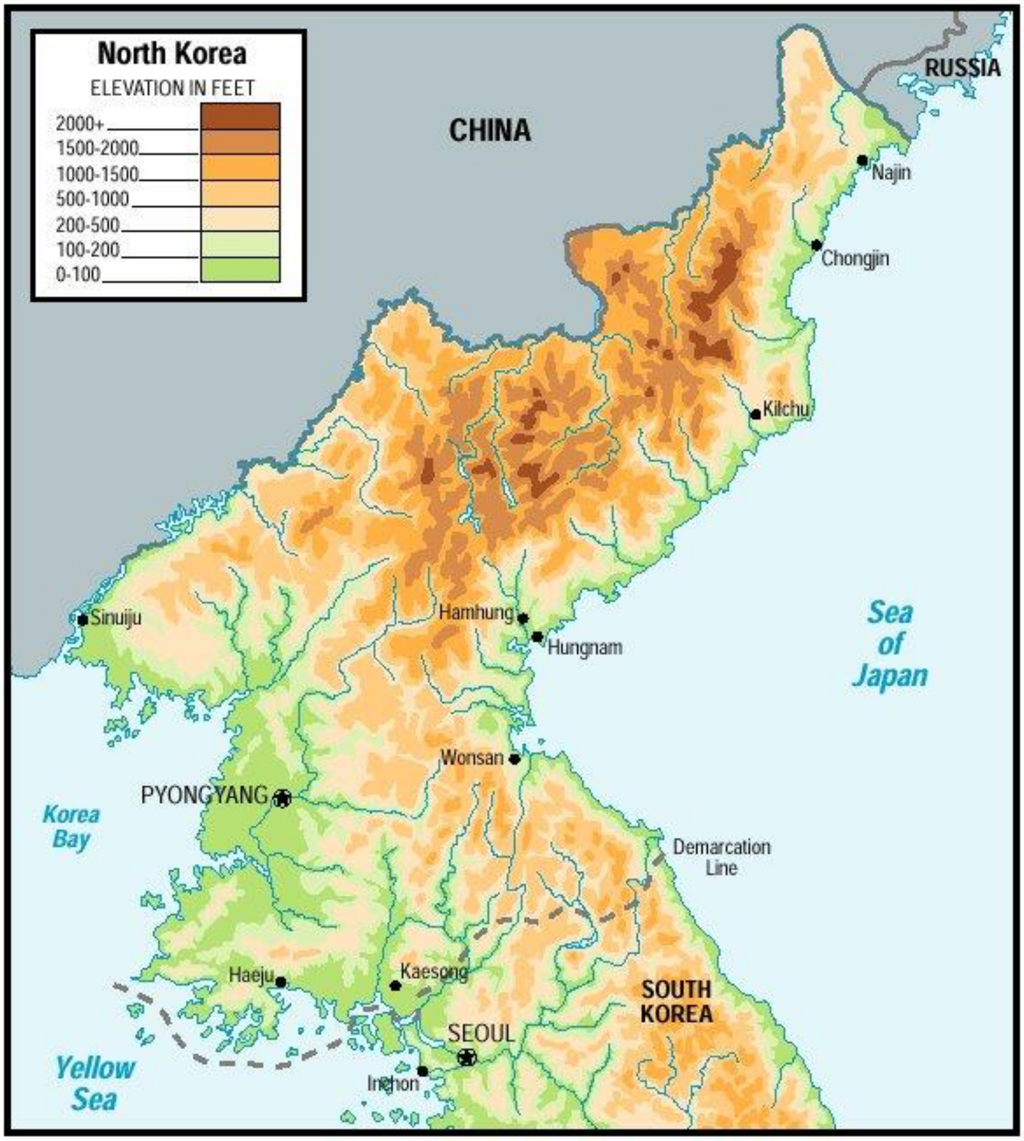
[6] Map published by the United Nations Department of Public Information, dated 2001, and available as https://reliefweb.int/map/democratic-peoples-republic-korea/reference-map-democratic-peoples-republic-korea.

Figure 1-2: Topographic Map of the DPRK[7]



The government of North Korea is a one-party, socialist system. North Korean politics has, since the formation of the DPRK, been dominated by the Kim family. Kim Il Sung, the "Great Leader", ruled the DPRK with a tightly controlled inner circle of advisors (Politburo) from just after World War II until his death in July of 1994. His thought and writings form the primary basis of the DPRK political framework, which has at its root the principal of "Juch'e", or national self-reliance[8]. The mantle of leadership then passed to the son of Kim Il Sung, Kim

[7] Map downloaded from GlobalSecurity.org in March, 2007, and available as http://www.globalsecurity.org/military/world/dprk/images/dprk-map-topo.jpg.
[8] Document in Authors' files [HT1].

Jong Il. Upon Kim Jong Il's death on December 17, 2011[9], leadership of the nation and the title of Chairman was passed to a third generation of the Kim family, then 27- (or 28, sources differ)-year-old Kim Jong Un, supported at that time by senior Kim family members and close advisors, although since that time Kim Jong Un has significantly consolidated his power and changed the staffing of many senior leadership positions.[10] [11]

The economy of North Korea, hobbled by years of Japanese occupation in the period prior to World War II, was shattered by the Korean War. Through political and economic discipline, and strategic aid from East Bloc allies, Kim Il Sung and his government were able to rebuild the North Korean economy by focusing on economic autarchy and heavy industries such as the extraction and refining of minerals. A series of national plans set output goals for key commodities such as iron and steel, coal, electricity, cement, fertilizer, and grain. Collectivized agriculture and state-owned companies reportedly accounted for about 90 percent of all economic activity in the early 1990s.[12] Key economic resources for the DPRK include:

- A well-trained, disciplined work force;
- An effective system for dissemination of technologies;
- The ability to rapidly mount massive public works projects by mobilizing military and other labor; and
- Extensive reserves of minerals.

The impressive economic gains of the 1960s and early 1970s, however, were slowed in the 1980s and especially early 1990s as a result of a number of factors, including:

- Foreign debt incurred in purchasing industrial equipment and oil.
- The global "oil crises" of the 1970s, and the related slowdown in the global economy.
- The decline and eventual collapse of the Soviet Union, and the resulting reduction in Soviet/Russian aid to the DPRK and in markets for many DPRK-made goods.
- Poor grain harvests in the early 1990s.

Estimates of gross national product (GNP) per capita in the DPRK are complicated by the fixed (but arbitrarily set) exchange rate between the DPRK Won and hard currencies (such as the US dollar); in recent years, the DPRK government has undertaken various monetary actions with impacts on the exchange rate, including a major devaluation of the Won versus the dollar in 2006 (from 0.45 to about .006 USD per Won[13]), and a controversial "currency reform" in late 2009.[14]

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[9] See, for example, BBC News Asia, "North Korean leader Kim Jong-il dies 'of heart attack'", dated December 19, 2011, and available as http://www.bbc.co.uk/news/world-asia-16239693.
[10] See, for example, Ruediger Frank (2011), *The Party as the Kingmaker: The Death of Kim Jong Il and its Consequences for North Korea*, Nautilus Institute NAPSNet Policy Forum, dated December 22, 2011, and available as http://www.nautilus.org/publications/essays/napsnet/forum/Kingmaker_Ruediger.
[11] See, for example, Joyce Lee and Josh Smith (2019), "Kim Jong Un consolidates power as North Korea shuffles leadership", *Reuters*, dated April 11, 2019, and available as https://www.reuters.com/article/us-northkorea-appointments/kim-jong-un-consolidates-power-as-north-korea-shuffles-leadership-idUSKCN1RN2YO.
[12] United States Department of Energy's Energy Information Administration (UDOE/EIA, 1996), *Country Analysis Brief, North Korea*. Part of USDOE/EIA World-wide Web site, WWW.eia.doe.gov/emeu/cabs/nkorea.html.
[13] XE.com currency converter (http://www.xe.com/currencycharts/?from=KPW&to=USD&view=10Y), accessed January 26, 2012.

"Black market" exchange rates between the dollar (and other hard currencies, such as the Euro) and the Won have typically been much higher (more Won per dollar) than the official rates. Estimates of per capita GNP in 1990 ranged from an official value of about US $2,000 (probably in 1990 dollars), down to estimates in the range of US $1,000 by international observers.[15] Per capita GDP has remained, at least by ROK estimates, in the range of $1000 per capita in the late 2000s.[16] The (U.S.) *CIA World Factbook* lists the DPRK's 2009 GDP per capita at $1800, expressed on a purchasing power parity (PPP) basis in 2010 dollars.[17] The online version of the *CIA World Factbook* as of 2020 lists the 2015 GDP per capita at $1700 per person on a PPP basis in 2015 dollars.[18] An article quoting the Bank of Korea listed GDP per capita in 2018 at slightly under $1300 per capita, presumably in current dollars, and also presumably not on PPP terms.[19]

Although North Korea has raw materials—particularly minerals—that are of interest to trading partners, it has produced few finished goods (with the exception of armaments) that are of high enough quality to attract international buyers. The DPRK's major trading partners as of 1990—the reference year for the time series in this study—were China, Russia, Iran (reportedly trading oil for armaments), and Japan. The DPRK had limited trade with other Asian nations, as well as, on and off, with some European and other nations. The value of imports to North Korea exceeded that of exports by $600 million in 1990. Trade in 1991—both exports and imports—was already down markedly from 1990.[20]

1.2.2. Changes in the DPRK since 1990

The economic, if not social and political, landscape in the DPRK changed markedly during the 1990s. In the early 1990s, the North Korean government openly admitted the country's failure to achieve the economic goals of its most recent seven-year plan.[21] Although little data have been available from inside the DPRK, information from outside observers of the country indicates that the North Korean economy was at best stagnating, and most probably in considerable decline, through the mid-1990s.[22] This economic decline has been both a result and a cause of substantial changes in energy demand and supply in North Korea over the decade of the 1990s, largely

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[14] See, for example, S. Haggard and M. Noland (2010), *The Winter of Their Discontent: Pyongyang Attacks the Market*, Peterson Institute for International Economics Policy Brief Number PB 10-1, dated January 2010, and available as http://www.piie.com/publications/pb/pb10-01.pdf.

[15] 1990 GDP estimates for DPRK using a "purchasing power parity" measure of production and value that adjusts for the prices of key commodities in different countries are closer to $2000 per capita.

[16] ERINA, quoting the Bank of Korea (ROK) lists $989 (USD) estimated per capita GDP for the DPRK in 1996, $757 in 2000, and $914 in 2004 (Page 50, Chapter 5 of *Northeast Asia Economic Databook 2005*, dated approximately December, 2005,. The *DailyNK* (2012) quoted a ROK source as estimating per capita GNI (gross national income) for the DPRK in 2010 as $1074 (Park Seong Guk, *DailyNK*, dated 18 January 2012, and available as http://www.dailynk.com/english/read.php?cataId=nk00100&num=8696). Factoring in inflation, the GDP/GNI per capita estimates for 2004 and 2010 were nearly the same.

[17] United States Central Intelligence Agency (2012), *The World Factbook*, "East and Southeast Asia: Korea, North", previously available as https://www.cia.gov/library/publications/the-world-factbook/geos/kn.html, as updated 5 January 2012.

[18] US Central Intelligence Agency (CIA, 2020), "Korea, North", available as https://www.cia.gov/the-world-factbook/countries/korea-north.

[19] See, for example, Benjamin Katzeff Silberstein (2019), "North Korea's economic contraction in 2018: what the BoK numbers tell us", *North Korean Economy Watch*, dated July 26th, 2019, and available as https://www.nkeconwatch.com/category/statistics/gdp-statistics/.

[20] Korea Foreign Trade Association (1993), *Major Economic Indicators for North Korea*.

[21] The Economist Intelligence Unit (1994), *South Korea, North Korea No. 1 1994*. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.

[22] Far Eastern Economic Review (1995), *1995 Asia Yearbook, North Korea*.

continuing to this day. Observers of the DPRK economy have suggested that at least a modest improvement took place in the years around 2000—ROK sources, for example, estimated that the DPRK economy grew approximately 6 percent in 1999, and another 1.3 percent in 2000[23]. An estimate from 2010 by the Bank of Korea showed the DPRK economy (as measured by GDP) growing at 0.4 percent in 2000, and by amounts varying from 1.2 to 3.8 percent annually from 2001 through 2005, followed by a period of slow decline (-0.5 to -1.2 percent/yr) in all years from 2006 through 2010 except 2008, when growth of 3.1 percent was estimated, meaning essentially zero overall growth in the DPRK economy from 2006 through 2010.[24] Other observers, however, tended to argue that most of any economic upturn in the DPRK economy in the years 2000 through 2005 appears to have been driven by food and other aid from abroad, inputs that have diminished over the last few years of the 2000s.[25]

As suggested above, estimates of the DPRK's GDP over time are complex, typically difficult to evaluate, and vary considerably from source to source. Quoting the Bank of Korea, the website "Trading Economics" provides the chart shown in Figure 1-3.[26] Here, the DPRK economy is estimated to have expanded through much of the first half of the 2010s, and again in 2016, but to have contracted in 2017 and 2018, presumably, at least in part, as a result of UNSC sanctions restricting DPRK imports and exports. The same source projects DPRK GDP growth in 2020 and the next few years as follows:

> "GDP Annual Growth Rate in North Korea is expected to reach -5.50 percent by the end of 2020, according to Trading Economics global macro models and analysts expectations. In the long-term, the North Korea GDP Annual Growth Rate is projected to trend around -1.00 percent in 2021 and 1.30 percent in 2022, according to our econometric models."

A North Korean economist, however, said in an interview that the DPRK economy in fact expanded by 3.7 percent during 2017, the first full year in which stringent UNSC sanctions were in place. Benjamin Katzeff Silberstein, an analyst of the DPRK economy and the author of the article in which the quote of the DPRK economist ("Ri Gi Song, a professor of the Institute of Economics at the Academy of Social Sciences") rightly suggests that "[e]ven though North Korean economic data has become somewhat more public and plentiful in the past few years, there are still undeniable political imperatives in publishing data that makes the country appear resilient in the face of sanctions. After all, if sanctions are not "working" (whatever that may

[23] Korea Trade-Investment Promotion Agency (KOTRA) data (formally available from http://www.kotra.or.kr/main/info/nk/eng/main.php3, visited 6/3/02) in "South/North Korea's Trend of Real (GDP) Growth Rate", which lists the Bank of Korea as a Source. Similar growth in the North Korean "GNI" was also cited in data provided to Nautilus by the Korea Energy Economics Institute.

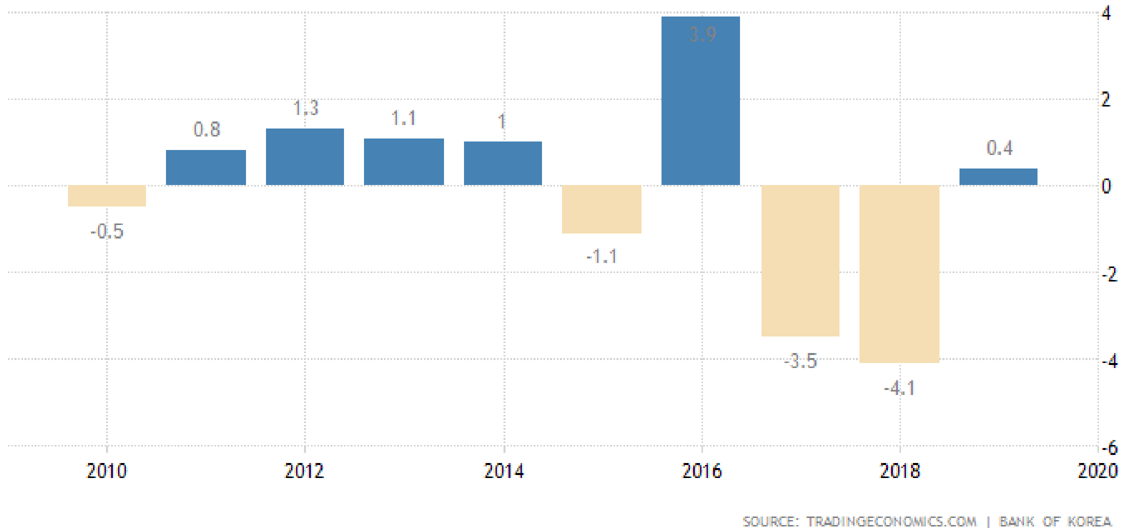
[24] Bank of Korea (2011), New Release: Gross Domestic Product Estimates for North Korea in 2010, dated November 3, 2011, and available as http://www.nkeconwatch.com/nk-uploads/GDP_of_North_Korea_in_2010.pdf.

[25] For example, N. Eberstadt (2001), *If North Korea Were Really "Reforming", How Could We Tell—And What Would We Be Able To See?* states "...official claims of 'turning the corner' and 'completing the Forced March' notwithstanding, the DPRK remains in dire economic straits". Eberstadt goes on to cite the UN Food and Agriculture Organization's finding that DPRK cereal production in 2000/2001 "is expected to be fully a third below the level of 1995/96", and asserts, based in part on the DPRK's meager reported export earnings in the first half of 2001, that "The country's export capabilities are likewise in a state of virtual collapse…".

[26] Trading Economics (2020), "North Korea GDP Annual Growth Rate", undated, but apparently mid-2020 or later, and available as https://tradingeconomics.com/north-korea/gdp-annual-growth-rate.

mean), what's the point in keeping them? That, of course, doesn't mean that such figures are accurate, wholly or partially."[27]

Figure 1-3: Estimated Changes in GDP in the DPRK, 2010 through 2019



Among the energy-sector changes on the supply side in the DPRK since 1990 have been:

- A vast drop in imports of fuels (particularly crude oil and refined products, but coal and coke as well) from the Soviet Union and Russia. An index of these imports declined from a value of over 140 in 1987 to 8.7 in 1993, and crude oil imports from Russia in 1993 were on the order of one-tenth what they were in 1990,[28] and have fallen to practically zero since.
- A steady decline in the exports of coal to China between 1988 and 1993, with the value of those exports receding in 1993 to approximately a tenth what they were in 1990. This fall may have been a sign of reduced output in the DPRK coal industry, particularly as coal imports to North Korea from China remained near the same level (in dollar terms) from at least 1982 through the early 1990s.[29]
- Since 2000, and particularly since 2010, however, the exports of coal and other raw mineral products (largely iron and steel scrap and metals ores) to China have increased dramatically, with coal exports to China reaching 2.8 million tonnes in 2005, 4.6 million tonnes by 2010 and over 22 million tonnes, by 2016, before reported trades (at least) declined due to the

[27] Benjamin Katzeff Silberstein (2018), "North Korea's economic growth – from Pyongyang's perspective", *North Korea Economy Watch*, dated October 15, 2018, and available as part of https://www.nkeconwatch.com/category/statistics/gdp-statistics/.

[28] U.S. Bureau of the Census (1995a), *The Collapse of Soviet and Russian Trade with the DPRK, 1989-1993: Impacts and Implications*. Prepared by N. Eberstadt, M. Rubin, and A. Tretyakova, Eurasia Branch, International Programs Center, Population Division, U.S. Bureau of the Census, Washington, D.C., USA. March 9, 1995.

[29] U.S. Bureau of the Census (1995b), *China's Trade with the DPRK, 1990-1994: Pyongyang's Thrifty New Patron*. North Korea Trade Project Memorandum, International Programs Center, Population Division, U.S. Bureau of the Census, Washington, D.C., USA. May 1995.

impacts of UNSC sanctions.[30] [31] This is one manifestation of a recent increase in investment in the DPRK by Chinese businesses, particularly in the raw materials sectors, but also, to some degree, in manufacturing.[32]

- A change in oil refining equipment at the Ponghwa Chemical Factory to augment the amount of light petroleum products (principally gasoline) that the DPRK can produce from the crude oil imported from China.
- Significant new imports of vehicles, most recently including electric bicycles/scooters, since 2010.
- Expanded import and use, especially since 2010, of small-scale generation equipment, including solar photovoltaic panels and diesel and gasoline generators by households, businesses, and other organizations in the DPRK.

Oil import restrictions have reduced the availability of refined products in the DPRK. These problems arose partly (if indirectly) from economic sanctions related to the nuclear proliferation issue (see below), and partly from North Korea's inability to pay for oil imports with hard currency. This lack of fuel, particularly for the transport sector, has probably contributed to the DPRK's economic malaise since 1990. Another factor contributing to the decline in the country's economic fortunes has been the inability (again, partly due to lack of foreign exchange, and partly due to Western economic sanctions) to obtain key spare parts for factories, including factories built with foreign assistance and/or technology in the 1970s.[33] Also, as mentioned above, there has been, in the years since 1990, a virtual halt in economic aid, technical assistance and barter trade on concessional or favorable terms from Russia and other Eastern European nations. This reduction, coupled with a sharp decline in similar types of assistance from China (including, in the years between 1995 and 2000, a sharp reduction in crude oil shipments to the DPRK), had resulted in a total estimated loss of aid to the DPRK economy of more than $ US 1 billion per year[34] by the mid-1990s. The DPRK's trade deficit as of 2000 stood at $US 856.88 million,[35] remained at near one billion dollars through 2004,[36] and was over one billion dollars in

[30] N. Aden, "North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Dr. Aden's paper is available as http://nautilus.org/wp-content/uploads/2012/01/0679Aden1.pdf.

[31] Figure for 2010 DPRK coal exports to China from United Nations Comtrade database, http://comtrade.un.org/db/dqBasicQuery.aspx, accessed 8/2012. Reported coal imports into China from the DPRK in 2011 were an even higher 11.2 million tonnes, more than double the 2010 value.

[32] Issues related to Chinese investment in the DPRK, and changes in DPRK policies that have made investment possible, are addressed in the Nautilus Institute Policy Forum Online 06-70A, August 23rd, 2006, "DPRK's Reform and Sino-DPRK Economic Cooperation" , by Li Dunqiu (https://nautilus.org/napsnet/napsnet-policy-forum/dprks-reform-and-sino-dprk-economic-cooperation/). See also Professor Li's presentation as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as http://www.nautilus.org/DPRKEnergyMeeting/Papers/Li.ppt. Professor Li describes two "waves" of recent Chinese investment in the DPRK, with a first wave of investment led by private companies and businessmen, mainly from China's northeast provinces, and the second wave described as "mostly represented by large state-owned enterprises, in areas like heavy industry, energy, mineral [resources] and transportation".

[33] As of 1995 the DPRK's trade deficit was estimated at $879 million (United States Department of Energy's Energy Information Administration (UDOE/EIA, 1996), *Country Analysis Brief, North Korea*. Part of USDOE/EIA World-wide Web site, previously available as WWW.eia.doe.gov/emeu/cabs/nkorea.html.)

[34] United States Department of Energy's Energy Information Administration (UDOE/EIA, 1996), *Country Analysis Brief, North Korea*. Part of USDOE/EIA World-wide Web site, previously available as WWW.eia.doe.gov/emeu/cabs/nkorea.html.

[35] *Joongang Ilbo*, Lee Young-jong, "North Korea Overseas Trade Reaps $1.97 Billion For Last Year," Seoul, 06/04/01. The figures come from the ROK's Korea Trade Investment Promotion Agency (KOTRA).

2009 and 2010,[37] before declining markedly through 2016, as a result of increased imports of coal and other goods, then rising to on the order of $2 billion or more in 2017 and 2018 (sources differ), mostly with China, and probably mostly due to the impacts of UNSC sanctions.[38]

1.2.3. Impacts of flooding and food shortages

The economic difficulties mentioned above have been exacerbated by an untimely combination of climatic events. The early 1990s saw a series of poor grain harvests in the DPRK. Compounding these difficulties, 1995 and 1996 brought severe flooding to many areas of the DPRK, washing away topsoil from areas at higher elevation, and burying many areas of crucial low-lying farmland in tens of centimeters of silt or sand.[39] An additional blow to North Korean agricultural production was dealt by a tidal wave, caused by a typhoon at sea, that swept over and heavily damaged a long dike on the west coast of the DPRK in September of 1997, inundating hundreds of thousands of hectares of rice fields. The combined effects of flooding and poor harvests—even before the damage from the tidal wave was factored in—were a food shortage severe enough to spur the DPRK government to take the unusual step of publicly requesting food aid from the international community. Additional floods and tidal waves in several areas of the country caused damage to agricultural areas in 2006, and left tens of thousands of residential homeless. This cycle of misery caused by flooding returned to the DPRK in the summers of 2007, 2010, 2011, 2018 (exacerbated by extreme heat during the growing season) and, most recently, 2020.[40]

Many observers of the DPRK, particularly in areas away from the major cities, have reported that in many periods over the past three decades official rations have been far from sufficient to meet dietary requirements, that people are supplementing their rations with tree-bark, grass, and whatever other semi-edible materials they could obtain, and that those people seen in the streets

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[36] As estimated by ERINA (Economic Research Institute for Northeast Asia) in Chapter 5 of *Northeast Asia Economic Databook 2005*, dated approximately December 2005. ERINA's estimates are based on data from the Korea Trade-Investment Promotion Agency (KOTRA) for trade between the DPRK and nations other than the DRPK, plus figures on trade between the Koreas from the ROK Ministry of Unification. Page 53.

[37] Bank of Korea (2011),"New Release: Gross Domestic Product Estimates for North Korea in 2010", dated November 3, 2011, and available as http://www.nkeconwatch.com/nk-uploads/GDP_of_North_Korea_in_2010.pdf.

[38] See, for example, Trading Economics (2020), "North Korea Balance of Trade", available as https://tradingeconomics.com/north-korea/balance-of-trade, Ben Heubl (2018), "North Korea's mysterious trade deficit with China -- in charts", *Nikkei Asia*, dated October 8, 2018, and available as https://asia.nikkei.com/Spotlight/Datawatch/North-Korea-s-mysterious-trade-deficit-with-China-in-charts, Alex Lockie (2018), "North Korea falls into $1.7 billion trade deficit with China — but something mysterious is keeping it afloat", *Business Insider*, dated Feb 21, 2018, and available as https://www.businessinsider.com/north-korea-17-billion-china-trade-deficit-suggests-mysterious-funding-2018-2 , and Maximilian Ernst and Eliana Kim (2020), "Economic Development under Kim Jong Un: The Added Value of Traffic Data and Established Indicators in the Study of North Korea's Economy", *North Korean Review*, Volume 16 Number 2, Fall 2020, pages 26 – 48. The latter includes estimates of DPRK trade derived from data from ROK's KOTRA (Korea Trade-Investment Promotion Agency).

[39] One such affected region is the Sinuiju area, where, after the 1995 floods, "…sand poured in from the Yalu River and destroyed all the rice fields in the region" (Bernard Krisher "Urgent Proposals To Get Food & Drugs To North Korea", extracted in *Northeast Asia Peace and Security Network Daily Report*, 30 May 1997. Nautilus Institute, Berkeley, CA, USA.

[40] See, for example, Cankor (2011), "DPRK Flood Damage Reports by KCNA", dated 8 August 2011, and available as http://vtncankor.wordpress.com/2011/08/08/dprk-flood-damage-reports-by-kcna/; United States Central Intelligence Agency (2010), *North Korea: Assessing the Impact of Flooding on Agricultural Output (U//FOUO)*, dated 15 December 2010, and available as http://www.fas.org/irp/cia/product/nk-flood.pdf, and *38 North* (2020), "How Extreme Flooding in the DPRK Affects Daily Life", dated September 23, 2020 and available as https://www.38north.org/2020/09/nkflooding092320/. On its home page for its DPRK program ("Democratic People's Republic of Korea", available as https://www.wfp.org/countries/democratic-peoples-republic-korea) the World Food Program notes the impacts of the 2018 floods and droughts on DPRK food production.

were thin and weak.[41] It is reported that in the 2000s official food distribution channels no longer functioned in many cities in the DPRK, especially in northern areas of the country, and that as a result residents are turning to unofficial "farmers' markets", which include produce grown on plots of land managed by individual farmers, for much of their food.[42] The consensus is that substantial (but unknown) numbers of citizens starved in the latter half of the 1990s, and possibly in recent years as well, and that hundreds of thousands more (at least) have been and continue to be malnourished and gravely at risk. Given drops in the amount of food aid being donated to the DPRK, the World Food Programme (WFP) warned in 2002 that it was facing a shortage of 611,000 tonnes of food in 2002.[43] The United States announced in 2002 that it would donate 100,000 tonnes to help alleviate this shortage,[44] and made other contributions in subsequent years. The WFP reported that significant food shortages in the DPRK continued as of 2006/2007, and continued to appeal to the international community for additional donations, though its program in the DPRK was revised in 2006 toward a more "developmental" focus at the request of the DPRK government.[45] [46] As of 2011, the DPRK, based on assessments by the World Food Program and the United Nations Food and Agriculture Organization, remained short of food due to poor harvests and limited ability to secure food imports.[47] WFP estimated that 40 percent of North Koreans were malnourished as of about 2018, despite some recent gains in food security up to that time.[48] Due to flooding, COVID-19, and other circumstances, a resurgence of extreme lack of food in the DPRK is feared for 2020 as well.[49]

Apart from the overriding human concerns associated with the food shortage, the chronic malnutrition and intermittent slow starvation reportedly suffered by the DPRK populace cannot help but decrease economic production still further, as poorly-fed people are less capable of work.[50] The flooding of 1995 and 1996 damaged an unknown number of irrigation dams and

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[41] See, for example, Jordan Weissmann (2011), "How Kim Jong Il Starved North Korea", *The Atlantic*, dated December 20, 2011, and available as https://www.theatlantic.com/business/archive/2011/12/how-kim-jong-il-starved-north-korea/250244/.

[42] See, for example, *North Korean Economy Watch* (2011), "Archive for the 'General markets (FMR: Farmers Market)' Category", several articles from 2011, available as http://www.nkeconwatch.com/category/farmers-markets/page/8/.

[43] Testimony by John Powell, Regional Director for Asia at the World Food Programme, before the Subcommittee on East Asia and the Pacific of the US House of Representatives International Relations Committee, May 2, 2002.

[44] *Reuters* (2002), "US to Donate 100,000 Tons Of Food To North Korea," Washington, 06/07/02.

[45] As of 2006, the WFP (in "Where we work - Korea (DPR), Food Security: Overview", then available as http://www.wfp.org/country_brief/indexcountry.asp?country=408) noted "The 2006 deficit is forecast by the UN Food and Agriculture Organization, WFP's sister agency, at some 800,000 metric tons (tonnes) – about 15 per cent of needs. Many of the country's 23 million people struggle to feed themselves on a diet critically deficient in protein, fats and micronutrients. Food is scarcest during the 'lean season', the five-month period prior to the autumn rice and maize harvests when stocks of the previous year's crops rapidly run down."

[46] As of March 2007, the WFP reported a DPRK food gap of "of 1 million tons, or about 20 percent of its needs", and noted that it could only fill a fraction of the DPRK's needs due to a "huge" drop in donations over the past two years (Reuters, "NORTH KOREA DESPERATE FOR AID AMID NUCLEAR WOES: U.N.", 2007-03-28, as summarized in Napsnet (Northeast Asia Peace and Security Network) Daily Report, 3/28/2007).

[47] See, for example, CHOE SANG-HUN (2011), "North Korea's Children in Need of Food Aid, Agencies Warn", *New York Times*, dated November 25, 2011, and available as http://www.nytimes.com/2011/11/26/world/asia/north-koreas-children-in-need-of-food-aid-agencies-warn.html?_r=1.

[48] United Nations World Food Program (WFP, 2019), "Democratic People's Republic of Korea interim country strategic plan (2019–2021)", dated February 2019, and available as https://docs.wfp.org/api/documents/WFP-0000101974/download/?_ga=2.156492411.118969858.1605138322-1978348243.1605138322.

[49] See, for example, James Fretwell (2020), "Why North Korea may be on the brink of another deadly 'Arduous March': famine Sanctions, flooding, COVID-19 and other 2020 conditions look eerily similar to what caused the devastating 1990s famine", *NK News*, dated September 4, 2020, and available as https://www.nknews.org/2020/09/why-north-korea-may-be-on-the-brink-of-another-deadly-arduous-march-famine/.

[50] Another way in which the food shortage likely has affected the economy is that scrap metal, some taken from industrial facilities, apparently has been (we do not know to what extent the practice continues) used as barter to obtain food via cross-

canals. Additional flooding in 1999 damaged both agricultural and industrial areas, as did flooding in more recent years. Cumulative damage to and "wearing out" of agricultural and other infrastructure, coupled with damage to farmlands (both related to climatic events and long-term degradation), means that it may be years before the DPRK is able to grow enough food to fully feed its populace again, even if the required agricultural inputs (fertilizer, machinery, and fuel for the machinery) do become more available.

1.2.4. Past and current international relations and potential impacts on the DPRK economy: negotiations, food aid, and the Agreed Framework

The DPRK maintains relatively good relations with Russia, China, and the countries of the former East Bloc, although, as noted above, direct assistance and concessional trade from these countries (except, arguably, China) has been substantially suspended for most of the last thirty years. Recent years—the mid-2000s through at least 2016, and probably continuing as of 2020, albeit at a lower and lower-profile level due to UNSC sanctions—have seen increasing investment by China in the DPRK, with investments focused on minerals extraction and similar industries. Relations with Japan, the United States, and the Republic of Korea remain tenuous, with the last two decades and more seeing cycles of apparent rapprochement scuttled by various political and military incidents. As a summary to provide context for the discussions of the DPRK energy sector in this Report, international negotiations with impacts on the DPRK economy that have taken place in the past three decades have included:

- *Negotiations regarding the provision of food aid to the DPRK*. The DPRK has allowed international aid organizations, including the World Food Programme, International Federation of the Red Cross, and various European aid agencies to set up residence in Pyongyang. In the early years of the 21st century, aid workers had reported growing access to areas of the country outside the capital, although still well below the desired level. In the years since 2005, however, these organizations have in many instances been forced to scale down their operations due to a sharp decrease in donations. The largest donor governments have been the ROK, the United States, Japan, and the European Union. Russia also reportedly provided a large amount of food aid to the DPRK, although outside of official U.N. channels. China has also been a significant donor of food aid to the DPRK.[51]
- *Talks relating to the "Agreed Framework*" (see section 1.4.5, below). In these talks the DPRK agreed to abandon its gas-cooled nuclear reactor program in exchange for an agreement by the US and the ROK to provide to the DPRK two pressurized water reactors and shipments of heavy fuel oil until the reactors are ready to run. An official groundbreaking for the reactors, attended by project personnel from several countries, was held in the DPRK in August of 1997, and work at the reactor site, though significantly delayed, was proceeding until about 2002 (see below). As of April 2007, the Agreed

border trade with China (*Korea Times*, "N. KOREA BARTERS SCRAP IRON FOR CHINESE FLOUR, CORN," Beijing, 05/18/97). Although the extent to which operational industrial facilities have been dismantled to trade for food is unknown, we find it conceivable that even if the DPRK does manage to obtain the needed inputs and investment to restart industrial production, many plants will be found to be inoperable due to key missing (sold for scrap) parts. In the same vein, there have also been reports from defectors that North Koreans have cut pieces of telephone and electrical wire to barter the copper in them to Chinese smugglers in exchange for food and other items (*Korea Times*, "RUMORS OF WAR RAMPANT IN N. KOREA," 05/23/97).

[51] See, for example, the *Dong-A Ilbo*, "Scale of yearly Chinese unconditional aid to N. Korea unveiled", June 24, 2012, available as http://english.donga.com/srv/service.php3?biid=2012062508548.

Framework had unraveled completely, although both parties continued to argue that the other party was obliged to fulfill its past commitments under the Framework.

- *Bilateral US-DPRK talks* that were underway during the Clinton administration largely stalled since George W. Bush assumed the presidency, with limited net progress during the eight years that President Barak Obama was in the White House, although there have been some (typically fleeting) moments of engagement and optimism. At a visit by U.S. Assistant Secretary of State James A. Kelly to the DPRK in October of 2002, the United States delegation confronted the DPRK with evidence that suggested that the DPRK was pursuing a program to enrich uranium for use in nuclear weapons. This event started a period in which the provisions of the Agreed Framework were in large part, and by degrees, scuttled by both the United States and the DPRK sides, leading to the DPRK's assembly and, in late 2006, again in May of 2009, and four more times since, testing of nuclear explosive devices.[52] US President Donald Trump has pursued engagement with the DPRK largely based on developing a personal relationship with DPRK Chairman Kim Jong Un. The two leaders met three times, in Singapore, Hanoi, and in a rapidly assembled June 2019 meeting at Panmunjom in the Demilitarized Zone (DMZ) between the ROK and DPRK. These summit meetings appeared to set the stage for additional discussions and engagement, but little progress has been forthcoming.[53] The DPRK's major motivations for improving relations with the United States include the desire to be removed from the U.S. list of terrorist-sponsoring nations, which would free it up to pursue aid from international financial institutions dominated by the United States, receiving security guarantees from the United States, and, more recently, easing/removal of United Nations Security Council sanctions on the DPRK economy, institutions, and individuals.

- During the period from late 2002 through early 2007, a set of negotiations known as the *Six-Party Talks* between the DPRK, its neighbors (China, Japan, the ROK, and Russia), and the United States have taken place. These negotiations have been marked by periods of action and agreement interspersed with periods of relative estrangement of the parties. In February of 2007, a tentative agreement was reached between the parties, the details of which were to have been developed by the parties in a series of "working group" meetings.[54] At the first session of the Six-Party Energy Working Group on February 17th 2007 in Beijing, the parties began to discuss the energy dimension of a new framework based on the Six-Party September 2005 Joint Principles and the February 13th Six-Party Agreement, under which the DPRK would abandon its nuclear weapons programs in return for energy and other assistance.[55] Like the Agreed Framework, the Six-Party Talks process, although it concluded some significant agreements, has similarly unraveled in recent years. By early 2012, informal discussions continued regarding the resumption of the Six-Party Talks, and in the

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[52] For example, International Atomic Energy Agency (IAEA), *IAEA Press Releases, Press Release 2006/17*, "DPRK Nuclear Test Statement by IAEA Director General", 9 October 2006, and available as http://www.iaea.org/NewsCenter/PressReleases/2006/prn200617.html; and Arms Control Association (2011), "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy", available as http://www.armscontrol.org/factsheets/dprkchron.

[53] See, for example, Ankit Panda (2019), "US-North Korea Doldrums Return After Third Trump-Kim Summit", *The Diplomat*, dated July 17, 2019, and available as https://thediplomat.com/2019/07/us-north-korea-doldrums-return-after-third-trump-kim-summit/.

[54] David von Hippel and Peter Hayes (2007), "Energy Security for North Korea", *Science*, dated 01 Jun 2007, Vol. 316, Issue 5829, pp. 1288-1289, DOI:.10.1126/science.1142090.

[55] See P. Hayes, *The Beijing Deal is not the Agreed Framework*, Nautilus Institute Policy Forum Online 07-014A: February 14th, 2007, available at: http://www.nautilus.org/publications/essays/napsnet/forum/security/07014Hayes.html/.

years since it has remained unclear whether the process will be revived, and if so, what form it might take if it is revived.

- *Bilateral ROK-DPRK talks* have taken place on an on-again, off-again basis since the two Koreas held their historic summit meeting in June 2000. The ROK has proposed several projects for economic cooperation, including connecting the two countries' railroad systems and building an industrial park in the border town of Kaesong. The Kaesong (or Gaeseong) industrial park project is ongoing, with several factories set up and working in the park; a power line from the ROK to Kaesong started operation in 2005.[56] Disagreements between the ROK and DPRK, and the ROK's reaction to ongoing DPRK weapons testing, eventually led the then-ROK leadership (the administration of President Park Geun-hye.) to withdraw ROK workers and officials from Kaesong (also sometimes referred to as "Gaesong") and to stop providing electricity and other support to the complex in 2015, and inter-Korean activities there have not yet resumed as of 2020.[57] Work on the rail interconnection progressed, but a test run of the system was canceled by the DPRK in 2006.[58] Other cooperation projects between the Koreas have included meetings of relatives separated by the division of the Korean peninsula, the organization of tours to the Mount Kumgang area of the DPRK (a project that has been on hold in recent years), and periodic food, fertilizer, medical, and other humanitarian aid provision from the ROK to the DPRK.[59] The current (as of 2020) ROK administration of President Moon Jae-in has been more proactive and accommodating than most previous ROK administrations in seeking to engage the DPRK in discussions, but so far without significant breakthroughs.
- *Bilateral Japan-DPRK talks* have usually broken down over allegations that the DPRK kidnapped some 11 Japanese citizens, a charge that the DPRK denies. Talks in April 2002 resulted in an agreement by the DPRK to investigate the Japanese cases and to allow Japanese wives of North Korean men to visit their families. The DPRK had hoped that that normalization of relations with Japan would result in a substantial package of reparations for Japan's colonial rule, similar to the aid that the ROK received in 1965, and which helped fuel the ROK's industrialization. Talks between the countries had not been held since 2008, however, before a reported January 2012 meeting in China between representatives of the two countries to discuss "terms for restarting intergovernmental negotiations".[60]

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[56] See, for example, *Nautilus Institute Policy Forum Online 06-64A*: August 3rd, 2006, "Gaeseong Industrial Complex in Steady Progress Despite a Series of Negative Incidents", Statement by ROK Ministry of Unification. Available as https://nautilus.org/napsnet/napsnet-policy-forum/gaeseong-industrial-complex-in-steady-progress-despite-a-series-of-negative-incidents/.

[57] See, for example, Grant Wyeth (2020), "Time to Reopen the Kaesong Industrial Complex? A Conversation With Jin-hyang Kim", *The Diplomat*, dated February 27, 2020, and available as https://thediplomat.com/2020/02/time-to-reopen-the-kaesong-industrial-complex-a-conversation-with-jin-hyang-kim//

[58] China English People's Daily Online, May 29, 2006, "DPRK military blames S. Korea for failure of test train runs". Available at http://english.people.com.cn/200605/29/eng20060529_269228.html. See also *The Rails Are Geopolitics: Linking North and South Korea and Beyond*, by Yonhap News and Georgy Bulychev, Dated May 24, and available as https://apjjf.org/-Georgy-Bulychev/2008/article.html.

[59] For example, The Telegraph, "North and South Korea talks: timeline of Pyongyang's nuclear ambitions", dated 8 February, 2011 (and available as http://www.telegraph.co.uk/news/worldnews/asia/northkorea/8310219/North-and-South-Korea-talks-timeline-of-Pyongyangs-nuclear-ambitions.html) provides a summary listing of events related to DPRK negotiations with the ROK and other parties from 2003 to early 2011, when military talks between the ROK and DPRK "to explore the possibility of re-starting negotiations were to begin.

[60] See, for example, *The Japan Times Online* (2012), "Japan, North hold secret talks in China", dated 1/10/2011; and *Taipei Times* (2012), "North Korea, Japan hold talks: media", dated 11 January 2012, and available as http://www.taipeitimes.com/News/world/archives/2012/01/11/2003522971.

- *Talks between the DPRK and EU nations* had, as of 2002, resulted in normalization of relations with all EU member states except France and Ireland. Australia and Canada had also normalized relations with North Korea, and all of these countries had sent delegations to Pyongyang to discuss bilateral and multilateral projects. It was hoped that these countries can play a significant role in providing development aid and training to the DPRK, but the implementation of that role, which looked very promising as late as September of 2002, has been largely on hold since then.
- *United Nations Security Council Resolutions/Sanctions on the DPRK* started in 2006 with a resolution agreed to following the DPRK's first test of a nuclear explosive device, and continued with a series of progressively more stringent resolutions and economic sanctions through 2017.[61] The most crucial of these resolutions, from the perspective of the DPRK energy sector, include those capping the DPRK's oil and oil product imports, and capping the DPRK's exports of coal, metals, labor, and other goods and services, thus limiting its ability to earn hard currency income.

Significant progress in any one of these areas of negotiation would likely lead to greater progress in all arenas, and, ultimately, to a gradual thawing of relations between the Koreas, the DPRK and Japan, and between the DPRK and the United States. Such an improvement in relations is a substantial, and even possibly absolute, prerequisite for re-starting the DPRK economy, and, by extension, a prerequisite to implement significant changes in the DPRK energy system.

Another bilateral dialog has been between the DPRK and Russia. These talks reportedly include discussions about restoring some of the DPRK's economic ties with Russia, and of Russian financial and technical involvement in specific DPRK energy and industrial projects, in particular the inter-Korean railway project and electrical grid interconnection between the countries. Given the historical economic relationship between the DPRK and Russia, and Russia's strong interest in revitalizing its own Far Eastern region, it is quite conceivable that Russia could play an important role in the rebuilding of the DPRK economy, particularly as (and if) the economy in the Russian Far East becomes more robust.

1.2.5. The DPRK Response to the COVID-19 Pandemic

Officially, the DPRK has reported no cases of coronavirus during the current global pandemic.[62] This report, however, appears at odds with DPRK requests for corona-virus related supplies from Medecins Sans Frontieres, UNICEF, the WHO, and others, as well as reported quarantines of foreigners and DPRK citizens, and the use of facemasks in the DPRK by most residents pictured in recent photos (with the exception of Chairman Kim Jong Un). Reports by observers outside the DPRK, including those receiving intelligence briefings, include descriptions of hundreds of covid-19 deaths among soldiers, a one-month military "lockdown", quarantines of thousands within and outside of the military, and other evidence of significant changes in life in the DPRK in recent months.

[61] For a summary of UNSC resolutions and sanctions related to the DPRK, see, for example, Arms Control Association (2020), "UN Security Council Resolutions on North Korea", last revised April, 2018, and available as https://www.armscontrol.org/factsheets/UN-Security-Council-Resolutions-on-North-Korea.

[62] *South China Morning Post* (Agence France-Presse), 2020, "North Korea insists it has no coronavirus cases, thanks to shutting borders, containment", dated 3 April, 2020, available as https://www.scmp.com/news/asia/east-asia/article/3078226/north-korea-insists-it-has-no-coronavirus-cases-thanks-shutting.

Whatever the actual COVID-19 situation is in the DPRK, it is clear that the DPRK's response to the pandemic has changed the way that the country operates its economy, including its energy sector. Worldwide, national and local "lock-downs" and "stay-at-home" orders have resulted in vast reductions in energy demand, particularly for transportation, in part causing, among other impacts, a vast drop in oil prices, and rapidly filling oil and gas storage depots. The DPRK's energy supply situation is unlike that of other countries, particularly for oil products, due to UNSC sanctions and resulting restrictions on its oil imports. This requires the DPRK to use "unofficial" means to obtain oil supplies and export coal, strategies that are likely more difficult to carry out during the pandemic, due to the need for cooperation by outside trading partners.

As noted above, official reports of the coronavirus situation in the DPRK are few and somewhat contradictory. Reports by those outside the DPRK, anecdotal and otherwise, therefore form the information base on which our analysis of energy supply and demand in the DPRK in 2020 must be built. Some of the reported changes in the DPRK that would affect energy supply and demand in the DPRK include:

- Quarantines of thousands of individuals, including a recent (April 28) report that the DPRK has extended its "COVID-19 National Emergency" through the end of the year, including a strengthening of quarantine procedures.[63]
- A one-month military "lockdown" in February and March.
- Curtailing of border crossing and travel between the DPRK and China, apparently since January 26.[64] More recent news reports suggest that these restrictions will continue for some months.[65]
- "[W]idespread stories of inflation and the hoarding of critical goods. Many schools have been closed [apparently, from at least February 20 through April 15, based on *Asia Times* reporting], social gatherings have been limited, and much tourism is suspended."[66]
- Announcement of construction of a new, modern hospital in Pyongyang.
- Shutdown of most air, rail, road, and ship travel into and out of the country
- A "huge economic loss" reported by DPRK state media.[67]
- An increase in the "price of gas", presumably gasoline.

[63] Hyemin Son, Leejin Jun, and Eugene Whong (2020), "North Korea Extends COVID-19 National Emergency to End of Year", *Radio Free Asia*, dated 2020-04-28, and available as https://www.rfa.org/english/news/korea/national-emergency-04282020184222.html?utm_source=AM+Nukes+Roundup&utm_campaign=ba43f31c3a-EMAIL_CAMPAIGN_2018_07_25_12_19_COPY_01&utm_medium=email&utm_term=0_547ee518ec-ba43f31c3a-391728633.

[64] Gabriela Bernal (2020), North Korea's silent struggle against Covid-19: Sources inside report via smuggled cellphones that official and unofficial measures have been surprisingly effective", Asia Times, dated March 31, 2020, available as https://asiatimes.com/2020/03/north-koreas-silent-struggle-against-covid-19/.

[65] *Radio Free Asia* (2020), ibid.

[66] Mitchell Lerner (2020), "History Shows North Korea Will Respond to the Coronavirus by Lashing Out: Will the pattern repeat?", *National Interest*, April 1, 2020, available as https://nationalinterest.org/blog/korea-watch/history-shows-north-korea-will-respond-coronavirus-lashing-out-139732.

[67] Chad O'Carroll (2020), "COVID-19 in North Korea: an overview of the current situation: Pyongyang officially claims no infections within its territory, and has taken strict steps to stave off an outbreak", dated March 26, 2020, available as https://www.nknews.org/pro/covid-19-in-north-korea-an-overview-of-the-current-situation/?t=1585236870435.

- Issues with industrial output due to lack of inputs and spare parts from China, affecting the mining sector as well.[68]
- A crackdown on cross-border smuggling.
- A demonstrable idling of the DPRK's maritime fleet, including many of the ships that have been implicated in unofficial trade in coal and oil products, starting with a recall of ships on January 22.[69] The *New York Times* summary of the situation as of late March concluded "The long-term disruptions to North Korea's revenue stream remain unclear, partly because the duration of the pandemic and its impact on maritime commerce are not yet known. But analysts said it was reasonable to assume damage has been done to North Korean agriculture, industry and the overall economy."

Our estimates of the impacts of these and other COVID-19-response measures by DPRK authorities and citizens, and the foreign traders that work with them, are reflected in our estimates of year-2020 DPRK energy supply and demand, as describe in Chapter 3 of this Report.

1.3. Summary of the Overall Energy Situation in the DPRK

Overall energy use per capita in the DPRK as of 1990 was relatively high, primarily due to inefficient use of fuels and reliance on coal. Coal is more difficult to use with high efficiency than oil products or gas. Based on our estimates, primary commercial energy[70] use in the DPRK in 1990 was approximately 70 GJ per capita, approximately three times the per capita commercial energy use in China in 1990, and somewhat over 50 percent of the 1990 per capita energy consumption in Japan (where 1990 GDP per-capita was some ten to twenty times higher than the DPRK). This sub-section provides a brief sketch of the DPRK energy sector, and some of its problems. Much more detailed reviews/estimates of energy demand and supply in the DPRK in 1990, 1996, 2000, 2005, 2008 through 2010, and 2014 through 2020 are provided in later chapters of this report.

1.3.1. Energy demand—sectors, fuels, and problems

The industrial sector is the largest consumer of all commercial fuels—particularly coal—in the DPRK. The transport sector consumes a substantial fraction of the oil products used in the country. Most transport energy use is for freight transport; the use of personal transport in the DPRK is very limited. The residential sector is a large user of coal and (in rural areas, though more recently, reportedly, in urban and peri-urban areas as well) biomass fuels. The military sector (by our estimates) consumes an important share of the refined oil products used in the

[68] Benjamin Katzeff Silberstein (2020), "The North Korean Economy: Coronavirus Measures Causing Economic Anxiety", *38 North*, dated March 27, 2020, available as https://www.38north.org/2020/03/bkatzeffsilberstein032720/.
[69] See Christoph Koettl (2020), "Coronavirus Is Idling North Korean Ships, Achieving what Sanctions Did Not", *New York Times*, dated March 26, 2020, available as https://www.nytimes.com/2020/03/26/video/coronavirus-north-korea.html, which also quotes Royal United Service Institute (RUSI) Project Sandstone (2020), "Rickety Anchor: North Korea Calls its Illicit Shipping Fleet Home amid Coronavirus Fears", dated 26 March 2020, and available as https://rusi.org/commentary/rickety-anchor-north-korea-calls-its-illicit-shipping-fleet-home-amid-coronavirus-fears.
[70] Primary energy counts all fuel use, including conversion and transmission/distribution losses. Commercial energy excludes, for the most part, use of biomass fuels such as firewood and crop wastes.

country. The public/commercial and services sectors in the DPRK consume much smaller shares of fuels supplies in the DPRK than they do in industrialized countries, due primarily to the minimal development of the commercial sector in North Korea. Wood and crop wastes are used as fuels in the agricultural sector, and probably in some industrial subsectors as well.

Key energy-sector problems in the DPRK include:

- *Inefficient infrastructure*: Much of the energy-using infrastructure in the DPRK is reportedly (and visibly, to visitors to the country) antiquated and/or poorly maintained. Buildings apparently lack insulation, and the heating circuits in residential and other buildings apparently cannot be controlled by residents. Industrial facilities are likewise either aging or based on outdated technology, and often (particularly in recent years) are operated at less-than-optimal capacities (from an energy-efficiency point of view).

- *Suppressed and latent demand for energy services*: Lack of fuels in many sectors of the DPRK economy has apparently caused demand for energy services to go unmet. Electricity outages are one obvious source of unmet demand, but there are also reports, for example, that portions of the North Korean fishing fleet have been idled for lack of diesel fuel. Residential heating is reportedly restricted in the winter (and some observers report that some public-sector and residential buildings have not received heat at all in recent years) to conserve fuel, resulting in uncomfortably cool inside temperatures.

  The problem posed by suppressed and latent demand for energy services is that when and if supply constraints are removed there is likely to be a surge in energy (probably particularly electricity) use, as residents, industries, and other consumers of fuels increase their use of energy services toward desired levels. (This is a further argument, as elaborated later in this report, for making every effort to improve the efficiency of energy use in all sectors of the DPRK economy as restraints on energy supplies are reduced.)

- *Lack of energy product markets*: Compounding the risk of a surge in the use of energy services is the virtual lack of energy product markets in the DPRK. Without fuel pricing reforms, there will be few incentives for households and other energy users to adopt energy efficiency measures or otherwise control their fuels consumption. Recent years have seen limited attempts by the DPRK government to reform markets for energy products, some private markets exist for local products like firewood, and some commercial fuels have in recent years reportedly been traded "unofficially" (on the black market), but for the most part, energy commodity markets in the DPRK essentially do not exist.[71] Energy consumers are also unlikely, without a massive and well-coordinated program of education about energy use and energy efficiency, to have the technical know-how to choose and make good use of energy efficiency technologies, even when and if such technologies are made available.

[71] In his paper and presentation "Changes In The North Korean Economy And Implications For The Energy Sector: Is North Korea Really Short of Energy?", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, William B. Brown discusses the state of DPRK energy markets, and notes that by one measure of electricity cost, the ratio of the price of rice to the price of a kilowatt-hour of electricity, power was one hundred times as expensive in the United States in 2006 than it was in the DPRK. See https://nautilus.org/napsnet/napsnet-special-reports/changes-in-the-north-korean-economy-and-implications-for-the-energy-sector-is-north-korea-really-short-of-energy/.

1.3.2. Energy supply—resources, technologies and processes

North Korea's major energy resource is coal. The DPRK has substantial reserves of both anthracite and brown coal, though the quality of its coal reserves varies substantially from area to area. There is little, if any, coal cleaning (washing and sifting of coal to remove impurities such as sulfur and ash) in the DPRK. There have been reports of some operating oil wells in North Korea, with production starting around 2000, but these reports are far from fully substantiated. Modest oil resources reportedly have been located offshore in DPRK waters and have been the subject of reported agreements between the DPRK and, variously, other countries and foreign companies. All crude oil and some petroleum products were imported as of 1990 from Russia, China, and Iran, plus some purchases on the Hong Kong spot market. Since 1990, crude oil imports have been restricted by economic and political factors. Two operating oil refineries produced (as of 1990) the bulk of refined products used in the country. As of 1995 and 1996 (and from 2000 through 2020), only one of the two refineries was apparently operating most of the time, and imports of refined products had not expanded sufficiently to replace the lost production. A third, simple, smaller refinery on the West Coast of the DPRK reportedly operates sporadically when crude oil shipments are available.

1.3.3. Summary of electricity demand and supply

The estimated per-capita electricity end use in the DPRK in 1990 was about 1,500 kWh per capita. By comparison, overall 1990 electricity demand in South Korea was about 2,200 kWh per capita.[72] Per capita electricity consumption in the DPRK has declined very substantially since, due largely to reduced availability of power, though also as a result of reduced economic activity. As with coal, the bulk of the electricity demand in the DPRK is in the industrial sector, with the residential and military sectors (by our estimates) also accounting for significant fractions of electricity use.

Electricity generation as of 1990 was primarily hydroelectric and coal-fired, in approximately equal proportions, with a small amount of oil-fired electricity generation capacity associated with the oil refinery at Sonbong and in two other plants. Much of the generation capacity was installed in the 1970s and 1980s, although a significant portion of generation facilities—particularly hydroelectric facilities—date back to the Japanese occupation.[73] Many of the hydroelectric facilities in the DPRK are reported to be of the "run-of-river" variety, which means that their output is more subject to variations in stream flow than plants that rely on larger impoundments with greater water storage. Since 1990, the ratios of hydro to "thermal" power production have varied from year to year, for reasons described in the Chapters that follow.

The DPRK has the coal resources necessary to expand thermal power generation, but it is not clear that the coal mining or transport infrastructure is capable of supplying coal to power stations at a rate much greater than that prevailing in 1990. Given weather patterns in the subregion, North Korea probably has at least a modest wind power resource, yet untapped (and largely unmapped), but it is far from equally distributed throughout the nation, with average winds in many of the most populous onshore areas (including the western coastal plains) being

[72] Korea Energy Economics Institute (KEEI, 1991), *Yearbook of Energy Statistics, 1991*. KEEI, Seoul, Republic of Korea.
[73] Many of the hydroelectric facilities built during the Japanese occupation were reportedly disabled or dismantled by the Japanese (during retreat from the Peninsula) or by the USSR but were later refurbished with technical assistance and equipment from the USSR.

relatively light. The DPRK also has some remaining undeveloped hydroelectric sites, and a solar energy resource that is similar to that in the ROK, Japan, and Central Europe, that is, useful, but not exceptional.

Power generation facilities are reported to be in generally poor, and often failing, condition and sometimes (because they are based on technologies adopted from China or the Former Soviet Union) not well adapted to the coal types with which they are fired. As a consequence, the generation efficiency of the thermal power stations in the DPRK is reportedly low. Thermal power plants generally lack all but the most rudimentary pollution control equipment and also, in almost all cases, lack any kind of computerized combustion control facilities. In-station use of power is reportedly fairly high, and "emergency losses" of power have been reported at major stations.

The system of electricity dispatching is inefficient, minimally or not at all automated, and prone to failure. Estimates of transmission and distribution (T&D) losses vary from an official 16 percent up to more than 50 percent, but any estimates of T&D losses are difficult to confirm, as there is minimal end-use metering in the DPRK.[74]

1.4. Environmental, social, and political background

The DPRK energy sector in general, and the electricity supply system in particular, is a major source of environmental problems both within and—in the case of regional and global pollutants—outside of the country. As such, the status of the environment has a significant bearing on the future development of the DPRK electrical system. Similarly, the social and political history and current situation in the DPRK constrains the options (and likely directions) for energy sector development. In the following paragraphs we present a very brief review of the environmental, political, and social setting for the DPRK energy sector.[75]

1.4.1. Summary of environmental problems in the DPRK, including those associated with energy use

The DPRK occupies an area of 122.7 thousand square kilometers, of which roughly three-quarters (as of 1990) were classified as forests, and about 20 thousand km^2 (2 million hectares) are used for agriculture. Except for the coastal plains (primarily on the West side of the peninsula), the topography is rugged and mountainous. North Korea's forests were overexploited during the Japanese occupation, and badly damaged during the Korean War; as a consequence they are not well-stocked, and only about a third of the forest area is classified as "productive". A significant reforestation effort has, however, been underway.

Rainfall in the DPRK averages slightly over one meter per year, and the climate is temperate, with hot, humid summers and cold winters. A branch of the Northern Pacific Equatorial Current

[74] That is, for the most part, even as of 2020, power is reportedly simply provided to most consumers without metering, so "sales records" as such do not exist as they do in most other nations.

[75] Additional discussion of the environmental situation in the DPRK can be found, for example, in D. Von Hippel and P. Hayes, "Environmental Problems and the Energy Sector in the Democratic People's Republic of Korea (DPRK)", *Asian Perspective*, Vol 22, No. 2, 1998, pp. 51 – 77; and in P. Hayes (2009), "Unbearable legacies: The Politics of Environmental Degradation in North Korea", *Global Asia*, Volume 4, Number 2, dated June 2009, and available as https://www.globalasia.org/v4no2/cover/unbearable-legacies-the-politics-of-environmental-degradation-in-north-korea_peter-hayes.

raises the temperature of Korean coastal and near-shore waters, resulting in highly productive fisheries.

Although the North Korean leadership has declared that environmental protection is of paramount importance,[76, 77] observers have noted a host of environmental problems in DPRK. Among these problems are:

- Industrial pollution of rivers;
- Urban air pollution (including sulfur and nitrogen oxides, the precursors of acid precipitation) from industrial facilities and virtually uncontrolled combustion of coal in residential, industrial, and power plant boilers;[78]
- Indoor air pollution from domestic combustion of coal and biomass fuels;
- Pollution of surface- and groundwater from agricultural practices (fertilizer and pesticide application, irrigation) and from insufficient (or absent) sewage treatment systems;
- High per-capita greenhouse gas emissions (from high per-capita coal use);
- Pollution of waters by drainage from mines; and
- Potential environmental problems stemming from national efforts to fill tidal flats on the western side of the peninsula to create new farmland.

The DPRK suffers from a lack of sufficient trained personnel and analytical equipment for use in enforcing existing environmental laws, meaning that environmentally-sound practices are likely to be sporadic at best. In addition, DPRK environmental laws, while in principle stringent and well-intended, lack the specificity needed to be easily implemented or enforced. In the short run, the absence of an effective regulatory infrastructure means that the extent to which the DPRK takes environmental considerations of any kind into account in planning and operating its energy system is likely to be externally, rather than internally, motivated. For example, progress in making coal-fired power stations less polluting is much more likely if environmental performance is tied to technical aid (from the United States, the ROK, the EU, the United Nations, or others).

1.4.2. The impact of the 1995/1996 floods and the food crisis

The floods of 1995 and 1996, apart from causing damage to irrigation structures and possibly major damage to hydroelectric facilities, have likely exacerbated the process of soil depletion that was already well underway. As noted above, sediment from upland areas has been deposited on important rice paddy areas. Some 90,000 hectares of paddy land were reported to be under large deposits of sand and debris as of 1996, and fuel was lacking for the excavation machinery and other equipment needed to rapidly rehabilitate paddy land and restore irrigation

[76] Kim Il Sung "set forth the principle that the problem of environmental protection should be taken into account ahead of socio-economic development and that every possible measure should be taken for environmental protection ahead of production and he has seen to it that the principle be kept with credit".

[77] Hayes, P, (1993a), *Cooperation on Environmental Issues with the DPRK*. Nautilus Institute, Berkeley, California, USA. October 29, 1993.

[78] This problem has been notably reduced in recent years with the considerable reduction in industrial activity and overall energy use in the DPRK.

systems.[79] It seems likely (though as yet only conjecture) that the sediments deposited by the 1997 and subsequent floods bear industrial and agricultural pollutants that may poison soils in some areas for years to come—although the flooding may also have served to flush pollutants from and rejuvenate soils in some areas. Sediment loss from upland soils was probably higher that it would have otherwise been due to the poor condition of forest stocks—forests in good condition help to prevent erosion.

The food shortages exacerbated (in large part) by the floods[80] are also likely to have a long-term impact on forests and on other vegetation. Lack of agricultural products has reportedly sent North Koreans to foraging intensively for edible and semi-edible wild plants. There have been reports from the late 1990s through at least the early 2010s of people eating preparations made from bark stripped from trees, though visitors to the DPRK suggest that bark use for food was not common in the mid-2000s, at least. Stripping of bark from trees is likely to at best expose trees to greater risk from pests, diseases, and other environmental threats, and at worst, kill the trees, further exposing areas to erosion problems. References to consumption of "grass porridge" or "grass meal" as a food of last resort also have appeared frequently in anecdotal reports of life in the DPRK over the past two decades and more.[81] Over-exploitation due to desperate foraging may also endanger or extinguish rare or threatened species of flora and fauna in the DPRK's natural habitats.

1.4.3. DPRK agricultural conditions and food situation since 1996

In the middle year of the decade from 2000 to 2010, the DPRK's agricultural situation showed some signs of improvement. The World Food Programme and the Food and Agriculture Organization reported that the DPRK produced 3.54 million metric tonnes of food in 2001-2002, a 38 percent increase over two years earlier and the most since 1995. This included an estimated 1.35 million tonnes of rice (milled basis), 1.4 million tonnes of corn, and 100,000 tonnes of wheat. That left the DPRK with an estimated food deficit for 2001-2002 of around 1.47 million metric tonnes, down from 2.2 million tonnes a year earlier.[82] The increased food production was not sufficient to make up for the drop in donations that resulted in part from a shift in international attention to the situation in Afghanistan. Improved harvests in more recent years have reduced the DPRK's food deficit, and food donations from ROK increased for a time,[83] but WFP/FAO estimates (see above) still projected a substantial DPRK food deficit in 2006, continuing through the years that followed to various degrees.[84]

[79] United Nations Food and Agriculture Organization (UNFAO) and World Food Programme (WFP, 1996), *Special Alert No. 267, Democratic People's Republic of Korea*.

[80] There is some evidence that the food shortages of more recent years are in large part a result of structural problems in the DPRK agricultural sector that date back to 1990 or before.

[81] See, for example, Good Friends: Research Institute For North Korean Society (2011), "North Korea Today No. 411", dated July 13, 2011, and available as http://goodfriendsusa.blogspot.com/2011/07/north-korea-today-no-411-july-13-2011.html. Though such anecdotal reports are certainly not systematic surveys and may to some degree reflect the bias of the reporting organization, they may offer an indication of ongoing problems, if not a definitive statement of their extent or severity nationwide.

[82] Government of the United States of America, "North Korea - Mild winter, dry spring could affect 2002/03 crops," April 10, 2002; IU, "North likely to face greater food shortages," April 4, 2002.

[83] ROK food donations to the DPRK in 2006 reportedly declined substantially from previous years.

[84] See, for example, Benjamin Katzeff Silberstein (2019), "North Korea's Food Situation: Bad but not Catastrophic", *38 North*, dated May 29, 2019, and available as https://www.38north.org/2019/05/bkatzeffsilberstein052919/.

1.4.4. The DPRK social and political system, and its influence on the energy and electricity sector

The "Juch'e", or autarchic, philosophy of the DPRK government has shaped the electricity and energy sectors in the DPRK. Development of indigenous resources—notably coal—has taken precedence, as has "reverse engineering"[85] and other techniques of developing technologies that can be produced domestically. Another major factor in shaping the DPRK's electricity and energy-consuming infrastructure has been the influence of Russian advisors and aid. The former Soviet Union was intimately involved in designing, and often providing equipment for, constructing, and even operating thermal power plants, industrial plants, and many other elements of the DPRK economy. As a consequence, Russian design criteria and operating practices are widely used in the DPRK. In many cases, the Russian-designed plants provided to the DPRK operate much less efficiently than comparable (current) processes in other countries, contributing to the overall inefficiency of the DPRK economy.[86]

The use of oil for electricity generation has been limited primarily to a single heavy-oil-fired power plant associated with an oil refinery, although in recent years work has been underway to convert that plant to use coal (see section 5.2.3 of this Report). Some smaller older diesel-engine generators may be in use as well,[87] and at least one fairly new large diesel-type generator was reported installed in an industrial setting around 2000. In recent years (since about 2010) large numbers of diesel- and gasoline-fired generators have been imported to the DPRK from China. We have not heard reports of any natural gas-fired generation, and the DPRK lacks facilities for importing liquefied natural gas, or LNG, at least in significant quantities. The focus on domestically produced energy technologies, and the corresponding lack of technology imports (especially in the years since 1990, though there have been reports of some modest energy technology imports recently) has resulted in an energy sector that is notably inefficient.

The North Korean workforce is literate, disciplined, and hard-working; these attributes were key in allowing the DPRK to make the economic strides that it did during the phase of heavy industrialization in the two decades following the Korean War. The DPRK workforce, however, suffers from a lack of technological training because of the DPRK's political isolation. In addition, the relatively low rate of growth of the population means that the workforce is aging. This trend may cause average workforce productivity to decline over the long term (all else being equal, as the ratio of active workers to retirees declines), and may present problems in retraining workers for new, higher-technology jobs (for example, to make goods that would be competitive in export markets). Academics and engineers involved in the basic sciences and in applied research and development probably also suffer lower productivity due to limited and tightly controlled contact with their peers in other countries, as well as a lack of up-to-date research equipment.

[85] In "reverse engineering", a device or technology is acquired from outside the country, disassembled, and evaluated to figure out how it works and how it was made. A domestic process for production of the item is then designed.

[86] In some cases, reportedly, the infrastructure exported to the DPRK from the former Soviet Union was built to extra-rugged specifications for longevity under DPRK conditions. Often, this involved a tradeoff that resulted in reduced energy-efficiency.

[87] Diesel generators were reportedly often incorporated into industrial plants built with USSR assistance to provide back-up power. It is likely that some newer generators have also come into use in recent years, particularly in, for example, military installations which reportedly build in more redundancy than other facilities, and in buildings and industrial plants serving organizations and markets from outside the DPRK.

The DPRK government has shown a preference for massive construction projects. This predilection, plus the ability to muster large workforces rapidly, is helpful when constructing hydroelectric impoundments and barrages (seawalls), as well as in conducting other large public works such as recovering from floods, but is less helpful in constructing smaller, more specialized, and more efficient equipment. The large outlays (reportedly up to $890 million per year, at one point[88]) by the government for massive monuments honoring the Kim regime have siphoned off money and labor that could have been used for energy-sector projects or other (arguably more useful) social infrastructure projects.

Another workforce issue is that a significant fraction (probably on the order of 15 percent) of the potentially economically active males is in the armed forces of the DPRK.[89] The duration of mandatory military service for men is reportedly up to ten years. Although soldiers often participate in public works projects and in some other civilian economic activities (such as harvesting of crops), the proportion of workers in the active armed forces (and the time spent by the five to seven—depending on the estimate—million reservists in undergoing military training) undoubtedly acts as a drain on the overall DPRK economy.[90]

In the years since about mid-2002, the DPRK's government has initiated several economic reforms leading to currency devaluation, wage, and (for some commodities) price reforms, and the limited recognition (and later, suppression, and still later, tacit acceptance) of private markets. These reforms have at times to some degree improved the availability of some commodities, but have also resulted in economic dislocation, as prices for commodities such as rice and other cereals have risen to the point where a worker's official monthly salary would buy only a few kilograms of basic foodstuffs, and as the general food distribution system, which formerly provided much of the food needs of residents, had ceased to operate in many areas of the country. DPRK delegations to meetings outside the DPRK have expressed the desire to obtain training on market creation and operation and noted the government's commitment to proceeding with economic reforms, but much remains to be done in these areas.

The process of DPRK economic reform, according to observers, is complex and not in a single direction, as internal struggles between DPRK officials who want to reform the economy, and those that want to maintain state control of markets, result in liberalization of some markets at times, but moves toward tighter control of other markets at other times. Overall, the direction of

[88] *Nikkei Shimbun,* 5/19/97, "ROK VICE PRIME MINISTER UNDERSTANDS JAPAN'S CAREFUL STANCE ON FOOD AID TO DPRK". Page 8.

[89] This rough estimate assumes a standing army of about 1 million men and a total of about 7.5 million men in the 18 to 65 age group, the latter from the DPRK's official 2008 Census. Estimates of the size of the army vary. Wikipedia, in its listing of the sizes of the world's armies ("List of countries by number of military and paramilitary personnel", available as https://en.wikipedia.org/wiki/List_of_countries_by_number_of_military_and_paramilitary_personnel), puts the DPRK military at 1.28 million troops, which at 50.4 troops per 1000 people in the country, gives the DPRK more soldiers per capita than any other country by a factor of two, with the runner-up being Israel. At about 1.3 million troops, the DPRK military is among the top four largest armies. Recent estimates based on the 2008 DPRK Census have suggested that the armed forces might be slightly smaller. *The Hankyorreh* ("[North Korea Census 2008] Korean People's Army estimated to number 700 thousand troops", dated 19 March, 2010, and available as http://english.hani.co.kr/arti/english_edition/e_northkorea/411106.html) suggested "..while a precise determination is impossible, it can be estimated that the scale of the Korean People's Army is 702,372 troops plus some additional, unspecified number. This differs markedly from South Korean Ministry of National Defense estimates, which put the size of North Korea's regular army at 1.19 million people as of December 2008. In view of the fact that 27 percent of enlisted men in the South Korean military as of 2008 were non-commissioned and commissioned officers with addresses outside their bases, analysts say there are grounds for viewing the Defense Ministry's estimates on the scale of the North Korean army as inflated."

[90] This in addition to the direct financial outlays for maintenance of the armed forces.

change during the middle years of the 2000s was toward market liberalization, but not all changes in DPRK economic policy implemented in the years since have been in that direction—some have been quite the opposite.

1.4.5. The “Agreed Framework” and KEDO

As a condition of the October 1994 Agreed Framework signed by the governments of the United States and the Democratic People’s Republic of Korea, the DPRK was to be supplied with two pressurized-water-type light-water nuclear reactors for electricity generation (referred to as PWRs or LWRs) in exchange for abandoning its existing graphite-moderated nuclear research reactors and taking further steps to comply with nuclear safeguards. Work at the reactor site (at Kumho, near the Sea of Japan/East Sea of Korea port city of Sinpo in the DPRK) began in August of 1997.[91] Under the agreement, until the reactors were completed the Korean Peninsula Energy Development Organization (KEDO) had an obligation under the Framework to supply 500,000 metric tonnes (te) of heavy fuel oil (HFO) to the DPRK annually. KEDO oil deliveries started in 1995, and deliveries in each "HFO year" (not necessarily corresponding to calendar years) thereafter totaled the agreed annual amount until December 2002, when deliveries were suspended.[92] The oil provided by KEDO was intended to be used to fuel electricity generation and district heating facilities.

This transfer of PWR technology under the Agreed Framework was sought by the DPRK as a means to maintaining both a civilian nuclear program and the threat of a military nuclear program. At the same time, the Framework was attractive to other nations (led by the United States) as a means to start the thawing of relations with the DPRK, as a way to lessen the probability of nuclear weapons proliferation, and as a means to exert better international control over the DPRK nuclear program. Funding for the PWR transfer was from the Korean Peninsula Energy Development Organization, which was formed in the mid-1990s, and which obtained its financing mostly from the ROK, with some additional inputs from the United States (particularly for HFO purchases), Japan (US$1 billion) and the European Union.[93] Following the erosion of relations between the United States and the DPRK in late 2002, and the DPRK’s subsequent withdrawal, in January 2003, from the international Treaty on the Non-Proliferation of Nuclear Weapons (NPT), and its related re-starting of previously frozen nuclear facilities, KEDO suspended construction on the PWR project. The project was formally terminated in mid-2006, and KEDO was disbanded.

Although energy efficiency and renewable energy measures could conceivably provide the same energy services to the DPRK economy as would the PWR, and could do so on at least a similar time scale and for lower cost,[94] energy efficiency measures are not, or at least to date have not

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[91] “KEDO breaks ground for reactor Project in N. Korea”, *The Korea Herald*, No. 13,639, August 20, 1997. Seoul, ROK. Page 1.

[92] Korean Peninsula Energy Development Organization (KEDO, 1996), *Korean Peninsula Energy Development Organization, Annual Report, 1995*. KEDO, Washington, D.C., July 31, 1996. "Appendix 1: HFO Deliveries" from Korean Peninsula Energy Development Organization (KEDO) *Annual Report 2001*, obtained from www.kedo.org, 5/31/2002. Information on suspension of oil deliveries from *Korean Peninsula Energy Development Organization, Annual Report, 2003*, obtained as http://www.kedo.org/pdfs/KEDO_AR_2003.pdf, 3/16/2007

[93] Though funding for KEDO has come from the countries indicated, the DPRK will be obliged to repay the funds loaned to build the PWRs. KEDO and the DPRK signed an agreement on June 24, 1997, specifying penalties to the DPRK if the DPRK fails to repay the loan (http://www.kedo.org/pdfs/ProtocolNonPayment.pdf).

[94] Von Hippel, D., and P. Hayes (1995), *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*. Nautilus Institute Report, Nautilus Institute for Security and Sustainable

been, politically substitutable for the PWR transfer.[95] The PWR transfer—or some similar arrangement that would allow the DPRK to acquire a working nuclear power reactor—has been considered a necessary first step to a political opening by North Korea, an opening that could lead to investments—including investments in energy efficiency—that will serve to integrate the economy of the DPRK with the other economies of the region. This integration would enhance stability and security in the region in the medium and long-term and is the underlying logic implicit in the hopes of US and ROK policymakers to achieve a "soft landing" for the DPRK economy and polity. A possible revival of the Six-Party talks (or a similar process) may offer a way of achieving an end to the DPRK's nuclear weapons program without the (eventual) construction of a PWR in the DPRK, but it is not yet clear whether other combinations of energy assistance will be considered by the DPRK leadership to be an adequate substitute for the modern nuclear power reactors promised under previous agreements. The DPRK's announced and apparently near-completed construction (if not yet operation) of their own, small, domestic LWR, and the DPRK's uranium enrichment facility revealed in 2010, have further complicated nuclear discussions with other parties, but may offer additional opportunities as well.[96]

1.5. Guide to Remainder of Report

The remainder of this report is organized as follows:

- In **Chapter 2**, we describe the key assumptions and background information that we used in preparing revised energy supply/demand balances for the DPRK for the years 1990 and 1996. The key results and uncertainties of our estimates for those years are presented as well.
- In **Chapter 3**, we give overviews of the methods, results, assumptions, and uncertainties of our analysis of the DPRK supply and demand for energy resources and fuels in the years 2000, 2005, 2008 through 2010, and 2014 through 2020. Estimates for the years 2000 and 2005, like those for 1990 and 1996, are as revised from previous analyses based on input from colleagues and from new sources of information. Estimates for the years 2008 and on are also based on our research, and include information from colleagues attending the June 2006 and March, 2008 DPRK Energy Experts Working Group Meetings, as well as the September 2010 DPRK Energy and Minerals Experts Working Group Meeting and many other sources.
- In **Chapter 4** of this report, we briefly renew what is known about the DPRK's natural resource base, focusing on fossil fuels and renewable resources including forests. Chapter 4

Development, Berkeley, California, USA. P. Hayes and D.F. Von Hippel (1997), "Engaging North Korea on Energy Efficiency". Chapter 9 in *Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula*, Young Whan Kihl and Peter Hayes, editors. M.E. Sharpe, Armonk, NY. Von Hippel, D.F., and P. Hayes (1996) "Engaging North Korea on Energy Efficiency". *The Korean Journal of Defense Analysis*, Volume VIII, No. 2, Winter 1996. Pages 177 - 221.

[95] For a much more thorough discussion of this issue, see D. von Hippel et al. (2001), *Modernizing the US-DPRK Agreed Framework: The Energy Imperative*. Nautilus Institute Report, February 2001. Available at http://nautilus.org/wp-content/uploads/2011/12/ModernizingAF.pdf.

[96] See, for example, Siegfried S. Hecker (2010), *A Return Trip to North Korea's Yongbyon Nuclear Complex*. NAPSNet Special Report, dated November 22, 2010, and available as http://www.nautilus.org/publications/essays/napsnet/reports/a-return-trip-to-north-korea2019s-yongbyon-nuclear-complex; Peter Hayes (2010), *DPRK Enriched Uranium Highlights Need for New US DPRK Policy*, dated November 22, 2010, and available as http://www.nautilus.org/publications/essays/napsnet/forum/dprk-enriched-uranium-highlights-need-for-new-us-dprk-policy; and D. von Hippel and P. Hayes (2010), *Engaging The DPRK Enrichment and Small LWR Program: What Would It Take?*, NAPSNet Special Report, dated December 23, 2010, and available as https://nautilus.org/napsnet/napsnet-special-reports/engaging-the-dprk-enrichment-and-small-lwr-program-what-would-it-take/.

also provides updated results of our brief analysis of the "energy efficiency" resource in the DPRK, in which we presernt our revised estimates of the potential cost and resource savings from the application of several key energy efficiency options for the DPRK energy demand and supply sectors.

- Estimates of electricity supply and demand in the DPRK from 1990 through 2020, with additional estimated end-use detail from 2010 through 2020, are provided in **Chapter 5**. This Chapter provides additional detail on the resources and infrastructure for electricity supply in the DPRK, and electricity demand by sector, as well as discussions of the meaning of the electricity sector analytical results for engagement of the DPRK on electricity sector topics.

- **Chapter 7** extends the description of the DPRK's resource endowment and related infrastructure by providing detail on what is known about the status of the non-energy minerals sector, including existing mining infrastucture and institutions in the DPRK, along with a summary of some of the key challenges facing the minerals sector. The resource picture described in Chapters 4 and 7, plus the capacity of the North Korean people, constitutes a key feature of the base on which future economic and energy development in the DPRK will be built, and must be considered in any plan for DPRK energy sector assistance.

- In **Chapter 8** of this report, we present a brief sketch of our revised analyses of "Rebuilding" and other future (through 2050) pathways, including pathways for the DPRK economy and energy sector, and describe some of the preconditions and impacts on the energy sector of such a path. Also described in Chapter 8 are a list of institutional changes—ranging from training to establishment of energy pricing practices to strengthening of regulatory agencies to setting out clear and consistent rules for commerce with foreign companies—that the DPRK should adopt and be assisted with in order to work toward rebuilding.

- Following on from the quantitative exploration of different DPRK energy futures in Chapter 8, in **Chapter 9** we address the implications of a possible collapse of the DPRK's government Although in this updated analysis we continue to emphasize that in our view, even given the multiple challenges facing the DPRK and its young leader, such a collapse is **<u>not</u>** likely, considering the possible implications of such a collapse provides insights into which policies by the international community are likely to be helpful in any kind of DPRK transition, whether abrupt or gradual and managed.

- In **Chapter 10** of this Report, we conclude by providing a summary listing of what we see as the key issues and options for constructive cooperation between the DPRK and the countries of Northeast Asia (and other regions) on energy-sector and related issues. Our suggestions as to attractive energy sector technologies and processes for energy sector redevelopment in the DPRK are also outlined in summary fashion. As such, Chapter 10 provides suggestions on a number of areas for international cooperation, including providing technical and institutional assistance in implementing energy efficiency measures, promoting better understanding of the North Korean situation in the ROK, working to open opportunities for independent power companies to work in the DPRK, and cooperation on technology transfer for energy efficiency and renewable energy. Key and attractive energy sector technologies and processes for energy sector redevelopment in the DPRK are identified, including rebuilding of the electricity transmission and distribution system—including both "top-down", or major overhaul/replacement, or "bottom-up" approaches, the latter using rapidly-developing renewable energy microgrid technologies to provide local power first, then knit together a functioning grid. Rehabilitation of power plants and other coal-using infrastructure, rehabilitation of coal supply and coal transport systems, development of alternative sources of small-scale energy and implementation of energy-efficiency measures, rehabilitation of rural infrastructure, advanced investigation of regional electricity grid interconnections, and gas supply and demand infrastructure development are considered in Chapter 10 as well. Also discussed, in response to the DPRK's construction and operation of a uranium enrichment facility and its construction of its Experimental Light Water Reactor, are possibilities for international cooperation with the DPRK on peaceful activities in the nuclear energy arena.

- **Attachments** to this report present detailed results of the estimates of DPRK supply and demand in 1990, 1996, 2000, 2005, 2008 through 2010, and 2014 through 2020, and present details on the data, assumptions, and analytical approach used in preparing those energy balance estimates. The attachments volume also presents details of our estimates of the potential costs and savings associated with the implementation of energy efficiency and related measures in the DPRK, of our estimates of key pollutant emissions (acid gases and greenhouse gases) in the DPRK in each of the years for which energy balances have been estimated, summary tables and graphics, and other analyses related to DPRK energy infrastructure.

2. Estimated 1990 and 1996 Supply/Demand Energy Balances

As a backdrop to the discussion of cooperation strategies and other recommendations discussed in Chapter 10 of this Report, as well as to the estimates of energy demand and supply for later years (Chapter 3) and for the electricity sector in particular (Chapter 5) this Chapter describes the inputs to and results of our estimated 1990 and 1996 energy demand-supply balances for the DPRK. In this Chapter we provide a brief description of the overall approach we used in assembling the estimated supply and demand balance for the DPRK in 1990 and updating it to 1996 (section 2.1). Next, we provide more detailed descriptions of the estimation procedures used for each major part and sub-part of the balance:

- The final demand for the fuels used in the North Korean economy in 1990 and 1996, by economic sector and (in some cases) subsector, is detailed in section 2.2.
- Section 2.3 covers energy supply (domestic energy resource production, imports, and exports) for non-electric fuels
- Fuel transformation processes, including electricity generation, transmission, and distribution, are described in Section 2.4.

The final section of this chapter, section 2.5, presents our estimated 1990 and 1996 DPRK energy supply and demand balances, and discusses some of the key results and uncertainties in the balances, their ramifications, and the questions that they pose for follow-up research. The approach used here, as well as the discussion that follows, are in large part taken from our earlier work. The reader should note, however, that the 1990 and 1996 balance estimates, and the detailed results reported, have changed somewhat from those presented in our earlier reports, as we have incorporated recently-obtained information about the status of the DPRK energy sector in 1990 and 1996. The approach used to prepare the 1996 energy balances, that is, to update the 1990 balance based on reported or inferred changes in the energy sector between 1990 and 1996, is the same general approach used to prepare energy balances for subsequent years (2000, 2005, 2008 through 2010, and 2014 through 2020), as presented in Chapter 3. This Chapter therefore describes the basic approach to preparing energy balances in subsequent years, thus the data and results presented in Chapter 3 are incremental to the data and results presented here, focusing on changes between the years covered.

2.1. Goals and approach in preparing 1990 and 1996 supply/demand balance

To assess measures to improve the energy sector of the DPRK (or any country), including the potential for energy efficiency improvements, implementation of renewable energy sources, or, in the case of the DPRK substantial energy sector redevelopment, it is first necessary to learn something about the way that energy is supplied and used in the area under study. One way to obtain a single-sheet "snapshot" of the energy system in a particular country in a given year is to assemble a **supply-demand balance**. This type of table lists the sources of the fuels used in the economy, shows the processes that produce or refine primary fuels for end-use consumption (such as electricity generation facilities), and lists the final demands for fuels, typically by sector.

The work presented in this document builds on Nautilus research, funded by the W. Alton Jones Foundation, which culminated in a 1995 report entitled *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*, plus further research in 1997, funded by the Northeast Asia Economic Forum/East-West Center, that produced *Demand and Supply of Electricity and Other Fuels in the Democratic Peoples' Republic of Korean (DPRK)*. In our 1995 work, we prepared an estimated energy supply/demand balance for the DPRK for the year 1990 that synthesized the information available to us on the North Korean economy and energy sector. In the 1995 report, the energy balance results were used to estimate the (by any measure, considerable) potential for energy-efficiency improvements in the DPRK. Our 1997 work produced an estimated energy balance for 1996 and used it as the starting point for quantitative energy "scenarios[97]" for the DPRK for 2000 and 2005. Our 2002/2003 report, *The DPRK Energy Sector: Estimated Year 2000 Energy Balance and Suggested Approaches to Sectoral Redevelopment*, prepared with funding from and in collaboration with the Korea Energy Economics Institute, updated our analysis to a 2000 "base year". Our 2007 report, *Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths*, provided a further update to a 2005 base year, and our last (before the current report) comprehensive published version of our DPRK Energy Analysis work was *Foundations of Energy Security for the DPRK: 1990-2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment*, extending the analysis to the years 2008 and 2009.[98]

In preparing the 1990 energy balance estimate, we:

- Collected available energy and other data on DPRK. The documents assembled included international and regional publications providing statistics (energy, industrial and agricultural output, infrastructure) on the DPRK; documents (in Korean) on the DPRK energy and economic situation obtained from South Korean (ROK) studies and other sources such as Russian analysts; official statistics provided by the DPRK government; historical documents on energy use in ROK; and other documentation from the authors' files.
- Collected energy statistics and other energy-sector data on economies that are likely to be similar, in some ways (such as types of infrastructure) to that of the DPRK (or were similar at some time in the relatively recent past). This process included collection of energy sector intensity data from the international literature[99] for the People's Republic of China, the Former Soviet Union, and the countries of Eastern Europe.

[97] Nautilus typically uses the term "scenario" to refer to fictional, typically qualitative narrative "snapshots" of what the future might hold based on uncertainty in key parameters (see, for example, A *Korean Krakatoa? Scenarios for the Peaceful Resolution of the North Korean Nuclear Crisis*, Nautilus Institute, dated August 2003, and available, as http://nautilus.org/wp-content/uploads/2011/12/DPRKscenarios2003.pdf), whereas "path" or "pathways" present linear, often quantitative descriptions of future conditions that are derived from current conditions, assuming certain changes. Based on these definitions, the 2000 and 2005 analyses contained in our 1997 work would be referred to as energy paths, but at the time we referred to them as "scenarios". In this report, which focuses on quantitative results in looking at future possibilities for the DPRK energy sector, we tend to use the terms "path" and "scenario" interchangeably.

[98] David von Hippel and Peter Hayes (2012), *Foundations of Energy Security for the DPRK: 1990-2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment*, NAPSNet Special Reports, dated December 18, 2012, and available as https://nautilus.org/napsnet/napsnet-special-reports/foundations-of-energy-security-for-the-dprk-1990-2009-energy-balances-engagement-options-and-future-paths-for-energy-and-economic-redevelopment/,

[99] In particular, the Energy Analysis Program at Lawrence Berkeley Laboratory, Berkeley, California, USA.

- Synthesized the information available and organized it by balance element (supply, transformation, demand), by fuel, and by subsector (when possible). We further categorized the types of information we collected as direct data on the energy system of the DPRK, including the *amount of energy produced or consumed*, and capacities of key infrastructure; data on *activities* relevant to energy use in DPRK, including the physical output (tonnes of steel produced, for example) in key subsectors, and other physical, social, and demographic factors such as population and agricultural land area; and data on the *intensity* of energy use. In the case of energy intensities in particular, very little information specific to the DPRK was available, so analogous and "placeholder" data from other countries, usually China or the former Soviet Union, were often used.

The detailed inputs to and results of our 1995 work are presented in the 1995 report described above. This report was disseminated widely to specialists on Korea and on energy analysis in developing countries, with briefings in Washington, Tokyo, and Seoul. Copies of this earlier study were supplied also to DPRK authorities. The 1990 energy balance produced as above was revised to reflect comments on the original 1995 study and information recently received. It was then used as the starting point for estimating and projecting year 1996, 2000, 2005, 2008, and 2009 energy supply and demand, as described below.

Countries maintain statistics on energy supply and demand at differing levels of detail and aggregation; some have very good statistics, while others do relatively little data gathering, and what information does exist is of poor quality. These differences are often reflected in international compendia of energy statistics, such as the IEA/OECD Energy Statistics and Balances, which rely on data from the various countries themselves, as well as other sources[100]. In the case of the DPRK, it is probable that fairly good statistics on energy supply and demand do exist, but these data are probably in many different hands, and may not have been assembled to provide a coherent picture for the DPRK energy economy as a whole.[101] In addition, the North Korean government is reluctant to provide data to outsiders.[102] As a consequence, our efforts to assemble an energy supply and demand balance for DPRK had to rely on what few official statistics were available, augmented by data from a host of other sources, as detailed below.

Although the process that we followed in evaluating energy supply and demand in the DPRK is bound to produce energy balances that "fit" the DPRK poorly in some areas, it is our hope that in future collaboration with DPRK energy experts we will be able to use the balance described and

[100] For the case of the DPRK, the IEA (International Energy Agency) had not (as of 1995) significantly updated its country-specific energy balances and other statistics for several years, as it has judged the incremental data that has been available to it to be untrustworthy (IEA, John Soderbaum, personal communication, 1995). In addition, the DPRK energy balances available from the IEA are at a highly aggregate level, with little sectoral detail.

[101] Those familiar with the operation of the DPRK bureaucracy suggest that probably no one in the DPRK, with the possible exception of Kim Jong-il and a few of his closest advisors (and now Chairman Kim Jong Un), has had (or has) statistics that describe the entire span of the DPRK's energy economy. Any given government or Party official would have custody of statistics bearing only on his or her direct responsibilities, and no more. In addition, reports are reportedly frequently altered as they are passed up the chain of command to present to supervisors a rosier picture of, for example, energy or industrial production. These alterations mean that when and if the overall statistics for the economy are actually compiled for top officials, they are likely to be in error. It should be noted that some observers, however, feel that the trend toward exaggeration of statistics in the DPRK has changed somewhat in recent years (for example, since 2000), and that the few official DPRK statistics that are made available to outsiders are, in fact, now relatively reliable.

[102] This applies especially to those from outside DPRK, but probably applies to the internal sharing of information, for example, between government organizations, as well. Many countries, however, share this trait to varying degrees.

presented below as a starting point to develop better information for use by both the international community and by the DPRK itself. Moreover, as the balance is built up from many independent observations, estimates, and assumptions, we feel that the probability is reduced that any one off-base assumption or erroneous piece of data has considerably altered the overall accuracy of the assessment.

It should be noted that other estimates of DPRK energy supply demand balances have been developed over the years, and we have consulted those estimates available to us, and in some cases, collaborated with other researchers developing balances. Notable among other estimates of DPRK energy balances are those developed by our colleagues at the Korea Energy Economics Institute (KEEI), as described in a presentation to the 2006 DPRK Energy Experts Working Group Meeting by Dr. Kyung-Sool Kim of KEEI.[103] The International Energy Agency (IEA) also maintains some energy statistics, including an estimated energy balance, for the DPRK.[104]

2.1.1. Study approach

Our approach in preparing an estimated 1990 supply-demand balance for the DPRK proceeded in several steps, as follows:

1. Collect available energy and other data on the DPRK. The documents assembled (most of which are referenced in the footnotes, bibliography, and/or attachments volume to this study) included:
   - International and regional publications providing statistics (energy, industrial and agricultural output, infrastructure) on the DPRK.
   - Documents (in Korean) on the DPRK energy and economic situation obtained from South Korean (ROK) studies and other sources such as Russian analysts.
   - Official statistics provided by the DPRK government.
   - Historical documents on energy use in the ROK.
   - News reports from around the world related to the DPRK's economy and/or energy system.
   - Other documentation from the authors' files, and personal conversations and correspondence with others interested and conversant in DPRK issues.
2. Collect energy statistics and other energy-sector data on economies that are likely to be similar, in some ways (such as types of infrastructure) to that of the DPRK. This process included collection of energy sector intensity data from the international literature[105] for the People's Republic of China, the former Soviet Union, and the countries of Eastern Europe.

[103] Kyung-Sool Kim, "DPR Korean Energy Demand/Supply Analysis: Energy Balance Sheet 2003", prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as https://nautilus.org/?s=DPR+Korean+Energy+Demand%2FSupply+Analysis%3A+Energy+Balance+Sheet+&cat=0&lang=&sort
[104] The IEA's most recent (2009) energy balance for the DPRK, for example, is available as https://www.iea.org/countries/korea-democratic-peoples-republic-of.
[105] In particular, the Energy Analysis Program at Lawrence Berkeley Laboratory, Berkeley, California, USA.

3. Synthesize the information available and organize it by balance element (supply, transformation, demand), by fuel, and by subsector (when possible). We further categorized the types of information we collected as:

   - *Direct data on the energy system* of the DPRK, including the amount of energy produced or consumed, and capacities of key processes (including power plants)
   - *Data on activities relevant to energy use in the DPRK*, including the physical output (tonnes of steel produced, for example) in key subsectors, and other physical, social, and demographic factors such as population and agricultural land area.
   - *Data on the intensity of energy use*. In this case, little information specific to the DPRK was available, so analogous and "placeholder" data from other countries, usually China or the former Soviet Union, were often used.

4. Use the data collected to estimate energy supply and demand by fuel, transformation process, sector and subsector, incorporating judicious (it is hoped) assumptions and placeholder values where necessary. These estimates have been prepared in an easily-modified Microsoft Excel "workbook" of many linked "spreadsheets" covering the supply of and demand for energy, so that as more information becomes available, from DPRK officials or others, our balance can be updated and improved.

We chose 1990 to be the base year for our estimated supply/demand balance for several reasons. First, it was (as of the start of our work in 1994/95) sufficiently recent to pertain to current conditions, but sufficiently far in the past that we could expect to find relatively complete energy and economic statistics. Second, 1990 represented a watershed year for the DPRK economy, in that after 1990 the continuing withdrawal of financial and other aid, as well as trade credits, from the former Soviet Bloc has contributed to a spiral of decreasing production and consumption in virtually all sectors.[106] As a consequence, we felt that 1990 was a reasonable choice to represent a North Korean economy operating on a roughly "business as usual" basis, at least for the period before the dissolution of the Soviet Bloc.

The output of steps 3 and 4 above are synthesized as part of the workbook titled "Estimated/Projected Energy Supply/Demand Balances: Democratic People's Republic of Korea (DPRK)", an updated version of which is printed out as Attachment Volume 1 to this report. A printout of an additional workbook, used to prepare estimates of annual fuel use in the DPRK military, is provided as Attachment Volume 2. Though the remaining sections of this chapter provide detail on how the elements of the estimated supply/demand balance were assembled, the reader is urged to refer to the Attachments for additional information, details on data and assumptions used, and specific references.

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[106] Some observers, in fact, argue that 1989 was the peak year for the DPRK economy and energy sector, and that spending on public works (for example, venues for the 13th World Festival for Youth and Students, held in Pyongyang in July of that year—see, for example, "Photos Highlight 50-Year State History-On Occasion of Golden Jubilee of DPRK", formerly available at http://www1.korea-np.co.jp/pk/058th_issue/dprk50thann/98090201.htm) helped to begin the downward slide of the DPRK economy, which accelerated when the Soviet Union/Russia began withdrawing economic support for the DPRK. It has been argued that the DPRK's spending in hosting the Youth Festival reduced needed investment in other key sectors (including the energy sector), contributing substantially to an economic decline that started in 1990. See "Energy 'Crisis' Threatens Economy", Pukhan (Seoul, ROK) March 1993, pages 39-45, by Naeoe Tongsin reporter Kim Sang-hwan. Economic activity in the DPRK in 1990 was apparently slightly less than in 1989.

An estimate of the potential for energy efficiency and renewable energy measures in the DPRK was discussed in some detail in the 1995 report mentioned above and in other papers prepared by the authors.[107] A version of this analysis updated to recent years is presented in Section 4.5 of this Report.

Our overall approach to preparing a DPRK energy supply-demand balance for 1996:

- Starts with the estimates of demand and supply prepared above for the 1990 "base year"
- Modifies the 1990 estimates of demand for electricity and other fuels to reflect reports of recent changes in conditions in the DPRK. These included population growth, reduced availability of oil products, observed changes in the transport system, and reported reductions in industrial, agricultural and fisheries output.
- Revises our 1990 estimates of electricity supply to meet 1996 electricity demand and to reflect information about recent changes in thermal and hydroelectric generating capacity.
- Estimates 1996 oil supply in a way that reflects available information, including the capacities, product slates, and utilization of the oil refineries in the DPRK, and quantities of refined products reportedly imported by the DPRK, and reportedly exported to North Korea by the DPRK's trading partners, during 1996.
- Revises oil products demand as initially estimated to meet the overall supply for each of the major classes of oil products (heavy fuel oil, diesel oil, gasoline, and kerosene).
- Sets the level of coal and biomass supply to meet demand, re-adjusting supply of other fuels as necessary to produce a rough balance in overall supply and demand.
- Evaluates the implications for demand for heavy fuel oil supplied in 1996 by KEDO.

In updating our 1990 energy balance to 1996, as well as in subsequent research, we contacted specialists in DPRK energy issues and economics, including those who deal or dealt with the DPRK in business and/or regularly visit or visited there, to obtain their data, thoughts and observations on recent developments the DPRK. Except where explicitly cited in the notes presented in Attachment 1 or in this chapter, these sources have chosen to remain confidential.

Key changes in the DPRK energy sector between 1990 and 1996 included:

- A reduction in the supply of oil products due to the virtual cessation of crude oil supplies from the Former Soviet Union.
- A considerable reduction in industrial production, which reduced demand for (and thus production of) coal and electricity. Disentangling the causes of the decline in industrial output is difficult, but lack of oil products for industrial plants and goods transportation, lack of foreign exchange capital to pay for parts to repair industrial and mining equipment, and lack of international markets for DPRK industrial goods all played roles.

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[107] Von Hippel, D. F., and P. Hayes (1995), *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*. Nautilus Institute for Security and Sustainable Development, Berkeley, CA, USA. December 1995. P. Hayes and D.F. Von Hippel (1997), "Engaging North Korea on Energy Efficiency". Chapter 9 in *Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula*, Young Whan Kihl and Peter Hayes, editors. M.E. Sharpe, Armonk, NY. Von Hippel, D.F., and P. Hayes (1996) "Engaging North Korea on Energy Efficiency". *The Korean Journal of Defense Analysis*, Volume VIII, No. 2, Winter 1996. Pages 177 – 221, available from https://www.tandfonline.com/doi/abs/10.1080/10163279609464577.

- A reduction in transport generally, and a reduction in the use of oil products in the transport and agricultural sectors, with biomass and human and/or animal labor serving as partial substitutes for gasoline and diesel fuel.

The key assumptions and data used in preparing our estimated supply and demand balances for 1990 and 1996 are presented below by sector (for demand) and by fuel group (for supply). In each case, details of the data, calculations, assumptions, and sources used are presented in Attachments 1 and 2 to this report.

2.2. Summary of Methods and Data used to Estimate 1990 and 1996 Demand for Energy

Our estimated DPRK supply-demand balance breaks final fuel demand into the following sectoral categories:

- *Industry*, including many different subsectors;
- *Transport*, including road, rail, water, air and "non-specified" transport modes;
- *Residential*, which is further divided into the urban and rural subsectors;
- *Agricultural,* including field operations and a "processing/other" category;
- *Fisheries*, divided into fuel used in large ships and in processing and other operations;
- The *Military* sector, including accounting for each branch of the military (ground, air, and naval forces), and estimates for energy use in manufacturing military equipment and in military "buildings and other";
- The *Public and Commercial* sectors;
- *Non-Specified/Other* energy use, a placeholder category; and
- *Non-Energy* use of fuels.

Our methods for estimating the amount of fuel used in each of these sectors are discussed below. In some cases, the discussions below overlap with the descriptions of methods used to evaluate 1990 and 1996 electricity use by sector as described in section 5.3 of this Report.

2.2.1. The industrial sector in 1990

The industrial sector in the DPRK consists of a variety of energy-intensive heavy industries and a number of light industries. To estimate energy use in this sector, our basic approach has been to gather all of the data on the physical output of specific industrial products that we could find, and multiply those physical output figures by per-unit energy intensities obtained mostly from studies of Chinese industries.[108] In a very few cases, we had and used anecdotal figures for

[108] An alternative approach would have been to obtain output figures expressed in monetary terms and use energy intensities per unit financial output. Unfortunately, the command-and-control nature of the DPRK economy, coupled with the fixed and essentially arbitrary exchange rates of the DPRK currency with hard currencies such as the dollar, make this approach unusable for most subsectors. Because of the lack of true markets in DPRK (until recently, and even now limited to only selected classes of goods), the prices of goods have no particular relationship to the actual value that the goods would have in a market economy (even a partial market economy like China's), thus cross-national comparisons of per-monetary-unit intensities are highly problematic (when one of the nations is North Korea).

energy intensities of key industrial plants in the DPRK, and in a few other cases we were able to use historical energy intensities from the Soviet Union as provided by a colleague in Russia.[109]

It has been estimated that 60 percent of the industrial infrastructure in the DPRK was developed with substantial technical assistance from the former Soviet Union. As such, for many subsectors we realize that it would have been more appropriate to use energy intensity factors from the USSR experience than to use Chinese factors, but we have not as of yet had access to sufficient energy intensity data from the USSR to allow us to do so. Happily, our limited experience thus far has been that industrial energy intensities in the USSR and in China were often not terribly different.

Note that we have made the general assumption that industries in the DPRK are at least 10 percent more energy intensive than those in China whenever Chinese energy intensities were used, and 15 percent more energy intensive than USSR where Soviet energy intensities were used. Although these estimates are little better than guesses, we believe that they are appropriate given (among other reasons) A) the testimony of travelers to DPRK about the generally poor condition of North Korean industrial facilities; B) the vintage of most industrial plants in DPRK (few were built more recently than the 1970s, and some are leftovers from the Japanese occupation of the 1930s and 1940s); C) the low quality of much of the DPRK's coal, which contributes to poor combustion efficiencies; and D) reports of how Soviet industrial designs were “beefed up” to allow equipment to stand up under difficult conditions in the DPRK.

The output units and energy intensities we used for each industrial subsector, and their sources in the literature, are provided in Table 2-1. The specific methods used to derive fuel use for each subsector are detailed in the "Industry" pages of Attachment Volume 1. Notes on the methods used for selected subsectors are provided below.

[109] Data for energy intensities in several industrial subsectors was provided to us by Dr. V. Kalashnikov (personal correspondence, September 1997).

Table 2-1: Energy Intensity Assumptions by Industrial Subsector

ENERGY INTENSITY ESTIMATES USED IN ESTIMATES OF FUEL USE IN THE DPRK INDUSTRIAL SECTOR, 1990			
Industrial Subsector	Output Units	Fuel Use Intensity (tce/Unit)*	Electricity Use Intensity (kWh/Unit)*
Iron and Steel	te crude steel	1.85	805
Cement	te clinker	0.235	110
---Fraction of input fuel as coal		90%	
Fertilizers--Ammonium	te NH_3	1.71	5,760
---Additional Heavy Oil and Naptha used as Feedstock		0.55	
Fertilizers--Superphosphate	te P_2O_5	9.71	16,258
Other Chemicals--Carbide	te Ca Carbide	0.82	4,571
Other Chemicals--Caustic Soda	te	0.96	2,413
Pulp and Paper**	te pulp	0.89	1,674
Other Metals--Zinc	te	2.72	4,228
Other Metals--Copper	te	1.88	1,364
Other Metals--Aluminum	te	2.11	17,655
Other Metals--Lead	te	2.96	203
Other Minerals***	te Magnesia	0.43	110
Building Materials--Glass	50 kg case	0.0339	34
Building Materials--Bricks	10,000 pieces	2.39	
Textiles--Printing and Dyeing	running meter	4.39E-04	
Textiles--Vinalon fiber	te	6.032	5,400

* Intensities shown are adjusted upward to take into account 10 and 15 percent "intensity inflators" used when applying energy intensities from Chinese and Russian data (respectively) to DPRK Industrial sub-sectors. Fuel is coal except as noted.

** Assumes that half of non-electric fuel use for paper production is provided by mill wastes and other wood by-products (but fuel use intensity shown includes both use of wood and coal).

*** Intensity shown for magnesite production is use of heavy fuel oil (not coal) per tonne of product.

Please see "Industry" section of Attachment 1 for detailed notes and data sources.

In the *Iron and Steel* industry, we have used an official estimate of steel production (assumed to be raw steel) that is somewhat higher than estimates from outside observers, and substantially higher than steel output estimates for the years since 1990. Although our method for calculating solid fuel consumption in this industry uses separate intensities for coal and coke use, we have not tried to account separately for non-energy use of coke, that is, for that fraction of the carbon in coke that becomes carbon in steel. For electricity consumption in the industry, we have used an energy intensity based on 1965 and 1980 values in Soviet steel plants (700 kWh/tonne, before application of the "Intensity Inflator" described in Table 2-1).[110] By way of comparison, intensities in "key, medium and small plants" in China as of 1987[111] were somewhat higher (890 kWh/tonne).

For the *Cement* industry, after reviewing available estimates, we have concluded that the official output figures (13.9 million tonnes) from the National Report of DPRK to UNCED (dated 1992), may be somewhat overstated, and thus use a somewhat lower estimate of output (11 million tonnes) for 1990. This is generally consistent with the report by dprkguidebook.org that "[t]he country's overall cement industry is made of a total of 30 plants and has a total capacity of about 12 Mt/yr."[112] We use a DPRK-specific coal-use intensity that is slightly higher than energy intensities for Chinese plants,[113] and quite close to the 1980 intensity reported for cement plants in the former USSR.

Our data for the *Fertilizer* industry should be considered incomplete. Although we reviewed several different estimates for overall fertilizer production, there are several different nutrients provided by fertilizers, and several different compounds, delivering vastly different amounts of nutrient per unit weight of compound, for each nutrient.[114] We have used DPRK-specific coal- and electricity-use intensities for ammonium production, and an assumption that overall consumption of nitrogen fertilizer was 600,000 tonnes of nitrogen.[115] Depending on the formulations of nitrogen fertilizer used, this figure could be roughly consistent with other estimates of nitrogen and overall fertilizer use and production. Included in our calculus is an estimate of nitrogen fertilizer imports from the former Soviet Union, which reportedly amounted to about 100,000 tonnes (N basis) in 1990.[116] We assumed that essentially most of the nitrogen fertilizer is based on ammonia produced via the DPRK-specific industrial process outlined (by a DPRK official)[117] and that the energy needed to convert ammonia to the other forms of nitrogen fertilizers used (including urea, ammonium nitrate, ammonium sulfate) is either included in the energy intensity we used, or is minimal relative to the energy needed to manufacture ammonia[118]. Based on a process diagram for the Hamhung Fertilizer complex, we estimated that roughly half of the coal used in ammonia manufacture is used as a feedstock. We categorized this fraction as a non-energy fuel use. Also categorized as non-energy use are inputs of heavy oil and of naptha (a light hydrocarbon product) to fertilizer manufacture, as a recent source indicates that key DPRK fertilizer factories make use of these feedstocks.[119] Another major facility for production of both fertilizer and chemicals/plastics is the Namhŭng Youth Chemical Complex,

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[110] V. Kalashnikov, personal communication, 9/97.
[111] Ross, M. and L. Feng (1990), "The Energy Efficiency of the Steel Industry of China". *Energy*. V. 16, No. 5, pp. 833-848, 1991.
[112] Dprkguidebook.org (undated, but probably 2006 or 2007), "Main Industrial Sectors & Business Opportunities", formerly available as http://dprkguidebook.org/contents_3.htm.
[113] Document in authors' files [CE1].
[114] For example, a tonne of anhydrous ammonia (NH_3) delivers approximately 820 kg of nitrogen, while a tonne of ammonium sulfate ($(NH_4)_2SO_4$) provides only about 210 kg of nitrogen.
[115] Document in authors' files [H1].
[116] We have thus assumed that the DPRK produced about 500,000 tonnes (as N) of nitrogenous fertilizers).
[117] Document in authors' files [HT1].
[118] The electricity intensity of urea manufacture in China, for example, appears to be two orders of magnitude less than that for ammonia.
[119] R.V. Misra, "Agriculture and Fertilizer Situation in DPR Korea", formerly available as http://www.fertilizer.org/ifa/publicat/PDF/2006_crossroads_misra_slides.pdf (from the International Fertilizer Industry Association), and presented as part of the "IFA Crossroads ASIA-PACIFIC 2006 Conference 'Growing markets, nurturing success'", Chiangmai, Thailand, 13-16 November 2006.

located near Anju, in South P'yŏng'an Province. This complex, reportedly built in 1976 with Japanese, French, and West German equipment, has a total capacity of 550,000 tonnes/yr (all outputs), including 400,000 tonnes of urea and 20,000 tonnes of synthetic fibers and resins (Orlon, polyethylene, and others). It uses electricity from the nearby Ch'ŏngch'ŏn River Thermoelectric Power Plant. The plant is reported to have added equipment in 2000 to produce sodium carbonate, and "…has a French-built polyethylene production facility that uses intermediates of propylene and butane. There is also equipment imported from Japan that is used to produce ethylene, ethylene oxide, and ethylene glycol."[120] Figure 2-1 provides a photo of another major fertilizer complex, at Hungnam

Figure 2-1: Photo of Hungnam Fertilizer Complex, South Hamgyong Province[121]

We have a rough figure for the production of superphosphate fertilizer (P_2O_5); have assumed that all superphosphate fertilizer is made from elemental phosphorous (which may not be correct); and have calculated the energy needed to manufacture superphosphate based on its phosphorous content. This method may overstate the energy needed to make phosphate fertilizers.

Although other fertilizers, including potassium fertilizers, are in use in DPRK, we have no data on production of these compounds. Because the volume of nutrients other than nitrogen (N) and phosphorous (P) required by plants is substantially less than the amount of N and P needed, the energy needed to manufacture these other fertilizers may be small relative to that required to make N and P fertilizer.

Energy use in our *Other Chemicals* category is limited to the coal, electricity, and petroleum products used in the production of carbide, a feedstock for the synthetic fibers and plastics

[120] From the Nuclear Threat Initiative (NTI, 2011), "Namhŭng Youth Chemical Complex", prepared for NTI by the James Martin Center for Nonproliferation Studies at the Monterey Institute of International Studies, available as http://www.nti.org/facilities/609/.

[121] Photo from dprkguidebook.org (date not provided, but probably 2006 or 2007), "Main Industrial Sectors & Business Opportunities", formerly available as http://dprkguidebook.org/contents_3.htm.

industry, and caustic soda. Other compounds, including sulfuric and nitric acids, are produced in fairly large (though uncertain) quantities in the DPRK, but we were unable to locate suitable energy intensity data. For carbide, we were guided by a process diagram for the Hamhung Chemical complex in DPRK that allows the calculation of rough coal and electricity use intensities. These values (particularly the coal use) appear to be slightly higher than similar values for Chinese industry. This fact is not entirely surprising, given the fairly unique coal-based process for carbide manufacturing used in this complex. The energy used in caustic soda (sodium hydroxide) manufacturing was calculated using USSR and Chinese figures for coal and electric energy intensities (respectively).

It has been reported (by DPRK officials[122]) that 30 percent of all oil (assumed to mean refined products) use goes into making carbide. This assertion would seem to be at odds with the coal-based process used at the Hamhung plant, and has also been contradicted by reports by others. As a result, we have assumed that carbide manufacture is not, in fact, a major use of fuel oil. If one assumes, however, that carbide is a precursor to virtually all plastics manufactured in DPRK, we may not have accounted for all of the carbide produced in the DPRK as of 1990. This possibility is supported by the fact that our assumed production of carbide by the Hamhung plant (350,000 tonnes) would likely be more than consumed solely in the production of textile fiber, given the level of DPRK textile production that we are using (see below).

In the *Pulp and Paper* sector, estimates of paper output from the Economist Intelligence Unit[123] were coupled with coal and electric energy intensities from Chinese data, and include a working assumption that 50 percent of the (non-electric) fuel energy needed required to produce pulp and paper is provided by wood wastes or other by-product fuels such as "black liquor".[124] This assumption ultimately may or may not prove to be correct for the DPRK; we have seen reports that disposal in rivers of paper mill wastes in some areas of North Korea is a significant environmental problem, suggesting that by-products such as black liquor are in fact not used as fuels.

For the production of *Other Metals*, our analysis includes only Zinc, Copper, Lead, and Aluminum. Although these are apparently the non-ferrous (non-iron) metals produced in the greatest volumes in the DPRK, they are hardly an exhaustive list of the metals found or produced there. Chinese coal- and electricity-use intensities were used to estimate the amount of fuel used in producing these products. The electricity intensities used for all of these metals except aluminum also include the electricity needed to mill the metal ores. The collapse of a barter deal with international food corporation Cargill Inc. in mid-1997 has been attributed to the DPRK's inability to supply the requisite quantities of zinc in exchange for wheat. This inability to produce zinc suggests that the minerals sector may have been operating at very low capacities by 1997, and/or that fuels and/or minerals transport facilities may not have been available to export the zinc.

In the *Other Minerals* category, we include magnesite, a refractory mineral present in abundance (and high quality) in the DPRK and produced in significant quantities (approximately one

[122] Document in authors' files [HT1].

[123] The Economist Intelligence Unit (1994), *South Korea, North Korea No. 1 1994.* The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.

[124] "Black Liquor" is a byproduct of the kraft pulping process that includes lignin, hemicelluloses and other components liberated by heat and chemical treatment from the cellulose wood fibers used in paper.

million tonnes) as of 1990.[125] For magnesite, we used a reported estimate for the intensity of heavy fuel oil use in DPRK magnesite refining,[126] and assumed that electricity requirements per tonne of magnesite produced would be similar to that needed to process chemically similar cement "clinker" from limestone.

In the *Textiles* industry, we started with estimates of the running meters of textiles produced in the DPRK, applied an average weight per meter figure (approximately a quarter kilogram per meter), and assumed that essentially all fabric was made of the "vinalon" fiber manufactured at the Hamhung complex (and other places). Most of the coal used for textile production is thus used in manufacturing vinalon from carbide; some is also used in the printing and dyeing of fabrics. The coal and electric energy intensities of vinalon production were estimated based on a process flow diagram provided by DPRK officials.[127]

Although *Building Materials* can be expected to be an important subsector for DPRK industry, we could find no data for the DPRK output of key materials (other than cement, which is accounted for separately). To estimate placeholder fuel consumption values for two key products—glass and bricks—we made the assumption that the per-capita production of these items in the DPRK in 1990 were similar to per-capita production in China in the same year. Using per-capita figures derived from Chinese data, we applied a DPRK population estimate to derive figures for total glass and bricks production in North Korea, then applied Chinese energy intensity values for these products to estimate the use of coal and electricity by the subsector.[128]

To provide sufficient demand to meet estimates of fuel supply in 1990, we included placeholder values for coal, petroleum product, and electricity use in *Non-specified* industries. These values amount to approximately 15, 13, and 15 percent of the total industrial demand for these fuels, respectively.

2.2.2. Changes in industrial output for 1996

The detailed calculations and data that we used to produce our 1990 estimates of energy use in the industrial sector, and to update them to 1996 and beyond, are presented in Attachment 1. Our estimates of 1996 industrial output relative to 1990 are presented in Table 2-2.

[125] Trigubenko, M. (1991), "Industry of the DPRK". Paper presented at Korea Development Institute symposium, Seoul, ROK, October 1991. Quoted in The Economist Intelligence Unit (1993?), *China, North Korea Country Profile 1992-1993*. The Economist Intelligence Unit, London, United Kingdom.

[126] The value supplied, 300 kg oil equivalent per tonne of magnesite produced, is similar to estimates for coal use in magnesite production elsewhere in the world.

[127] Document from authors' files [HT1].

[128] The coal use intensity for glass production that we used (from Chinese experience) is about 15 percent lower than that reported for Soviet plants in 1965 (V. Kalashnikov, personal communication, 9/97).

Table 2-2: Assumptions for Changes in Industrial Production in 1996

Subsector	1996 Production Relative to 1990
Iron and Steel	35%
Cement	40%
---- fraction of heat from heavy oil	10%
Fertilizers	25%
Other Chemicals	30%
Pulp and Paper	30%
Other Metals	30%
Other Minerals	30%
Textiles	30%
Building Materials	30%
Non-Specified Industry--non-oil fuels	33%
Non-Specified Industry--diesel oil	20%
Non-Specified Industry--heavy oil	30%

For the steel and cement subsectors, we assumed production in 1996 of 2.1 and 4.4 million tonnes, respectively, or somewhat lower than 1992 production estimates from ROK sources.[129] We assume that fertilizer production decreased to less than 25 percent of its 1990 value in 1996, which is intended to be roughly consistent with the reported decrease in agricultural fertilizer availability. "Other chemicals" production (including carbide) for 1996 was set 30 percent of 1990 levels. Production in most other industrial subsectors is also assumed to be 30 percent of the 1990 value in 1996, consistent with anecdotal estimates of utilization of productive capacity standing at 20 to 50 percent due to lack of fuel and spare parts.[130] For all industries, in 1996, we assume that the energy intensity (fuels use per unit output) was 110 percent of 1990, as industrial equipment (including boilers, for example) are generally less efficient when partially or intermittently loaded then when operating at near full capacity, and factoring in the probable lower average efficiency of DPRK industrial equipment in 1996 relative to 1990, due to greater difficulties in obtaining spare parts and other maintenance supplies.

2.2.3. Transport sector

The transport sector in North Korea is concentrated on the movement of freight, principally by rail. Visitors to the DPRK have noted that there is relatively little vehicle traffic on city streets and roads, and that the main form of personal transport appears to be walking. This is aided by the fact that the apartments in which most urban dwellers live are typically located close to their places of work. Based on these observations, we have assumed 1,200 average passenger

[129] Far Eastern Economic Review (1995). *1995 Asia Yearbook, North Korea*.

[130] It is certainly possible that even the drastically reduced levels of industrial production that we assume may be greater than actual production. A 1997 analysis by the US Department of Defense reportedly suggests that DPRK industrial production (presumably as of early or mid-1997) was one-tenth of the level of five years earlier (*Chosun Ilbo*, "POSSIBILITY OF COUP IN DPRK: HONG KONG MAGAZINE", 06/19/97).

kilometers traveled per year in 1990 in motorized transport by the roughly two-thirds of the population that is "economically active". This translates to about 800 kilometers of travel in cars, trains, and buses per person (all residents) per year, which is greater than the 1990 level of passenger transport in China, but less than that in India (and far less than that in industrialized countries[131]).

We have relatively little direct quantitative information on the DPRK transport sector and its energy requirements but have attempted to derive estimates for energy use in the five transport subsectors described below.

The *Road* transport subsector is divided into passenger transport and freight transport. For freight transport, we started with a figure of 42 million tonnes as the amount of freight transported by road (as estimated by the Korea Foreign Trade Association[132]) but had to guess at an average transport distance of 75 kilometers. Another assumption was that about 24 percent of the freight transport occurred in diesel trucks, somewhat under 5 percent (probably mostly in rural locations) in trucks fitted with biomass gasifiers, and the rest in gasoline trucks. Although this is just an assumption, it is informed by 1) the fairly large fraction of gasoline in overall petroleum product consumption as reported by Choi;[133] and 2) the probability that a great deal of freight as of 1990 was transported in the ubiquitous locally-produced 2.5 tonne (capacity) gasoline trucks that make up the bulk of the military transport fleet (see discussion of this sector below). Energy intensities for freight transport by truck are taken from USSR data (from the 1970s) and inflated by 20 percent to account for what is probably an older, more poorly-maintained vehicle stock in the DPRK, operating on what were on average more difficult roads.

Our estimate of gasoline used in civilian autos starts with an estimate, obtained by recent visitors to the DPRK, that there were approximately 15,500 civilian autos (including taxis) in Pyongyang, and very few outside the capital city. These autos, which as of 1990 were all imported (Nissan, Volvo, and smaller Mercedes sedans) during the 1970s and 1980s, were assumed to travel an average of 8,500 km per year (fairly low for an auto in an industrialized nation, but possibly still high for DPRK), and were assumed to have an average fuel economy of 11 km/liter (26 miles per gallon).

For other passenger road transport, we assumed that 30 percent of motorized public passenger transport was by road[134], and that 50 percent of this (bus) transport was in diesel vehicles. We adapted energy intensity estimates from 1985 Chinese data, marked up by 20 percent as for freight transport.

Rail transport in the DPRK was and is fueled by diesel oil and by electricity. An ongoing program of electrifying the DPRK rail system had increased the fraction of freight hauled by electric engines as of 1990. We assumed this fraction to be 87.5 percent.[135] For freight

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[131] Sinton, J., editor (1996), *China Energy Databook 1996 Edition*, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.
[132] Korea (ROK) Foreign Trade Association (1993), "Major Economic Indicators for North Korea, 1993".
[133] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea,* Research Institute for National Unification (RINU), Seoul, (ROK).
[134] The Economist Intelligence Unit (1994), *South Korea, North Korea No. 1 1994*. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.
[135] The Economist Intelligence Unit (1994), *South Korea, North Korea No. 1 1994*. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.

transport, we began with an estimate of 169 million tonnes of freight carried by rail,[136] but were forced again to make a guess as to the average distance (300 km for electric rail, 250 km for diesel rail) of freight transport. We again used marked-up USSR energy intensities for both diesel and electrically powered freight locomotives (see the "Transport" section of Attachment 1 for specific values and sources).

We assumed that practically no passenger transport is by diesel rail, as railways between most cities are reportedly electrified. The residual 70 percent of motorized public passenger transport not provided in road vehicles was assumed to take place in trains (or trams), at an efficiency of 13.2 kg coal equivalent per thousand passenger kilometers. The latter is an average 1989 efficiency for US commute-time train transit.[137] While trains in the DPRK are probably less efficient than US trains, their load factors are probably significantly higher.

Our estimate of oil use in transport of freight by *Water* in the DPRK (excluding international shipping) started with an estimate of 18 million tonnes of freight transported[138], and assumed an average transport distance of 200 kilometers. A Chinese energy intensity of 9.9 kg coal equivalent per thousand tonne-kilometers was used,[139] and is in the range of energy intensity values for Soviet maritime freight transport, but it may still be too low for the DPRK situation.

The civilian *Air transport* subsector in the DPRK is quite limited. We assumed that the non-jet-engine planes among the 24 total aircraft that reportedly made up the 1990 North Korean civilian fleet would be used an average of 300 hours per year, and that the planes themselves are mostly AN-24 propeller planes (a Soviet design from about 1960), with similar fuel consumption to that which we calculated for AN-24s in military use in the DPRK. The DPRK reportedly purchased three Tupolev Tu-154 jets (similar in size to the Boeing 727) between 1976 and 1978,[140] which we assume were used about 750 hours per year. For both the jets and non-jets, the estimates of operating hours that we used are probably more likely to be high than low, given the age of the airline fleet and probable difficulties in obtaining spare parts and aviation fuel. We assumed that the few (4 or 5) international airlines that flew into and out of the DPRK as of 1990 provided all of their own fuel. Thus, the DPRK made no contribution to international aviation bunkers.

A final category of *Non-specified transport* was added to account for electricity and petroleum product use not included in the categories above. Pipeline transport of crude oil or oil products within the DPRK is one possible use of fuels in this group. For 1990, we have used placeholder values of 1.0 million and 0.6 million GJ of petroleum products and electricity, respectively, in this category.

Our estimates of energy use in the transport sector in 1990 currently includes no coal consumption, although coal may have been used to a limited extent as a fuel on some isolated railways, in older ships, and/or in trucks powered by gasifiers. As noted above, we have

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[136] Korea Foreign Trade Association (1993), *Major Economic Indicators for North Korea*.
[137] Gordon, D. (1991) *Steering a New Course: Transportation, Energy and the Environment*. Island Press, Washington, D.C., USA.
[138] Korea Foreign Trade Association (1993), *Major Economic Indicators for North Korea*.
[139] In comparing this value with the energy intensities we estimate for DPRK military ships, this intensity seems quite low, perhaps by an order of magnitude or more. The low value of the Chinese shipping energy intensity may be due to the much larger ships that are probably used to transport freight in China.
[140] Federal Research Division, US Library of Congress (1993), *North Korea, A Country Study*. Edited by Andrea M. Savada. Research completed 1993. US Government Printing Office, Washington, DC, USA. Available (in part) on the World-wide web at https://www.loc.gov/item/2008028547/.

assumed, based on anecdotal reports, that trucks fueled with biomass in some form (possibly charcoal) were (and are) in use in the DPRK, possibly remnants from the Japanese occupation of Korea during WWII.[141] We assume that these vehicles convert biomass (or charcoal made of biomass) to "producer gas" (a gas produced by pyrolysis—a process of partial combustion—of biomass or other fuels) for use in internal combustion engines,[142] although it is possible that some vehicles are steam-driven. We assume that the overall efficiencies of biomass-fueled trucks are on average about 50 percent of the efficiency of their gasoline-driven analogs, although this may be somewhat of an over-estimate.

2.2.4. Transport sector activity changes for 1996

Transport-sector calculations and data that we used to produce our estimates of energy use in the transport sector in 1990 and beyond are presented in Attachment 1. Key assumptions for 1996 are as follows:

- Road Freight—down to 32 percent of 1990 value in 1996, roughly following the decrease in industrial and food output. Use of biomass-fueled trucks increases to move 7.6 percent of road freight in 1996, up from an assumed 4.6 percent in 1990, and the fraction of freight carried in diesel trucks was assumed to decrease modestly, to about 20 percent of the total. Energy intensities for all gasoline- and diesel-fueled trucks, and buses were assumed to be 10 percent higher than in 1990, reflecting poorer fuel economy caused mostly by poorer maintenance (due to lack of parts and lubricants, for example) and a generally aging stock of vehicles. The energy intensity for cars (kilometers per liter) was assumed to be 5 percent higher than in 1990.

- Electric Rail, Water Freight—down to 40 of 1990 values in 1996. Diesel rail freight also declines to 40 percent of 1990 values.

- Road, Rail Passenger (except civilian auto)—down to about 44 percent of 1990 levels per capita in 1996 for diesel buses, although nearly 60 percent of 1990 levels for travel in gasoline buses, reflecting the assumption that more smaller buses, for example, minibuses and vans, were in use in 1996. These changes reflect a shortage of transport facilities and general "belt-tightening".

- Civilian Auto passenger kilometers traveled—100 percent of 1990 value in 1996, reflecting an observed continued presence of autos in and around Pyongyang (if not so much in other areas), as well as reports of (used) vehicle imports from Japan and elsewhere during the 1990s, with the addition of vehicles perhaps offset by less travel per vehicle due to reduced supplies of fuel and spare parts.

- Air transport—down to 80 percent of 1990 value in 1996, with the ratio of fuel consumed in propeller and jet aircraft remaining the same as in 1990.

[141] Professor Y.S. Jang, 1995, personal communication.
[142] A photo of a gasifier-powered truck appears at the end of this Chapter.

2.2.5. The residential sector in 1990

Our estimate of energy use in the residential sector begins with the assumption that 60 percent of the approximately 22 million people in the DPRK as of 1990 (excluding the 1.2 million persons in active units of the military) lived in urban areas,[143] and that the average number of persons per household in both urban and rural households was 4.65 in 1990.[144]

For the *Urban* subsector, we assumed, based on the observations of visitors to the DPRK (including the authors), that the average urban household lives in a multi-story building in an apartment of approximately 50 square meters.[145] We further assumed that the vast majority of these buildings are at least nominally heated using coal-fired boilers supplying hot water or steam to the apartments in the building, although some buildings use district heating systems that use steam provided from power plants, central district heating boilers (often, as in Pyongyang, co-located with power plants), and industrial cogeneration. Based on a series of very rough estimates (see Attachment 1) we estimate that somewhat under 9 percent of urban households used district heat (from both dedicated central district heat boilers and central combined heat and power systems as of 1990. For urban households using coal-fired heating systems, meaning either boilers in their buildings supplying heat to all (or many) apartments, or coal stoves in individual dwelling units, for 1990 we applied an average figure of 30 kg coal equivalent/m^2 from Chinese data, increased by 20 percent to account for the colder (on average) climate in the DPRK, to derive an average household use of 2.2 tonnes of coal per year, or about 53 GJ/household-yr. We further assumed an average electricity use of about 770 kWh per household (HH)-year in 1990. This is about 2.4 times the average household use of electricity in the ROK in 1975,[146] but is roughly consistent with a household using several electric lights, a small refrigerator (if used), a few small appliances, and a household's share of common electricity use (pumps, lighting) in common areas of multi-family buildings.

For urban sector cooking, we assumed that in 1990 petroleum-based cooking fuels (liquefied petroleum gas, or LPG, and kerosene) were used exclusively in Pyongyang, but were not used extensively elsewhere.[147] Usage of these fuels per household was assumed to be about 9.3 GJ/yr, approximately half the energy used reportedly used in wood-fueled stoves in rural households in the Kumgang area. We also assumed, as a placeholder estimate, that 16 percent of urban households used charcoal for cooking, mostly for specialty foods, at a rate of 150 kg/HH-yr. This assumption produces a charcoal demand consistent with the charcoal production we estimate (see section 2.3.4). All other urban cooking is assumed to be provided by coal or (much more rarely) electricity, with cooking use of those fuels subsumed in the overall coal and electricity use figures cited earlier.

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[143] Document in authors' files [HT1].

[144] This figure is an extrapolation from a single area (the Ongjin area) in southern DPRK (Document in authors' files [FC1]). Although it may not be an accurate weighted average figure for the country as a whole, it is probably fairly close, based on the authors' own observations in the Western DPRK village of Unhari in 1998.

[145] This size dwelling would be roughly consistent with conditions in parts of China (Liu, F. (1993), *Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects*. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33867 UC-350.

[146] Kim, E.-W., H. Kim, H.-K. Lim, C. Nahm, M.-C. Shin, and Y. Kim (1983), *The Electric Future of Korea*. Resource Systems Institute, Honolulu, Hawaii, USA. Research Materials RM-83-8.

[147] Document from authors' files [FA].

For *Rural* households, we reviewed estimates of household fuel use provided by DPRK officials for three areas of the country. Based on these data, which may or may not prove representative for the country as a whole, and on other anecdotal information, we estimated that in 1990 50 percent of rural households used coal for heating and cooking, 2 percent used LPG for cooking (a guess on our part), and that the rest use wood or biomass fuels. These assumptions, and the fuel use rates for each fuel, are detailed in the "Residential" pages of Attachment 1 to this report. Electricity use in rural households was assumed to be less, on average, than in urban households, namely 512 kWh per HH-year.

2.2.6. Residential sector changes by 1996

In the residential sector, we assumed the following changes from 1990 conditions:

- Population growth averaging a small 0.08 percent annually through 2000.[148]

- The fraction of the population living in urban areas increases slightly, to about 60.3 percent in 1996. We have heard unsubstantiated reports of involuntary urban-to-rural migration, plus reports of residents of northern cities relocating to the countryside where food can more easily be foraged, but we assume for the sake of preparing this estimate that these movements, at least through 1996, were slightly more than balanced by rural to urban migration, greater net population growth in urban areas than in rural areas, and/or other demographic shifts.

- Through a combination of austerity and fuel unavailability, that residential end-uses of coal declined to 75 and 60 percent of 1990 values in the urban and rural subsectors, respectively, while the fraction of households using coal for heating and cooking declined to about 82 percent in urban areas and 38 percent in rural areas, offset in part by increased use of biomass fuels. Urban use of electricity and heat per household is estimated to have declined to 57.5 percent of 1990 levels in 1996, with rural electricity use declining to about 45 percent of 1990 levels (due to relatively lower availability of electricity in rural areas). Rural biomass use per household is assumed to decrease by about 10 percent relative to 1990, as the greater number of households using biomass fuels due to reduced availability of coal is more than offset by a combination of the impacts of tighter supplies of firewood and reduced levels of cooking and heating in households. The use of charcoal—which as we understand it is used in the DPRK mostly as a fuel for cooking special dishes, rather than as a routine cooking fuel—is assumed to decline to 75 percent of 1990 levels, and the use of kerosene and LPG in urban and rural homes decrease to about 52 and 47 percent, respectively, of their 1990 levels

[148] The US Central Intelligence Agency ("Korea, North", *CIA Factbook, 2001* (World Wide Web Version), USCIA, Washington, D.C., USA, 2001, https://www.cia.gov/the-world-factbook/countries/korea-north/) lists a 2001 estimated growth rate of 1.22 %/yr and a total population of just under 22 million. The USDOE Energy Information Administration listed a year 2000 population of 21.7 million in its North Korea Country Analysis Brief (www.eia.doe.gov/emeu/cabs/nkorea.html, visited 5/2002). A file of "DPRK Energy Data" provided to Nautilus by the Korea Energy Economics Institute (KEEI, 2002) suggests a year-2000 population of 22.175 million and a growth rate of 0.4 percent annually (with the growth rate decreasing substantially between 1990 and 2000) but uses a year-1990 base population of 20.221 million for the DPRK. While recognizing the extreme difficulty in estimating DPRK population, we continue to assume that year 1990 population was 22 million (as official estimates suggest) and adopt the figure provided by KEEI as the year 2000 population. This implies a very modest net total increase in population over the decade, which is certainly consistent with food shortages and anecdotal but fairly widespread evidence of lack of proper food rations, as well as medical care, for the DPRK populace, offsetting the impacts of a national government program to increase the population.

as a result (primarily) of reduced fuel availability.[149] The fraction of homes using these fuels is assumed to have declined slightly from 1990 levels as well.

2.2.7. The agricultural and fisheries sectors in 1990

To estimate fuel use in the agricultural sector, we started with the area of field crops grown in the DPRK, approximately 1.7 million hectares[150]. We have divided energy use in the agricultural sector into two components, accounting separately for the fuel used in *Field Machinery* and that used for *Processing of crops and other applications*.

To estimate the petroleum product consumption in field machinery in 1990, we applied a Chinese figure for annual fuel consumption of 41 liters of diesel oil per hectare (ha) farmed[151] to the total DPRK field crop area. By way of comparison, this equates to approximately 6 hours of tractor use per hectare per year if one assumes 1) an average fuel consumption rate of 195 grams per horsepower hour;[152] and 2) a 28-hp tractor, the size that is apparently common in the DPRK. If tractors are typically used at less than full power, this tractor-hours-per-hectare figure would increase. Official DPRK sources suggest that there are seven to eight tractors per 100 hectares of field crops, which would imply on the order of 10 to 20 days of tractor operation per tractor per year. This level of tractor use seems low, but is not entirely implausible given A) the fairly narrow time windows that Korean weather provide for planting and harvesting crops; B) the large amount of hand labor used in North Korean agriculture; and C) the probable scarcity of fuel and spare parts for tractors in DPRK, even as of 1990.

Electricity use in field machinery was estimated using a Chinese value of 126 kWh/ha-yr.[153] Most electricity use would probably be for water pumping.

Chinese energy intensities were also used to estimate the coal and petroleum products used in crop processing and other applications. In this case, we estimated intensities by dividing the figures for consumption of coal and electricity in Chinese agriculture (1987 values) by the total area of rice crop cultivated, then applied the resulting coefficients to the area of rice crops (650,000 ha[154]) cultivated in the DPRK. This procedure, of course, yields intensity figures that are approximations at best; the ratio of rice hectarage to area of all crops were doubtless somewhat (though probably not vastly) different in China than in the DPRK, as were agricultural practices and agricultural yields, both of which would affect the energy used in processing crops.

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[149] We assume that availability of LPG and kerosene for cooking would be more limited in rural areas than in urban areas, hence the smaller percentage of rural households that are assumed to use oil fuels. Based on our experience, however, there may be a countervailing effect of increased use of kerosene (and diesel) for lighting as electricity has become less available, particularly in rural areas, in the evening hours.

[150] Document in authors' files [KJ1].

[151] Liu, F. (1993), *Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects*. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33867 UC-350.

[152] Liu, F., W.B. Davis, and M.D. Levine (1992), *An Overview of Energy Supply and Demand in China*. Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-32275 UC-350. Available as https://pdfs.semanticscholar.org/efea/52764ce6a4fc75a7ac0d6c41ce55619b0f50.pdf.

[153] Liu, F., W.B. Davis, and M.D. Levine (1992), *An Overview of Energy Supply and Demand in China*. Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-32275 UC-350. Available as https://pdfs.semanticscholar.org/efea/52764ce6a4fc75a7ac0d6c41ce55619b0f50.pdf.

[154] Document in authors' files [KJ1].

Lastly, we summed figures provided by DPRK officials for straw and bran used as fuel in agricultural operations. This sum provided an initial estimate of the biomass fuel used by the sector. Some wood is probably used in the sector as well, but we have no quantitative data to describe this use.

Very little data are available to describe energy use in the fisheries sector of DPRK. The approach we used was to start with the tonnage of *larger fishing vessels* (about 438,000 tonnes, and 360,000 horsepower[155]), to guess at the average annual usage of the fishing fleet, and to apply a Chinese coefficient for energy use intensity of ships, expressed in energy per horsepower-hour. We assumed that 85 percent of the DPRK fishing fleet was in service, and that those ships spent an average of 200 days at sea, were underway an average of 12 hours per day, and operated at an average of 50 percent of full power when underway. Our best guess is that this estimate for the activity of the North Korean fishing fleet is high, if anything, but the Chinese energy intensity is probably a low value for the DPRK.

For other uses of energy in the fisheries sector, including petroleum used by smaller fishing collectives and in fish processing, and electricity use in processing operations, we have prepared estimates based on a report as to the number of fishing collectives and the number and size (on average) of motorized boats used by each collective[156]. We assumed the same average of 200 days per year, 12 hours per day of operation assumed for larger ships but assumed that only 75 percent of boats were in operation in 1990, and that average power use was 25 percent of full power.

It is possible that some coal, or even wood, is used in ships and/or in the processing of fisheries products, but we have thus far assumed that none is used.

2.2.8. Changes in the agricultural and fisheries sectors as of 1996

We assumed no significant change in the area cropped between 1990 and 1996, but that the electricity used in field operations decreased to 90 percent of its 1990 value by 1996 as a result of decreased agricultural output and flood damage, while oil products use (diesel) decreased to 30 percent of the 1990 value by 1996, consistent with observations of greatly reduced farm mechanization due to fuel shortages over the first half of the 1990s. For coal, electricity, and biomass used in crop processing, we assumed that these would decrease with the significant decrease in the amount of crops harvested, with cereal crop harvest estimates as the metric to calculate a ratio of output in 1996 versus 1990. We also assumed that per-unit crop use of these fuels would be 90 percent of 1990 levels, due to fuel shortages, lack of spare parts for key equipment, and other factors. In the fisheries sector, we assume that 1996 fishing effort (as reflected in fuels use in fishing) was approximately 30 percent of 1990 effort, and that the mechanized processing of fisheries products was 45 percent of 1990 levels, consistent with reports of a recent sizable reduction in marine products output.[157]

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[155] Document in authors' files [IF1]; *Seoul T'ongil Kyongje*, dated January 2002, pages 38-50, article by Hong Mi-ri entitled "North Korean Industries (Part IX): Fisheries Industry"; and *WORKING PAPER 6, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA REPORT OF THE FISHERIES DEVELOPMENT PROGRAMMING MISSION*, prepared for the Food and Agriculture Organization of the United Nations, dated November 1998, and available as http://www.fao.org/tempref/FI/CDrom/aquaculture/a0845t/volume2/docrep/field/.!52305!383547.htm (Table 1).

[156] Document in authors' files [IF1]; and *Seoul T'ongil Kyongje*, dated January 2002, pages 38-50, article by Hong Mi-ri entitled "North Korean Industries (Part IX): Fisheries Industry".

[157] Noland (1996) quotes Y.S. Lee (1995) as reporting a reduction in marine products output between 1989 and 1993.

2.2.9. Public and Commercial sectors

As in the fisheries sector, we have essentially no direct data on the use of fuels in public and commercial buildings (which we define to include institutional buildings such as nurseries, schools, and hospitals) in the DPRK. To provide a "ballpark" (approximate) estimate of these quantities, we started with our estimate of urban residential floor space and applied the ratio of residential urban floor space to public and commercial floor space (approximately 0.3) that prevailed in the "heating zone" of China as of 1989.[158] We then applied coal use intensities (from the same source) to this total. To estimate electricity use, we derived an annual electricity use intensity of 33 kWh/m^2, derived from Chinese data (but about 10 percent higher to account for cooler average temperatures), and applied it to our public/commercial floor space estimate. In order to bring the sum of electricity demand in the agricultural, public/commercial, and military sectors up toward (but not quite to) the approximately 25 percent share of total electricity demand that these sectors reportedly account for, we included an additional placeholder value of 7 million GJ/yr for other uses of electricity in the public/commercial sector. We assumed that 15 percent of public/commercial floorspace in 1990 was heated using district heating systems, and that public and commercial sector buildings used wood and biomass fuels in 1990 in an amount equal to 5 percent of their use of coal (on an energy-content basis). We assumed that oil use in the public/commercial sector was modest in 1990, at 0.3 percent of coal use, with 90 percent of oil use in the sector in 1990 being kerosene, and the rest LPG. Our estimate of energy use in the public and commercial sector in the DPRK might be improved by collecting and applying intensity figures representative of Soviet-style construction.

2.2.10. Commercial/Public/Institutional sector changes by 1996

For all activities in this sector, we assume that total floor space per unit residential floor space to have remained constant at 1990 levels through 1996, but that coal consumption per unit floor space decreased to 75 percent of 1996 levels, and electricity and heat use per unit floor space (and for other sectoral electricity use) declined to 57 percent of 1996 levels, similar to the decline in urban residential electricity use. At these levels of 1996 energy use, the commercial/public/institutional sectors are assumed to have fared better than the industrial or residential sectors, reflecting a rough balance of slowly declining “official” activities in the sector with increasing “private” commercial activities. In addition, and consistent with the reports of observers of the DPRK, we have assumed a level of wood/biomass use in the sector equal to10 percent of coal use in 1996. Wood/biomass use in the public and commercial sector in the DPRK in 1996 was likely to be concentrated in more rural areas, and in areas of the country where supplies of coal and electricity were curtailed. Oil use is assumed to increase somewhat with the reported increase in private sector activities, to a level equal to 0.5 percent of coal use, with oil use split evenly between kerosene and LPG use.

2.2.11. The military sector in 1990

Although we have thus far been able to obtain essentially no direct data on energy use in the military sector in the DPRK, the DPRK military is monitored closely by the military and intelligence community in the United States and elsewhere. For our study, this attention has

[158] Liu, F. (1993), *Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects*. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33867 UC-350.

meant that there are reasonably good data on the stocks of energy-using equipment in the DPRK military. These data on stocks can be used as the basis for estimates of fuels consumption. Our approach to estimating fuel use in the DPRK armed forces has been to use these stock figures together with data and estimates of vehicle/aircraft/vessel fuel capacities and estimates of the amount of "practice time" that each piece of equipment might receive in a year. Of these three types of information, our estimates of equipment use are by far the most speculative. The methods and data used to prepare our estimates of fuel use by the DPRK military sector are presented in Attachment 2 and are summarized (and augmented) in the "Military" section of Attachment 1. In addition, the methods and key assumptions that we used in preparing estimates for the different military subsectors are summarized below.

To estimate the energy used by the DPRK *Ground Forces*, we started with estimates of the total number of mobile equipment and vehicles in seven classes:

- Tanks
- Amphibious Vehicles (used for fording rivers and lakes, landing on seashores, or operating in wet terrain)
- Armored fighting vehicles
- Truck- and Tank-mounted artillery and missiles
- Jeeps and motorcycles
- 2.5 tonne trucks
- Other trucks and utility equipment.

Using information on the number of the different types of regiments and other units in the DPRK Army,[159] and on the equipment stocks in each type of unit,[160] we estimated the personnel and equipment totals in the DPRK Army. This exercise yielded a personnel total somewhat lower (936,000 versus 1.066 million) than the total reported personnel active in the Army, so we multiplied the resulting equipment totals by 1.14 to "true-up" to the total reported force strength. Next, we used data from two US sources[161] that described the various equipment types (size, range, fuel capacity, weight, and engine power) to estimate the fuel consumption per kilometer of vehicle travel. We assumed average speeds during maneuvers ranging from 15 to 30 kilometers per hour and assumed that the vehicles would be active during maneuvers about 50 percent of the time (except for engineering utility vehicles, which were assumed to be active 25 percent of the time). We further assumed that 20 percent of the stock of all types of vehicles and equipment are unusable (due to lack of fuel or spare parts, ongoing maintenance, or just age and decay) at any given time, and that the Army conducts maneuvers approximately 1,000 hours per year, but that heavy armaments (tanks, armored vehicles, amphibious vehicles, and self-propelled guns and missiles) are used in training only 100 hours per year. Interestingly, a single

[159] US Defense Intelligence Agency (1990?), *North Korea, The Foundations for Military Strength*. US Defense Intelligence Agency, Washington, DC, USA.
[160] US Headquarters Department of the Army (1982), *Opposing Force Training Module, North Korean Military Forces*. Department of the Army, Washington, DC, USA. February 1982. Field Manual No. 34-21.
[161] US Headquarters Department of the Army (1982), *Opposing Force Training Module, North Korean Military Forces*. Department of the Army, Washington, DC, USA. February 1982. Field Manual No. 34-21.US Department of Defense (1994), *North Korea Handbook*. US Department of Defense, Washington, DC, USA.

type of vehicle--the DPRK's 2 1/2 tonne trucks--dominates both the numbers of vehicles in the DPRK Ground Forces (over 75 percent) and our estimate of fuel used by those forces (about 90 percent). These and other trucks nominally in military use often, based on our own direct observations and that of many others, are used for both civilian (goods and human transport) and military purposes, often simultaneously.

We used our estimates of fuel used by light vehicles, trucks, and utility vehicles in the ground forces to estimate the amount of fuel used by support vehicles in the DPRK Air Force and Navy. We did this by applying simple ratios of the personnel in each branch to the Army fuel use total.

For *Aircraft* in the DPRK Air Force, we used estimates of each class of aircraft[162] and information on the early-1980s stocks of specific aircraft[163] to estimate the current stocks by model of plane (or helicopter). Most of the DPRK's aircraft are antiquated, with many models dating from the 1960s or before. Of the approximately 1,400 aircraft in the DPRK inventory, approximately 750 are fighters, 80 are bombers, 300 are transport aircraft (90 percent of which are smaller single-engine Russian AN-2 biplanes), and the remainder are helicopters.

Information on aircraft range, size, and fuel capacity was gleaned from the US documents mentioned above, from *Jane's All the World's Aircraft*,[164] and from other sources.[165] These data were used to estimate the "fuel economy" of the planes and helicopters in the DPRK stock. Based on the assumption that these aircraft receive minimal use--due to their typically advanced age, scarcity of fuel and parts, and the DPRK's typically ground-oriented military doctrine--we assumed fairly minimal annual operating hours of:

- Fighters and Bombers: 24 hours per year
- Transport Planes: 50 hours per year
- Military Helicopters: 32 hours per year.

It is quite possible that some aircraft receive substantially more use than we have assumed, but it is more likely that many aircraft are entirely or effectively in "mothballs" (long-term storage) and receive little or no use. For most aircraft, we assumed that their average airspeed while on training or practice missions is about 80 percent of their reported maximum speed, interpreted to mean that average fuel consumption was about 80 percent of fuel consumption implied by consideration of the fuel capacity, range, and maximum airspeed of the different aircraft as reported in the literature.[166]

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[162] As supplied in US Defense Intelligence Agency (1990?), *North Korea, The Foundations for Military Strength*, US Defense Intelligence Agency, Washington, DC, USA, available in part as http://www.fas.org/irp/dia/product/knfms/knfms_toc.html.
[163] US Headquarters Department of the Army (1982), *Opposing Force Training Module, North Korean Military Forces*. Department of the Army, Washington, DC, USA. February 1982. Field Manual No. 34-21.
[164] Jane's (1990/91, 1981/82, 1972/73, 1968/69), *Jane's All the World's Aircraft*. 1990/91, 1981/82, 1972/73, and 1968/69 editions. Jane's Publishing Co., N.Y., NY, USA.
[165] Chant, C., (1990), *Air Forces of the World*. Brian Trodd Publishing House, Ltd. Taylor, J.W.R., and G. Swanborough (1979), *Military Aircraft of the World*. Ian Allen Ltd., UK (1979).
[166] This is admittedly a rough approximation, as published aircraft ranges may not be quoted at maximum airspeed, and the relationship between airspeed and fuel consumption is not linear (see, for example, page 252 in Warren F. Phillips (2004), *Mechanics of Flight*, published by John Wiley and Sons).

Our estimates of fuel use in *Naval* vessels used a similar approach: figures on current total numbers of ships by class in the DPRK Navy were combined with an older[167] inventory of numbers of ships by model to yield estimates of the current number of ships by model and type of ship (including submarines). The DPRK's forces include few ships of any size (by naval standards), consisting mostly of smaller (40- to 400-ton displacement) missile attack boats (numbering about 40) and patrol craft (over 400), with a number of amphibious craft designed to land troops on beachheads (about 200) and 24 diesel-electric submarines.

We then compiled information on the engine power for each model in this inventory of ships and used a benchmark figure of 0.38 lb of diesel fuel per horsepower (hp)-hr of operation,[168] [169] plus an assumption that at cruising speed, naval ships operate at approximately half-throttle (that is, they are using half of the total horsepower available). For submarines, we used a figure of 0.50 lb of diesel per hp-hr.[170] These data were used to estimate the fuel consumption for each vessel per hour of operation.

We assumed, based primarily on conjecture, that amphibious naval vehicles would be in operation only 50 hours per year, that submarines would operate 100 hours per year, and that all other vessels would operate 800 hours per year (many of the latter may be dual-use vessels). The reasons for assuming these low operating levels (the US Naval fleet reportedly has had an operating tempo upwards of 60 percent, or over 5000 hours per year) are the same as those cited above for the low number of operating hours per aircraft. These operating assumptions were multiplied by the per-unit fuel consumption figures and the number of ships of each type and summed to yield overall fuel consumption by the Navy.

In an additional exercise, we estimated the amount of fuel used in *Manufacturing Military Equipment*. This calculation was done by estimating the total weight of iron and steel in the Army and Navy equipment inventories (aircraft were assumed to be all imported), applying estimates of the average of lifetimes of each equipment type (assumed to be 20 years for large Ground Force equipment, 10 years for small armaments, and 30 years for ships and boats), and using these figures to derive an average amount of iron and steel needed per year in military manufacturing to replace equipment reaching the end of its nominal lifetime. A Chinese figure of 250 kg coal equivalent per tonne of steel,[171] multiplied by an intensity inflator of 1.1, was assumed to be required for each of the approximately two meltings required to fabricate military equipment.[172] It was further assumed that the fuel (assumed to be coal) used in melting iron and steel for military goods represents roughly 60 percent of the total coal needed for military manufacturing. An estimate of the electricity requirements by this sector was prepared by applying the ratio of electricity to coal consumption estimated for the civilian iron and steel industrial subsector to the coal use estimate for military manufacturing.

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[167] US Headquarters Department of the Army (1982), *Opposing Force Training Module, North Korean Military Forces*. Department of the Army, Washington, DC, USA. February 1982. Field Manual No. 34-21.

[168] Although this value is derived from a reference that dates to WWII, it is apparently not unreasonable. Conversations with a US dealer of large marine engines indicates that even the best current (as of the mid-1990s) diesels were not vastly more efficient (0.32 to 0.33 lb/hp-hr), and that the value we are using would be justified (perhaps even low) for the older (1960s and 1970s) engines that likely make up the bulk of the DPRK fleet.

[169] Chapman, L.B. (1942), *The Marine Power Plant*. McGraw-Hill, N.Y., N.Y., USA.

[170] Freedman, N. (1984), *Submarine Design and Development*. Naval Institute Press, Annapolis, MD, USA.

[171] Ross, M. and L. Feng (1990), "The Energy Efficiency of the Steel Industry of China". *Energy*. V. 16, No. 5, pp. 833-848, 1991.

[172] P. Zimmerman, personal communication, 1995.

Armed forces of on the order of 1.2 million people do not exist without a substantial stock of military buildings. As in other sectors, however, we currently have no information on energy use in these structures. To compile estimates of fuel use in military buildings, we have assumed that there are 20 million square meters of floor space in such buildings (about 17 square meters per active member of the armed forces), and that they are heated with the same type of coal-fired equipment (and at the same efficiency) used for residential and public/commercial buildings. Electricity consumption per square meter in these buildings was assumed to be twice that in civilian public and commercial building (55 kWh/m^2-yr).

We have included a placeholder value of an additional 10 million GJ annually to account for other uses of electricity in the military. End-uses covered by this assumed allotment as of 1990 could include fixed radar sites and the DPRK's nuclear research program (nominally a civilian operation), which we estimate may have had an electricity demand in 1990 of approximately 5 MW, as there was and is no electricity production by the DPRK's 25 MW thermal (though often referred to as “5 MW electric”) research reactor at Yongbyon (prior to its shut-down as part of the Agreed Framework). An additional 9.6 million GJ/year placeholder allotment was assumed for other uses of coal in the military, along with an additional 100,000 GJ/year for other uses of petroleum products.

2.2.12. Changes in military fuel use by 1996

Our assumptions and calculations for fuel use in the DPRK military are presented on Attachments 1 and in Attachment 2. We assume that there was a 13 to 20 percent decline in ground forces active hours (that is, exercises in which fuel-using vehicles and armaments are actually in use) from 1990 to 1996, a 16 to 33 percent decline in aircraft use,[173] and about a 30 percent decline in the use of the most actively used naval vessels. Force sizes were assumed, based on the documents available, to have changed only modestly, with the notable exception being the addition of amphibious hovercraft. Military manufacturing was assumed to decrease to 70 percent of 1990 levels by 1996. Changes assumed in energy use by military buildings with included a 45 percent decline in electricity use for military activities relative to 1990 levels, along with a 5 percent decrease in the use of coal and wood fuels to meet end-uses typically served by coal, and a 5 percent decrease in the use of oil products. The decline in military electricity use was assumed to be partially the result of changes in the DPRK’s nuclear program under the terms of the Agreed Framework.[174] Wood use in the military was assumed to be negligible in 1990, when coal supplies were generally available, but we assume that wood use in the military by 1996 represented 10 percent of the total coal and wood used, as some military units, particularly in rural areas, found the need to supplement inadequate coal supplies with wood and biomass for heating and cooking.

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[173] The decline in aircraft use that we assume can be thought of as consistent with a reduction in the supply of spare parts for the DPRK’s (mostly) vintage Soviet-type aircraft, as well as reduced availability of fuels.

[174] As noted by Noland (1996), our estimate of fuel use by the DPRK military is rather narrowly focused on fuel used by military equipment, in manufacturing of particular pieces of military equipment, and use of fuels in military buildings. In fact, the DPRK armed forces are reported to control a large fraction of the DPRK economy and are reportedly involved many enterprises outside of those we have modeled. For these enterprises, however, separating military from civilian activities is probably, at best, very difficult, if not impossible. In any case, the energy associated with these activities owned and operated by the DPRK military in what would be designated in most countries as “civilian” sectors is already included in our energy accounting for the DPRK’s national energy balance and is not “missing.”

2.2.13. Non-Specified/Other sectors

This category was included to help balance supply and demand if sufficient demand could not be accounted for in the sectors described above. At present the only entries here for 1990 are placeholder values of 5.9 million GJ of petroleum products consumption, of which 1.7 million GJ is diesel oil, and the rest kerosene, plus an estimated 0.47 million GJ of heat from the Yongbyon reactor, placed in the "hydro/nuclear" balance category.[175] No non-specified sector energy uses were included in the 1996 energy balance.[176]

2.2.14. Non-energy use

This balance row includes wood fuel used as a feedstock for commercial wood (such as lumber) production, and coal and oil used as a feedstock for the fertilizer industry (for ammonia production—see description in the Industrial Sector discussion above). In addition, non-energy use includes petroleum products such as lubricants, bitumen for asphalt, waxes, and petroleum coke. We assume that coal used as a fertilizer feedstock was used at about 25 percent of its 1990 level in 1996, that non-energy petroleum products use declined to about 25 percent of 1990 levels (consistent with the overall decline in industrial production), and that biomass used as "roundwood" (lumber feedstock) was at 60 percent of 1990 levels by 1996.

2.3. Summary of information on energy supply in the DPRK as of 1990 and 1996

In this section we describe the energy uses estimated to have been available in the DPRK as of 1990 and 1996. Note that some of these resources were and are used to generate electricity and are thus also described in section 5.2.2 of this Report.

2.3.1. Energy resources

The major primary energy resources used in North Korea are as follows:

- *Coal*, almost all of which is domestically produced. The types of coal mined in DPRK are anthracite and brown coals.
- *Wood and Biomass*, including fuelwood and commercial wood harvested from the DPRK's extensive but degraded forest area, and crop residue biomass.
- *Petroleum*, including imported crude oil and a smaller amount of imported refined petroleum products.
- *Hydroelectric power* from a number of hydroelectric plants (see Section 2.4.1).

2.3.2. Coal resources in 1990 and 1996

Coal is (and was) produced in many areas of the DPRK. The major coal type mined is anthracite coal, a hard coal that is typically high in carbon and is relatively rare world-wide (though common in Korea and in adjacent areas of China). Second in importance is much lower-quality brown or lignite coal. The DPRK's reserves of coal are significant, sufficient for on the order of

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[175] Calculated based on thermal output for the Yongbyon reactor of 25 MW, and a 1990 capacity factor of 60 percent (see "Yongbyon 5-MW(e) Reactor" from http://www.globalsecurity.org/wmd/world/dprk/yongbyon-5.htm for estimates of Yongbyon capacity factor).

[176] The Yongbyon reactor's heat output for 1996 is taken to be zero, as the reactor was shut down under the terms of the Agreed Framework at the time.

1,000 years at current consumption levels, but the quality of the coal is uneven. The heat contents of coals mined in one major district alone (the Anju district on the west side of the DPRK) vary from 1,000 to 6,000 kcal/kg,[177] with ash contents from 12 up to 65 percent. Untreated coals of this quality can be expected to have a low efficiency of combustion, and the large volumes of bottom and fly ash generated when these coals are burned create a disposal problem.[178]

Approximately one-half of the coal reserves in the important Anju mining area (located northwest of Pyongyang) are located under the seabed. The DPRK currently lacks the technology to effectively and safely extract this coal, which includes some of the higher-quality coal in the area. In mines in the Anju district that are in areas close to the sea, it was reportedly already necessary, as of the mid-1990s (or even before), for miners to pump six tonnes of seawater per tonne of coal mined, due to saltwater intrusion into the low-lying coal seams.

Estimates of the amount of coal mined in DPRK vary quite widely, even for a single year, depending on the source of the information. Official estimates were as high as 85 million tonnes of coal (for 1989), although estimates by the ROK's National Unification Board (NUB[179]) suggested that the total for 1990 was only 33.2 million tonnes. Further confounding the evaluation of these estimates is the issue of energy contents. Official DPRK figure place the average (apparently) value for coal energy content at 4500 kcal/kg, while the NUB apparently assumes an average energy content that is on the order of that used for high-quality anthracite coal.[180, 181]

We have assumed, in preparing our estimate, that the production of coal in 1990 was 70 million tonnes, of which 49 million tonnes was anthracite coal, and 21 million tonnes was brown coal.[182] We have taken the figure of 4500 kcal/kg as the weighted-average energy content for this coal. Our guess, based on the documents we have reviewed in compiling this report, is that both of these estimates are on the high side for 1990, though some observers suggest otherwise.

Imports and exports of coal and coke to and from the DPRK were of modest scale in 1990, relative to domestic demand. The DPRK imported about 209,000 tonnes of coke in 1990 (probably from the Former Soviet Union), and 2.38 million tonnes of bituminous coal from China.[183] The DPRK also exported 1.17 million tonnes of anthracite to China[184] and about 530,000 tonnes to Japan[185] in 1990, so DPRK was a net importer of both coal and coke in that

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[177] "Standard" bituminous coal (a "tonne of coal equivalent, or tce) is defined as 29.3 GJ/tonne, or 7000 kcal/kg, so 6000 kcal/kg represents coal of relatively high energy content, while coal of 1000 kcal per kg would be considered of quite poor quality.

[178] Combustion efficiencies decline in part because a large volume of inert material (ash) must be heated up by the burning coal. "Fly ash" denotes that fraction of coal ash that leaves the boiler with the hot exhaust gases and is trapped by ash collection devices or emitted to the atmosphere. "Bottom ash" is that fraction of the inert material in the coal that remains in the bottom of the boiler after the coal is combusted.

[179] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK).

[180] Jang, Young Sik (1994), *North Korean Energy Economics*. Korea Development Institute.

[181] It is possible that the NUB estimate is expressed in tonnes of oil equivalent, which would put it even closer, in energy terms, to the official figure (Y.S. Jang, personal communication, 1995).

[182] Document in authors' files [HT1].

[183] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK). Jang, Young Sik (1994), *North Korean Energy Economics*. Korea Development Institute.

[184] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK).

[185] Derived from Japan customs statistics, available as http://www.customs.go.jp/toukei/info/index_e.htm, and http://www.customs.go.jp/toukei/download/index_d012_e.htm (the latter last visited 4/2010).

year, but imports comprised only a few percent of the total coal supply. It is likely that imported coal was used primarily for special industrial processes such as metallurgy. We assumed that coke imports to the DPRK stood at about 53 percent of their 1990 levels by 1996,[186] and that coal imports (based on China Customs statistics) were at 18 percent of 1993 levels in 1996. DPRK coal exports to China were recorded at 22 percent of their level in 1993, but overall DPRK coal exports to China, Japan, and other nations were about 76 percent of 1993 levels, and 28 percent of 1990 levels.

2.3.3. Petroleum

There are reportedly oil and gas reserves in offshore areas of the territory of the DPRK,[187] but the country lacks the technologies to effectively explore and develop these resources alone. In recent years (see Chapters 3 and 4), the DPRK has entered into agreements to develop its oil resources and has by at least one report produced some crude oil from an onshore well. As of 1990, however, all of the petroleum products used in DPRK were either derived from imported crude oil refined in DPRK or were imported refined products. Crude oil imports as of the first half of the 1990s came from four main sources:

- *Iran*, principally in trade for North Korean armaments;
- *China*, in trade for various goods and for hard currency;
- *The Former Soviet Union*, previously on soft terms but more recently on a much more strict hard-currency basis;[188] and
- *The open market*, for example, through Hong Kong or Singapore.

The Korean Foreign Trade Association[189] lists total crude oil imports of 2.43 Mte (million tonnes) from the first three sources in 1990, while Choi[190] cites a total of 2.8 Mte crude oil imports from all sources. Some sources suggest that the 2.8 Mte estimate is too high, so we have used a figure of 2.6 Mte total crude oil imports in preparing the 1990 energy balance.

In addition to refining these crude oils in its own refineries (see below), the DPRK also apparently purchased (as of 1990) some refined products on the open market. These products, principally diesel fuel, heavy oil, gasoline, and kerosene (in that order of importance) sum to a total of approximately 640,000 tonnes of oil equivalent.[191]

[186] This includes coke imported from China (as reported in China Customs Statistics, as compiled by Nathanial Aden, 2006. For related analysis, see also N. Aden, *North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications*, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Dr. Aden's paper is available as http://nautilus.org/wp-content/uploads/2012/01/0679Aden1.pdf), plus an assumed 10 percent additional to account for small-volume imports from Russia and other countries.

[187] DPRK sources place estimates of total oil reserves at 6 to 10 billion tonnes. Although we have been told by independent sources that oil deposits do indeed exist beneath the DPRK and its offshore territory, we have been unable to confirm the extent of those deposits.

[188] Some sources indicate that in recent years exports of oil from the Former Soviet Union to the DPRK have fallen to as little as a tenth of the pre-end-of-cold-war level (Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK); and Alexander Karabanov, 1993, personal communication).

[189] Korea Foreign Trade Association (1993), *Major Economic Indicators for North Korea*.

[190] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK).

[191] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK).

As noted above, in the late 1980s and early 1990s, the DPRK was receiving substantial supplies of crude oil from China, Russia, and the Middle East (notably Iran and Libya). Since then, supplies from Russia have reportedly essentially ceased, and shipments from the Middle East have virtually stopped as well. Data from Choi[192] suggest that crude oil imports declined by 23 percent between 1990 and 1991 alone. In 1996, the only crude oil reported to be entering the DPRK had come via pipeline from China. Chinese customs statistics for 1996 show oil shipments into the DPRK at about 940,000 tonnes per year, a rate similar to that which had prevailed for most of the 1990s.[193] [194] According to the Korean Energy Economics Institute,[195] the DPRK received 80,000 tonnes of crude oil from Libya in 1995, but no similar shipments were reported in 1996. Table 2-3 presents crude oil import figures provided by KEEI for 1989 through 1995, plus our crude oil imports figures from China for 1996.

Table 2-3: Crude Oil Imports to the DPRK (thousand metric tonnes)

Exporter	1989	1990	1991	1992	1993	1994	1995	1996*
China	1,140	1,160	1,100	1,100	830	1,050	1,020	940
Russia	500	410	-	-	-	-	-	-
Libya	-	-	200	200	80	100	80	-
Iran	920	980	220	220	-	210	-	-
Total	2,650	2,450	1,890	1,520	910	1,360	1,100	940

Source: KEEI, 1996, personal communication with Mr. Dongseok Roh; based on Chung Woo Jin, *The Energy Industry of North Korea*, 1996.

* China Customs Statistics from 1996.

In addition to the refined products produced at the Chinese-built refinery from Chinese crude oil received in 1996,[196] China provided a small amount of "official" (reported in customs statistics) refined products to the DPRK during 1996. These are assumed to be primarily gasoline, and based on China Customs Statistics, totaled about 68,000 tonnes. This figure is on the order of 80 percent of the total of official exports of refined products from China to the DPRK in 1993.[197] Additional imports of refined products during 1996 reportedly were received from Russia (approximately 100,000 tonnes, assumed to be half gasoline and half diesel oil), plus "one half of

[192] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK).
[193] *China Custom Statistics*, 1996 (Information obtained via personal communication from Mr. David Fridley, Lawrence Berkeley National Laboratory).
[194] China Customs Statistics data as compiled by Nathanial Aden in 2006, 2008, and 2010. See, for example, N. Aden (2006), *North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications* as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Mr. Aden's 2006 paper is available as http://nautilus.org/wp-content/uploads/2012/01/0679Aden1.pdf.
[195] Korean Energy Economics Institute (KEEI, 1996). Personal communication from Mr. Dongseok ROH, Electricity Policy Division.
[196] See "Oil" worksheet of Attachment 1 for an estimate of 1996 refined product output by this refinery.
[197] Sinton, J., editor (1996), *China Energy Databook 1996 Edition*, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.

the output" of a 750,000 tonne/yr (output capacity) refinery across the Tumen river in China. We assume that this refinery's actual production is no more than 600,000 tonnes per year. We further assume that the output of this small Chinese refinery was of the same composition (by product type) as the Chinese-built refinery on the west coast of the DPRK, but that fuel exports from the Chinese refinery to the DPRK were weighted slightly toward motor fuels and away from HFO, relative to the refinery's product slate.[198] To reflect KEDO's provision of refined product (HFO) to the DPRK during 1996, we used reported and expected deliveries during the "1996 HFO Year" (11/1/95 to 10/31/96), which total approximately 500,000 tonnes of HFO.

2.3.4. Wood and biomass

Approximately 9 million hectares (ha) of the DPRK was covered with forests as of 1990. Unfortunately, the extensive mining of these forest resources during the decades of Japanese occupation of Korea (ending in World War II), coupled with generalized devastation of the Korean peninsula during the Korean war in the early 1950s, left the forest stocks of DPRK in generally poor condition. A significant reforestation effort, totaling some 2.5 million hectares of plantations by 1993, was reported to be taking place as of the early 1990s,[199] and was mentioned periodically in North Korean news reports. A total of 3 million hectares were classified as "productive forests".

Various figures have been given for the level of domestic wood production in the DPRK, ranging from about 4 million[200] to approximately 16 million cubic meters of wood. We have used a value, 6 million m^3, somewhat below the range provided in official DPRK estimates[201] that sets wood used for firewood at 8 - 10 million m^3. Official DPRK estimates set wood for charcoal production at 0.8 to 1 million m^3, wood for construction at 3 - 5 million m^3, and approximately 500 - 650 thousand m^3 for industrial fuelwood and for paper production.[202] Based on our assessment of the DPRK forest resource base (see Chapter 4), we use somewhat lower estimates for 1990 in some of these categories—930,000 m^3 wood for charcoal production, and1 million m^3 wood for construction—but use 650 thousand m^3 for the total wood used as industrial fuelwood and for pulp and paper production.

In addition to its domestic production, the DPRK also imported (at least until fairly recently) wood from the Russian Far East. Teams of workers from the DPRK are (or at least routinely were) sent to harvest wood in Russia and the DPRK retained a share of the wood harvested in exchange for the labor (reportedly approximately one third). There appears to be a discrepancy between sources as to the magnitude of these imports, but we have assumed a total of 1.5 million m^3 of roundwood (logs) were imported annually from Russia.[203] Much of this wood was

[198] Fridley, D. (1996), Lawrence Berkeley National Laboratory (personal communication).
[199] Document in authors' files [HT1].
[200] Document in authors' files [TP1]; also the UN Food and Agriculture Organization's *Global Forest Resource Assessment 2005*, from which DPRK data are available at www.fao.org/forestry/site/32086/en/prk.
[201] Document in authors' files[T1].
[202] When wood volumes are specified, it is important to note whether they are listed as "solid" or "stacked" volumes, as the latter implies a lower density, and thus lower energy content per cubic meter, than the former. The volume estimates that we are using appear to be in solid cubic meters, thus we have assumed a conversion factor of 1.5 cubic meters per tonne in estimating the energy content of these wood resource flows.
[203] A document in the authors' files lists imports of 2.5 million cubic meters from Russia [TP1, p. 4], but other sources list these imports at 230 kcu.m./yr, and also list the number of DPRK workers sent to Russian forests at 16-20,000 annually. An abstract from a 1990s report on the Russian Far East forestry sector (CINTRAFOR Working Paper Abstract, "The Forest Sector in the Russian Far East: Status and Near-Term Development", by Ekaterina Gataulina and Thomas R. Waggener, 1998, formerly

probably used as commercial wood (lumber and other products) with milling wastes used for fuelwood, manufacture of small items, paper-making, and other applications.

We found a limited amount of direct information on the consumption of non-wood biomass for fuel. A document in our files[204] reports that a total of 3.1 million tonnes of crop residue (straw and bran) was used in agriculture in 1990. In addition to this figure, we have assumed a total of 2.55 million tonnes of crop residues were used, primarily in the rural sector, in order to provide sufficient biomass supply to meet demand for fuel and other uses. Although this figure (revised relative to some previous versions of this report) is plausible, given the areas and reported yields of crops in the DPRK, it is may still be somewhat high, indicating that our estimate for 1990 wood/biomass fuel demand in the rural residential subsector (see below) may remain somewhat on the high side.

The DPRK biomass production potential probably was damaged in some areas by the floods of 1995 and 1996. In addition, increased foraging in response to the food shortages in the DPRK may end up having a long-term detrimental impact on the forests of the DPRK. For 1996, we assume that sufficient domestic wood and biomass resources were available to meet demand, and that wood imports remained at the same level as in 1990, although this assumption has yet to be fully confirmed.

2.4. Transformation Processes in 1990 and 1996

We have included the following fuel-transforming processes in the estimated DPRK supply-demand balance:

- *Electricity Generation*, including thermal power generation fueled with coal and oil products, and hydroelectric generation;
- *District Heat Production*;
- *Petroleum Refining*;
- *Coal Production and Preparation*; and
- *Charcoal Production* from wood.

Also included in the balance are categories for *Coke Production*, which is not accounted for separately from other coal use (as we lack adequate information on coke production in the DPRK), but could be at some point; *Other Transformation*, for future inclusion of major transformation processes that we may not have yet taken into account (or may be used in the future); *Own Use*, for use of fuels during transformation processes (such as electricity used in power plants); and *Losses*, for losses of fuels between the point at which they are produced and the point at which they are consumed.

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available as http://www.cintrafor.org/research_tab/links/WP/WP63.htm) suggests that the average productivity of Russian forest workers as of 1994 was "360 m3 per worker (roundwood equivalent)", presumably per annum. This suggests, if the productivity of DPRK work crews were similar, that the DPRK crews might harvest up to about 7 million cubic meters per year, assuming the same rate of production (and the same access to harvesting equipment--which may well not be a given) as Russian crews. If, as has been reported, DPRK harvesting crews brought home approximately a quarter or a third of their harvest (the rest remaining in Russia), annual imports of wood back to the DPRK would be in the range from 1.4 to 2.4 million tonnes. We assume that 1990 imports of wood to the DPRK from the RFE were at the lower end of this range.

[204] Document in authors' files [HT1].

2.4.1. Electricity generation in the DPRK, 1990 and 1996

Chapter 5 of this Report provides a detailed description of our analysis of the DPRK electricity sector through the year 2020. In this section we focus on what was known about electricity generation in the DPRK as of 1990 and 1996, information that forms the basis of our analysis of sectoral activity and changes in later years. As such, to provide the reader with information relevant to the chapter topics in both places, there are some overlaps between the coverage of this section and of Chapter 5 for the early years of our analysis.

There are reportedly over 500 electricity generation facilities in the DPRK. Of these, however, only 62 major power plants operate as part of the (nominally) interconnected transmission and distribution grid, with the remaining plants being primarily small, isolated hydroelectric facilities and/or facilities associated with industrial installations. One estimate suggests that 85 percent of total national generation took place in the 62 major power plants in the 1990s; other, unofficial reports suggest generation at smaller plants is insignificant. The 62 "major" plants reportedly include 42 hydroelectric plants and 20 thermal plants. Of the thermal plants, 18 are reportedly fired primarily with coal.[205] The power generation system in general suffers from a lack of spare parts (particularly for plants built with USSR assistance), as well as a lack of testing equipment for use in maintenance activities.

2.4.1.1. Total electricity generated and losses, and district heat production, in 1990

Our estimate of electricity generation starts with the assumption that gross generation in North Korea in 1990 totaled 46 TWh of electricity.[206] This estimate is somewhat closer to official DPRK estimates (60 TWh and higher) and UN estimates (55.5 TWh[207]) than to estimates by ROK sources (27.7 TWh[208]), Russian sources (35 TWh[209]), and more informal estimates of 31-32 TWh,[210] but the latter may be a consumption rather than a production figure. To split total generation into thermal and hydroelectric generation, we adopted the official DPRK figure, which indicates that slightly more than half (about 54 percent) of all electricity generation occurred in thermal plants in 1990.[211] To provide separate estimates of coal-fired and oil-fired electricity generation, we started with an estimate of generation in the DPRK's largest oil-fired plant. We then assumed, based the available partial accountings of the number, type, and size of generating facilities, and on more informal reports, that generation in this plant (the Oung gi plant, associated with the refinery at Sonbong) comprised 100 percent of all oil-fired generation in 1990. Subtracting total oil-fired generation from total thermal generation yielded our estimate of total coal-fired generation.

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[205] Document in authors' files [EE1].
[206] Document in authors' files/personal correspondence.
[207] Choi Su Young (1993), *Study of the Present State of Energy Supply in North Korea*, Research Institute for National Unification (RINU), Seoul, (ROK).
[208] ROK Ministry of Unification (1996), "Electric Generation Capacity and Actual Generation". Obtained from World-wide web site http://www/unikorea.go.kr/eng/ja/table/enk21.htm (but link no longer in service).
[209] Moiseyev, V. (1996), *The Electric Energy Sector of the DPRK* Paper presented at the workshop on "Security on the Korean Peninsula," November 21, 1996, Diplomatic Academy, Moscow, sponsored by the Center for Nonproliferation Studies at the Monterey Institute of International Studies (with funding from the Rockefeller Foundation).
[210] A. Karabanov (1993); personal communication.
[211] Document in authors' files [EE1].

For losses, we used the official estimate that 10 percent of net generation is lost in electricity transmission, and an additional 6 percent in distribution (T&D).[212] These estimates are in aggregate similar to current Chinese values for such losses but may be optimistic. Except in the Pyongyang region, the DPRK power grid as of 1990 was (and reportedly largely still is, as of 2020) dispatched literally by phone and telex, and outages on the grid are frequent. As records of power consumption at the end-user are not at all common in DPRK, however, there is probably limited opportunity to determine the true extent of transmission and distribution losses.[213]

There was, as of 1990, a considerable but unknown amount of self-generation of electricity by industry. We do not know whether this generation is accounted for in the total electricity generation estimate that we have used, but since our estimate for total generation is more likely to be high than low, we assume that self-generation has been adequately taken into account.

There is also an unknown but substantial amount of district heating in the DPRK, some of which reportedly uses steam generated in fossil-fueled power plants (this in addition to steam and hot water provided by the 11,000 small- to mid-sized boilers reportedly used in buildings and industries in the DPRK) and by stand-alone district heat boilers located in major power plants along with boilers for electricity generation.[214] Our rough estimate, based on numerous assumptions, is that as of 1990 somewhat under 11 million GJ of total heat for district heating was generated, of which about 75 percent was from power plants, with the remainder from heat-only district heating plants. We assumed average heat losses of 15 percent between the district heating or combined heat and power plants and heat consumers. This assumption does not have a direct effect on estimates of electricity production or use but does affect the amount of heat that consumers receive from combined heat and power plants. If district heating from power plants proves more extensive that we have estimated, it would likely increase our estimate for coal used in the power sector, because it would increase the heat output of combined heat and power plants (such as the Pyongyang plant), which would in turn mean an effective decrease in the electricity generation efficiency (because more heat is diverted to heat production). Increasing our estimate of district heating would, however, reduce our estimate for coal used in the urban residential and public commercial sectors, because more heat supply would be accounted for by district heat and combined heat and power plants, rather than stand-alone coal boilers and stoves.

2.4.1.2.Detail of existing thermal generating facilities

Although there are discrepancies between the various estimates of the installed capacity of thermal electricity generating capacity in the DPRK,[215] we have assumed that the total installed

[212] (Document in authors' files [EP1].

[213] Other reports indicate that total electricity losses in the DPRK were on the order of 25 percent of generation in 1990, but the 25 percent figure includes routine and emergency station losses and "own use" as well as T&D losses. Our estimate of 16 percent T&D losses, coupled with our estimates of own use and emergency station losses, yield an overall loss rate that is also in the 25 percent range.

[214] A document in the authors' files, citing a DPRK source [NKES-01], indicates that the Pyongyang power plant has two district heating boilers rated (each, we presume) at 210 tonnes of steam/hr, or 100 Gcal/hr. Based on a very rough calculation, two boilers of this size could supply space heat and hot water for tens of thousands of households (perhaps 50,000 to 100,000).

[215] Choi (1993), for example, cites a total capacity for coal-fired generating stations of 2,850 MW in 1991, while the United Nations lists 4,500 MW of thermal capacity for 1989 through 1992. Other documents in our files list a total of 2,900 MW of

and potentially usable[216] thermal generating capacity as of 1990 was approximately 3,200 megawatts. Table 2-4 provides our best attempt, compiled from a number of sources, at a plant-by-plant accounting of the capacities and vintages of some of the thermal generating facilities in the DPRK as of the early 1990s. The total of the listed plants (6 plants, 2,850 MW as of 1990) comes up short of both the 20 thermal facilities reportedly connected to the grid and to the 4,500 MW of capacity that has been reported in official documents to be the overall total. If our 3,200 MW total is correct, this figure means that the additional 14 reportedly grid-connected thermal facilities have an average capacity of about 25 MW each. We assume that there existed (and may still exist) additional smaller and/or industry-associated plants that fit this description but updated or more accurate information on this topic is needed to fully complete the picture.

Table 2-4: Major Thermal Generating Facilities in the DPRK as of 1992[217]

#	Name		Capacity (MW)	Fuel	Year Completed
1	Pyongyang		500	Coal	1968
2	Bukchang		1600	Coal	1985
3	Chongjin		150	Coal	1984
4	Chonchonang		200	Coal	1979
5	Oungi		200	Oil	1973
6	Sunchon		200	Coal	1988
7	East Pyongyang		50	Coal	1992
TOTAL OF LISTED PLANTS			**2900**		

Of the major thermal power plants that are connected to the national transmission and distribution (T&D) grid, only two were reported to be oil-fired as of 1990. Of these, one was the 200 MW plant at Sonbong (listed as "Oungi" in the table above, and also referred to sometimes as "Oung gi" and "Unggi" by other sources) where many of the KEDO heavy fuel oil (HFO) deliveries were made. Figure 2-2 provides a photo of the control room at the Pukchang ("Bukchang", in the table above) Thermal Power Plant, the DPRK's largest.

capacity as of 1990 in the largest seven thermal plants alone, and still others list "official figures" of up 6,000 MW of thermal capacity in 1990. We have adopted the United Nations figure as our estimate for 1990.

[216] It has been reported that a large number of the smaller power plants reportedly included in official estimates of overall generation capacity were essentially built as "shams" to satisfy authorities and were actually never actually capable of generating power.

[217] Please see Attachment 1 for a listing of the sources used in developing this table.

Figure 2-2: Control Room at Pukchang Thermal Power Plant[218]

Since 1990, the only reported major addition to the roster of large thermal power plants has been the completion in the early 1990s of the (reportedly) 150 MW East Pyongyang plant. Reports indicate that only 50 MW of the 150 MW plant were actually completed by the early 1990s, and only with great difficulty, as Russian assistance was not available at that time to complete the work on the plant that was started in the 1980s in collaboration with the USSR. Although the Korea Energy Economics Institute (KEEI) reports that a new 600 MW plant called Dongpyungyang at Nakrangku, Namposhi was completed in 1996, we do not know if the Dongpyungyang plant is an addition to an existing plant in the Pyongyang area (perhaps East Pyongyang?), or a completely new plant, or whether it in fact ran in 1996—although sources indicate that it hasn't. Given these uncertainties, we have assumed for the purposes of modeling that the total coal-fired generation capacity in 1996 was the 3,200 MW reported in 1990, plus 50 MW for the addition of the East Pyongyang plant. Several other thermal generating facilities have been reported to be under construction in the DPRK. A roster of these plants is provided in Table 2-5. We do not know the present status of construction of these facilities. We have been told that, as of 1996, thermal power plant construction had stopped except at the East Pyongyang power plant. See Chapter 3 for estimated updates on the capacities and status of power production facilities as of 2000 and 2005.

[218] Photo from dprkguidebook.org (date not provided, but probably 2006 or 2007), "Main Industrial Sectors & Business Opportunities", available as http://dprkguidebook.org/contents_3.htm.

Table 2-5: Thermal (fossil fueled) Generating Facilities Reported to be Under Construction or "Planned for Construction" in the DPRK as of About 1996[219]

#	Name	Capacity (MW)	Fuel	Year Started	Year Completed
1	Pyunghung(?)	200	Coal		
2	Suncheon(?)	200	Coal		
3	Dongpyungyang	600	Coal		1993 - 1996
4	Kimchaek	150	Coal	1988	
5	Hamhyng central	100	Coal	1994	
6	12wol	150	Coal		1993
7	Haeju	Unknown	Coal	1990	
8	Ahnju	1200	Coal	1989	
9	Hamheung	150	Coal	1989	
	TOTAL OF LISTED PLANTS	**2,750**			

To calculate the fuel used by thermal power plants, we have assumed that coal-fired plants use heavy fuel oil primarily as a start-up fuel in 1990, with HFO constituting about 2.0 percent of the total heat value of input fuel. Using figures for electricity generation by fuel type derived as indicated above, we then calculated the fuel requirements for thermal electricity generation using gross generation efficiencies in 1990 of 29.5 percent for oil-fired plants[220] and 28 percent for coal-fired plants. The efficiency figure we have assumed coal-fired plants is somewhat lower than the average heat rate (30 percent) reported in the Chongjin plant in the Sonbong area but is comparable to Chinese electricity generation efficiencies for thermal plants of late-1970s vintages.[221, 222]

The "own use" of electricity in oil-fired and coal-fired plants was assumed to be 8 and 9 percent of gross generation, respectively. These own use values are those quoted for the Oungi and Chongjin plants, respectively,[223] and are relatively high compared to typical thermal power plants. For coal-fired plants, we assumed an additional "emergency loss" rate in 1990 of 5 percent (accounted for in the "own use" row of the energy balances), which is a bold extrapolation from experience at the Pyongyang power station,[224] and may be indicative of poor operating conditions in all DPRK coal-fired power plants. For 1996, we increased this rate to 7.5 percent of gross generation in coal-fired plants.

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[219] Please see Annex 1 for a listing of the sources used in developing this table. Due to differences in nomenclature and translation between sources, there may be some plants that actually appear twice on this list.

[220] This value is substantially lower than an official (we assume) figure of 35 percent quoted in UNDP (1994) (*Studies in Support of Tumen River Area Development Programme*, as prepared by KIEP, Seoul, ROK for the UNDP, July, 1994). An efficiency of 35 percent seems too high oil-fired generation in the DPRK, given reports about the condition of the oil-fired plant at Sonbong. The 29.5 percent efficiency we have used is consistent with information we have received about the Sonbong plant's recent operations.

[221] Sinton, J., editor (1996), *China Energy Databook 1996 Edition*, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.

[222] It should be remembered that most of the thermal power plants in the DPRK were built with assistance from the USSR—the example of efficiencies in Chinese plants is used here only as a benchmark.

[223] UNDP (1994), *Studies in Support of Tumen River Area Development Programme*. Prepared by KIEP, Seoul, ROK for the UNDP, July, 1994.

[224] Document in authors' files [EE1].

2.4.1.3.Detail of existing hydroelectric facilities

The DPRK is a mountainous country with substantial rainfall. It thus has fairly extensive total potential for hydroelectric development. The DPRK's ability to mobilize massive work forces for public works projects such as dams has helped the country to tap this potential, and as of 1990 approximately 4,500 of an estimated 10,000 to 14,000 MW of hydroelectric potential had been developed. Table 2-6 provides a listing of those major hydroelectric facilities about which we have capacity information. The 20 plants on this list built prior to 1990 account for approximately 3,100 of the 4,500 MW of hydroelectric capacity reportedly in service as of 1990, and probably comprise about half (numerically) of the grid-connected hydroelectric plants. Electricity from several plants on this list (Supung, Ounbong, T'aep'enmang, and Weewong) is exported to China. Note that the capacities listed in Table 2-6 exclude the portions of power generated in those four plants that is sent to China. Including that portion of the capacity reportedly under contract to China (700 MW) raises the total 1990 capacity accounted for by the facilities in Table 2-6 to about 4,000 MW, over 85 percent of the total hydro capacity reported.

Many of the smaller hydroelectric facilities in operation in the DPRK, are reportedly of the "run-of-river" type, meaning that relatively little water is impounded behind the dams. Although this would tend to suggest that electric output from the DPRK's hydro plants may be more likely to be subject to the vagaries of the weather—poor rainfall months or years resulting in lower-than average electricity production—than systems with more impoundment-type dams, it has been suggested that the larger plants, including those initially designed and built during the Japanese colonial era, reportedly combine impoundment and run-of-river elements, resulting in relatively high capacity factors.[225] Figure 2-3 presents a photo of one of the "cascades" of the Kangae (also referred to as "Kanggye") hydro power plant, showing a series of turbine-generator units floating on the surface of the river. It is unclear what fraction of the capacity of the Kangae cascade the units in the photo represent.

[225] As an example of the potential of the combined impoundment/run-of-river design to produce power consistently, Prof. Y.S. Jang (personal communication, 1996) reports that the capacity factor of hydroelectric plants in North Korea was over 70 percent during 1943.

Table 2-6: Major Hydroelectric Generating Facilities in the DPRK[226]

#	Name	Capacity (MW)	Year Completed	Year Refurbished
1	Supung	400		
2	Kymgansang cascade	13.5	1930	1958
3	Puren cascade	28.5	1932	
4	Puch'on-gang	260	1932	1956
5	Chanjin-gang	390	1936	1958
6	Hoch'on-gang	394	1942	1958
7	Tonno-gang	90	1959	
8	Kangae	246	1965	
9	Ounbong	200	1970	
10	Sodusu-1	180	1974	
11	Sodusu-2	230	1978	
12	Sodusu-3	45	1982	
13	Taedong-gang	200	1982	
14	Mirim	32	1980	
15	Ponhwa	32	1983	
16	Hwan-gang	20	198?	
17	Tonhwa	20	198?	
18	T'aep'enmang	90	1989	
19	Weewong	200	1989	
20	Nam-gang	200	1994	
21	Dokro river	36		
TOTAL OF LISTED PLANTS		**3,307**		

Figure 2-3: Photo of Kangae Hydro Power Plant[227]

[226] Please see Attachment 1 for a listing of the sources used in developing this table.
[227] From document in the authors' files [OS-4-19-2012, page 37].

Table 2-7 presents our summary of hydroelectric plants reported to be under construction or planned as of the early 1990s. Although the capacities of these plants—to the extent that they have been assigned an estimated value—add to nearly 3,000 MW, we had little information about how far construction on these projects (if any) had progressed as of 1996 (see Chapter 5 for analysis of more recent hydroelectric plant additions). The only exception was the Kumgang Mountain plant, a first phase of which (reportedly about 125 MW) was opened in 1996. We were told that, as of 1996, construction on all hydro plants except the Kumgang Mountain plant (which reportedly has political and military importance beyond its role in the power sector) was at a standstill.

Given the location and extent of the flooding in the DPRK during 1995 and 1996, it always seemed probable to us that the DPRK hydroelectric system had sustained significant damage. Until about 2000, however, the reports that we could glean either yielded no information about the impacts of flooding on hydro production or indicated minor damage to smaller facilities. In about 2000, information from a source that we consider reliable indicates that reservoir siltation and perhaps mechanical damage at major hydroelectric facilities had in fact taken place, to the extent that the effective capacity factor of hydroelectric facilities in 1996 was on the order of 15 percent. We have modeled this reduction in usable hydroelectric capacity by assuming that available hydro capacity at existing facilities fell by about 3250 MW from 1990 values by 1996 as a result of flood damage,[228] offset slightly by additions to capacity.[229] We have further assumed, based on conversations with those familiar with the situation, that 1996 power production for China from Chinese-controlled plants were reduced to about 28 percent of their 1990 levels as a result of flood damage to the hydroelectric stations on the DPRK/Chinese border. Note that the electricity produced by these plants for China is not included in our energy balances as "exports" from the DPRK to China, since those plants are in fact owned and controlled by China.

[228] Several sources that have been to the DPRK recently said they had no knowledge of major damage to large hydroelectric facilities. Another source had heard of damage to "one or two" "small to medium-sized" (less than 10 MW) plants.

[229] KEEI (Korean Energy Economics Institute, 1996; personal communication from Mr. Roh Dongseok, Electricity Policy Division) cites an 800 MW increase in capacity from the newly opened Kumgang Mountain plant. Earlier ROK estimates had also placed the (expected) capacity of this plant at 800 MW, although its capacity under the phases completed as of the late 1990s and/or accounting for existing reservoir levels is probably in the range of 100 - 150 megawatts. The Kumgang mountain plant was also referred to in announcements in the DPRK press, but without reference to plant capacity.

Table 2-7: Major Hydroelectric Generating Facilities Reported to be Under Construction or "Planned for Construction" in the DPRK[230]

#	Name	Capacity (MW)	Year Started	Year Completed
1	Taechun	750	1983	
2	Kumgang Mountain	800	1985	1996 (1st Phase)
3	Sodusu-4	200	1990	
4	Namkang	Unknown	1983	
5	Youngwon	Unknown	1986	
6	Ehrangcheon	Unknown	1986	
7	Jabgjakang	240		
8	P'och'on	820		
9	Oranch'on	180		
10	Heech'on	Unknown	1989	
11	Kymyan-gang	Unknown		
TOTAL OF LISTED PLANTS		**2,990**		

Our estimate for the supply of hydroelectric power in 1990 starts with the overall generation of 46 TWhe described above, of which slightly less than half (46 percent) is assumed to be generated in hydro plants.[231] These two figures, taken together, imply an overall capacity factor for hydroelectric facilities of about 54 percent. We counted the hydro input energy to electricity generation assuming an efficiency conversion of 100 percent output electricity to input energy, as is done in United Nations statistics.[232] The "own use" of electricity in hydro plants was assumed to be 0.3 percent of gross generation, which corresponds to ROK conditions in 1970,[233] and is also similar to values for Chinese plants.

2.4.1.4.Status of the Transmission and Distribution Network

The unified electrical grid in the DPRK apparently dates to 1958.[234] The DPRK T&D system must nominally manage a fairly complex grid of 62 power plants, 58 substations, and 11 regional transmission and dispatching centers. Our limited information on the DPRK T&D system as it stood in 1990 (and for the most part, is assumed to stand today) is presented below.

[230] Please see Attachment 1 for a listing of the sources used in developing this table.
[231] Document in authors' files [EE1].
[232] Note that the actual conversion efficiency of energy in falling water to electricity in hydro plants is typically less than 100%, on the order of 70 to 90 percent.
[233] Kim, E.-W., H. Kim, H.-K. Lim, C. Nahm, M.-C. Shin, and Y. Kim (1983), *The Electric Future of Korea*. Resource Systems Institute, Honolulu, Hawaii, USA. Research Materials RM-83-8.
[234] Moiseyev, V. (1996), *The Electric Energy Sector of the DPRK* Paper presented at the workshop on "Security on the Korean Peninsula," November 21, 1996, Diplomatic Academy, Moscow, sponsored by the Center for Nonproliferation Studies at the Monterey Institute of International Studies (with funding from the Rockefeller Foundation).

Main Transmission Lines, Substations, and Dispatching Centers

A general map of the electricity transmission system in the DPRK is provided as Figure 2-4, and a similar map from another source with power station and other titles in English is provided as Figure 2-5. The main transmission lines in the DPRK are rated at 220 and 110 kV (kilovolts).

The main transmission lines in the DPRK include (but are not limited to) the following:

- A 220 kV line from the Bukchang (also referred to as "Pukchang") thermal power plant to the Vynalon substation
- A 220 kV line from the Vynalon substation to the Chanjin-gang power station
- A 220 kV line from the Bukchang thermal power plant to the Chanjin-gang power station
- A 220 kV line from the Chanjin-gang power station to the Kangae hydro power station via the Taedong-gang hydro power station
- A 220 kV line from the Kangae hydro power station to the Ounbong hydro power station
- A 220 kV line from the Bukchang thermal power plant to a substation located southeast of Pyongyang (probably named "Pyongyang No. 2") via the Songchon substation
- A 220 kV line from a substation located southeast of Pyongyang to the Pyongyang thermal power plant
- A 220 kV line from the "Central center" in Pyongyang to the Chonchonang thermal plant
- A 110 kV line from the Chonchonang thermal plant to the Supung hydro power plant. The Taechon hydro power plant is also connected to this line.
- A 110 kV line from a substation located west and slightly south of Pyongyang (probably named "Pyongyang No. 1") to the Supung hydro power plant via the Sin-Anju substation. The Taechon hydro power plant is also connected to this line.
- A 110 kV line from a substation located west and slightly south of Pyongyang to the "Central Center" in Pyongyang
- A 110 kV line from a substation located southeast of Pyongyang to the "Central Center" in Pyongyang
- A 110 kV line from the Pyongyang thermal power station to the "Central Center" in Pyongyang
- A 110 kV line from the "Central Center" in Pyongyang to the Buckchang thermal power station.
- A 110 kV line from the Pyongyang thermal power station to the substation located west and slightly south of Pyongyang
- A 110 kV line from the Chanjin-gang hydro power station to the Danchon switching station, via another substation or switching station
- A 110 kV line from the Danchon switching station to the Chongjin substation (and Chongjin thermal plant)

In the Tumen River area, the system of 110 and 66 kV transmission lines has been estimated to include:[235]

- A 110 kV line from the Chongjin substation (and Chongjin thermal plant) to the Puryong area and North to the Chinese border at Haeryong
- A 110 kV line from the Chongjin substation (and Chongjin thermal plant) to the Aoji area
- A 110 kV line from the Chongjin substation (and Chongjin thermal plant) along the coast to the Unggi and Sonbong area
- A 66 kV line from the Chinese border at Haeryong further north along the border to Onsong
- A 66 kV line from Onsong to the Hunyung area
- A 66 kV line from the Hunyung area to the Aoji area
- A 66 kV line running east in a loop near the border from the Aoji area through the Unggi and Sonbong area.
- A 66 kV line from the Puryong area to the Musan area.

In addition to these lines, there is reportedly a 60 kV line supplying power (possibly from the Supung hydro plant) to a remote area of China. There are certainly other transmission lines in the DPRK, but we do not, at present, have their specifications. In some locations, 66 kV lines (or possibly 60 kV lines—sources differ on the voltage specification) are used for transmission, as well as for bulk distribution. In particular, it is reported that 66 kV line is used in the regions of Kongonwon, Saebyol, and Onsong.[236]

In addition to 66 kV/60 kV feeder lines to distribution systems, 10 kV and 3.3 kV lines are used for bulk distribution of power. Secondary distribution voltages are reportedly 380 and 220 volts,[237] although some outlets are supplied at both 110 and 220 volts.

As of early 1992, the DPRK had plans to build 200 km of 220 kV power lines, 60 km of 110 kV lines, and 500 km of 66 kV lines per year through the year 2000.[238] Although we do not know the status of these construction projects, we assume that progress has not achieved targeted levels. Also, as of 1992, the DPRK had plans to build a 330 kV transmission system, with implementation to start within 2 years, and planned, in the long term, to build a 500 kV transmission system. We assume that little progress has been made on either of these higher-voltage systems.

[235] Document in authors' files [EP1].
[236] UNDP (1994), *Studies in Support of Tumen River Area Development Programme*. Prepared by KIEP, Seoul, ROK for the UNDP, July 1994.
[237] Document in authors' files [EP1].
[238] Kilometers of line here probably refers to conductor-kilometers.

Figure 2-4: Overall Map of the DPRK Electric Power Grid

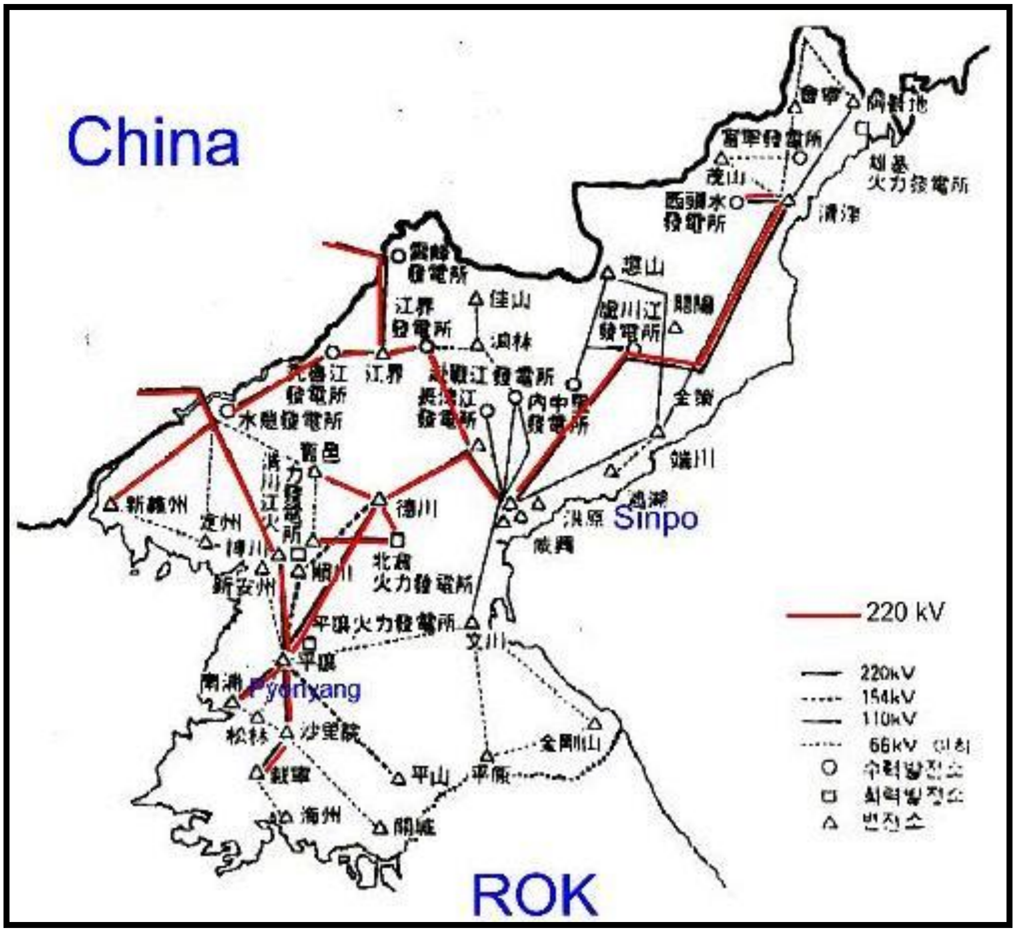
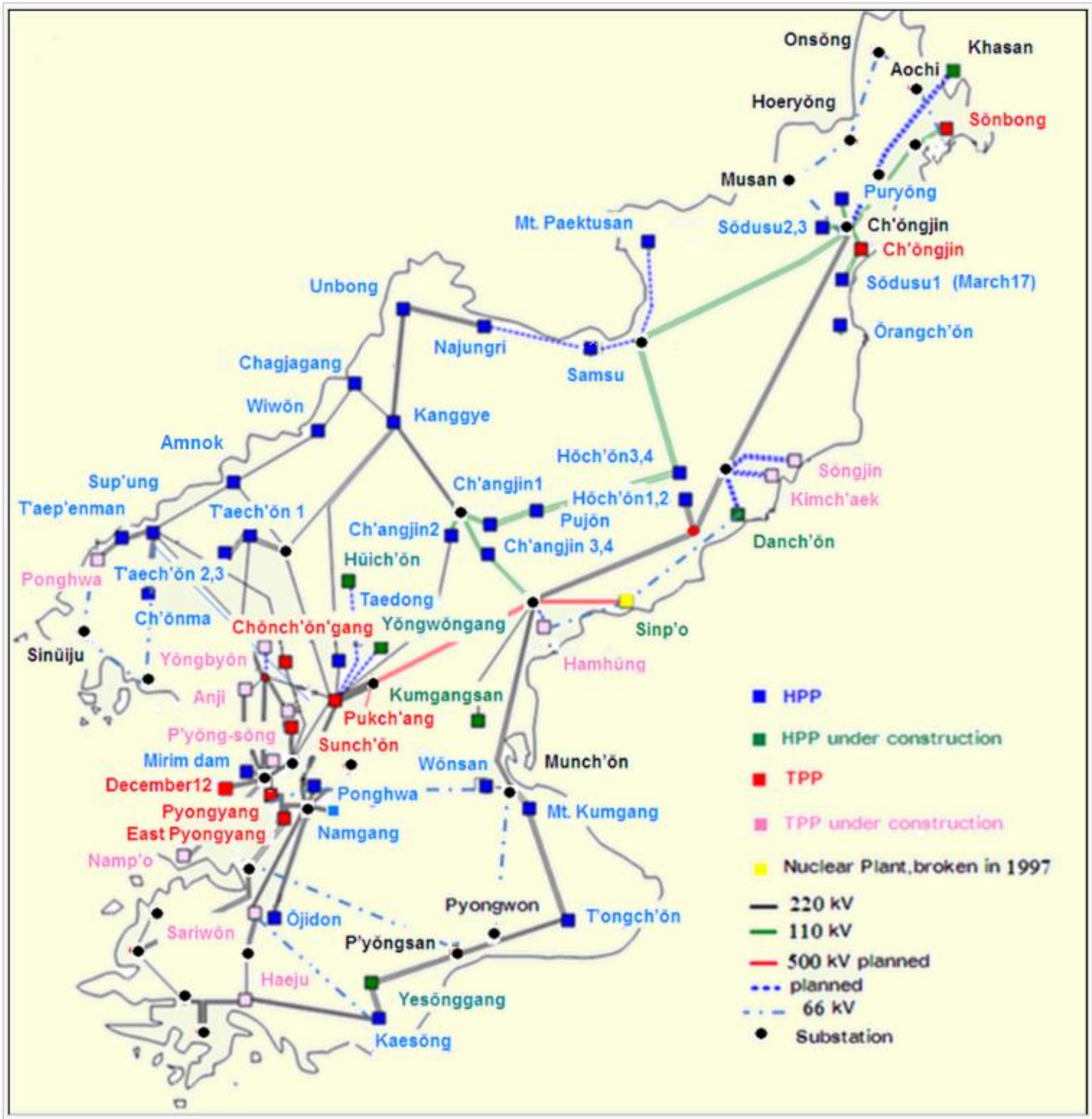


Figure 2-5: Map of the DPRK Electric Power Grid[239]



There were, as of about 1990, reportedly 58 substations on the DPRK grid at the highest transmission voltage levels.[240] We have capacity information about only four of these,[241] and

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[239] From document in the authors' files [OS-2-27-2012, page 38]. The legend entry "Nuclear Plant, broken in 1997" likely refers to the groundbreaking for the KEDO nuclear reactors at Kumho/Sinpo, and dates this map to sometime after 1997.

[240] More recent estimates provided by experts suggest that there may be somewhat under 80 transmission substations in the DPRK designed to operate with nominally 220 kV inputs, with perhaps another 200 transmission substations operating at the 66 kV/11 kV levels, 2500 11 kV distribution substations, and about 15,000 transformers to distribute power to consumers.

[241] Capacity is supplied in units of million volt-amps (MVA).

names for a number of others. These data are provided in Table 2-8. A substation in the Sonbong area is reportedly rated at 110 kV, and there are (or were to be by 1995) two 110 kV substations and one 220 kV substation in the Chongjin district.[242] The substations in the DPRK are reportedly antiquated—based on obsolete Russian and Chinese technology—and are also poorly maintained. Our assumption is that most or all substations would need to be replaced, or at least substantially refurbished, to bring the DPRK grid up to modern standards. We do not have a detailed current estimate for the costs of updating or replacing existing transmission lines and substations in the DPRK. As a benchmark from our earlier analysis, however, using 1990s cost estimates presented in the context of Tumen River area infrastructural development would appear to indicate that a mixture of new 110 and 220 kV transmission lines and substations in the DPRK will cost in the range of $250,000 to $500,000 per conductor-kilometer (most lines will have at least two conductors)[243] in mid-1990s dollars. Estimates of transmission lines in South Korea were similar, about $150,000 to $300,000 per conductor-kilometer for 154 kV lines, and $400,000 to $600,000 per conductor-kilometer for 345 kV lines. Costs for substations, again from ROK sources, were about $10 million for 154 kV units, and $36 million for 345 kV substations as of the late 1990s.[244] Costs for transmission lines vary considerably with the capacity and voltage of the line, the topography to be covered, and other variables. In addition, costs for transmission lines and substations may have increased, particularly in recent years, faster than inflation, due to the increase in commodities prices (especially metals) that preceded the recent global recession. As a rough total estimate based on the figures above, assuming an average transmission line costs cost of $250,000 per conductor kilometer, a total length of (2-conductor) line to be replaced of about 5,000 kilometers (also a very rough estimate), and 58 substations and 11 control centers to be replaced (or refurbished) at a cost of $10 million each yields an extremely rough, order-of-magnitude estimate of about $3 billion—in 1995 dollars—for the costs of replacing the entire DPRK electricity grid.[245] In 2020 dollars, this estimate would be above $5 billion, which we would suggest is definitely a lower bound for possible costs, especially as it does not include either the costs of either distribution lines or transformers (lower-voltage lines and transformers within cities and towns, and connecting buildings and other loads to the grid) or any power plant refurbishment. Given the rugged topography of the DPRK, costs might be much higher, although the use of existing substation sites and power line rights-of-way (as well as the possibility of using some existing equipment) might be a mitigating factor. If we had to guess, we would say that this estimate is probably a factor of 5 low if done more comprehensively and with more current costs, although, as noted later in this report, the approach used to redevelop the DPRK grid—for example, whether "top-down" or "bottom-up", and with which generation resources, may have a huge bearing on overall costs. Depending on

[242] UNDP (1994), *Studies in Support of Tumen River Area Development Programme*. Prepared by KIEP, Seoul, ROK for the UNDP, July 1994.

[243] UNDP (1994), *Studies in Support of Tumen River Area Development Programme*. Prepared by KIEP, Seoul, ROK for the UNDP, July 1994.

[244] Representative costs for transmission lines and substations supplied by KEPCO (personal communication, 8/14/97). The costs for substations shown are at the low end of the range supplied. Enclosure costs can increase the costs of substations. Costs shown here are in approximately mid-1990s USD.

[245] Again, it must be stressed that this is the roughest of estimates. It would not surprise us if a more thorough estimate of the costs of replacing/refurbishing the DPRK transmission grid was within the range of $2 to $10 billion, exclusive of any costs for refurbishing the power plants themselves. As noted, also excluded from these estimates are costs of refurbishing distribution systems (if necessary). Simply installing electricity meters on the distribution feeders to the (very roughly) 5 million households and other electricity users in the DPRK alone would likely cost on the order of $0.25 to $1 billion dollars for even relatively simple meters.

the materials used in the existing substations,[246] there may be environmental issues and costs associated with substation replacement.

Table 2-8: Partial Listing of High-voltage Substations on the DPRK Electrical Grid[247]

#	Name	Capacity MVA	Units
1	Changjingang	48	1x28, 1x20
2	Chongjin	165	1x100, 1x5, 1x60
3	Pyongyang No. 2	100	2x50
4	Vynalon	200	2x50, 1x100
5	Pyongyang No. 1		
6	Undok		
7	Munsan		
8	Kilju		
9	Hamhung		
10	Songchon		
11	Sepo		
12	Nampo		
13	Kusong		
14	Sinuiju		
15	Pyongsong		
16	Sin-Anju		

The T&D system is nominally controlled by the Electric Power Production and Dispatching and Control Centre (EPPDCC) in Pyongyang and by 11 regional dispatching centers. The names of the regional centers are provided in Table 2-9.

[246] Possibly including, for example, costs and risks associated with disposal of PCBs, or (polychlorinated biphenyls), which are likely present in older substations and transformers as insulating oils.
[247] Document in authors' files [EP1].

Table 2-9: Listing of Regional Control Centers on the DPRK Electrical Grid[248]

#	Name	Location (city)
1	North Kamgyong	Chongzin
2	Ryanggang	Hyesan
3	Chagang	Kanggye
4	South Hamgyong	Hamhung
5	South Pyongan	Pyongsong
6	Kangwon	Wonsan
7	North Hwanghae	Sariwon
8	Nampo	Nampo
9	South Hwanghae	Haeju
10	Kaesong	Kaesong
11	North Pyongan	Siniju

Reported Status of Transmission Network

For transmission and distribution losses, for 1990, we used the official estimate that 10 percent of net generation is lost in electricity transmission, and an additional 6 percent in distribution.[249] These estimates are in aggregate similar to Chinese values of the same period for such losses,[250] and comport with independent reports of loss rates (as noted above) but may still be optimistic for the DPRK. As records of power consumption at the end-user are apparently not common in DPRK, there is probably limited opportunity to determine the true extent of transmission and distribution losses.

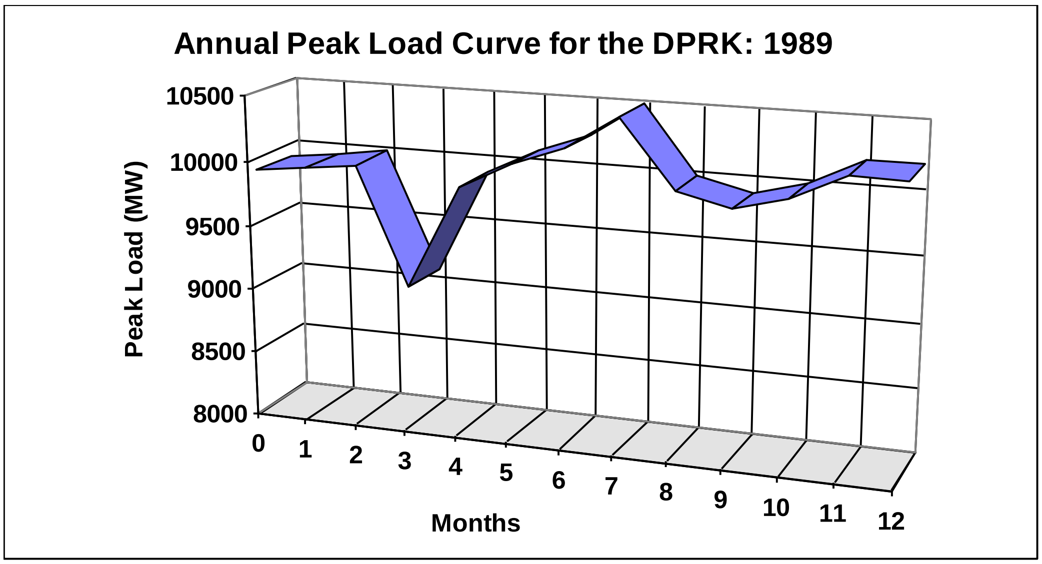
As of 1989, load shedding was reportedly already frequently practiced, with 1,000 MW shed in the winter season (November/December) and up to 2,000 MW shed in the spring (March/April/May) as water levels in the hydroelectric reservoirs decreased and only minimum hydro power generation was available. It is not clear to us, however, whether load shedding at that time was principally a function of lack of generation resources, of unavailability of generation units, or of defects in the T&D system, or, more likely, was a complex combination of these factors.

The reported annual variation of peak load for the year 1989 is provided in Figure 2-6. We do not know to what extent the load figures in this graphic may be overstated, or to what extent load shedding, if any, is reflected (either included or excluded) in the curve. The curve shows peak power demand in the DPRK to be (or at least, to have been) relatively insensitive to changes in seasons, with demand in July being about 5 percent higher than average, and demand in March being about 10 percent lower. The stability of the peak over the year is not unreasonable, given the extent to which industrial electricity demand was dominant over demand in the other sectors in the DPRK at the time, given that most heating in the DPRK is non-electric, and given that

[248] Document in authors' files [EP1].
[249] Document in authors' files [EP1].
[250] Note, however, that transmission and distribution data in Chinese energy statistics often only include losses on transmission and major distribution systems, with losses from smaller distribution systems counted as a part of end-use consumption by industry, residences, and others. As a consequence, published statistics for T&D losses in China will typically be much smaller, closer to 5-8 percent of generation.

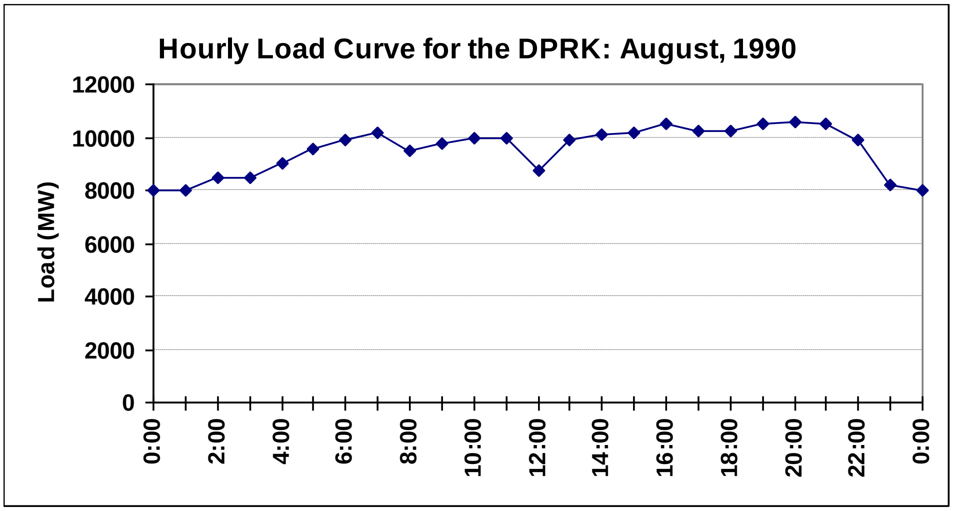
there was (and continues to be) relatively little air conditioning in the DPRK. 1989 was, however, an unusual year for the DPRK, in that it was the year in which the DPRK hosted a massive international youth festival that likely resulted in at least somewhat atypical load patterns. In addition, it has been reported that schedules in industrial plants in the DPRK at least were (as of 1990) coordinated to make maximal use of electricity supplies. It is conceivable that the summer peak has something to do with higher use of fans and some air conditioning in institutional buildings, but this is only speculation on our part, as it could also be related to demand related to the youth festival and/or to an all-out push to have all power generation facilities operating during that period. Why demand should be lower in March, we do not know, unless what is being reported in Figure 2-6 is actually peak power supplied, which could be lower in March due to lack of availability of hydroelectric resources.

Figure 2-6: Annual Peak Load Curve for the DPRK as of 1989



The variation of peak load over time during a weekday in August 1990 is provided in Figure 2-7. Peak load appears to have exceed baseload at that time by about 30 percent, which is somewhat less than in many countries. Again, the large portion of power demand accounted for by the industrial sector is probably the reason why the ratio of peak power to baseload power was not greater. Based on the load curve shown in Figure 2-7, the load on the DPRK grid peaked broadly in the early evening (about 7 PM to 9 PM), with a minor peak in the morning (about 7 AM). The timing of these peaks is fairly typical of grids with a substantial number of residential consumers, though grids in most countries will typically show a much higher morning and evening peaks relative to baseload than is indicated in Figure 2-7. There is a relatively substantial dip in demand at about the noon hour, which could possibly be explained by industrial facilities shutting down (partially) when workers take their lunch. Some factories, as of the early 1990s, were also known to phase their workdays to allow maximum use of baseload capacity (for example, in Hamhung). There also may well have been unmet demand during peak times during 1990, meaning that the actual peak would have been higher if supplies of electricity had been sufficient. It is worth keeping in mind that this is just one "snapshot" of a daily load pattern, and may or may have been representative of conditions in general as they were in 1990 (let alone in more recent years), though it is all we have to use at present.

Figure 2-7: Example Hourly Load Curve for the DPRK in August, 1990



Dispatching Capabilities and Systems

Connections between the elements of the T&D system were, as of the early 1990s, reportedly operated literally by telephone and telex, without the aid of automation or computer systems. This system results in poor frequency control, poor power factors, and power outages[251]. Outages on the grid are reportedly frequent, and the process of reacting to outages and isolating areas where the outages occur is cumbersome and slow, often resulting in a cascading series of outages (and further delays in restoring power). Poor frequency control and low power factors can damage end-use equipment and can shorten the life of T&D components.[252] In addition, outages result in significant economic losses because of lost industrial production and services. As of 1990, the Electric Power Production and Dispatching and Control Centre (EPPDCC) for the DPRK grid lacked direct access to even the most rudimentary data from power plants and substations, having direct readout of neither measurements such as voltage, current, active power, frequency, nor status indicators such open/closed conditions of circuit breaker or switch positions. The only exceptions to this lack of access, as of 1990, were links to three power plants, but even these links were reportedly "slow and outdated". (See below for information on the status of projects to update the dispatching system.)

As of the mid-1990s, when a transmission fault or power plant failure disrupted the system, or when voltages or frequencies at load centers fell below permissible levels, the EPPDCC staff were obliged to guide remote operators in restoring the system through the aforementioned system of telephones and telexes, and without access to complete system information on which

[251] A now-completed UNDP-funded project, "Electric Power Management System" was only designed to address control systems at four critical power plants and four substations around Pyongyang.
[252] Hayes, P. (1997), "Supply of Light-Water Reactors to the DPRK". Chapter 3 in *Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula*, Young Whan Kihl and Peter Hayes, Editors. M.E. Sharpe, Armonk, New York, USA.

to base their instructions. There is no indication that this system has changed substantially since, beyond the installation of the a few upgrades in a limited area under projects undertaken with the United Nations Development Programme (see below).

It has been reported that as of 1996, the DPRK grid did not really function as a single unified grid any longer, but as a group of mostly independent regional grids. We do not know what technical or operating problems (among those noted above and below) are central in preventing operation of the unified grid, but identifying and solving those central problems will likely be one (but not the only) requirement if a large power plant (such as the KEDO nuclear reactors, on which construction ceased in the mid-2000s) or a large power transfer to the DPRK (such as the 2 GW power transfer proposed by the ROK in mid-2005) are to be used effectively and safely in the DPRK.

Technical Parameters of the T&D System, and Technical Challenges to Integration with Systems in Other Countries

The power grid in the DPRK operates at a nominal frequency of 60 Hz (Hertz, or cycles per second). As of the 1990s, frequency control was poor (and reportedly remains so), however, and the actual frequency on the system often reportedly fell to 57 to 59 Hz, and sometimes as low as 54 to 55 Hz (based on reports as of 1990).[253] [254]

Of the neighboring countries, both China and Russia have electricity systems that operate at 50 Hz, while the grid in the Republic of Korea operates at 60 Hz. This difference means that in order to interconnect the DPRK grid with the Chinese and/or Russian grid, as has been contemplated under the Tumen River Area Development Programme (TRADP), it will either be necessary to convert from 60 Hz to 50 Hz or from 50 Hz to 60 Hz at the intersection of the power grids using an AC/DC/AC power converter (for additions discussion on this point, see Chapter 5).

Although the ROK power grid operates at nominally the same frequency as the DPRK grid[255] it is virtually certain that interconnection of the grids, in their present form, will require some power conditioning at the point of interconnection to assure that the power entering the ROK meets ROK standards for frequency and other attributes. The best way to achieve this outcome (short of wholesale refurbishment/replacement of the DPRK grid to ROK standards) is probably to add a station near the DPRK/ROK border that converts the AC (alternating current) power from the DPRK to DC (direct current) power, then back to AC power synchronized with the ROK system for export to the south. This conversion process would be carried out using a series of solid-state devices. Power losses through these types of AC-DC-AC system are minimal,

[253] The historically poor control of frequency, and frequent loss of power, on the DPRK grid has reportedly figured in determining the efficiency of industrial equipment in an interesting way. To make sure that the USSR-built industrial equipment installed in the DPRK would hold up under the prevailing conditions of poor power quality, Soviet engineers typically augmented (usually older) USSR designs to make the DPRK plants extra-rugged. These more rugged plants were thus probably more electricity-intensive, on the whole, than typical Soviet plants of the same types and vintages.

[254] Our own power measurements in the DPRK in 1998 and 2000, in fact, showed a much wider range of frequency variation—with frequencies dropping at times to the 45 Hz range.

[255] The fact that the power grids in the Koreas operate at a different frequency than most of the rest of continental Asia (and virtually all of Europe) is probably a legacy of the Japanese colonial period (and possibly of US influence in the ROK). Japan uses both 50- and 60-cycle grids ("Listing of Countries with their Frequency and Voltage", provided on ZZZAP Power World-wide Web site http://azap.com/countries.html).

typically much less than one percent. The cost of AC-DC-AC systems of the size that would be required was estimated to be on the order of US $125 million per GW of capacity[256] in the late 1990s, or on the order of 5 percent of the costs of the PWRs that were to have been transferred to the DPRK by KEDO.

This information about the types and costs of technologies required for power inter-conversion costs suggests (to us) two interesting questions related to the ordering of ROK assistance (if forthcoming) in revamping the DPRK grid:

- Should the first step in assistance be to interconnect the two grids, so that power can be sold (for example) from reactors built on the Sinpo site (where the KEDO-provided PWRs were to have been, and where their substantial foundations and other infrastructure remain), to the ROK (or so that the ROK can supply power to the North); or would the ROK (and, ultimately, a unified Korea) be better served by revamping the DPRK system first to make it suitable to synchronize with the ROK grid (effectively creating one Korea-wide system), thus avoiding (at least some) power conditioning costs?[257]
- Would it be less expensive and technically less risky (again assuming the power from any PWRs located in the DPRK is to be substantially sold to the ROK) to simply connect the reactors to the ROK grid, but not (at least initially) to the DPRK grid? Doing so, of course, could face political difficulties quite apart from its practicality. In this case, it would almost certainly be necessary to build a new transmission line from the reactor site to the ROK border.
- Might it be more effective to rebuild the DPRK grid piecemeal, by developing new (or substantially refurbished) "mini-grids", perhaps at the county level, each supported by their own local generation, and designed to augment local economic redevelopment?

As we enter the 2020s, these options have been augmented by another possibility, that is, redeveloping the DPRK grid from the bottom-up, by building mini-grids focused on renewable energy (mostly small hydro and solar photovoltaic plants) to serve local areas, and eventually knitting these systems together into a new "smart grid". This option is discussed further later in this Report. Interconnecting the DPRK with the grid systems of other neighboring countries is also a topic that is being explored and should be considered further.

Status of Projects to Upgrade T&D System

In the early-to-mid-1990s, a project carried out by the United Nations Development Programme (entitled "Electric Power Management System") was undertaken in the DPRK. The overall intent of this pilot project was to install modern monitoring, modeling, and planning hardware and software in the Pyongyang EPPDCC to enable the grid operators to detect and model system

[256] Order-of-magnitude cost estimate obtained in conversation (1997) with G. Jutte of Siemens Power Transmission and Distribution, Limited. Indications at that time were that per-unit costs for these systems were declining. There are many technical issues that will have to be considered when and if AC-DC-AC converters are to be used in Korea, including the line voltage on the DPRK side, the distance over which the power must be transferred, and many others. The AC-DC-AC systems could also be used to inter-convert 50 Hz and 60 Hz power at the borders of the DPRK with China and Russia, suggesting that the $460 million interconnection cost listed above may be somewhat high (or may include different/additional hardware).

[257] A variant of this pathway has been proposed whereby the DPRK grid could be stabilized by adding gas-turbine plants along the ROK side of the DPRK/ROK border and operating the gas turbines to maintain proper frequency on the DPRK transmission system. We do not know what additional investments to upgrade the DPRK grid would be required to make this proposed scheme technically feasible.

conditions in real time. The project was to include monitoring and data transmission systems at eight remote locations on the grid, including four power plants and four substations. The pilot project, once completed, was to be replicated throughout the grid, so that ultimately power control and dispatching capabilities would be brought up to international standards.

As of 1996, a personal computer-based local area network (LAN), complete with LAN software and software for modeling the T&D system, had been installed at EPPDCC, and operators had received some training in the use of the facilities. Microwave links with the eight remote power plants and substations had been established and activated, and the remote stations had been fitted with the necessary sensors and transducers for data acquisition. The hardware for the various components of the system was supplied by primarily Chinese contractors. Jae-Young Yoon[258] reported on the outcome of the project as follows:

> "Some important new systems have been added with help from the international community. A supervisory control and data acquisition (SCADA) computer system, used for the monitoring and distribution of electricity, was supplied from China by the United Nations Development Programme (UNDP) in the 1990s and has been operating in the power plants of Supung, Jangjingang, Pyongyang, and Puckchang [listed as "Bukchang" in Table 2-4] as well as in the substations of Chungjin, Pyongyang #2, Pyongyang #3, and Wonjin.
>
> "These new systems still have to interface with aging, made-in-the-DPRK parts. While the SCADA system has a relatively modern electricity control mechanism, the protective relaying systems (which are necessary to identify problems in the system and keep them from spreading) are domestically made in the DPRK and are of unknown quality; in addition, it is unclear how well they have been maintained. This may limit the ability of the DPRK to effectively use the SCADA system to protect its power system."

As of our last information (approximately 1996), the DPRK and UNDP (in some combination) were preparing a pre-feasibility study to extend the system installed to the entire grid, but to our knowledge no substantial activity of this type has occurred.

We do not know how well the systems installed under the pilot project are operating, or whether they have contributed significantly to overall system reliability in the DPRK.

Some of our assumptions as to the changes in the electricity supply system between 1990 and 1996 are described above. These changes as to changes in electricity supply, plus changes not mentioned above, can be summarized as:

- The addition to the system in the early 1990s of the first 50 MW unit of the (reportedly) 150 MW East Pyongyang coal-fired power plant
- The average 1996 capacity factor of coal-fired power stations was approximately 70 percent of the value we assume for 1990, or about 58 percent overall.
- Effective hydroelectric capacity from existing facilities fell by about 3,250 MW from 1990 values (to 1,250 MW) by 1996 because of flood damage[259] offset by some additions to

[258] Yoon, Jae-Young (2011), "The DPRK Power Sector: Data & Interconnection Options", *The Korean Journal of Defense Analysis*, Vol. 23, No. 2, June 2011, pages 175–190. Available as http://www.kida.re.kr/data/kjda/03_Jae-Young%20Yoon.pdf.
[259] Several sources that have been to the DPRK recently said they had no knowledge of major damage to large hydroelectric facilities. Another source had heard of damage to "one or two" "small to medium-sized" (less than 10 MW) plants. Still another

capacity.[260] Electricity production from the Chinese-controlled generator units in joint China/DPRK dams along the border rivers shared by the two countries decreased to 28 percent of their 1990 levels.

- The average capacity factor of hydroelectric generating stations was at about 90 percent of the level in 1990, or about 49 percent overall (but effective capacity is much lower).
- Thermal plants fueled exclusively with heavy fuel oil were assumed to have a 1996 capacity factor 71 percent of that in 1990, or about 52 percent overall.
- We assumed that coal-fired plants used HFO in 1996 as both a start-up fuel and to augment poor quality coal, with HFO constituting about 6.2 percent of the total heat value of input fuel. Much of this HFO was supplied by KEDO.
- Transmission and distribution losses were assumed to have been 50 percent higher, as a fraction of net plant output, than in 1990, as are "emergency losses" at thermal power plants. The efficiency of thermal power plants is assumed to have declined due to lack of spare parts and general degradation of boiler and combustion air pre-heat systems (in part due to maintenance difficulties and in part due to the impact of using high-sulfur fuels).

2.4.2. Petroleum refining

The DPRK has two major oil refineries. Various estimates have placed the total refining capacity at these plants between 3 million tonnes[261] and 4.5 million tonnes.[262] Capacities in this range would be adequate to process the volume of crude oil that is reported to have been imported in the years before 1990 (see, for example, Table 2-3, above). Our best information is that crude oil imported from China via a pipeline was refined in the DPRK's 29,000 barrel per day (bpd, or about 1.45 million tonnes/yr[263][264]) Chinese-designed refinery in the northwest DPRK. This refinery, named the Ponghwa Oil Refinery, was reportedly built in the late 1950s. It is designed to take Chinese crude oils (such as Daqing or Liaohe[265]). We assumed that the product slate of this refinery is the same as that of refineries of similar design in China, with product fractions (on a weight percentage of input basis) of 45 percent HFO, 22 percent gasoline (low octane), 20 percent diesel oil, 4 percent kerosene, and 5 percent liquefied petroleum gas (LPG) and refinery gas.[266] The DPRK's other major refinery, the Sungri Oil Refinery is located in the town of Unggi, on the East Coast close to the Russian border and near Sonbong, has a reported capacity of 42,000 bpd (about 2.1 million tonnes/yr—though other sources suggest

source with recent knowledge of the situation in the DPRK states that there has been significant siltation to reservoirs and possibly structural damage to some turbine-generators, and that the combined damage to the plants will take years to repair. This latter point of view is reflected in our DPRK energy supply-demand estimate for 1996. See additional discussion in Chapter 2.

[260] See discussion in Chapter 2.

[261] United Nations estimate, as cited in Jang, Young Sik (1994), *North Korean Energy Economics*. Korea Development Institute.

[262] It is not clear whether these figures are given per tonne of crude oil input or per tonne of product output, though the difference between the two measures is unlikely to be more than 10 percent.

[263] *International Petroleum Encyclopedia*, 1996. Tulsa, Oklahoma Petroleum Publishing Company, Tulsa, OK.

[264] Other sources (document in the authors' files [OS-2-27-2012, page 45]) suggest that the current capacity of this refinery is 2.5 million tonnes/year.

[265] Fridley, D. (1996), then of Lawrence Berkeley National Laboratory (personal communication).

[266] Fridley, D. (1996), then of Lawrence Berkeley National Laboratory (personal communication).

capacity of 2.5 million tonnes/yr), with a reported fluid cracking facility of 7,300 bpd.[267, 268] The refinery was built in around 1968 by the Soviet Union, and expanded in 1970. As of 1990, this refinery probably processed much or all of the oil imported to the DPRK from the Soviet Union and from Middle Eastern countries. Sources suggest that inputs from the Soviet Union arrived by train, with imports also received by ship from Saudi Arabia, Indonesia, Malaysia, and Iran. A page from a Japan-based North Korean organization lists the storage capacity of the plant at 2 million tonnes (it is unclear whether this is tonnes of oil products, of crude oil, or both—but is most likely for crude oil and oil products combined).[269] A separate source reports much lower storage capacity of 30,000 tonnes of crude oil, 40,000 tonnes of diesel, 30,000 tonnes of heavy oil, 20,000 tonnes of gasoline, and 5,000 tonnes of lubricants[270]. A "panorama" of the "Sungri Chemical Plant Oil Refinery, Sonbong" from the "The People's Korea" (source as above) is provided below as Figure 2-8.

Figure 2-8: Photo of Sungri Chemical Plant Oil Refinery

In addition to these two major refineries, some of our contacts have suggested that the DPRK has one or possibly two other smaller refineries, possibly used (when operating) to produce fuel for the military, with capacities no larger than 10,000 bpd, and likely much smaller. These are reportedly of the "fractionating tower" type, without cracking facilities. One or both may be

[267] Some information about this refinery, and plans for its expansion, was at one time available on the UNIDO (UN Industrial Development Organization) World-wide Web site at http://www.unido.org, though it is unclear if that information remains available.

[268] International Petroleum Encyclopedia, 1996. Tulsa, Oklahoma Petroleum Publishing Company, Tulsa, OK.

[269] Sourced from web page formerly available as http://www1.korea-np.co.jp/pk/095th_issue/99051905.htm, dated 1999, by "The People's Korea", and titled "Rajin-Sonbong Region".

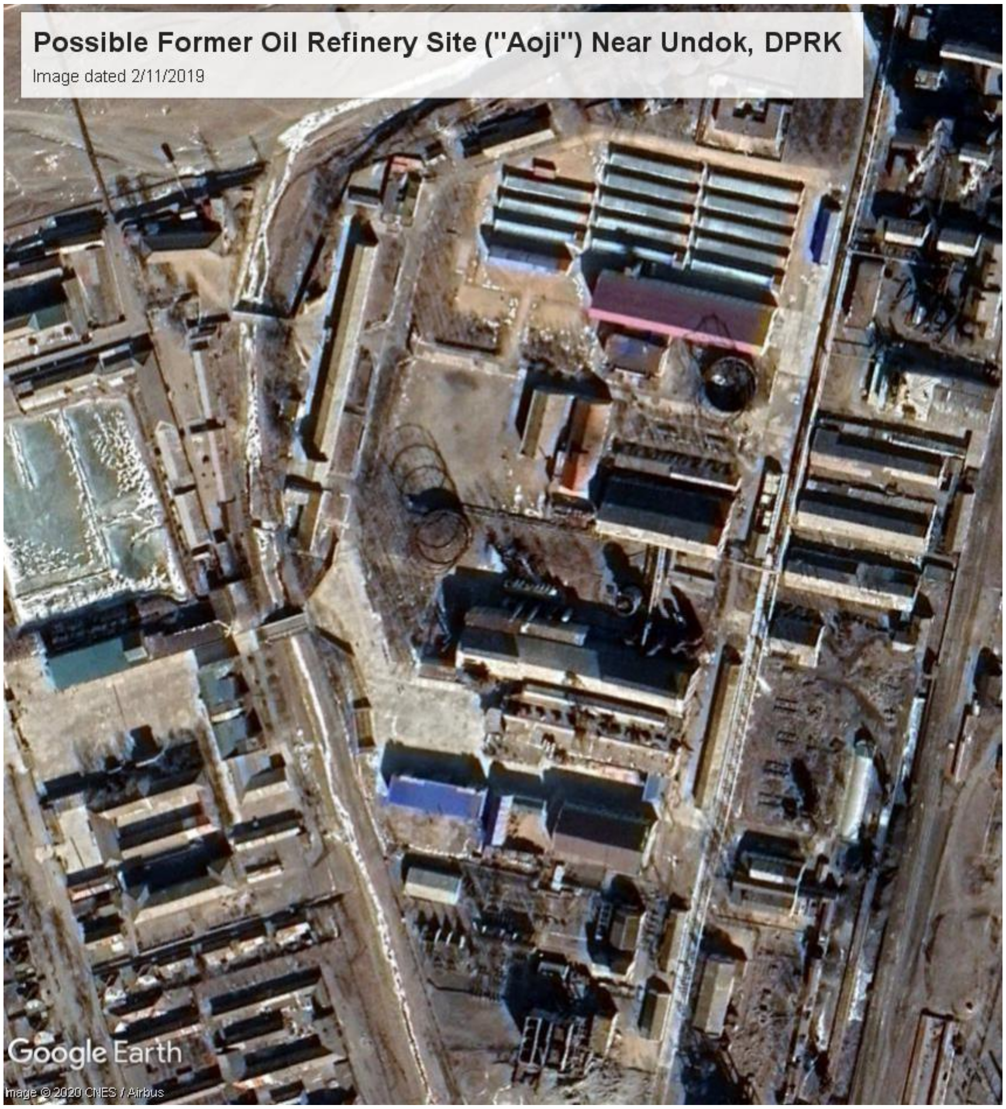
[270] Document in authors' files [OS-2-27-2012, page 44]. This source also lists the Sonbong port that serves the refinery as having two underwater pipelines from the end of the wharf to a loading buoy for crude oil (3500 m), plus (apparently) one each for loading and unloading gasoline, diesel, and fuel oil, with a crude oil (presumably) pipeline transit capacity of 2-3 million tons/year. The port is described as having docking capacity for two 6,000 ton, one 15,000 ton, one 30,000 ton, and one 250,000-ton tankers, plus storage tanks for crude oil in the following sizes: 9 tanks of 20,000 m^3, 10 tanks of 22,000 m^3 and one tank 400,000 m^3.

associated with chemical production complexes. One of these units is located on the West Coast of the DPRK and is associated with a small thermal power plant. We know nothing more about these facilities, but assume that their activity during 1990 and 1996,[271] if any, was minimal relative to the larger refineries, due to (at least) lack of crude oil.

Based on a 1954 CIA document, there were three oil refineries in the DPRK described as "Japanese-built" that operated during 1946 to 1950.[272] The "Wonsan Refinery, the Yongan Synthetic Oil Refinery, and the Aoji Synthetic Oil Refinery – which produced a total of 85,000 tonnes of refined products during this period". All three were heavily damaged by bombing during the Korean war, and as of 1954, only the Aoji plant appeared to be being rehabilitated. The closest industrial facility to the town of Aoji (in the DPRK's far northeast, near the Chinese/Russian border that appears to have (or have had) equipment (large oil tanks, stacks, and what appear to be electrical substation equipment, for example) consistent with oil refining is a few kilometers away in an area labeled as Undok in Google Earth Pro, at approximately coordinates 42.521, 130.348. This refinery does not look like it would have been in use as of 1990.

[271] An estimate for the operation of one of these refineries in the years 2000 and beyond is provided in 119of this report.
[272] U.S. Central Intelligence Agency (CIA, 1954), *Intelligence Memorandum: Reconstruction in North Korea* dated 26 July 1954, and available as https://www.cia.gov/readingroom/docs/CIA-RDP79T00935A000200370001-2.pdf.

Figure 2-9: Possible Former Oil Refinery Site Near Undok, DPRK as of early 2019 (Google Earth Pro Image)



In estimating the energy used during refining, we have used a value for oil consumption during refining derived from Chinese data, namely 0.0578 tonnes oil equivalent per tonne of crude oil processed.[273] This yields an overall energy efficiency in refining of just over 94 percent, which is not unreasonable, but could be somewhat high for the DPRK.

We have attempted, in preparing our estimated supply/demand balances, to account for production and consumption of the major refined petroleum products separately (see Attachment 1). We have done this somewhat differently, however, in the 1990 balance than in our estimated

[273] Shen, W.B. (1988), "Progress of Energy Saving in China's Petrochemical Industry". In Meyers, S. (Ed.), *Proceedings of the Chinese - American Symposium on Energy Markets and the Future of Energy Demand, Nanjing, China June 22-24, 1988*. Lawrence Berkeley Laboratory, Berkeley, California, USA.

balances for subsequent years. For 1990, we have essentially taken our estimates for demand by fuel, subtracted known imports, and then assumed that domestic production of petroleum products would meet the residual demand (less any exports). Our figures for 1990 refined products consumption--as measured by the fraction of total refined products demand accounted for by each separate product, differs from consumption data provided by Jang.[274] Data in the latter is taken from UN and IEA statistics, however, which may be suspect in the case of DPRK. For 1996 and beyond, we have used data on imports of crude oil to define the refinery inputs, together with the fractions of refinery output by product, plus imports, to estimate fuel supply by product, and adjusted our demand estimates to (roughly) meet those supply estimates.

The DPRK's refinery in the Sonbong region (reported capacity of 42,000 bpd, or about 2.1 million tonnes/yr) probably processed the load of Libyan crude oil that the DPRK received in 1995 but has reportedly been "in mothballs" (inactive) for most of time since then. We assume that only the DPRK's refinery near the Chinese border on the West Coast operated in 1996.

2.4.3. Coal production and preparation

Coal production in the DPRK is principally from underground mines (as opposed to open pit or surface mines), but most underground mines are not particularly deep. As noted above, much of the better coal in the large Anju field in western North Korea is near or in fact under the ocean, which presents extreme mining difficulties due to the need to constantly remove seawater from the mines, requiring constant pumping and, thus (typically) reliable supplies of electricity. Coal production in some mines in the DPRK is (or was, as of about 1990) reportedly almost completely mechanized, but mechanization is apparently limited in other mines.[275] We applied Chinese figures from the 1980s for coal and electricity use during coal mining[276] to estimate the own use of these fuels during coal production in DPRK.[277] These estimates could be either low or high. The difficulties with water intrusion (for example) would argue that a large amount of energy would be expended for pumping, and thus these estimates would be understated.[278] On the other hand, the probable higher degree of mechanization in at least the larger Chinese mines would argue that "own-use" of energy would be lower in coal mines the DPRK than in mines in China.

Coal washing is apparently not practiced in the DPRK, although it would be beneficial for many coal combustion applications. Coal briquetting to produce household fuel is practiced widely (based on our observations) but on a small scale—many briquettes are produced in hand presses. No quantitative data were available to us to describe how this preparation process works on average nationwide,[279] but our own 1998 and 2000 surveys as a part of the Unhari Wind Energy Project characterized the briquettes, at least in one village where we worked, as being on average 3 to 4 parts coal per part clay binder, and with the mass of the final, dried briquettes about 2.5 kg

[274] Jang, Young Sik (1994), *North Korean Energy Economics*. Korea Development Institute.
[275] Document in authors' files [H2-A2].
[276] Chinese language spreadsheet dated 12-Feb-93 provided by J. Sinton of Lawrence Berkeley Laboratory; Sinton, J. (1995), "Physical Intensity of Selected Industrial Products". Spreadsheet printout. LBL" Lawrence Berkeley Laboratory, Berkeley, California, USA.
[277] These own-use figures do not include the capture and combustion of coal-bed methane, which is employed in at least one DPRK coal mine.
[278] It is reported (Document in authors' files [VO1]) that in some areas of the Anju field 6 m^3 of water must be pumped to mine a tonne of coal. It is not known how representative this situation is of the Anju field as a whole or of all mines in DPRK.
[279] Document in authors' files [R1].

each.[280] Though this information is derived from a single locale, we would not be surprised if briquetting practices are fairly similar throughout the DPRK.

For 1996, we assumed that coal and biomass production could meet demand (as estimated based on the demand-sector parameters described earlier in this chapter), although coal production capacity probably decreased somewhat by 1996 because of flooding. We have heard that the coal mines in the important Anju district were flooded and badly damaged, which is entirely believable, given that many were below sea level to begin with. Despite the importance of this district, however, it did not produce a major fraction of the DPRK's coal even in 1990, when demand for coal was much higher than in 1996. As a consequence, unless flooding caused long-term problems with transport facilities (and the DPRK seems to have mobilized very quickly to clean up flood damage in many areas), we suspect that the floods by themselves did not have a major effect on national coal production.

We heard a report in the late 1990s that the quality of coal produced in the DPRK has fallen significantly since 1990, and as of 1996 had an average energy content of no better than 1000 kcal per kilogram. By way of comparison, "standard" coal has an energy content of about 7000 kcal per kg (29.3 GJ per tonne); productive soils that are rich in organic matter (such as the "black soils" of the Russian steppes) have about the same energy content as has been reported for DPRK coal. If the average energy content of coal mined in the DPRK is really 1000 kcal per kg, it implies one of two things: either the actual mass (as opposed to the energy content) of coal produced in the DPRK in 1996 was about twice (some 140 or more million tonnes) that produced in 1990 (70 million tonnes), or our estimate of total coal production in 1996 is significantly in error, or some combination of the two. We would venture to guess that the average energy content of coal that was mined in the DPRK in 1996 could have been less than the 4500 kcal/kg that we used as an average value for 1990, but not as low as 1000 kcal/kg, We certainly wouldn't rule out the possibility, however, that even our fairly low value for overall 1996 coal production (in TJ) is too high. If indeed the average energy content of coal mined in the late 1990s was in the vicinity of 1000 kcal/kg, the use of heavy fuel oil to augment coal in (particularly) utility and in industrial boilers would have become more important.

The reasons for the reported decline in coal quality in the DPRK are said to have centered on the lack of spare parts for mining equipment (and probably diesel oil to fuel equipment) that can be used to open new coal seams. Lacking sufficient working equipment, mining operations were forced to get what coal they could out of existing mines and seams, sometimes taking marginal coals that would, in better times, be left behind.[281] Another potential explanation for low recent coal production in the DPRK—an explanation that may also bear on the low energy content of the coal produced—takes into account social and political forces. An ROK observer has suggested that coal miners in the DPRK "are mostly those classified as belonging to hostile social strata and, as such, not even provided with minimum human living conditions.

[280] See, for example, page 24 of *Rural Energy Survey in Unhari Village, The Democratic People's Republic of Korea (DPRK): Methods, Results, and Implications*, David F. von Hippel, Peter Hayes, James H. Williams, Chris Greacen, Mick Sagrillo, and Timothy Savage, Nautilus Institute Report, dated May 20, 2001, available as http://nautilus.org/wp-content/uploads/2011/12/Unhari_Survey1.pdf.

[281] Recent mining practices may have also included removing the pillars and walls of coal that had been left in the mines during more normal mining operations, allowing the mines to collapse as the coal in these structures is removed. In addition to being dangerous to miners, these practices, if actually carried out (and we have no corroboration that they have been), would imply premature destruction of coal mines, as areas allowed to collapse are rendered much more difficult to mine further in the future.

Consequently, they are not eager to work at all".[282] We do not know to what extent this assertion of coal miner antipathy is an accurate reflection of general conditions in the DPRK, or to what extent worker unhappiness acted (or acts) to reduce coal production and/or coal quality.

2.4.4. Charcoal production

We have little information on the technologies used for charcoal production in the DPRK. Using a fuelwood input of 0.65 million cubic meters at 1.5 cubic meters per tonne,[283] we assume an efficiency of 30 percent to yield a charcoal output of approximately 2.1 million GJ (gigajoules) in 1990. An efficiency of 30 percent would be lower than that achieved in most commercial kilns in industrialized countries, but is probably somewhat higher than the average, for example, for earthen kilns in developing countries. We assumed that charcoal production continued to meet demand as of 1996.

2.5. Description of key results and uncertainties in 1990 and 1996 supply/demand balances

2.5.1. Energy Balances for 1990 and 1996

In this section we present our current best estimates, based on the information that we have reviewed, of energy supply and demand balances for the DPRK in 1990 and 1996. We intended, when we first prepared them in the 1990s, and have treated these as "living" documents, that is, estimates that can be (and have been) updated as reviewers and others come forward with suggestions for improvements and with better information. We hope that these balances, and the balances for 2000, 2005, 2008, and 2009, presented later in this Report, can be used as starting points for additional analysis and planning regarding the DPRK energy economy, including being adapted as bases for estimates of energy efficiency potential (that is, in a more thorough and detailed manner than the estimate we have prepared and presented in Chapter 4 of this report).

Although the balances that we have prepared are digests of a great deal of information, they also contain, necessarily, a great deal of conjecture on our part.

Units

Our summary, detailed, and petroleum products energy balances for 1990 and 1996 are presented as Table 2-10 through Table 2-15, below, and as the first pages of Attachment 1. We have presented these balances in a standard energy unit, the *Terajoules (TJ)*, a unit equal to 1000 *Gigajoules* (GJ). In some cases (the summary balance and some tables and graphs) we express results in *Petajoules (PJ)*, a unit equal to a thousand terajoules or a million GJ. For those who may be more familiar with other units, some standard conversions are:

- 41.84 GJ per tonne of oil equivalent (toe)
- 41.84 TJ per thousand tonne of oil equivalent (ktoe)

[282] "Energy 'Crisis' Threatens Economy", *Pukhan* (Seoul, ROK) March 1993, pages 39-45, by *Naeoe Tongsin* reporter Kim Sang-hwan.
[283] Document in authors' files [T1].

- 4.184 GJ per million kilocalories (Gcal)
- 4.184 TJ per billion kilocalories (Tcal)
- 29.3 GJ per tonne of standard coal equivalent (tce)
- 29.3 TJ per thousand tonne of standard coal equivalent (ktce)
- 3.6 GJ per million watt-hours (MWh)
- 3.6 TJ per billion watt-hours (GWh)
- 1.055 GJ per million British Thermal Units (MMBtu)
- 6.1 GJ per barrel of oil equivalent (boe)
- 6.1 TJ per thousand barrels of oil equivalent (kboe)

Table 2-10: Summary Estimated Energy Supply/Demand Balance for the DPRK, 1990

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	1,326	111	27	78	162	(0)	-	-	1,703
Domestic Production	1,301	-		78	150				1,529
Imports	68	111	27		12				218
Exports	44				0	0		-	44
Stock Changes									
ENERGY TRANSF.	(378)	(111)	83	(78)	(10)	3	9	120	(361)
Electricity Generation	(295)		(22)	(77)			8	166	(220)
Petroleum Refining		(111)	111					(1)	(1)
Coal Prod./Prep.	(63)							(9)	(72)
Charcoal Production					(10)	3			(7)
District Heat Production	(3)		(0)	(1)			3		(2)
Own Use			(6)					(12)	(18)
Losses	(16)						(2)	(24)	(41)
FUELS FOR FINAL CONS.	948.00	-	109.38	-	152.02	2.98	9.25	120.46	1,342
ENERGY DEMAND	948.01	-	109.38	-	152.02	2.97	9.25	120.47	1,342
INDUSTRIAL	672	-	28	-	6	-	-	70	776
TRANSPORT	-	-	38	-	2	-	-	11	51
RESIDENTIAL	189	-	7	-	86	3	6	11	302
AGRICULTURAL	10	-	5	-	45	-	-	3	62
FISHERIES	1	-	3	-	-	-	-	1	5
MILITARY	30	-	17	-	-	-	-	14	60
PUBLIC/COMML	33	-	0	-	2	-	3	11	48
NON-SPECIFIED			6	-			0		6
NON-ENERGY	14		6		12				31
Elect. Gen. (Gr. TWhe)	23.43		1.28	21.29					46.00

Table 2-11: Detailed Estimated Energy Supply/Demand Balance for the DPRK, 1990

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	1,325,571	110,742	26,622	78,075	161,941	(0)	-	-	1,702,951
Domestic Production	1,301,288	-		78,075	149,909				1,529,272
Imports	68,392	110,742	26,622		12,183				217,938
Exports	44,108				151	0		-	44,259
Inputs to International Marine Bunkers									-
Stock Changes									-
ENERGY TRANSFORMATION	(377,571)	(110,742)	82,762	(78,075)	(9,920)	2,976	9,251	120,464	(360,855)
Electricity Generation	(294,926)		(21,947)	(76,641)			7,884	165,600	(220,030)
Petroleum Refining		(110,742)	110,742					(593)	(593)
Coal Production/Preparation	(63,092)							(8,544)	(71,636)
Charcoal Production					(9,920)	2,976			(6,944)
Coke Production									-
District Heat Production	(3,417)		(73)	(1,433)			2,916		(2,008)
Other Transformation									-
Own Use			(5,960)					(12,408)	(18,368)
Losses	(16,136)						(1,549)	(23,592)	(41,277)
FUELS FOR FINAL CONSUMPTION	948,000	-	109,384	-	152,021	2,976	9,251	120,464	1,342,096
ENERGY DEMAND	948,009	-	109,384	-	152,021	2,973	9,251	120,467	1,342,105
INDUSTRIAL SECTOR	671,661	-	28,393	-	5,626	-	-	70,242	775,923
Iron and Steel	324,615							17,388	342,003
Cement	68,139		7,571					4,356	80,065
Fertilizers	23,994		4,573					18,891	47,458
Other Chemicals	11,203							6,616	17,819
Pulp and Paper	4,026				4,026			932	8,985
Other Metals	23,720							4,126	27,846
Other Minerals	-		12,600					396	12,996
Textiles	29,385							2,497	31,882
Building Materials	61,980							189	62,169
Non-specified Industry	124,600		3,650		1,600			14,850	144,700
TRANSPORT SECTOR	-	-	37,896	-	1,672	-	-	11,470	51,039
Road			32,571		1,672				34,243
Rail	-		1,949					10,870	12,819
Water	-		1,253						1,253
Air			1,123						1,123
Non-Specified			1,000					600	1,600
RESIDENTIAL SECTOR	189,274	-	6,600	-	86,140	2,973	6,134	10,718	301,840
Urban	129,155		6,256			1,814	6,134	7,420	150,780
Rural	60,119		344		86,140	1,159		3,298	151,060
AGRICULTURAL SECTOR	9,750	-	5,005	-	44,950	-	-	2,572	62,277
Field Operations			2,619					907	3,526
Processing/Other	9,750		2,386		44,950			1,664	58,750
FISHERIES SECTOR	1,132	-	3,137	-	-	-	-	524	4,794
Large Ships	-		2,681						2,681
Collectives/Processing/Other	1,132		456					524	2,112
MILITARY SECTOR	29,828	-	16,533	-	-	-	-	14,008	60,369
Trucks and other Transport			6,585						6,585
Armaments			263						263
Air Force			2,648						2,648
Naval Forces			6,937						6,937
Military Manufacturing	890							48	938
Buildings and Other	28,938		100					13,960	42,998
PUBLIC/COMMERCIAL SECTORS	32,646		98		1,632		2,644	10,932	47,952
NON-SPECIFIED/OTHER SECTORS			5,950				473		6,423
NON-ENERGY USE	13,718		5,771		12,000				31,488
Electricity Gen. (Gross TWhe)	23.43		1.28	21.29					46.00

Table 2-12: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK, 1990

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	110,742	5,275	12,962	6,224	2,160	-		137,364
Domestic Production	-							-
Imports	110,742	5,275	12,962	6,224	2,160			137,364
Exports								-
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(110,742)	25,332	19,357	16,583	8,849	11,560	1,080	(27,980)
Electricity Generation				(21,947)				(21,947)
Petroleum Refining	(110,742)	25,332	19,357	38,603	8,849	17,521	1,080	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(73)				(73)
Other Transformation								-
Own Use						(5,960)		(5,960)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	30,607	32,319	22,807	11,009	11,560	1,080	109,384
ENERGY DEMAND	-	30,606	32,317	22,807	11,008	11,566	1,080	109,384
INDUSTRIAL SECTOR	-	-	3,050	21,685	-	3,658	-	28,393
Iron and Steel								-
Cement				7,571				7,571
Fertilizers				915		3,658		4,573
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				12,600				12,600
Textiles								-
Building Materials								
Non-specified Industry			3,050	600				3,650
TRANSPORT SECTOR	-	23,220	12,926	627	399	-	724	37,896
Road		23,220	9,351					32,571
Rail			1,949					1,949
Water			627	627				1,253
Air					399		724	1,123
Non-Specified			1,000					1,000
RESIDENTIAL SECTOR	-	-	-	-	4,473	2,127	-	6,600
Urban					4,129	2,127		6,256
Rural					344			344
AGRICULTURAL SECTOR	-	-	5,005	-	-	-	-	5,005
Field Operations			2,619					2,619
Processing/Other			2,386					2,386
FISHERIES SECTOR	-	-	2,777	360	-	-	-	3,137
Large Ships			2,547	134				2,681
Collectives/Processing/Other			230	226				456
MILITARY SECTOR	-	7,386	6,859	134	1,798	-	356	16,533
Trucks and other Transport		6,476	109					6,585
Armaments		45	218					263
Air Force		494			1,798		356	2,648
Naval Forces		371	6,432	134				6,937
Military Manufacturing								-
Buildings and Other			100					100
PUBLIC/COMMERCIAL SECTORS					88	10		98
NON-SPECIFIED/OTHER SECTORS		-	1,700		4,250			5,950
NON-ENERGY USE						5,771		5,771

Table 2-13: Summary Estimated Energy Supply/Demand Balance for the DPRK, 1996

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	682	40	32	19	158	-	-	-	932
Domestic Production	683	-	-	19	148	-		-	850
Imports	12	40	39	-	14	-		-	104
Exports	12	-	1	-	4	-		-	16
Stock Changes	-	-	6	-	-	-		-	6
ENERGY TRANSF.	(251)	(40)	12	(19)	(8)	2	5	51	(248)
Electricity Generation	(208)	-	(25)	(19)	-	-	5	82	(165)
Petroleum Refining	-	(40)	40	-	-	-		(0)	(0)
Coal Prod./Prep.	(33)	-	-	-	-	-		(4)	(37)
Charcoal Production	-	-	-	-	(8)	2		-	(6)
District Heat Production	(2)		(0)				2		(1)
Own Use	-	-	(2)	-	-	-		(10)	(12)
Losses	(8)	-	-	-	-	-	(1)	(17)	(26)
FUELS FOR FINAL CONS.	431	-	44	-	150	2	5	51	684
ENERGY DEMAND	431	-	44	-	150	2	5	51	684
INDUSTRIAL	251	-	9	-	2	-	-	24	285
TRANSPORT	-	-	17	-	1	-	-	5	22
RESIDENTIAL	122	-	2	-	118	2	4	6	254
AGRICULTURAL	3	-	1	-	15	-	-	1	20
FISHERIES	1	-	1	-	-	-	-	0	2
MILITARY	25	-	13	-	5	-	-	8	52
PUBLIC/COMML	26	-	0	-	3	-	2	6	37
NON-SPECIFIED			-	-					-
NON-ENERGY	3		1		7				12
									-
Elect. Gen. (Gr. TWhe)*	16.61	-	0.91	5.32	-	-		-	22.84

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 2-14: Detailed Estimated Energy Supply/Demand Balance for the DPRK, 1996

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	682,118	39,874	32,166	19,160	158,306	-	-	-	931,626
Domestic Production	682,630	-		19,160	148,292				850,082
Imports	11,614	39,874	39,100		13,588	-			104,175
Exports	12,125		521		3,574	-		-	16,220
Inputs to International Marine Bunkers									-
Stock Changes			6,412						6,412
ENERGY TRANSFORMATION	(251,225)	(39,874)	11,979	(19,160)	(7,916)	2,375	5,280	50,769	(247,772)
Electricity Generation	(207,721)		(25,467)	(19,160)			4,729	82,238	(165,381)
Petroleum Refining		(39,874)	39,874					(213)	(213)
Coal Production/Preparation	(32,678)							(4,425)	(37,103)
Charcoal Production					(7,916)	2,375			(5,541)
Coke Production									-
District Heat Production	(2,468)		(163)				1,710		(921)
Other Transformation									-
Own Use			(2,266)					(10,186)	(12,452)
Losses	(8,358)						(1,159)	(16,644)	(26,161)
FUELS FOR FINAL CONSUMPTION	430,893	-	44,146	-	150,390	2,375	5,280	50,769	683,853
ENERGY DEMAND	430,897	-	44,146	-	150,390	2,374	5,280	50,770	683,857
INDUSTRIAL SECTOR	250,538	-	8,655	-	1,909	-	-	24,001	285,104
Iron and Steel	124,977							6,694	131,671
Cement	29,981		3,331					1,917	35,229
Fertilizers	6,515		1,129					5,130	12,774
Other Chemicals	3,697		-					2,183	5,880
Pulp and Paper	1,329				1,329			308	2,965
Other Metals	7,828							1,362	9,189
Other Minerals	832		3,326					131	4,289
Textiles	9,697							824	10,521
Building Materials	20,453							62	20,516
Non-specified Industry	45,230		869		581			5,391	52,070
TRANSPORT SECTOR	-	-	16,707	-	884	-	-	4,815	22,406
Road			14,528		884				15,412
Rail	-		779					4,815	5,595
Water	-		501						501
Air			899						899
Non-Specified			-					-	-
RESIDENTIAL SECTOR	121,735	-	1,785	-	117,606	2,374	3,669	6,359	253,529
Urban	92,747		1,649		15,135	1,455	3,669	4,685	119,340
Rural	28,988		136		102,471	919		1,674	134,189
AGRICULTURAL SECTOR	3,183	-	1,319	-	14,674	-	-	1,261	20,437
Field Operations			690					717	1,408
Processing/Other	3,183		629		14,674			543	19,029
FISHERIES SECTOR	509	-	998	-	-	-	-	236	1,743
Large Ships	-		804						804
Collectives/Processing/Other	509		193					236	939
MILITARY SECTOR	25,365	-	13,186	-	5,498	-	-	7,711	51,761
Trucks and other Transport			5,734						5,734
Armaments			211						211
Air Force			1,886						1,886
Naval Forces			5,261						5,261
Military Manufacturing	623		-					33	657
Buildings and Other	24,742		95		5,498			7,678	38,013
PUBLIC/COMMERCIAL SECTORS	26,180		131		2,618		1,612	6,387	36,927
NON-SPECIFIED/OTHER SECTORS			-				-		-
NON-ENERGY USE	3,386		1,365		7,200				11,951
Electricity Gen. (Gross TWhe)*	16.61		0.91	5.32					22.84

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 2-15: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK, 1996

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	39,874	8,545	5,185	18,422	518	(504)	-	72,041
Domestic Production	-							-
Imports	39,874	8,545	5,185	24,834	518	17		78,974
Exports				-		521		521
Inputs to International Marine Bunkers								-
Stock Changes		-	-	6,412				6,412
ENERGY TRANSFORMATION	(39,874)	8,183	8,090	(10,852)	1,618	4,070	871	(27,895)
Electricity Generation				(25,450)		(17)		(25,467)
Petroleum Refining	(39,874)	8,183	8,090	14,760	1,618	6,352	871	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(163)				(163)
Other Transformation								-
Own Use						(2,266)		(2,266)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	16,728	13,275	7,570	2,136	3,565	871	44,146
ENERGY DEMAND	-	16,729	13,274	7,570	2,137	3,565	871	44,146
INDUSTRIAL SECTOR	-	-	671	7,081	-	903	-	8,655
Iron and Steel								-
Cement				3,331				3,331
Fertilizers				226		903		1,129
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				3,326				3,326
Textiles								-
Building Materials								
Non-specified Industry			671	198				869
TRANSPORT SECTOR	-	10,378	5,180	251	320	-	579	16,707
Road		10,378	4,150					14,528
Rail			779					779
Water			251	251				501
Air					320		579	899
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	553	1,232	-	1,785
Urban					430	1,218		1,649
Rural					123	14		136
AGRICULTURAL SECTOR	-	-	1,319	-	-	-	-	1,319
Field Operations			690					690
Processing/Other			629					629
FISHERIES SECTOR	-	-	856	142	-	-	-	998
Large Ships			764	40				804
Collectives/Processing/Other			92	102				193
MILITARY SECTOR	-	6,352	5,248	96	1,199	-	292	13,186
Trucks and other Transport		5,639	95					5,734
Armaments		36	174					211
Air Force		395			1,199		292	1,886
Naval Forces		281	4,884	96				5,261
Military Manufacturing								-
Buildings and Other			95					95
PUBLIC/COMMERCIAL SECTORS					65	65		131
NON-SPECIFIED/OTHER SECTORS			-		-			-
NON-ENERGY USE						1,365		1,365

Total Energy Use

Our balance shows a total of 1703 PJ of primary (not end-use) energy estimated to have been used by DPRK in 1990, or about 77 GJ per person in the country. By way of reference, this is almost four times the per capita energy consumption in China in 1990, and only about a third less than per-capita energy consumption in Japan in the same year.[284] By 1996, this total had decreased to 932 PJ, or about 43 GJ per person, of which over one-sixth was biomass.

2.5.2. Energy supply, including exports and imports

Coal made up approximately 78 percent of the total energy supply in the DPRK as of 1990 (Figure 2-10), with wood and biomass contributing the second largest portion to the total national fuel input, at 9 percent. By 1996 (Figure 2-11), coal was less than 73 percent of supplies, and biomass contributed 17 percent. Hydroelectricity (counted at 3600 GJ per GWh electricity generated) accounted for about 4.6 percent and 2.8 percent of the national energy supply in 1990 and 1996, respectively, with imported crude oil and refined products supplying the remaining approximately 8 percent in 1990 and 1996. Imports—by energy content, about 51 percent crude oil, 31 percent coal and coke, 6 percent wood, and 12 percent refined petroleum products in 1990—made up only about 13 percent of the total energy used in DPRK. The fractions of total energy imports accounted for by crude oil and coal decreased substantially in 1996. In the exports row for 1990, our balance includes only coal exports (at about 44 petajoules per year in 1990, and 12 PJ in 1996), but no electricity exports, since electricity generated at border dams from generators owned by China, and not appearing as imports to China in China Customs Statistics, are not counted as exports in this version of our energy balances. Figure 2-12 and Figure 2-13 show the components of exports, imports, and domestic production by fuel type and for all fuels.

[284] Figures for China (from Sinton, J., editor (1996), China Energy Databook 1996 Edition, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900) do not include biomass energy use. Biomass energy use is a relatively large factor fraction of total fuels use in the case of China, but minimal in the case of Japan.

Figure 2-10: 1990 DPRK Energy Supply by Type

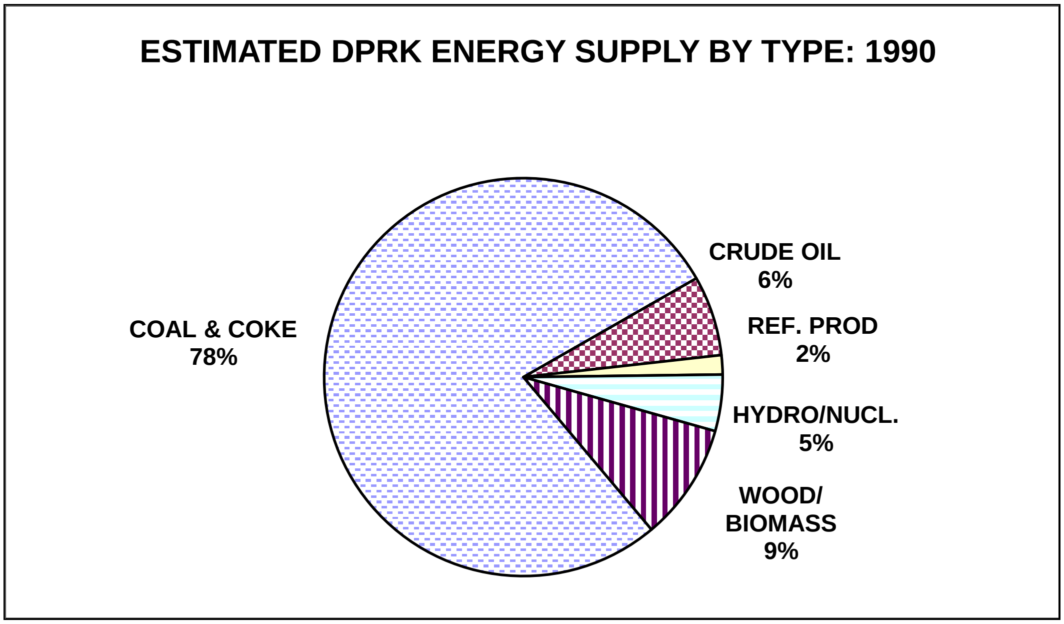


Figure 2-11: 1996 DPRK Energy Supply by Type

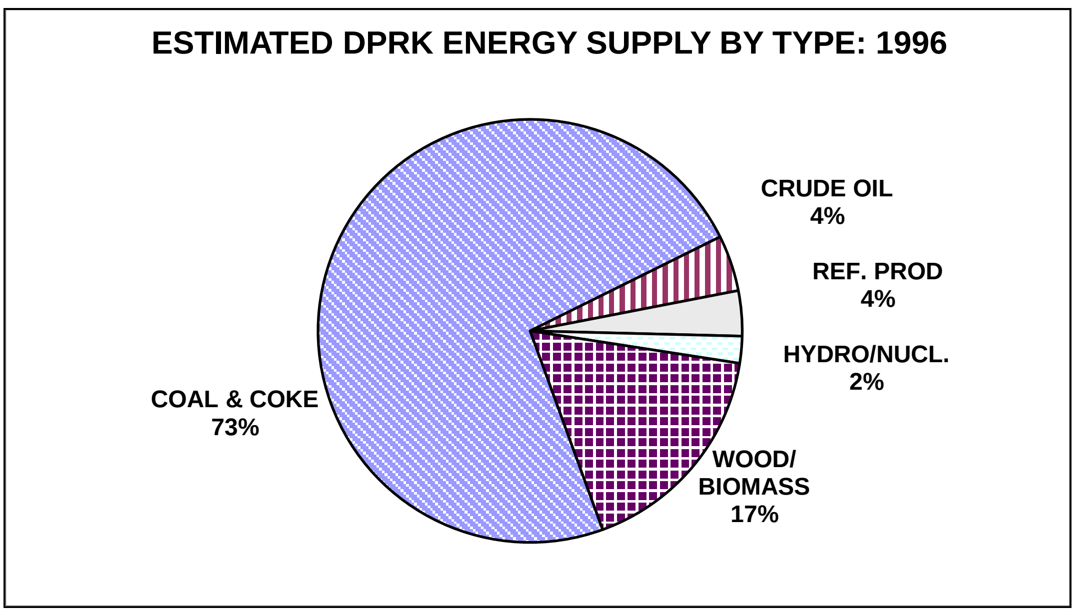


Figure 2-12: DPRK Energy Supply by Fuel and Source, 1990

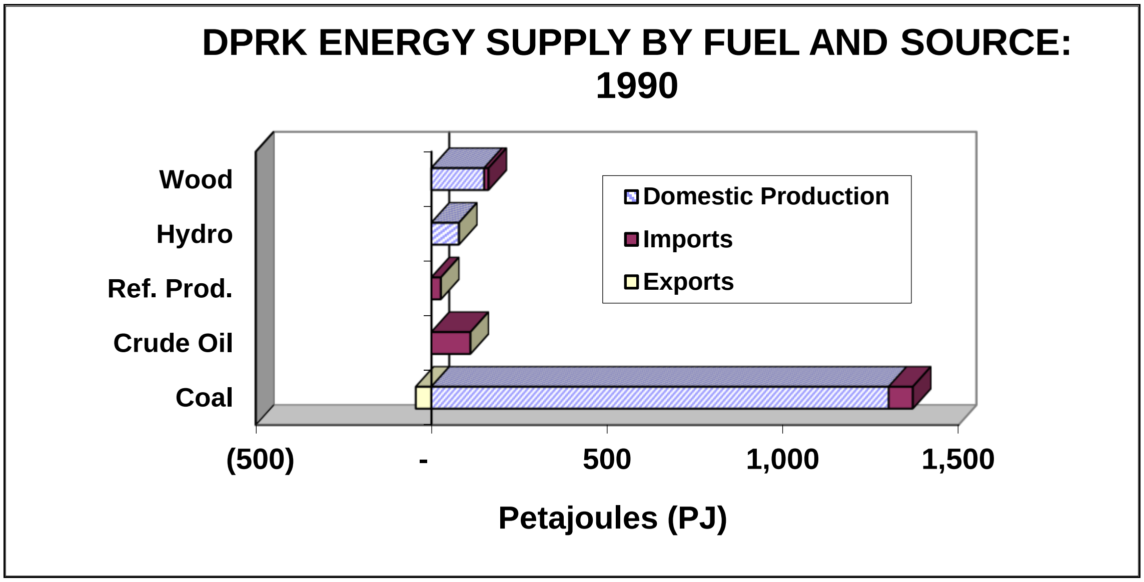
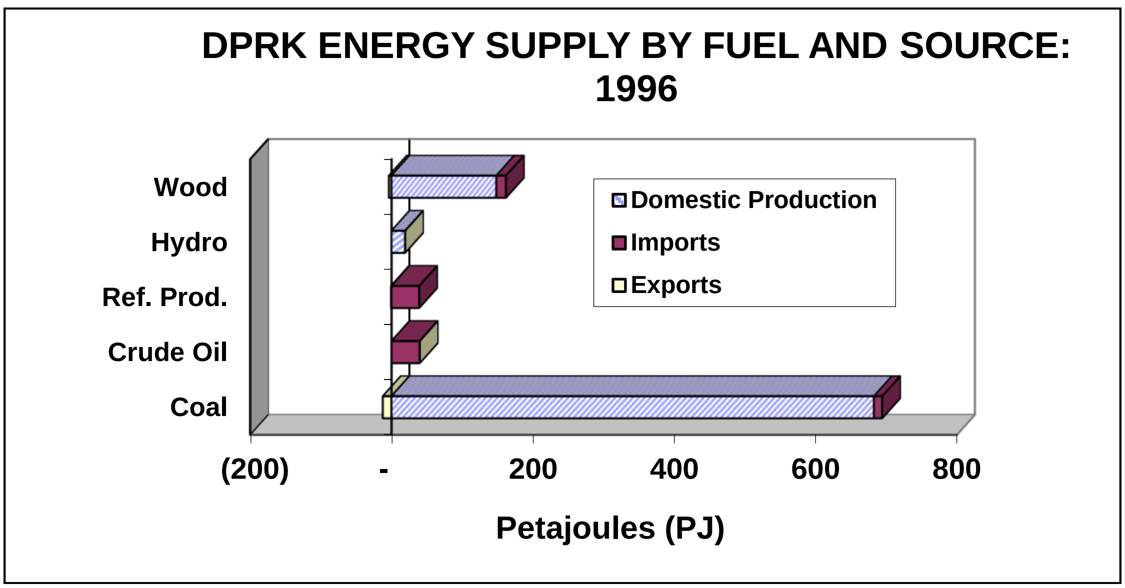


Figure 2-13: DPRK Energy Supply by Fuel and Source, 1996



2.5.3. <u>Energy transformation results</u>

The results of the energy transformation portion of our estimated supply/demand balance for the DPRK are as follows:

- Electricity generation is the most important energy transformation process in the DPRK, consuming 22 percent of total coal and coke supplied, 16 percent of refined petroleum products (domestically refined and imported), and all (by definition) of the hydro energy used in 1990, as well as 30 percent of coal and coke plus 35 percent of refined products (mostly KEDO HFO) in 1996.

- Petroleum refining uses all of the crude oil imported to the country and produced roughly 80 percent of the refined products used in DPRK in 1990, as opposed to approximately 50 percent of refined products in 1996. Petroleum refining losses (own use) amount to approximately 5.4 percent of the crude oil input to refining.
- Coal production in 1990 used 8.5 PJ of electricity, just under 5 percent of gross national generation, and 4.4 PJ in 1996 (also about 5 percent of generation).
- In 1990, charcoal production consumed 9.9 PJ of wood, producing 3.0 PJ of charcoal. Charcoal production in 1996 consumed 7.9 PJ of wood, producing 2.4 PJ of charcoal.
- "Own use" of fuels occurs for two fuel types: coal and electricity. The coal is consumed in coal mining operations at a rate equivalent to just under 5 percent of the total coal mined in DPRK. The use of electricity within electricity generating plants, including "emergency" losses of electricity, accounted for about 7.5 percent of gross electrical production in 1990, and 12.4 percent of gross generation in 1996.
- The "losses" category includes losses of coal (such as coal falling from coal trains or blown as dust from coal piles) at an assumed 1.2 percent of total production on a calorific basis. Electricity losses in 1990 totaled 23.6 PJ, 14.3 percent of total gross generation.[285] Losses in 1996 were proportionally higher, totaling over 16 PJ, or over 20 percent of generation. District heat losses were estimated at about 14 percent of heat production (counting heat produced in both dedicated district heating plants and central combined heat and power units) in 1990, and about 18 percent in 1996.

2.5.4. Energy demand in 1990 and 1996

Of the total final energy demand in the DPRK in 1990, 71 percent was estimated to be provided by coal, 11 percent by wood and biomass, 9 percent by electricity, 8 percent by refined petroleum products, and a fraction of a percent each by charcoal and heat (Figure 2-14). If charcoal and wood/biomass are excluded, the fraction of fuel demand provided by coal rises to 81 percent. Figure 2-15 shows energy demand by fuel for 1996. Relative to 1990, demand in 1996 showed a reduction in the shares of coal and petroleum products, and an increase in the share of wood and biomass.

[285] Note that this figure appears lower than the sum of the 10 percent transmission losses and 6 percent distribution losses that we assumed (based on official DPRK figures). This result is obtained because these factors were applied sequentially to the total net electricity generated after in-plant use and exports are accounted for.

Figure 2-14: 1990 Final Energy Demand by Fuel

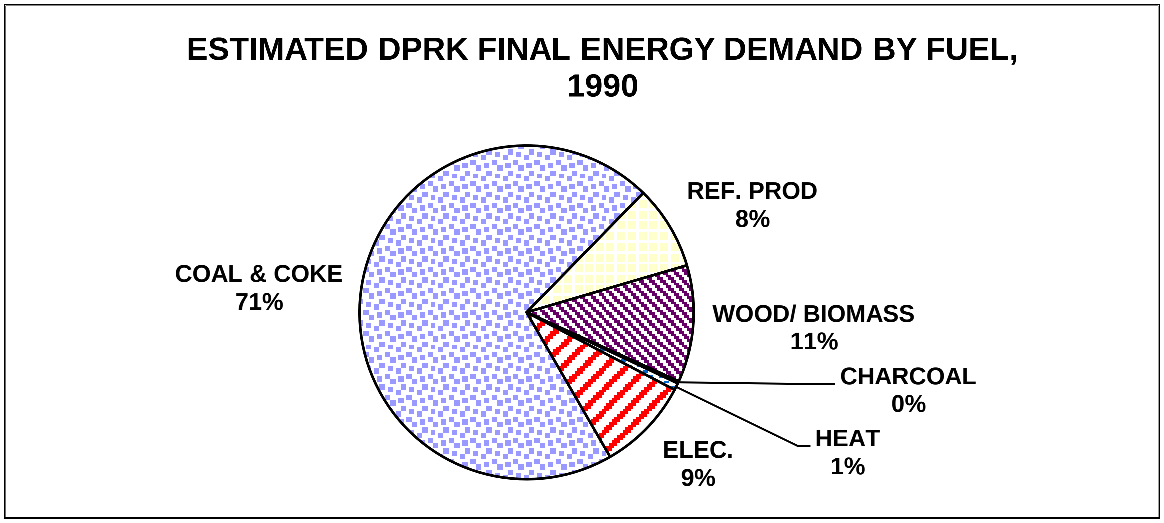
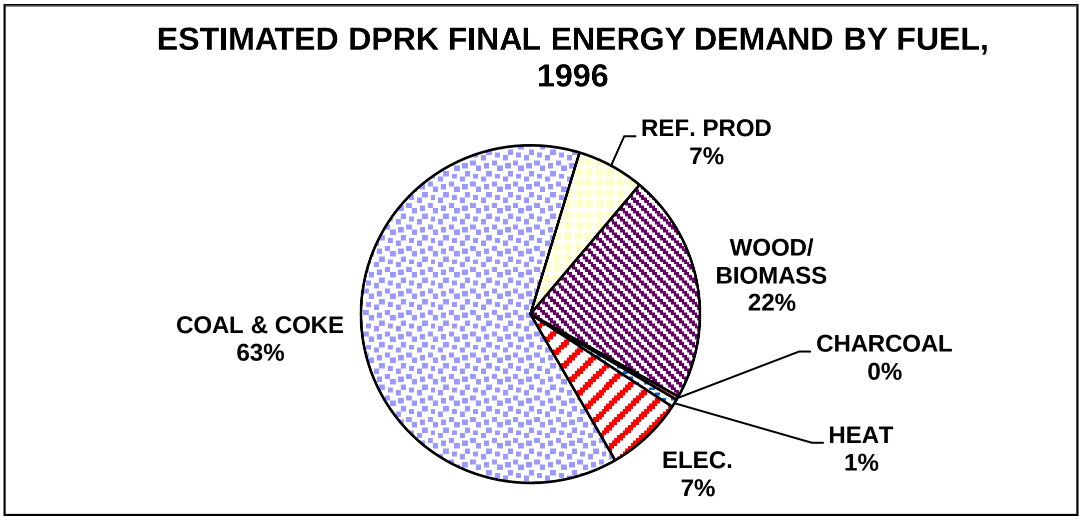


Figure 2-15: 1996 Final Energy Demand by Fuel



Looking at the sectoral shares of total energy demand, the industrial sector was estimated to be responsible for 776 PJ of total energy use, about 58 percent of all demand in 1990, but only 285 PJ (and 42 percent of demand) in 1996 (Figure 2-16 through Figure 2-19). In 1990, the residential sector contributed 22 percent of demand (29 percent of which was wood and biomass), and the transport, agricultural, military, public/commercial, and non-energy uses each contribute between about 2 and 5 percent to total fuel demand. The share of residential energy consumption increased markedly in 1996, due to the combination of reduced fuels use in other sectors and increased, relatively less efficient, use of biomass fuels in homes in rural areas.

Figure 2-16: Energy Demand by Sector, 1990

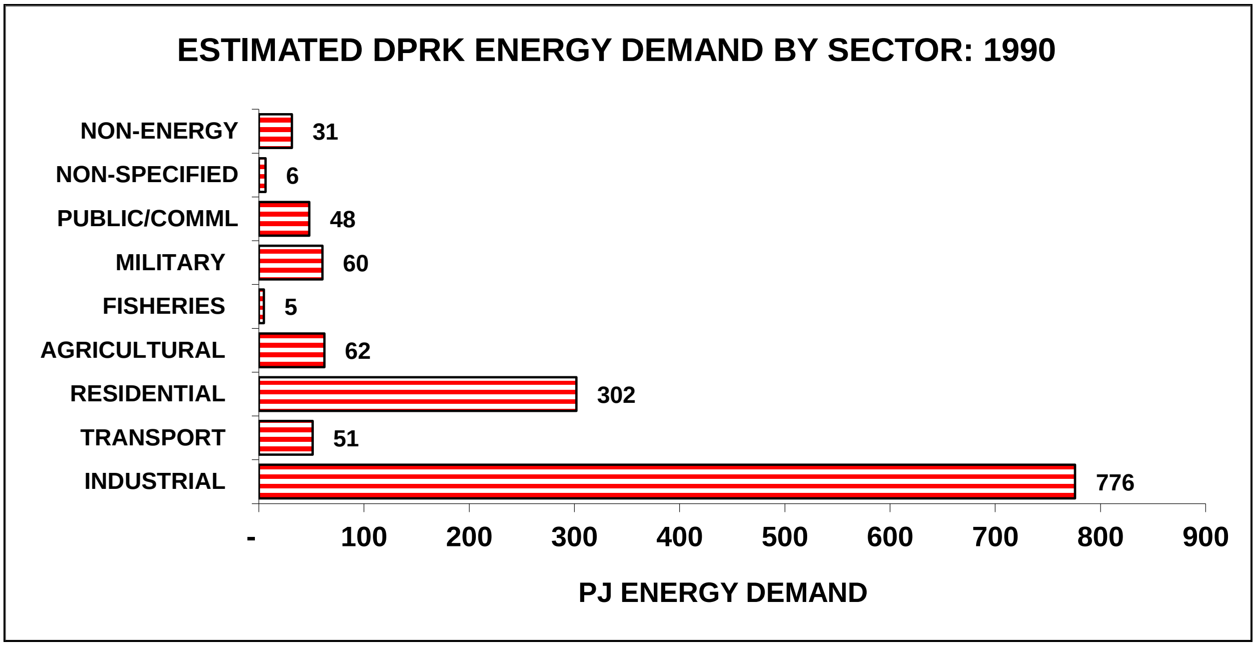


Figure 2-17: Energy Demand by Sector, 1996

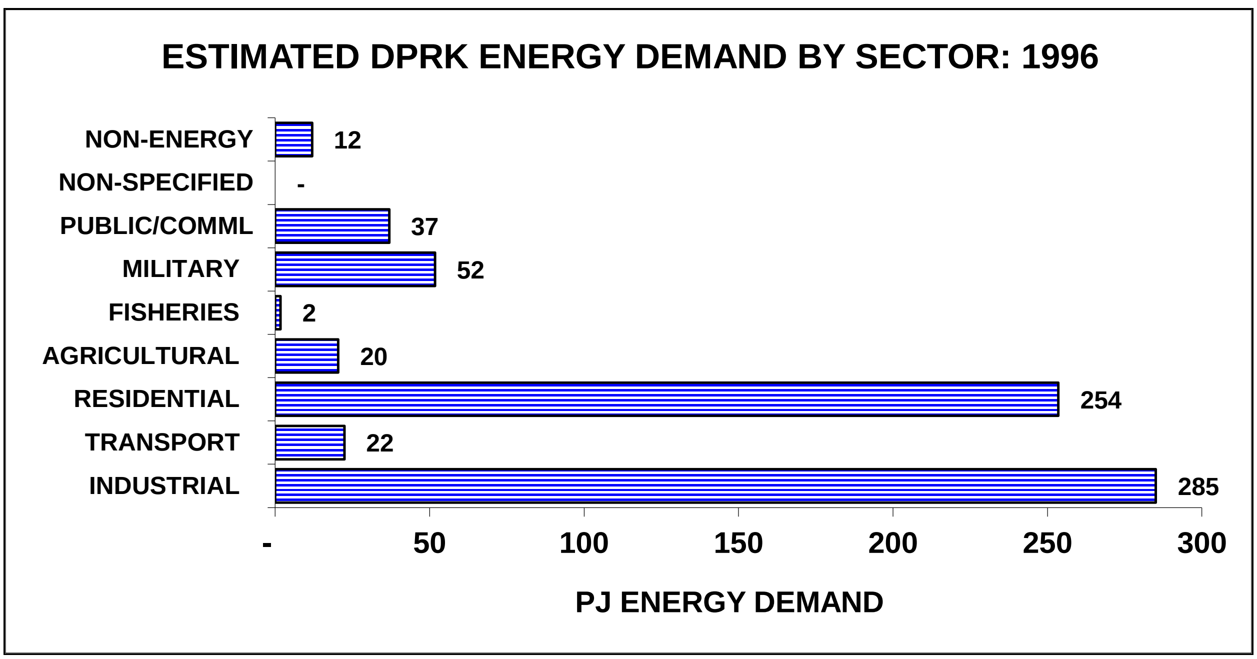


Figure 2-18: Share of Energy Demand by Sector, 1990

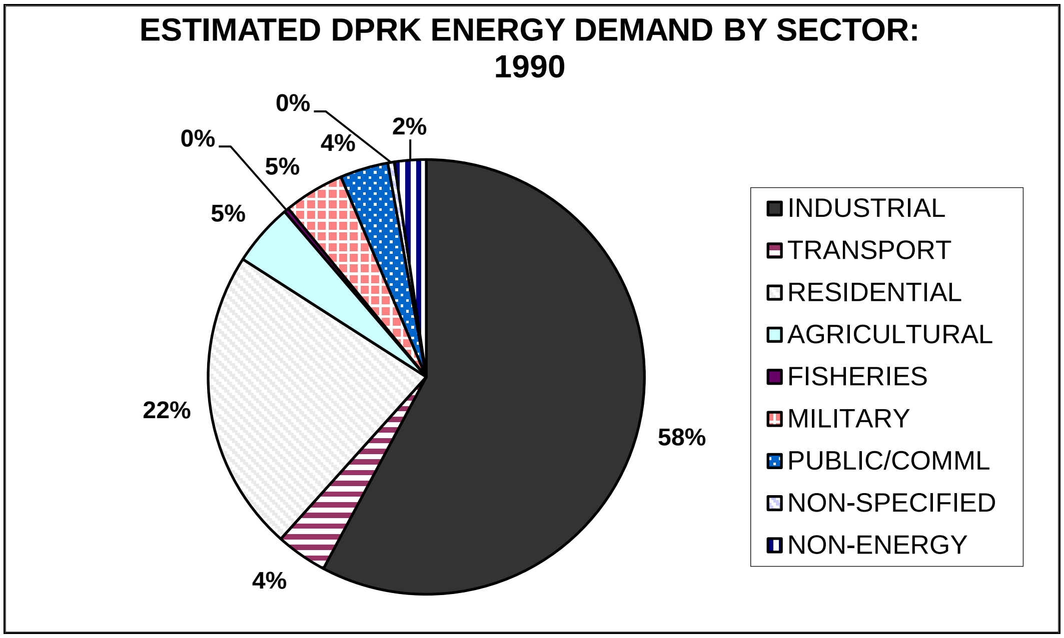
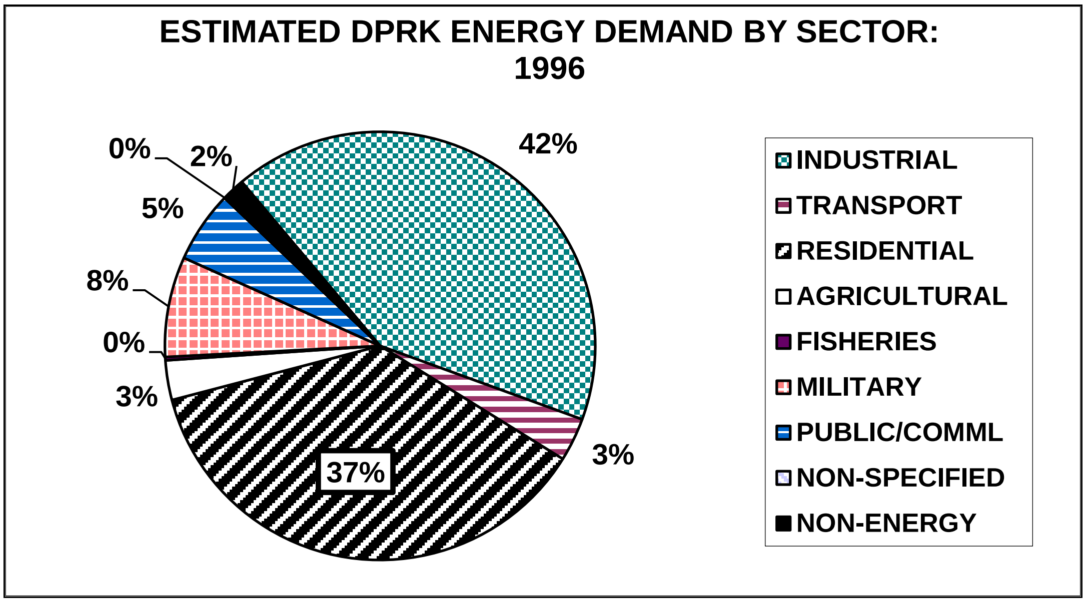


Figure 2-19: Share of Energy Demand by Sector, 1996



When consumption of specific fuels are considered, industry accounted for 71 percent of final demand of coal in 1990 (58 percent in 1996), while the residential sector accounted for 20 percent (28 percent in 1996), and others sectors contribute a few percent at most, with the military sector showing the greatest relative increase between 1990 and 1996 (Figure 2-20 and Figure 2-21).

Figure 2-20: Share of Coal Demand by Sector, 1990

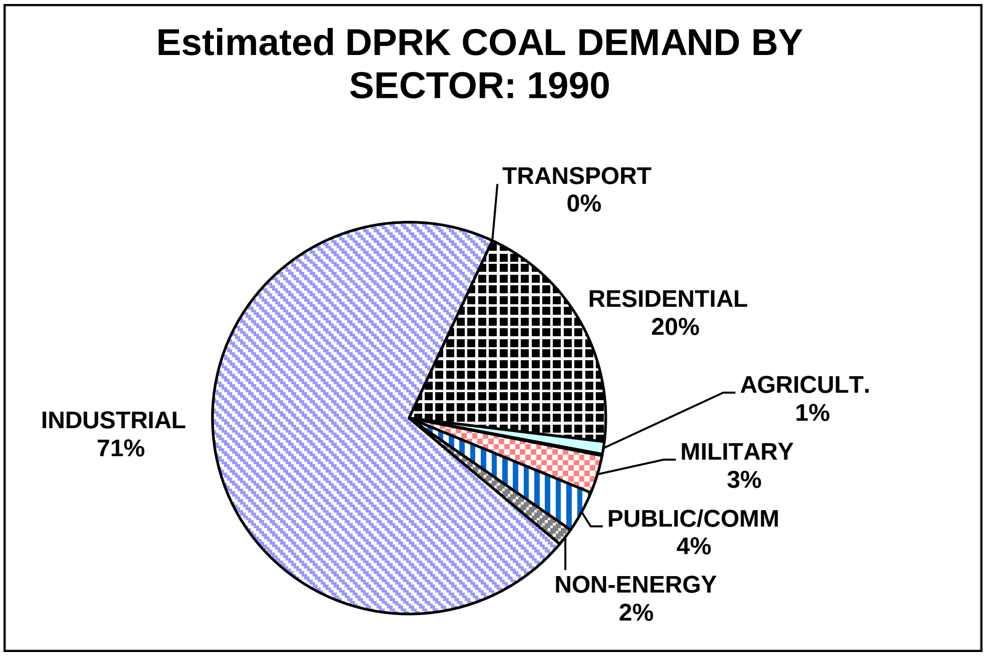
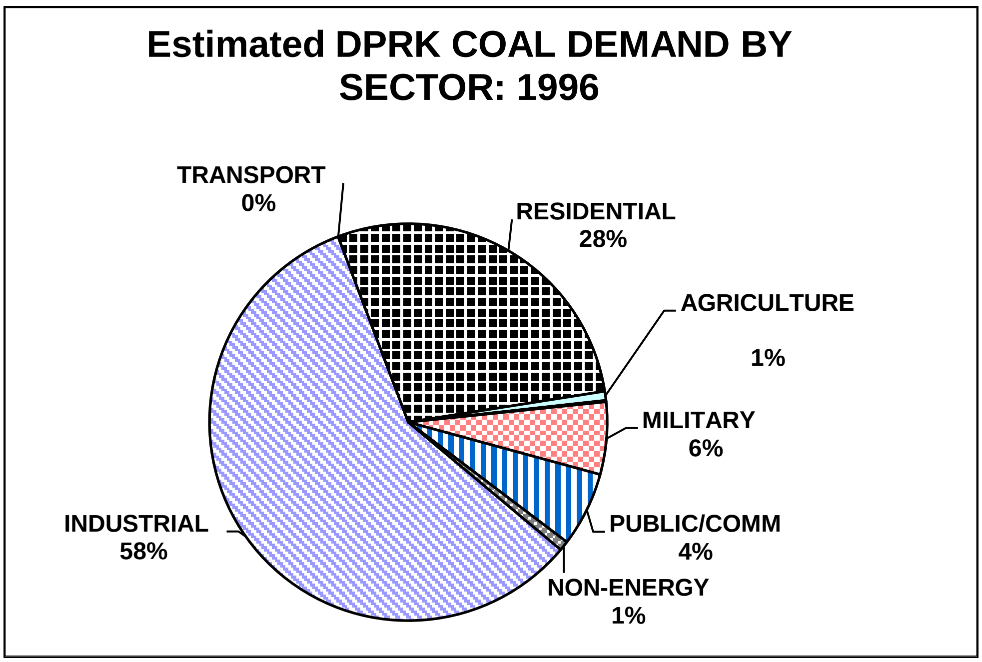
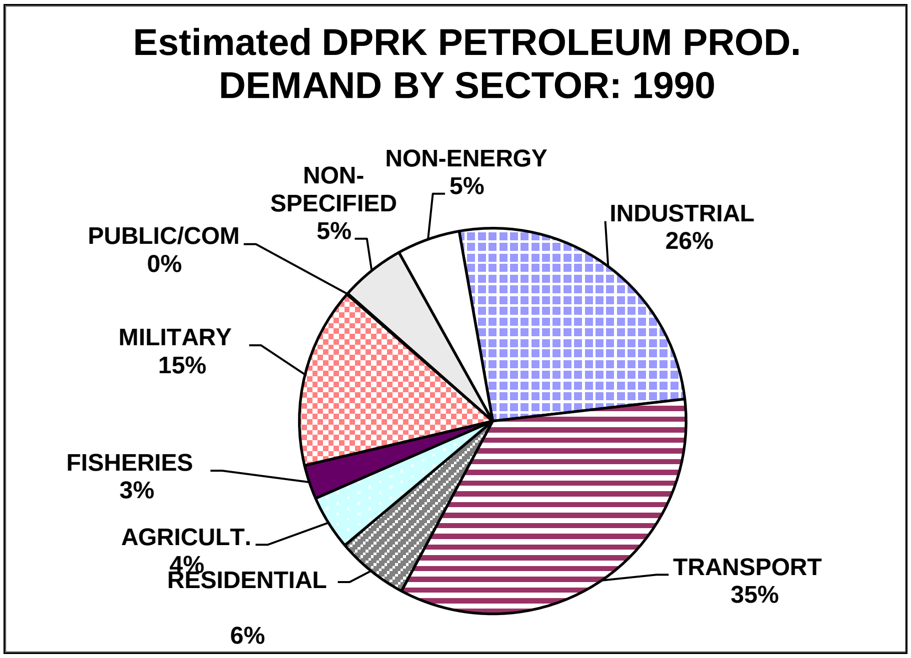


Figure 2-21: Share of Coal Demand by Sector, 1996



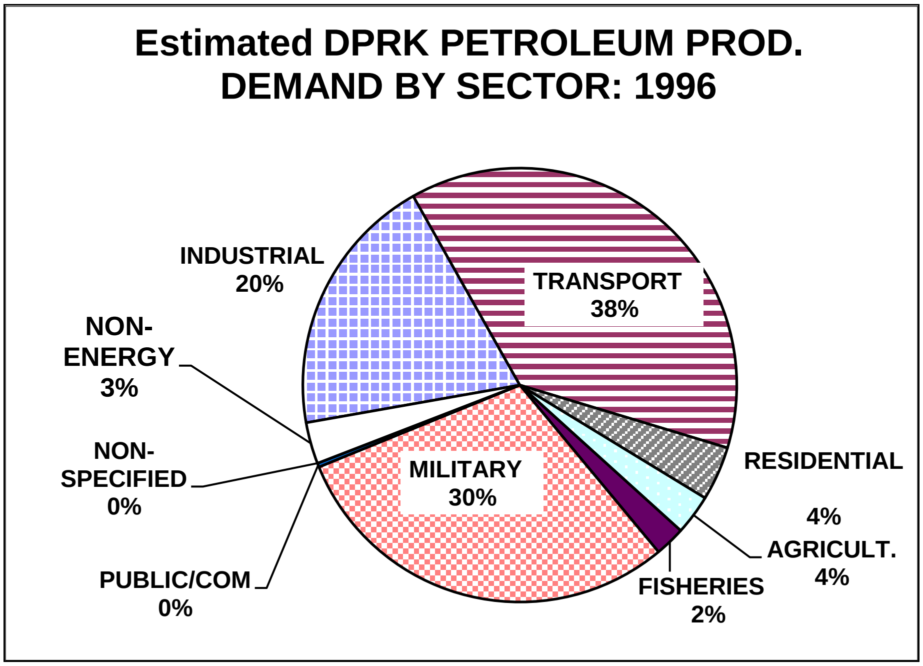
The major consumers of petroleum products in 1990 are estimated to have been the transport, industrial, and military sectors, with shares of 35, 26, and 15 percent, respectively (Figure 2-22). Note, however, that our estimate for industrial demand for oil products includes a rough estimate of oil use in magnesite production, an estimate of oil use in cement that is a guess, at best, and a placeholder value to account for what we estimate could be the rest of industrial oil demand. Our estimate of the shares of refined products consumption accounted for by the various fuel types varies in several ways from the estimates of production by product provided by Jang.[286] The major difference is that our balance includes much more use of heavy oil. Figure 2-23 shows the pattern of estimated petroleum products demand as of 1996, which differs from the 1990 pattern primarily in that military use of these fuels accounts for a much larger fraction (though somewhat less absolute demand) in 1996, with substantial decreases in the fraction of petroleum products used by the residential, industrial, and non-energy sectors.

Figure 2-22: Share of Petroleum Products Demand by Sector, 1990



[286] Jang, Young Sik (1994), *North Korean Energy Economics*. Korea Development Institute.

Figure 2-23: Share of Petroleum Products Demand by Sector, 1996



Industries in DPRK in 1990 are estimated to have used 58 percent of all electricity available for final demand. The transport sector (electric rail) is estimated to have used 10 percent, residences 9 percent, the military 12 percent, and the public/commercial sector approximately 5 percent of the electricity supplied to end-users (Figure 2-24). The pattern for 1996 is shown in Figure 2-25.

Figure 2-24: Share of Electricity Demand by Sector, 1990

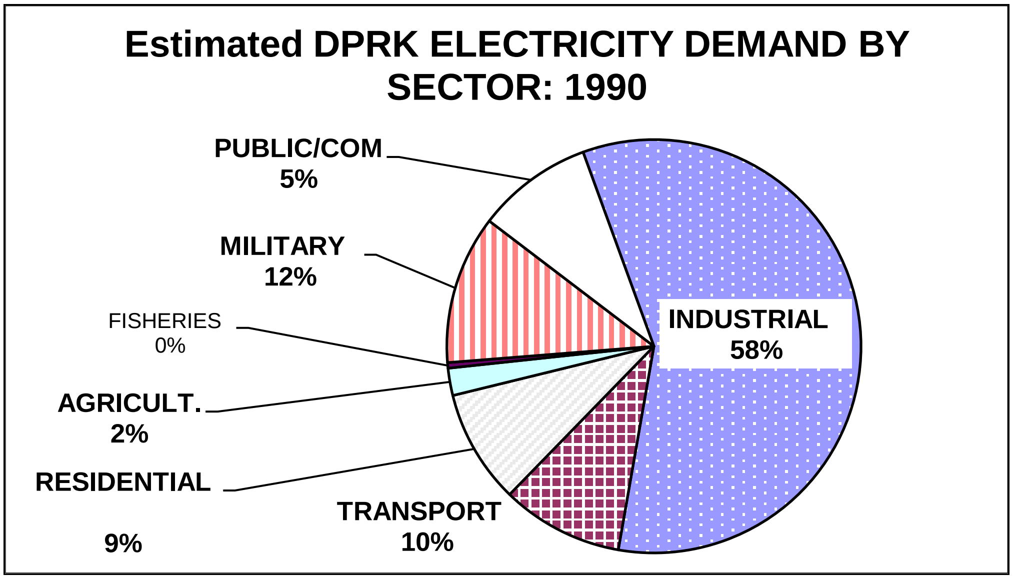


Figure 2-25: Share of Electricity Demand by Sector, 1996

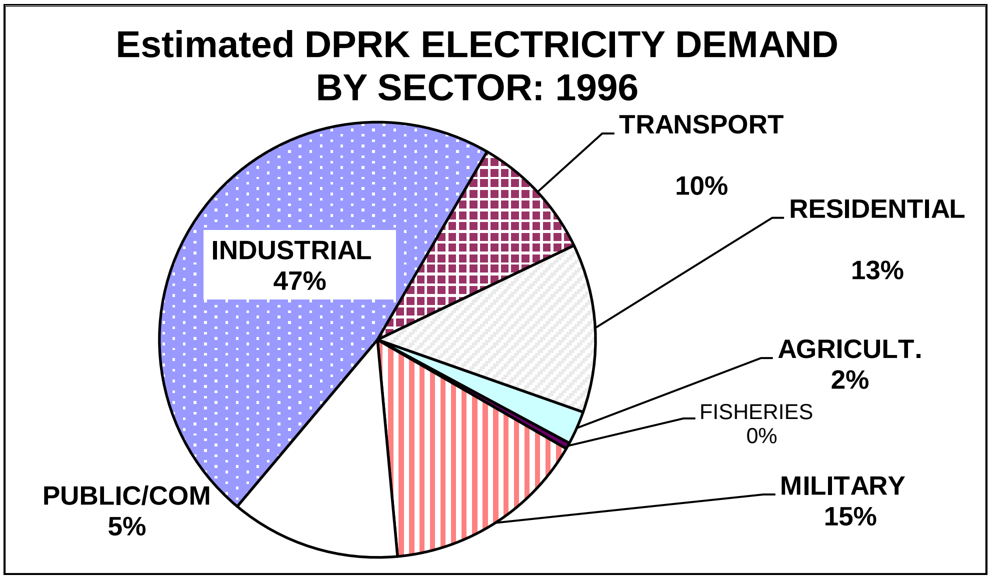


Figure 2-26 shows the estimated 1990 DPRK *Industrial* energy demand by fuel and by subsector. Coal was the dominant fuel in all subsectors except "Other Minerals", where we have included an estimate of petroleum products used for carbide production. The iron and steel production subsector is the largest consumer of coal in our estimate (nearly half of sectoral use, as shown in Figure 2-28), while iron and steel, fertilizers, other chemicals, and cement were together responsible for approximately 67 percent of industrial sector electricity use (Figure 2-30). The cement industry was another major consumer of fuels, accounting for an estimated 10 percent of industrial coal demand and 6 percent of industrial electricity demand in 1990. As noted, non-specified industries—consumption in which is specified primarily by placeholder values—accounted for a substantial fraction of fuel use in our 1990 estimate. We would hope to obtain better information to reduce this fraction. Figure 2-27, Figure 2-29, and Figure 2-31 present industrial sector results for 1996.

Figure 2-26: 1990 Industrial Demand by Subsector

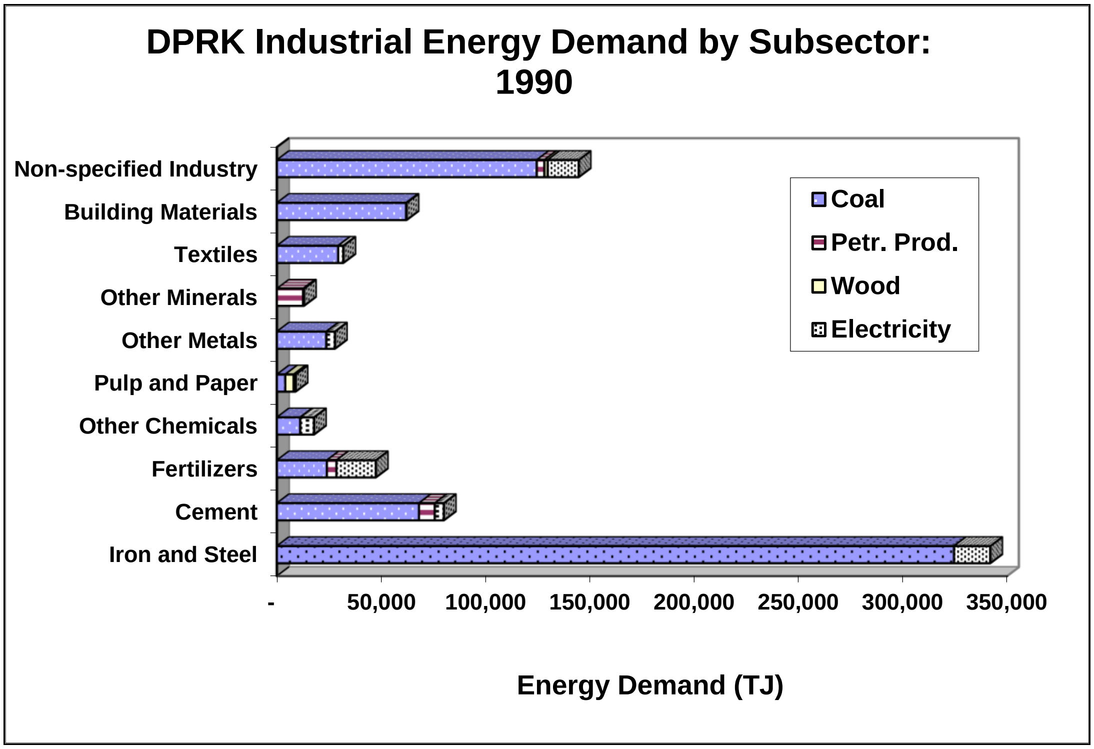


Figure 2-27: 1996 Industrial Demand by Subsector

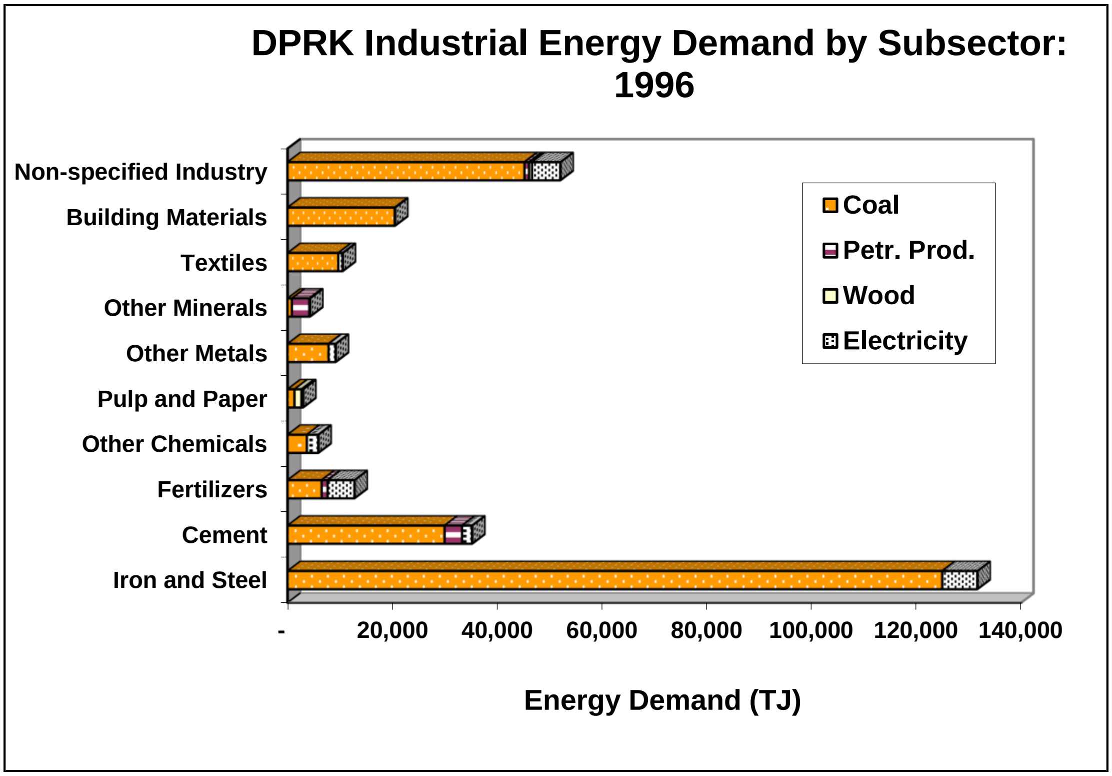


Figure 2-28: Shares of 1990 Industrial Coal Demand by Subsector

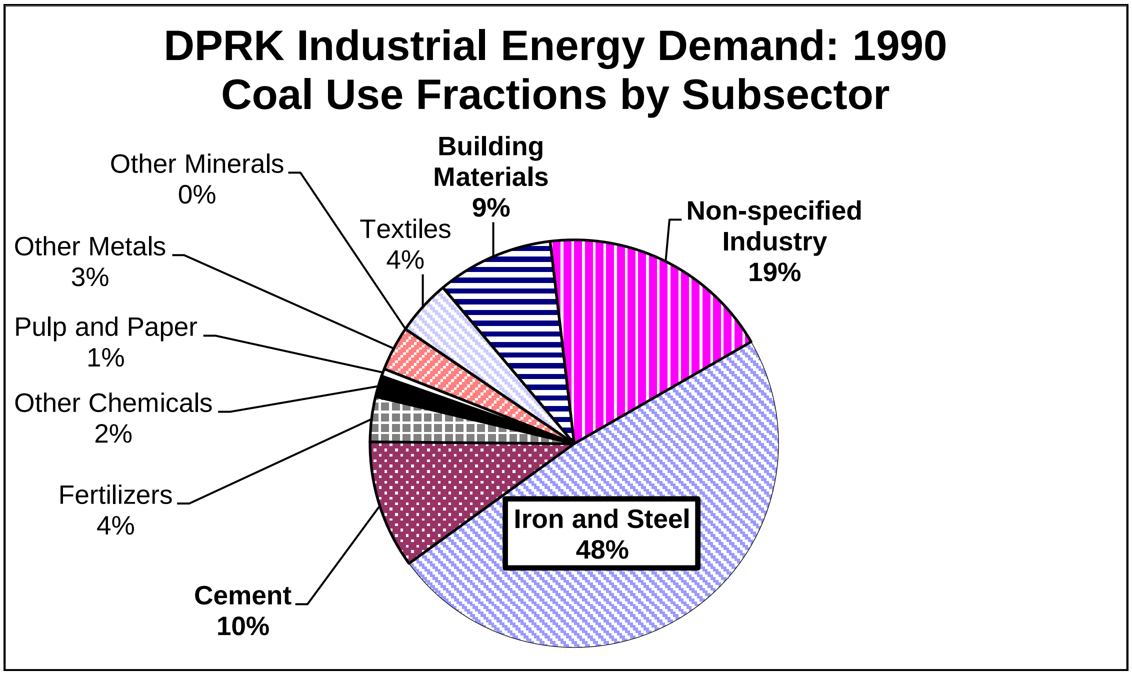


Figure 2-29: Shares of 1996 Industrial Coal Demand by Subsector

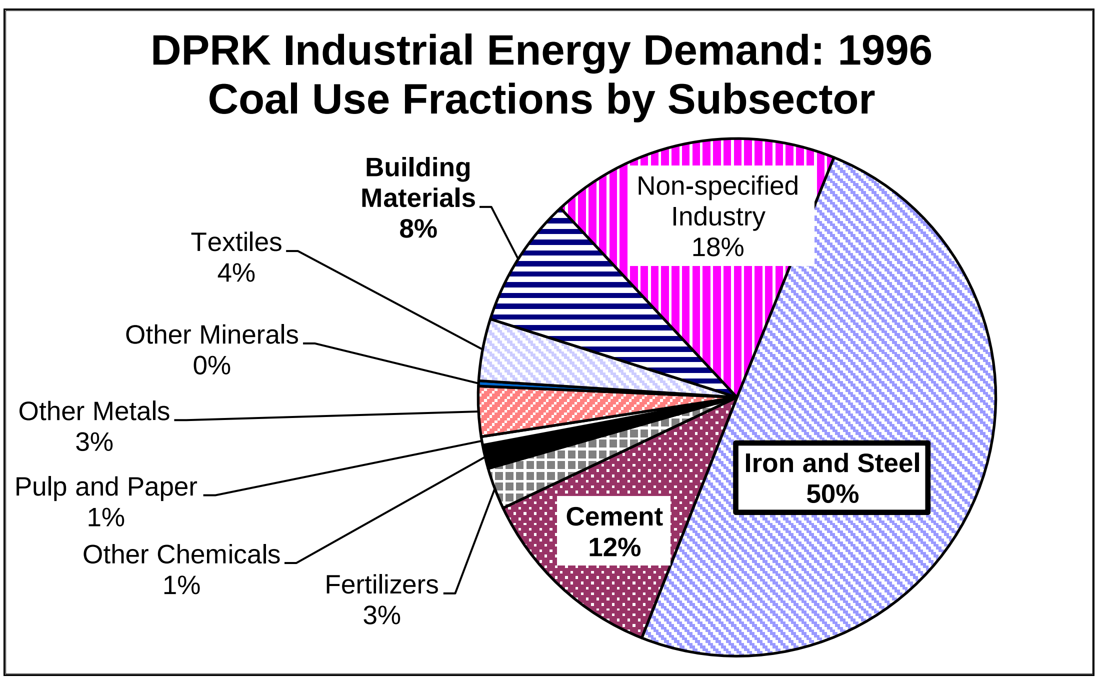


Figure 2-30: Shares of 1990 Industrial Electricity Demand by Subsector

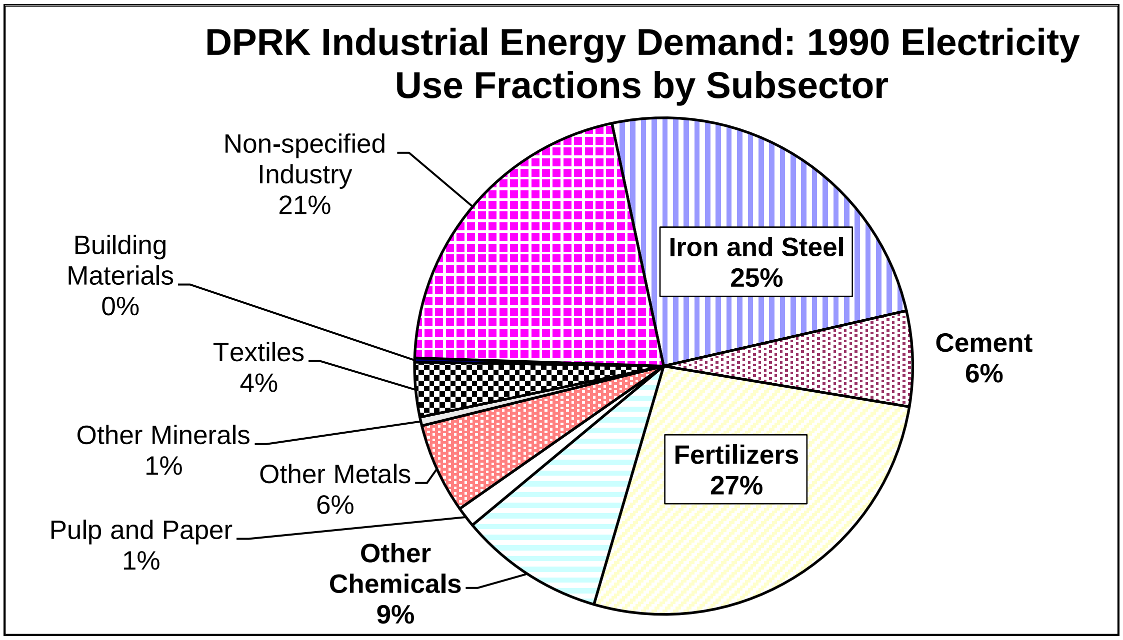
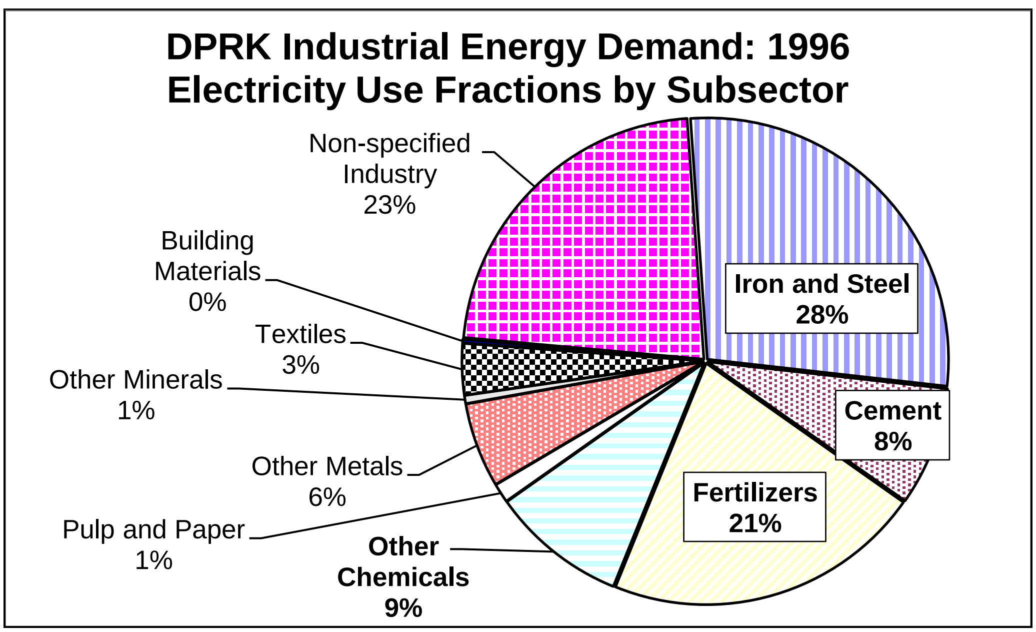


Figure 2-31: Shares of 1996 Industrial Electricity Demand by Subsector



Transport sector energy demand as of 1990 was dominated by petroleum products used in the road transport subsector, as shown in Figure 2-32. Again, the second greatest demand for fuels in the sector, as of 1990, was in the rail transport sector. The rail transport subsector is estimated to have consumed approximately 10,900 TJ of electricity in 1990, and less than one-fifth of that quantity of energy (1,950 TJ) in petroleum products (in this case, diesel oil). The air and water transport subsectors each consumed about 3 percent of the total transport petroleum products used, though these values must be regarded, pending receipt of better information, as order-of-magnitude estimates only (Figure 2-34). Similar qualitative patterns in subsectoral consumption, but with much lower absolute levels of fuels use, are shown for 1996 (Figure 2-33 and Figure 2-35).

Figure 2-32: Transport Energy Demand by Subsector in 1990

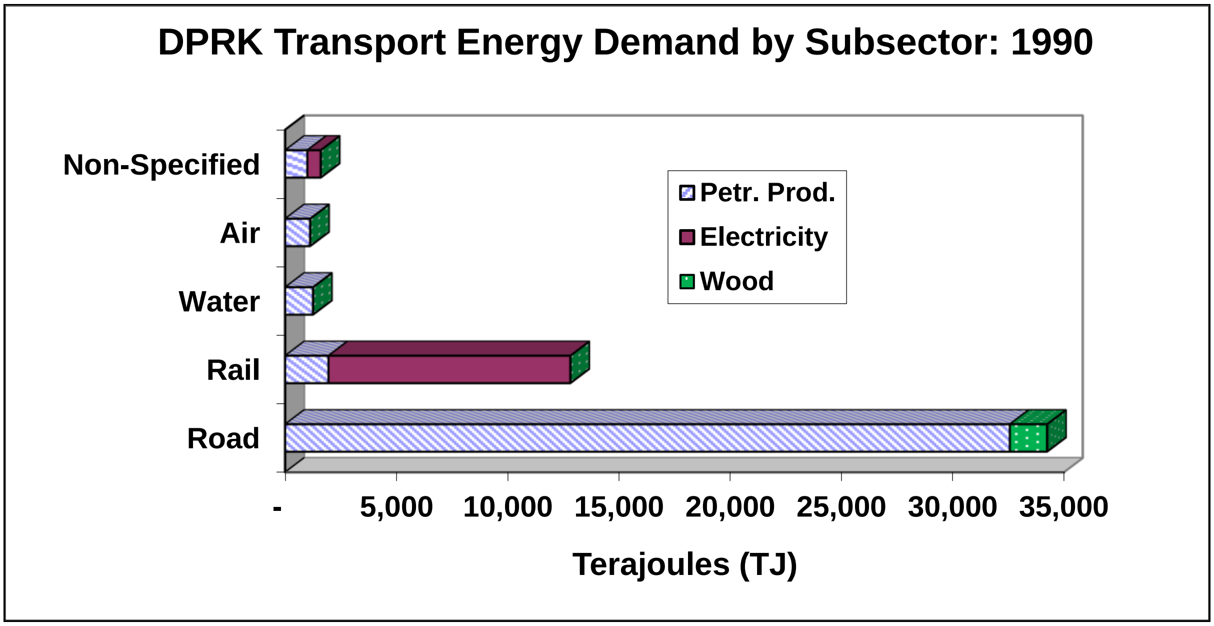


Figure 2-33: Transport Energy Demand by Subsector in 1996

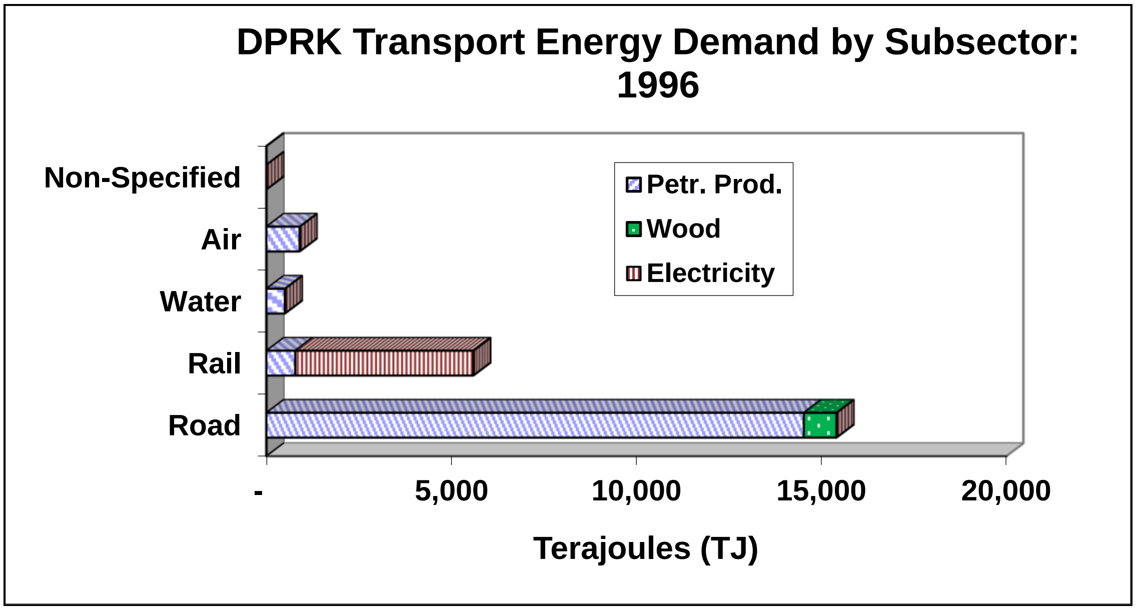


Figure 2-34: 1990 Shares of Transport Petroleum Demand by Subsector

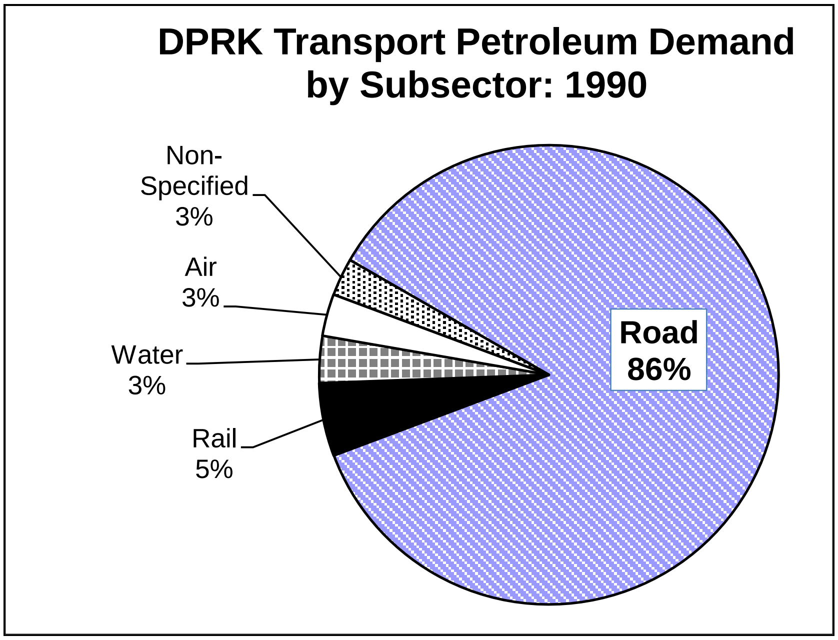
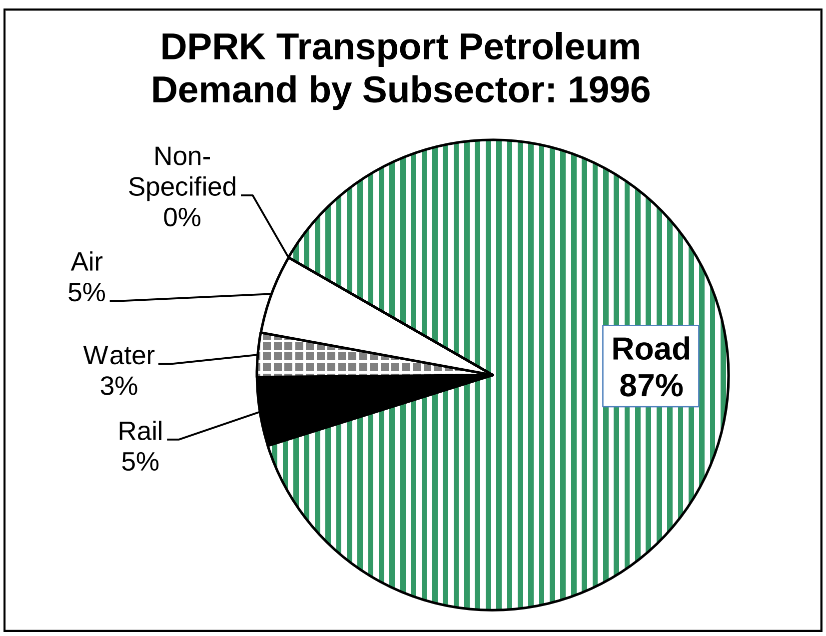


Figure 2-35: 1996 Shares of Transport Petroleum Demand by Subsector



Demand in the *Residential* sector, as shown in Figure 2-36 and Figure 2-37 (for 1990 and 1996 respectively), was dominated by coal and wood/biomass fuels. The urban and rural split of overall coal use by the sector is nearly 70/30, while more than twice as much electricity is estimated to have been used, in aggregate, in urban households than in rural households in 1990.

This ratio is even larger in 1996. Wood fuel use in 1990 was, by assumption, limited to the rural subsector, and amounts to approximately 6.6 (dry) tonnes of wood fuel use per household using wood fuel per year, or an average of somewhat under 20 kg per day. Refined petroleum products (kerosene and LPG) and charcoal were assumed to be used for cooking in urban households, with LPG and kerosene also used in a limited number (2 percent) of rural households. Use of these fuels contributes less than two percent to total sectoral energy demand. Demand for "commercial" (petroleum, coal, and electric) fuels in the residential sector declined significantly, in our estimate, between 1990 and 1996, while wood and biomass increased by about 25 percent relative to 1990 levels.

Figure 2-36: Residential Energy Demand by Fuel and Subsector, 1990

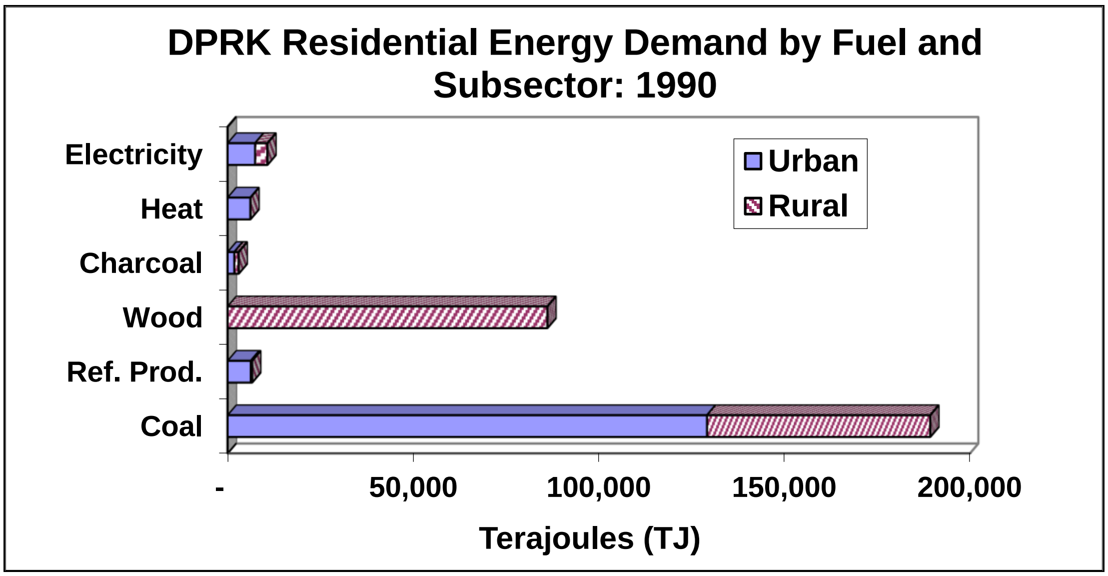
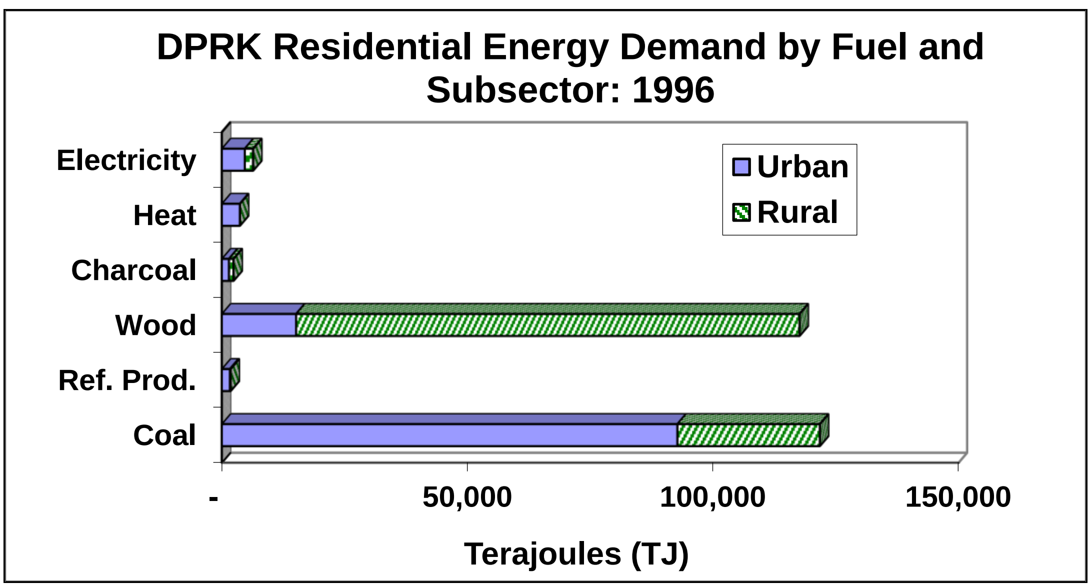


Figure 2-37: Residential Energy Demand by Fuel and Subsector, 1996



In the *Agricultural* sector, field operations and crop processing each contributed about half of total sectoral petroleum products demand in 1990, with a similar pattern in 1996. The use of coal is estimated to have totaled about twice the use of petroleum products in 1990, and over three times as much in 1996, though the extent of coal use in crop processing is not known. In terms of overall fuel use, agricultural wastes used in crop processing dominate, accounting over 72 and about 74 percent of total sectoral fuel demand in 1990 and 1996, respectively.

Our estimate is that energy demand in the *Fisheries* sector was fairly small, and quite uncertain. Most of the demand that we estimate for this sector was for diesel use by larger fishing craft. We have included a small amount of electricity use in the sector (520 TJ) in 1990, but this amount is calculated using US-based (Alaskan) estimates of electricity consumption per unit processing facility output, and thus could be significantly different in the DPRK.[287] Fisheries energy use in 1996 is estimated to have been 36 percent of the level estimated for 1990.

For the *Military* sector, our estimate of fuel use is divided into groups within the ground forces subsector: "trucks and other transport", and "armaments", including motorized guns and missiles, tanks, and armored personnel carriers. The other military subsectors are the Air and Naval forces, "military manufacturing", and "buildings and other". These divisions, and the amount of each fuel type estimated to have been used by the different military subsectors in 1990 and 1996, are shown in Figure 2-38 and Figure 2-39. Total estimated sectoral demand for coal and electricity was dominated by use in military buildings (48 and 23 percent of total sectoral energy demand, respectively in 1990); although these estimates are based on speculative estimates of military building floor area that have yet to be confirmed.

Estimates of the shares of petroleum product use in various types of military equipment are shown in Figure 2-40 and Figure 2-41 for 1990 and 1996, respectively. Notable results here include the large share of demand accounted for by 2 1/2 tonne trucks in use in the DPRK Army. When service vehicles from other service branches are included—and these were also likely to be 2 1/2 tonne trucks, for the most part, in 1990—the share of estimated military oil use by these trucks climbs to 43 percent. Aircraft accounted for about 14 percent of military petroleum demand in 1990, accounting for about the same fraction in 1996. Although aircraft use a great deal of fuel per hour of flight, we have assumed that their use (especially use of fighter and bomber aircraft) is very limited, and this assumption limits oil demand in the Air Force subsector. Naval patrol craft also are estimated to have accounted for a significant share of sectoral oil demand (27 percent in 1990), with tanks and other heavy armaments using a small fraction of total fuel demand, as their use in routine exercises by the DPRK military is estimated to be fairly limited (just 2 percent in 1990). Overall, in 1990, ground forces and naval forces each consume about 42 percent of total military petroleum products, with air forces using the remainder.

[287] by Greg Kelleher, Edward Kolbe, and Greg Wheeler (2001), *Improving Energy Use and Productivity in West Coast and Alaskan Seafood Processing Plants*, available as https://seafood.oregonstate.edu/sites/agscid7/files/snic/improving-energy-use-and-productivity-in-west-coast-and-alaskan-seafood-processing-plants.pdf. Tables 1 and 2.

Figure 2-38: 1990 Military Energy Demand by Fuel and Subsector

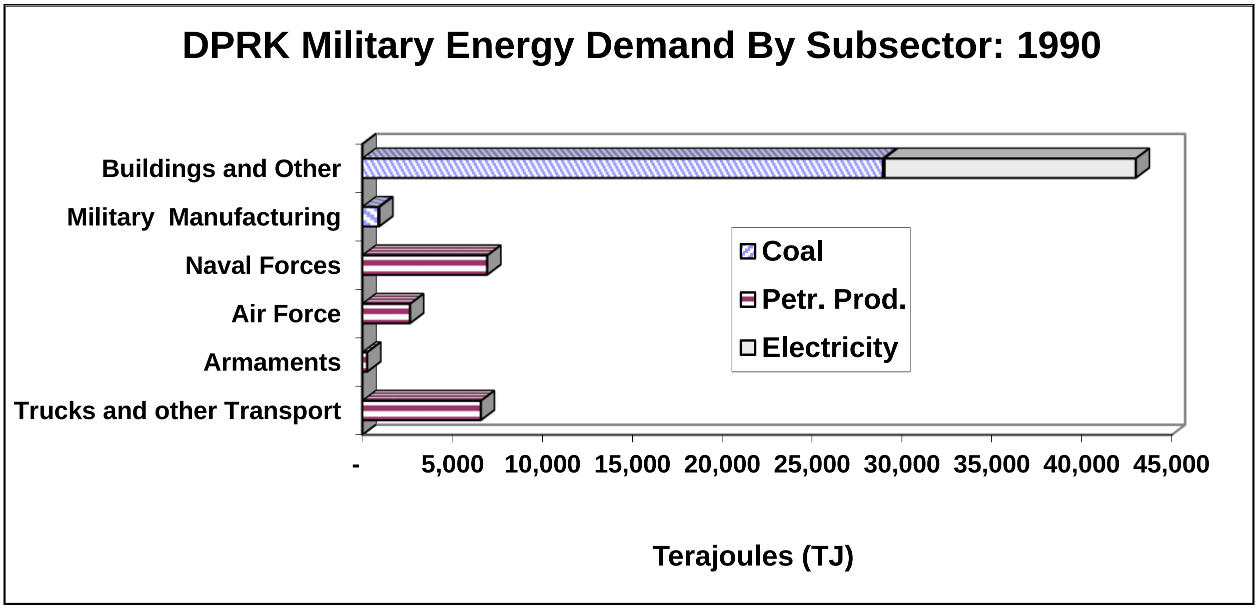


Figure 2-39: 1996 Military Energy Demand by Fuel and Subsector

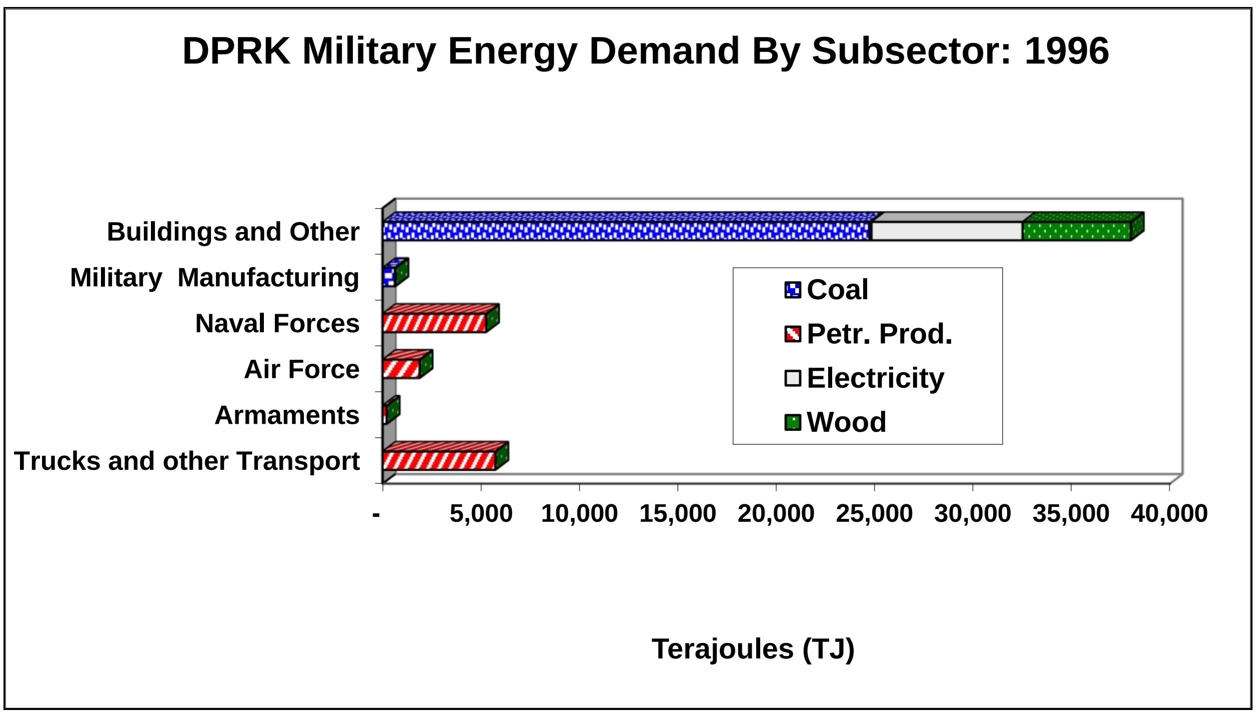


Figure 2-40: 1990 Military Petroleum Demand Shares

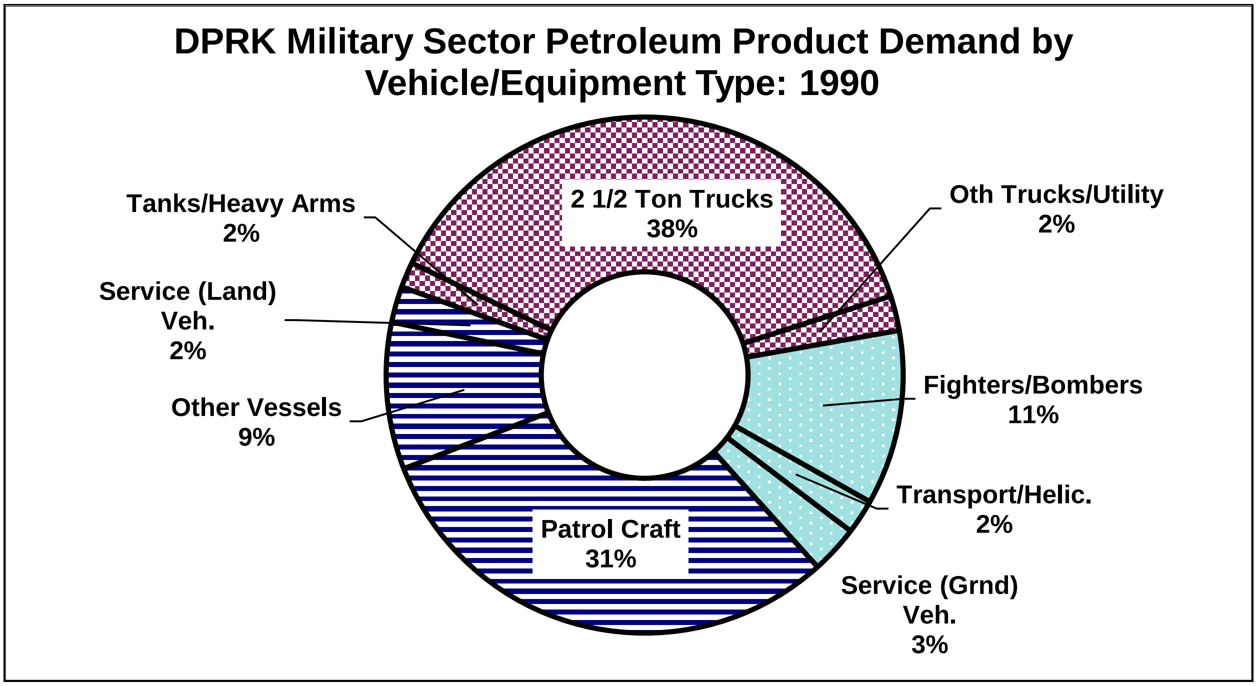
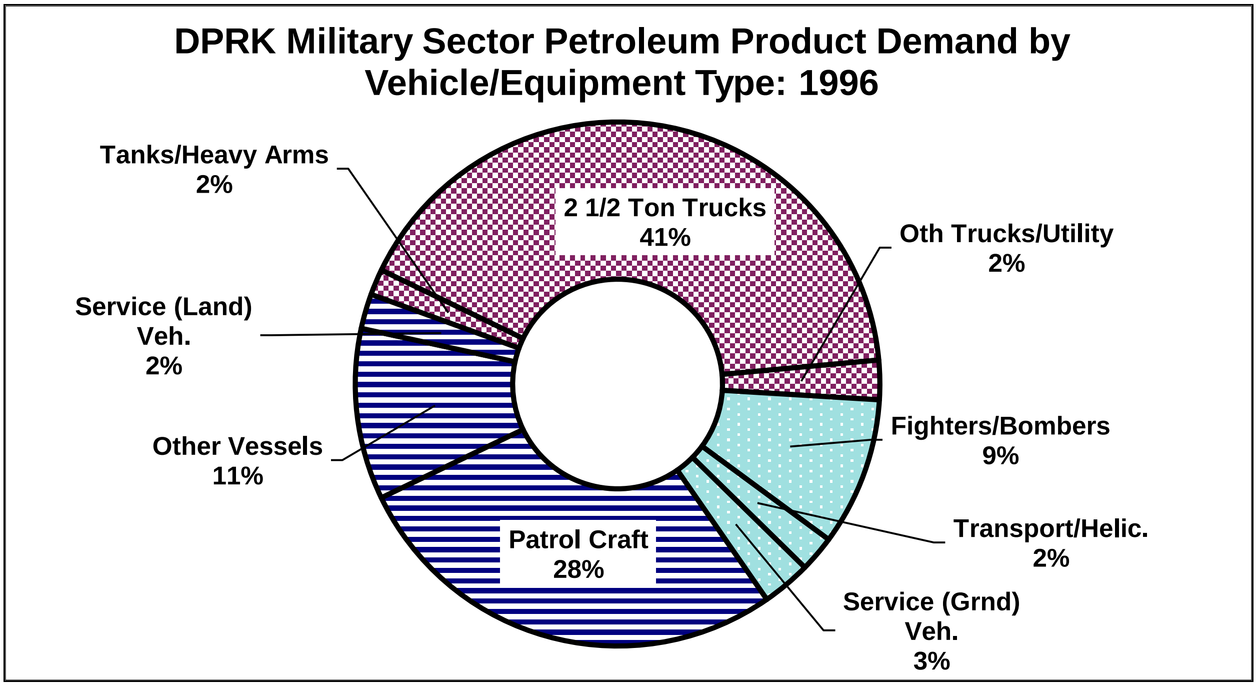


Figure 2-41: 1996 Military Petroleum Demand Shares



Our estimates of fuel demand in the *Public/Commercial* sectors are limited to coal, heat, and electricity used in public and commercial buildings, at roughly 33, 2.6, and 11 PJ, respectively, in 1990, and 26, 1.6, and 6.4 PJ in 1996, plus a small amount of use of refined products (about

0.10 and 0.13, in 1990 and 1996, respectively, or 0.3 and 0.5 percent of coal use) and wood for heating (1.6 PJ in 1990, and 2.6 PJ in 1996). We have included a relatively modest 5.8 PJ of petroleum products demand in the "*Non-Specified/Other*" sector to assist in balancing petroleum product demand with reported supplies in 1990, but this value is set to zero for the 1996 estimate. In the *Non-Energy Use* category we have included coal and oil products used as feedstocks in fertilizer production, other non-energy use of oil products (for example, as lubricants or road construction materials), as well as wood used in construction, furniture making, pulp for paper, and other non-fuel uses. These quantities were approximately 14, 5.8 and 12 PJ for coal, oil products, and wood, respectively, in 1990, and 3.4, 1.4, and 7.2 PJ, respectively, in 1996.

2.5.5. Key uncertainties in 1990 and 1996 energy balances: Energy demand

There is no doubt that our estimated balances would benefit greatly from additional and better information in many (if not all) of the areas we have covered. Notable among these areas where additional information would be welcome are:

- *Industrial Sector*
  - -- Production of all fertilizers by compound, and specifically, production of fertilizers other than nitrogen and phosphorous fertilizers. Also needed is information on how superphosphate is produced in DPRK.
  - -- Production figures and energy intensities for additional key metals and non-metallic minerals produced in DPRK.
  - -- Confirmation that the iron and steel-making energy intensities we have used are reasonable (they are more likely to be too low than too high).
  - -- Information on the extent of heavy fuel oil use in the Cement industry, and information on other uses of petroleum products in the industrial sector.
  - -- Information on extent of the use of coal and other feedstocks for production of other chemical products, including plastics and fibers other than vinalon.
  - -- Information on the use of biomass and wood fuels and waste products in the pulp and paper manufacturing subsector.
- *Transport Sector*
  - -- Average figures for the haulage distance (or tonne-km) for freight carried by the various major transport modes--train, truck, and ship.
  - -- Use of personal transport in DPRK, in the aggregate as well as by mode.
  - -- Information on the number of vehicles in the DPRK bus, fleet, with their average annual km traveled and fuel economy.
  - -- Average hours of flight time, and composition, of the DPRK airline fleet.
  - -- Information on the contribution of DPRK to international aviation bunkers (if any).
  - -- Information on the extent, modes, and efficiency of biomass use in the DPRK transport sector.

- *Residential Sector*
  - -- Confirmation that our estimates of household size are not vastly in error (though they seem roughly consistent with figures from the 2008 DPRK Census).
  - -- Specific information on the average floor area and energy use (coal, electricity, cooking fuels) in urban apartments (or confirmation that our estimates are reasonable).
  - -- Better information on the use of petroleum products in residential cooking.
  - -- Confirmation that our assumption that rural fuel use in the DPRK is reasonable, or information that would allow us to calculate a better weighted average.
  - -- Average electricity use in rural households.
- *Agricultural Sector*
  - -- Confirmation that our assumption as to fuel use per hectare in production of field crops is reasonable, or better figures, if available.
  - -- Information on energy used for irrigation pumping, including the fuel type (that is, the relative ratios of diesel, gasoline, and electric pumps).
  - -- Information on the use of fuels in the processing of agricultural products.
  - -- Information on the use of fuels in producing orchard crops, including silk manufacturing.[288]
- *Fisheries Sector*
  - -- Information on fuel used by the fishing fleet (larger ships), or at least information on the days per year that they are active.
  - -- Information on energy use by fishing cooperatives (though this is probably minimal compared with that used by large ships).
  - -- Data on the fuels (and amounts of fuels) used in processing fisheries products (and on the processing technologies/systems used).
- *Public/Commercial Sector*
  - -- Information on floor space in public/commercial buildings.
  - -- Better estimates for coal and electricity use per square meter in public and commercial buildings.
  - -- Information on any significant petroleum product use in the sector.
- *Military Sector*
  - -- Improved information/estimates on the average annual exercise tempos (hours per year in use) for military equipment, including tanks, trucks, light vehicles, planes, and naval vessels.

[288] Silkworms are fed on the leaves of mulberry trees.

- -- An estimate of what fraction of the DPRK's military hardware (by category) is typically operable/operated.
- -- A better-grounded estimate of military floor space.
- -- Any additional information on energy use in military buildings.
- -- Information on major uses of fuels in for special military technologies aside from energy use in weapons/vehicles or military buildings (though such data are admittedly unlikely to be made available).

- *Non-Specified/Other Sectors*
  - -- Information on major demand sectors that we may have omitted.
- *Non-Energy Use Sectors*
  - -- Information on non-energy uses of fuels other than the few we have cataloged, particularly for products such as bitumen/asphalt.

2.5.6. <u>Summary of key data gaps and uncertainties: DPRK energy supply in 1990</u>

- In the **Coal** sector, a wide range of different production estimates exist for 1990. The uncertainty (on our part) as to which estimate is more correct is compounded by uncertainty as to which average energy content is appropriate for coal produced in the DPRK.
- In the **Petroleum** sector, the statistics used are probably fairly accurate--and almost certainly not low--but should be confirmed if possible. Note that our initial estimate of demand for petroleum products for 1990, at least, appears to come up somewhat short of estimated petroleum products production (thus the use of placeholder values, for example, in “non-specified industry”—see section 2.5.4), thus it would be prudent to investigate whether the supply of these products is overstated, whether we have underestimated demand, or both.
- In the **Wood and Biomass** production sector, the figures available seem to be quite uncertain, but this lack of information is not unusual (even in countries where data access is <u>not</u> difficult) when it comes to statistics describing the use of these fuels. The production levels that we have used appear plausible, but better statistics on wood production and use, including a clear indication of the units of production (that is, solid or packed volumes, bone-dry, air-dried, or green weights) would be helpful. Our estimate for biomass production is predicated in part on total biomass use for fuel in the rural household subsector, which is a very uncertain estimate.

2.5.7. <u>Summary of key data gaps: DPRK energy transformation in 1990</u>

For **electricity generation** processes, the key need is for a substantiated, easily cross-checked value for overall electricity production. Other needs are:

- A complete accounting of all grid connected power generation facilities (capacity, location, dates of construction/updating, and availability for generation).

- An accounting, by class (size, thermal/hydro), of power plants not connected to the grid and connected only to local grids, including plants associated with industrial facilities (including industrial cogeneration).
- More complete information on district heating, from both heat-only plants and from electricity generation plants.
- Updated values for plant efficiencies, own-use rates, and "emergency losses".
- Data showing the relationship between annual rainfall and hydroelectric generation (or potential generation).
- More complete information on the impacts of the 1995 and 1996 floods on major hydroelectric plants and estimates of the work and time that were required to repair any damage to hydro reservoirs and equipment.
- Information on the status of fuel supplies to thermal power plants, including any shortages of fuel (and the cause of those shortages).

For the **Transmission and Distribution** system, important uncertainties include:

- The locations and design voltages of the complete set of power lines on the DPRK transmission grid.
- The actual level of transmission and distribution losses (though it is quite possible that accurate data on losses simply do not exist).
- The current status, capacities, and vintages of individual substations and regional control centers. This accounting of substations would include a description of the types of transformers now in use in DPRK substations.[289]
- The kinds of conductors and poles are currently in use, and the status of the transmission lines themselves (for example, have they been heavily damaged by scavengers?).
- The extent to which the DPRK electric system currently operates as a unified grid, and the extent to which it operates as a set of semi-autonomous regional of local networks.

Uncertainties and additional data needs in **other transformation sectors** include:

- In the **petroleum refining** sector, a better estimate of in-plant use of energy would be helpful, as would an idea as to the generation and use of electricity in refineries. A better idea of the output slate of refined products would be needed if the balance were to be expanded to account for production and consumption of more individual petroleum products.
- Better figures on in-mine uses of coal and electricity for **coal mining** are needed.
- Data on the types, capacities, and efficiencies of **charcoal** production facilities in DPRK are currently lacking.

[289] Older transformers in the US often contain large amounts of insulating oils known as PCBs (polychlorinated biphenyls). PCBs are quite toxic (to humans and other ecosystem elements) and should be disposed of with great care. If substations in the DPRK are to be replaced in great quantity, and prove to contain PCBs, the disposal of PCBs may prove to be a significant health, occupational, and environmental concern.

2.5.8. Key uncertainties in 1996 energy data

The assumptions that we have had to incorporate in our estimate of energy supply and demand in the DPRK in 1996 are many. Hard facts about the recent energy situation in the DPRK have been for the most part unavailable. Although our bottom-up method using physical and sector-by-sector balancing can handle some of the key uncertainties by forcing an explicit, cross-cutting consistency in the analysis, key uncertainties have been identified but not resolved in our method. In this section we highlight some of our major uncertainties regarding changes in the DPRK energy sector between 1990 and 1996.

- **Actual total generation in 1996**: we have various estimates of total generation in recent years, but do not know how much electricity was actually produced, or what fractions of the total have been from hydroelectric or thermal power plants.
- **Total generation capacity**: We have seen several different figures for total generation capacity in the DPRK, but do not have a definitive list of the plants that were reported to be grid-connected (including industrial cogeneration facilities), nor do we really know how much capacity was available or how much total generation had taken place in smaller plants not on the main DPRK grid.
- **The status of generation facilities in general**: Although it seems clear that there was enough capacity nominally available to generate the electricity called for in our estimated 1996 supply-demand balance, we do not know for certain what condition the generating plants in the DPRK were in, and so we do not know how much generating capacity was functionally available.
- **The status of large generation facilities now or recently under construction**: We do not know the status as of 1996 of several of the reported large thermal and hydroelectric plants that had been reported to be under construction, although many of those projects, in hindsight, appear not to have come to fruition. Also unknown is whether there was significant flood damage, as of 1996, to the sites of new dams (for example, the Kumgang Mountain project).
- **The status of the Korean plants shared with/generating for China**: Were the conditions and/or capacity factors at these shared plants better or worse than the rest of grid as of 1996?
- **Status of the T&D system**: To what extent was the T&D grid fully operational, at stasis, deteriorating, deteriorated, or somewhere in between? The status of the grid is one of the elements determining how much power was consumed during 1996. Some sources held that it would take an investment of $1 billion or more just to keep the system from getting worse, but others thought that the system was not getting any worse as of 1996 (though history seems, based on the reports of most observers, to have proven them wrong, at least for the years from 1996 on). Report as of 1996 indicated that power outages, at least in the Pyongyang area, were relatively rare—in contrast to the 1992 to 1994 period when outages were common, even in Pyongyang.
- **New transmission lines**: How much progress (if any) had been made on constructing the planned 300 kV and 500 kV transmission systems by 1996 is unknown, though it seems likely, based on information obtained since 1996, that little progress had actually been made. The status of these systems would affect the level of overall T&D losses, and on plans for connecting the PWRs to be supplied by KEDO to the DPRK grid.

- **Damage to coal mines**: We have assumed that sufficient coal mine capacity still existed to easily serve the constricted DPRK economy of 1996, but we do not know what the extent of flood damage to mines and mining equipment was as of that time.
- **Status of fuel transport infrastructure**: Were the fuel transport facilities (principally rail facilities) still sufficiently operable to transport the quantities of coal and other fuels that we estimated were used in 1996? Reserves of coal would not seem to be a problem, but lack of transport facilities due to lack of diesel fuel and/or lack of steel rails to repair the tracks and/or lack of electricity, for example, would have created problems in providing fuel to industries and other users, which would have implications for both coal and electricity demand.
- **The constitution of HFO use in the industrial sector**. We have assumed that most of the heavy fuel oil used in the industrial sector as of 1990 was consumed for magnesite production and (to some degree) for cement production. We have been told that magnesite production in 1996 was much less than in 1990, but we do not know with any precision how much production has declined. If magnesite production had declined to less than the 300,000 tonnes that we have assumed for 1996, it means either that much more HFO was used to augment coal in coal-fired power plants, as a co-fired fuel for cement manufacture, as an emergency fuel additive in the transport sector,[290] was used in some other way in the DPRK economy, or was somehow exported.[291] It is likely that HFO was used in other industrial subsectors as well, though the DPRK pattern seems to have been to use coal as a fuel and feedstock even in industries (such as production of synthetic fiber) where virtually every other installation in the world uses a different (that is, oil-based) feedstock to produce similar commodities.
- **The role of "unofficial" petroleum products imports**. We have tried to learn as much as possible about how oil and oil products were coming into the DPRK as of 1996, but uncertainties remain. How much oil crosses the Chinese and Russian borders to enter the DPRK in tanker trucks, train cars, coastal freighters, and individual barrels? Does the output of the small refinery in China that we understand has historically shipped oil products to the DPRK vary substantially from year to year?[292] Does the DPRK get a representative share of the output of that refinery, or are the products that the DPRK receives weighted toward the lighter fractions (of which the DPRK is and was more in need)? Definitive answers to these questions could alter our 1996 oil products balance somewhat but would probably have relatively little impact on the pattern of HFO supply and demand.
- **Biomass-fueled trucks**. Biomass or coal-fueled trucks in the DRPK certainly were relatively common in the period around and after World War II. Some of the people we have talked to swear that trucks fueled with producer gas generated in on-board gasifiers ("biomass trucks") predominated for goods transport outside Pyongyang, and we have seen

[290] We have been told that in recent years, HFO has been used, by some technical means not at all clear to us, as a fuel for trucks and other internal-combustion-engine transportation equipment. The extent of this use of HFO is not known, but we assume that it has been minimal relative to other uses of heavy fuel oil.

[291] Export markets for HFO accessible to the DPRK may have been limited, given a general glut of heavy fuel oil on the Asian market relative to other petroleum products as of the late 1990s.

[292] Our conversations with those who keep a finger on the pulse of the Chinese oil industry suggest that refinery capacity factors could vary from 50 to 80 percent depending on each refinery's allotment of crude oil input for the year (D. Fridley, personal communication, 1996).

pictures of such vehicles. Others who have extensive experience in the DPRK profess to have seen them not at all or rarely. If biomass trucks (like the one shown in Figure 2-42) were, contrary to our assumption, in relatively common use, it would indicate somewhat less tight supply of motor fuels in 1996. If, on the other hand, biomass trucks carry less than the 7.6 percent of road freight we have assumed, the estimated availability of gasoline (and diesel) for other uses would decrease somewhat.

Figure 2-42: Photo of DPRK Truck Powered by a Coal (and/or biomass) Gasifier[293]

[293] Peter Hayes, Jim Williams, and Chris Greacen, "Fuel and Famine: North Korea's Rural Energy Crisis". Presentation for the Energy and Resources Group Seminar, University of California, Berkeley, California, USA. November 1, 2000.

3. Estimated 2000, 2005, 2008 through 2010, 2014 through 2020 Supply/Demand Energy Balances

3.1. Overall Approach

Building on our work in compiling estimated energy balances for 1990 and 1996, our overall approach to preparing DPRK energy supply-demand balances for the years 2000, 2005, 2008 through 2010, and 2014 through 2020 included:

- Starting with the estimates of demand and supply prepared as above for 1990 and 1996.
- Modification of the 1990/96 estimates (and, for 2005 and on, year 2000 estimates) of demand for fuels to reflect reports of recent changes in conditions in the DPRK. These included changes in population, data (mostly from customs statistics of the DPRK's trading partners) on the availability of oil products and imports of energy-using products (such as vehicles and generators) and energy supply sources (such as solar photovoltaic panels) changes in the DPRK transport system observed by journalists and other visitors (ourselves included), and reported or implied reductions in industrial, agricultural and fisheries output. Reports as to the availability of electricity in different parts of the country also played a role in the estimation of year 2000 and 2005 (and more recent) electricity demand.
- Revision of our 1996 estimates of electricity supply to meet 2000-on electricity demand and to reflect information about changes, by each balance year, in thermal and hydroelectric generating capacity (and its availability).
- Estimation of 2000 through 2020 oil supply in a way that reflects available information, including the capacities, product slates, and utilization of the oil refineries in the DPRK, and quantities of refined products reported to be imported during those years (including product trades recorded in official statistics and products reportedly imported "unofficially").
- Revision of oil products demand as initially estimated to meet the overall supply for each of the major classes of oil products (heavy fuel oil, diesel oil, gasoline, kerosene, and LPG/other).
- Setting the level of coal and biomass supply to meet demand and re-adjusting supply of other fuels as necessary to produce a rough balance in overall supply and demand.

Overall, our approach to preparing the year 2000-on energy balances, in keeping with the paucity of information available (both inside and outside the DPRK) about the DPRK in general and about its energy sector in particular, was to obtain all the information remotely germane to the problem, sift through the information to see which pieces made sense, and fit with other data, and to try and use what was available to prepare an internally consistent energy balance. In so doing we collected information from reports by others, media reports, official statistics of DPRK trading partners, information on the DPRK from ROK government agencies, and the reports of visitors to and observers of the DPRK. In updating our 1990/96 energy balance to 2000 and beyond, we contacted specialists in DPRK (and broader Northeast Asian) energy issues and economics, including those who visit the country, to obtain their data, thoughts, and observations on recent developments the DPRK. Except where explicitly cited in the notes presented in Attachment 1 or in this chapter, these sources have chosen to remain confidential. Much of the analysis described here for the year 2000 energy balances was carried out for the 2002/2003 version of our energy sector analysis, and much of the analysis for the years prior to 2010 dates to our 2012 energy balances work but results for 2010 and before have been updated for this version of this Report to make it consistent with information and insights received since.

To further update energy balances to the year 2005, we took advantage of the invaluable input provided by the participants in the June 2006 DPRK Energy Experts Working Group Meeting, held in East Palo Alto, CA, USA, in collaboration with (and co-hosted by) Stanford University's Preventive Defense Project.[294] In addition, as in our earlier (2002/2003) work, we reviewed available literature and news reports, and contacted experts in the field to augment the information at hand. Much of the analysis described for the 2005 energy balances was carried out for the 2007 version of our energy sector analysis but has also been updated to reflect more recent information.

To produce updated estimated energy balances for 2008 and 2009, we similarly reviewed literature and news reports available to us, reviewed customs and other statistics (including the 2008 DPRK Census), consulted with experts including in the context of DPRK Energy Experts Working Group meetings in Beijing in 2008 and 2010.[295]

For the years 2010 and 2014 through 2020, we have used the same approach of gathering all available data and literature—ranging from published articles and news reports to UNSC documents and trade data—and reviewing it for insights as to economic activity and/or energy use in the DPRK. In addition to conversations with experts on DPRK energy use, we benefited from several meetings with technical delegations from the DPRK in the context of meetings on various Nautilus projects, most recently the Regional Energy Security project of which this report is a part, as well as a brief trip to the DPRK, as a part of our Building Energy Efficiency Training project, in 2009.[296]

The key assumptions and data used in preparing our estimated supply and demand balances for electricity and other fuels are presented below by sector (for demand) and by fuel group (for supply). Note that more detailed assumptions for electricity supply and demand estimates in particular can be found in Chapter 5 to this Report. In each case, details of the data, calculations, assumptions, and sources used are presented in Attachments 1 and 2 to this report.

3.2. Summary of Key Changes in the DPRK Energy Sector between 1996 and 2000

Changes in the DPRK energy sector between 1996 and 2000 were, for the most part, of a substantially more incremental nature than the changes in experienced during the first half of the

[294] Please see https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/ for information on and materials from this meeting.

[295] See https://nautilus.org/projects/by-name/dprk-energy/2008-meeting/ and https://nautilus.org/projects/by-name/dprk-energy/2010-meeting/ for information and materials from these meetings. The 2010 meeting also included a session on the minerals sector in the DPRK.

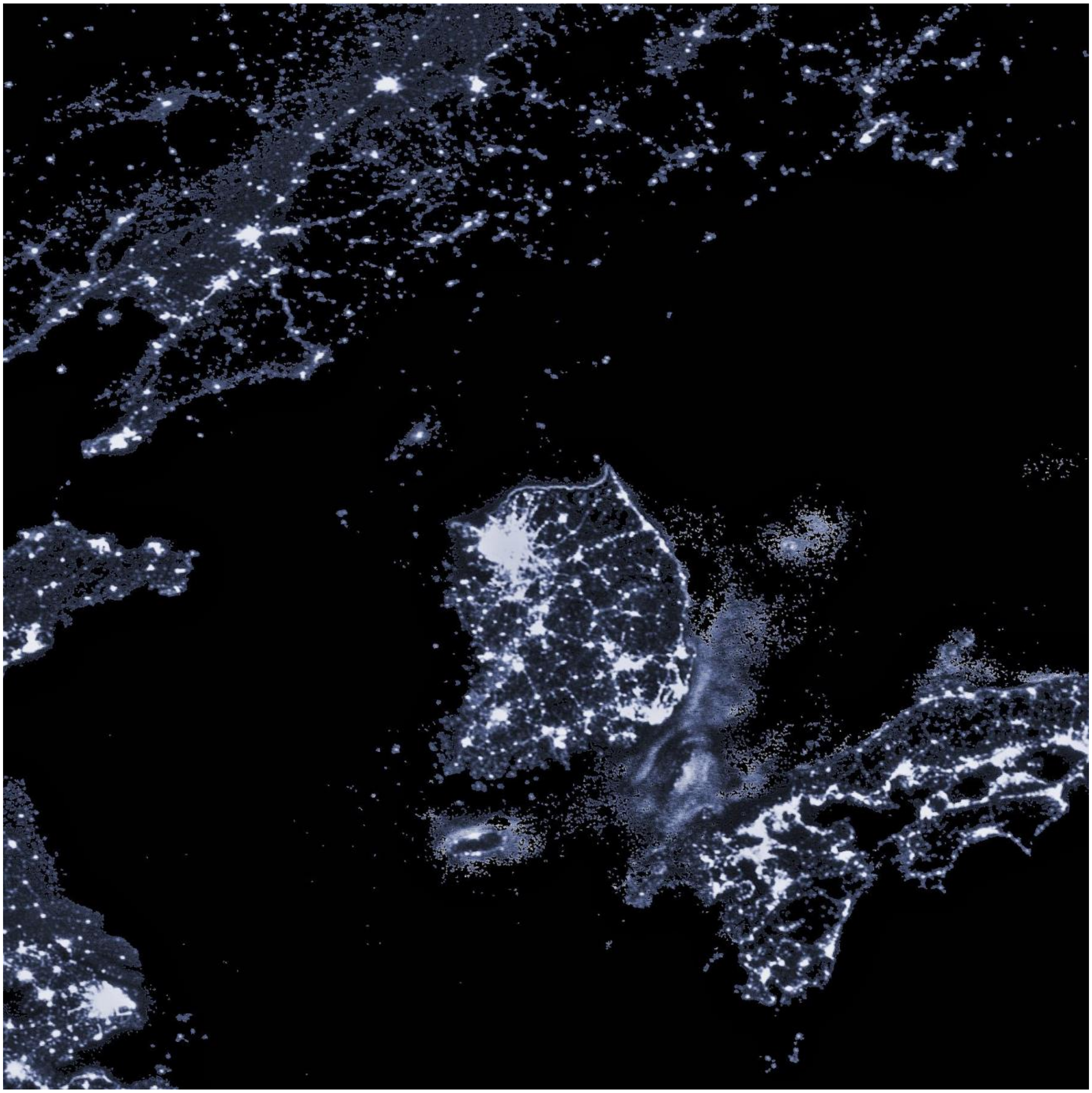
[296] For additional information on these projects, see, for example, "DPRK Building Energy Efficiency Training (2008 – 2011)" at https://nautilus.org/projects/by-name/dprk-buildings/, and the description of the 2010 East Asia Science and Security workshop, at https://nautilus.org/projects/by-name/science-security/workshops/2010-east-asia-science-and-security-meeting/. Information on the Regional Energy Security Project (2018 – 2020) will be forthcoming on the www.Nautilus.org website.

1990s (and described in Chapter 2 of this Report). Individual changes are discussed below (section 3.7). Among the key changes (or continuing processes) for the DPRK energy sector between 1996 and 2000 were:

- A continuing **decline in the supply of crude oil** from China, significantly reducing the overall output of the DPRK's remaining operating (Northwest Coast) refinery.
- Continuing degradation of **electricity generation infrastructure** due to lack of spare parts, maintenance not performed, or use of aggressive (high sulfur) fuels such as high-sulfur heavy fuel oil and used tires in boilers designed for low-sulfur coal.
- Continuing degradation of **electricity transmission and distribution** infrastructure, resulting in much **reduced availability of electricity** in most parts of the country away from Pyongyang. Figure 3-1, Figure 3-2, and Figure 3-3 present views of the lights of Northeast Asia from space as of 2000, 2010, and 2016, respectively, which suggest that significant amounts of electricity were available in the DPRK only in highly limited areas.[297]
- Continuing **degradation of industrial facilities** (including eyewitness reports of industrial facilities being dismantled for scrap), and the damage to industrial electric motors from poor quality electricity (electricity with highly variable voltage and frequency).
- Some **imports of used motor vehicles** (which are more efficient than existing vehicles made in North Korea).
- A continued decline in the **production of cement and steel**.
- Evidence of significant international trade in **magnesite (or magnesia)**.
- Some increase in **military activity**, relative to 1996.
- Continuing difficulties with **transport of all goods, especially coal**.
- Difficulties in **coal production** related to lack of electricity, as well as mine flooding (in the Anju region).
- Some **economic revival**, but mostly, it seems, associated with foreign aid and/or with areas of the economy that are not energy intensive.

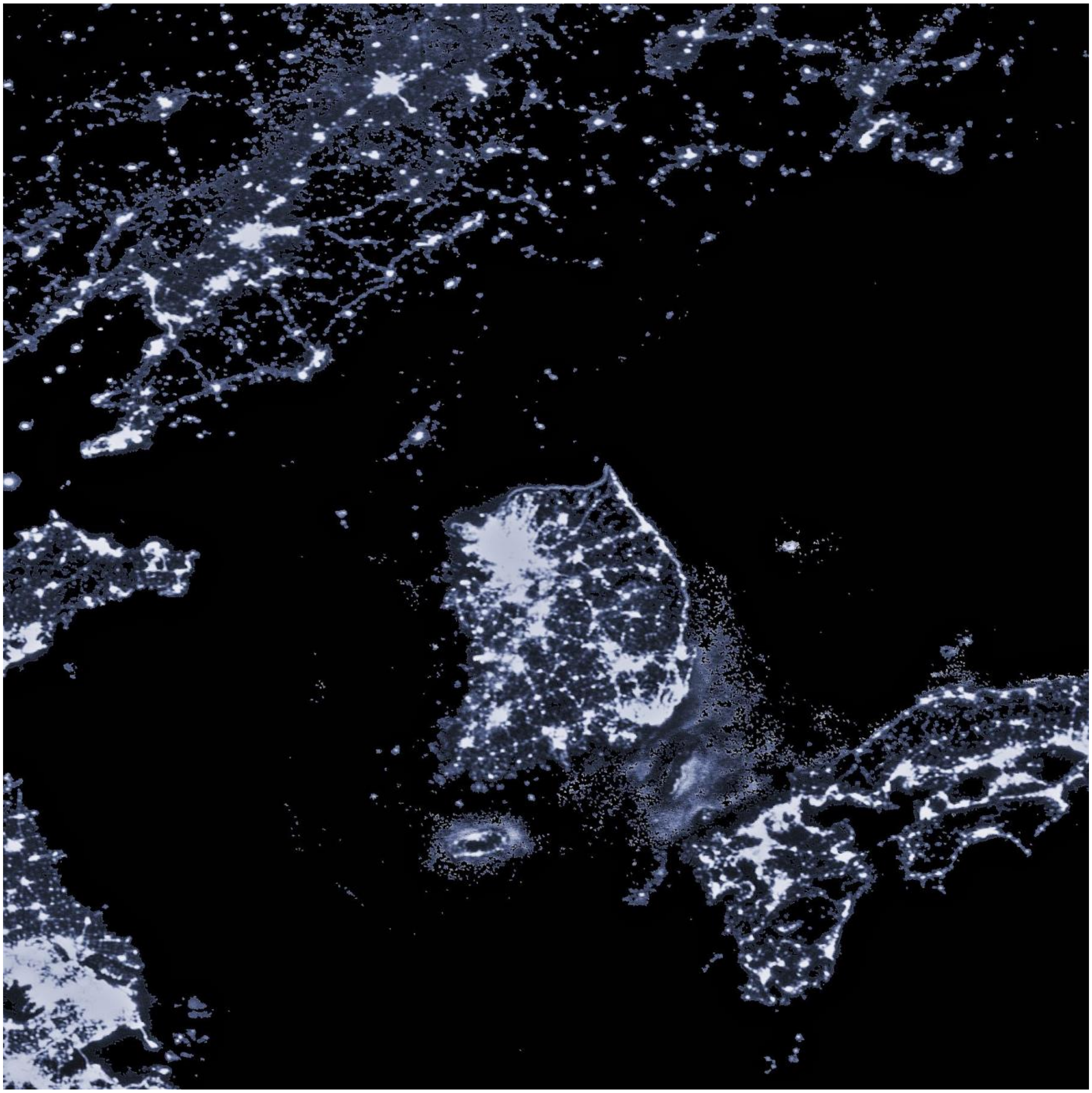
[297] These images should not, however, be used to infer specific changes in the DPRK between years, in part because the 2016 image was taken using a different satellite than the other images and may have been processed differently as well. The time of year during which the photo was taken may have an impact as well. In addition, when looking at "night lights" images of the DPRK in general, it is important to bear in mind that in some areas DPRK authorities have worked to limit the visibility of night-time lighting for security purposes, so the absence of light does not necessarily correlate directly with the absence of electricity supplies.

Figure 3-1: Korean Peninsula and Surrounding Area from Space, 2000[298]



[298] Generated from U.S. National Oceanographic and Atmospheric Administration (NOAA, 2012) National Geophysical Data Center website "DMSP-OLS Nighttime Lights Global Composites (Version 4)", using "stable lights average" image series. The image presented here has been enhanced by Nautilus from the originally downloaded image by a process of adjusting brightness, sharpening, and "colorizing" the overall image.

Figure 3-2: Korean Peninsula and Surrounding Area from Space, 2010[299]



[299] Generated from the same NOAA (2012) set of images referenced in the previous footnote, but with a "stable lights average" image for the year 2010 instead of the year 2000. Although it may be tempting to do so, readers are cautioned not to draw firm conclusions about changes in electricity use in the DPRK in the decade of the 2000s by comparing these two images. Although we have used the same procedure for enhancing both images, the original NOAA images have not yet been calibrated to assure that the same points of light yield the same intensity in images from different years (NOAA staff, personal communication, February 2012). Even with this consideration, however, it is clear that the growth between 2000 and 2010 in electricity use (as indicated by the extent of city lights) in China, and to a somewhat lesser extent in the ROK, has not been shared by the DPRK.

Figure 3-3: Korean Peninsula and Surrounding Area from Space, 2016[300]

[300] Extracted from global NASA image available as https://svs.gsfc.nasa.gov/vis/a030000/a030800/a030876/BlackMarble_2016_global_7km.png.

3.3. Summary of Key Changes in the DPRK Energy Sector between 2000 and 2005

The period between 2000 and 2005 was one in which the DPRK government put in place elements of economic change, including policies encouraging some forms of private markets and private production, at least on a small scale, and some price and wage reforms. For the energy sector, the government encouraged the development of small and medium-sized local power plants, particularly hydroelectric plants. Though most changes to the energy system in the DPRK seemed to be incremental, as in 1996 to 2000, most observers noted at least a modest improvement in the availability of energy services between 2000 and 2005, though these improvements are by no means uniformly distributed over the country. Individual changes are discussed in section 3.7, below. Among the key changes (or continuing processes) for the energy sector between 2000 and 2005 were:

- Some **economic revival**, but mostly, it seems, associated with foreign aid (especially from the ROK) and/or with areas of the economy that are not energy intensive (the developing of a flourishing restaurant trade in Pyongyang is an example of the latter that has been notable to visitors). Small markets in which individuals sell food and household items have become more numerous and visible. Gauging the overall economy, the (ROK) Bank of Korea reported a net gain in GDP in the DPRK of about 8 percent from 2000 through 2004, though the methods used for making this estimate were not transparent.[301] Chinese estimates also showed growth in the DPRK economy during the period, but slightly lower than that estimated by the Bank of Korea. Chinese estimates reported 0.5 to 1 percent per year GDP growth from 2000 through 2004, with 2 percent growth in 2005.
- The **substantial breakdown of the country's central distribution system**, accompanied, according to anecdotal reports, with changes in employment and pricing of basic foodstuffs such that workers were often obliged to have jobs, at least nominally, in both the official (that is, in state-run factories or other government workplaces) and the private sectors to survive.
- Significantly expanded **exports of coal and other raw mineral products** (largely iron and steel scrap and metals ores) to China, with reported coal exports to China reaching 2.8 million tonnes in 2005.[302] This is one manifestation of a recent increase in investment in the DPRK by Chinese businesses, particularly in the raw materials sectors, but also, to some degree, in manufacturing.[303] In general, DPRK imports from China showed a trend of

[301] William B. Brown, "Energy and Economy in North Korea", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/; see also William B. Brown (2006), *Changes in the North Korean Economy and Implications for the Energy Sector: Is North Korea Really Short of Energy?*, available as https://nautilus.org/napsnet/napsnet-special-reports/changes-in-the-north-korean-economy-and-implications-for-the-energy-sector-is-north-korea-really-short-of-energy/.

[302] N. Aden, "North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Dr. Aden's paper is available as http://nautilus.org/wp-content/uploads/2012/01/0679Aden1.pdf.

[303] Issues related to Chinese investment in the DPRK, and changes in DPRK policies that have made investment possible, are addressed in the Nautilus Institute Policy Forum Online 06-70A, August 23rd, 2006, *DPRK's Reform and Sino-DPRK Economic Cooperation*, by Li Dunqiu (https://nautilus.org/napsnet/napsnet-policy-forum/dprks-reform-and-sino-dprk-economic-cooperation/). See also Professor Li's presentation as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.

becoming more energy-intensive, and exports to China showed a trend of becoming more labor-intensive.

- Continued overcutting and ecological **degradation of biomass fuel supply** with reduction in fuel availability and related erosion, as coal remained hard to obtain, and wood and other forms of biomass continued to be heavily used for cooking and heating, especially in rural areas.

- For agriculture, there was some **land re-zoning to larger plots** to encourage more efficient production, and **new natural-flow irrigation waterways** have been constructed to replace some of the need for electric irrigation pumps. Some new wind-powered water pumps, probably for local drinking water, have been introduced in the Western DPRK. Mechanization in agriculture remained low, however.

- In the transport sector, the DPRK **imported thousands of automobiles and trucks, and tens of thousands of bicycles**, from China in the years 2000 through 2005.

- **Cessation of KEDO heavy fuel oil** deliveries in 2002.

- **Continued problems with production in the coal sector**, including with electricity supply to provide basic needs such as air supply, lighting, and pumping of water out of mines. There was some localized investment in coal mines by Chinese firms.

- **Discussions and agreements by the DPRK regarding oil and gas exploration**, including with the Chinese government, the Russian Gazprom, and at least one Western company.

- Supply of modest amounts, by the end of 2005, of **electricity to the Kaesong** industrial area from the ROK.

- **Electricity imports from China** (also modest in scale).

- Construction of **smaller, mostly hydroelectric power plants** (many of which, particularly those of sub-megawatt capacity, were possibly not connected to the main grid).

3.4. Summary of Key Changes in the DPRK Energy Sector from 2005 through 2009

The years 2006 through 2009 included some periods of marginally improved relations between the DPRK and the international community, as exemplified by agreements at the Six-Party Talks, but the period ended with relations between the Koreas and between the DPRK and the international community on a downward trajectory. Six-Party Talks agreements in February and October of 2007, a meeting between the leaders of the DPRK and the ROK, also in October of 2007, and the transfer of heavy fuel oil and materials and equipment to help rebuild energy infrastructure to the DPRK as a part of the Six-Party Talks agreements were highlights of the period. By the end of 2009, however, the Six-Party Talks were all but abandoned, the DPRK had conducted a second test of a nuclear explosive device, and had test-launched a rocket, bearing what it said was a communications satellite, on a trajectory over Japan,[304] and prospects

[304] See, for example, Arms Control Association (2011) "Chronology of U.S.-North Korean Nuclear and Missile Diplomacy", available as http://www.armscontrol.org/factsheets/dprkchron.

for additional near-term energy sector assistance from the international community looked bleak. Insofar as we can determine, changes in the DPRK energy sector through 2009 were modest, at best, with overall energy supply and demand conditions for the country changing relatively little over the period. A few of the notable occurrences and trends affecting the energy sector and broader economy in the DPRK from 2005 through 2009 include the following:

- Reduced **production of cereals** from 2005 through 2007, followed by a better crop in 2008, with another, but more modest, decline in production in 2009.[305]
- **Deliveries of heavy fuel oil** to the DPRK in 2007 and 2008 as part of the Six-Party Talks agreements reached during the period, with deliveries ceasing in late 2008 due to disagreements between the Parties.
- Continued increases, in most years, in exports of **minerals and coal to China**.
- Continued, relatively stable **exports to the DPRK from China of crude oil and oil products**, with some additional oil products sourced from other nations. In general, however, supplies of oil products are sufficiently constrained that relatively modest year-to-year differences in supply can have magnified impacts on some categories of transportation fuel use (as we estimate to have occurred in 2009—see below).
- Additional **flooding** in many years of the period (particularly 2007) and more recently, including severe flooding in the Northern part of the DPRK and other areas in 2010 and 2011 (see Figure 3-2).
- Continued efforts to construct new **hydroelectric facilities**, focusing, it appears, on medium-sized facilities (in the range of tens to a hundred or so megawatts of capacity in each of several installations), but with continued stated commitment to developing smaller hydroelectric plants (though with unknown total impact).
- Continued **slow degradation of electricity sector infrastructure**, particularly electricity transmission and distribution infrastructure.
- **Increased electricity imports from the Republic of Korea** for use in the joint ROK/DPRK Kaesong industrial area located just north of the border between the two nations.
- In recent years, **greatly expanded use of mobile phones in the DPRK**, with a network in at least the Pyongyang area developed by the Egyptian company Orascom. This change probably had relatively little impact on overall energy use in the DPRK (though one could surmise that Orascom was probably obliged to install diesel generators to provide back-up electricity supplies for its network) but may be a harbinger of substantial change in the way information flows in the DPRK.[306]

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[305] See, for example, FAO/GIEWS Global Watch (2008), "Severe Food Shortage in the Democratic People's Republic of Korea", dated 25 March 2008, and available as http://www.fao.org/3/AX998E/AX998E.pdf; and FAO/GIEWS (2010) *Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea*, dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.htm.

[306] See, for example, Alexandre Y. Mansourov. *North Korea on the Cusp of Digital Transformation*, Nautilus Institute NAPSnet Special Report, dated November 1, 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK_Digital_Transformation.pdf; and Peter Hayes, Scott Bruce and Dyana Mardon, NAPSnet Policy Forum 11-38: "North Korea's Digital Transformation: Implications for North Korea Policy", dated November 8, 2011, and

Figure 3-4: Flooding in Wonsan, DPRK in 2011[307]

3.5. Summary of Key Changes in the DPRK Energy Sector from 2010 through 2019

During the decade from 2010 to 2019, despite continued on-and-off negotiations resulting in little net change in relations between the DPRK with the international community, as well as a major leadership change as Kim Jong Il was succeeded, after his death, by his son and now DPRK Chairman, Kim Jong Un, a number of years, particularly in the middle of the decade, showed growth in the DPRK economy and modernization in some sectors and some geographic areas, most notably around Pyongyang. Continued missile (many since early 2016) and nuclear testing (four between 2013 and 2017[308]) by the DPRK kept the attention of the international community, but although the decade ended with a series of three meetings between United States President Donald Trump and Chairman Kim, breakthroughs in engagement were not forthcoming. Some of the key general attributes of the 2010s through about 2016 (see section 3.7 for additional details) included:

- Rapidly increasing (through 2016) exports of coal to China, with over 22 million tonnes of exports reported in 2016. A significant portion of these exports reportedly came from mines where investment by Chinese companies in joint venture arrangements with DPRK

available as http://nautilus.org/napsnet/napsnet-policy-forum/north-koreas-digital-transformation-implications-for-north-korea-policy/.

307 Photo originally labeled "File Photo: AP", from M. Weingartner (2011), "CIA Assesses Flooding in DPRK", *CanKor*, dated 3 April 2011, available as http://vtncankor.wordpress.com/2011/04/03/cia-assesses-flooding-in-dprk/.

308 See, for example, Nuclear Threat Initiative (2020), "North Korea: Overview", last updated October 2020, and available as https://www.nti.org/learn/countries/north-korea/.

organizations had modernized and expanded production. These coal exports generated over a billion dollars' worth of revenue annually for the DPRK in 2011 through 2016, despite rapidly declining coal prices after 2014.[309]

- Increasing imports, almost exclusively from China, of a range of goods in the transport sector, including cars, trucks, and motorcycles, at least through 2016, and to a lesser extent, 2017.
- Increasing imports of some small appliances, most notably TVs and DVD players.
- A rapid rise in the use of cellular phones in the DPRK.
- In the middle years of the decade, a rapid increase in the imports of electric scooters and/or bicycles, in quantities on the order of a hundred thousand in some years, indicating investments in personal mobility by households.
- Increasing imports of diesel and gasoline-powered generators.
- Increasing imports of solar photovoltaic panels and batteries for use with PV systems, which were put into wide use by households and small businesses to provide nighttime lighting and power/charging for small devices.
- Increasing activity in markets not covered by the central distribution system.
- Substantial growth in the DPRK textile finishing industry, where garment parts fabricated in China were imported, finished by DPRK workers, and exported again to China. In some years, this trade was between $500 and $800 million in exports from the DPRK, although factoring in the cost of the garment parts, DPRK net revenues were closer to $100 to 150 million annually.
- Significant reported remittances to the DPRK from DPRK citizens, and sometimes officials, working in various capacities abroad, from ranging from manual labor gangs in the Russian Far East providing construction and timber harvesting labor to operating Korean restaurants in South Asia.
- Modification of the Pongwha Chemical Company to produce more light products, particularly gasoline, from each barrel of crude oil imported from China.
- Completion of several medium-sized (megawatts- to tens-of-megawatts scale) hydroelectric power generation facilities, although some plants subsequently had operational problems related, apparently, to rushed construction and/or materials (such as concrete) of inadequate quality.
- Many construction projects, mainly but not exclusively within Pyongyang, have been noted by visitors, along with at least anecdotal reports of increased vehicle traffic.

Starting in 2016 and continuing through 2017, United Nations Security Council sanctions on the DPRK came into effect, with several impacts and results (both intended and unintended) on the DPRK economy from at least 2017, and ongoing as of this writing (late 2020):

[309] Based on UN Comtrade statistics, the DPRK received an average of over $100 dollars per tonne for its coal exports to China during 2011 and 2012, but prices began to fall thereafter, to just over $50 per tonne by 2016, before climbing to over $80 per tonne in 2017, which export volumes (at least as reported) were constrained by UNSC sanctions.

- Official oil products imports from Russia and (especially) China, declined markedly, although a number of authors, including the UNSC "Panel of Experts" tasked with monitoring sanctions on the DPRK, reported the rise of a shadowy network of maritime traders and substantial "off-books" trades (smuggled oil), primarily from China and Russia.
- Similarly, official coal exports from the DPRK declined substantially after 2016, because of UNSC sanctions, but the decline was reportedly at least partially made up for by off-books coal trades, again mostly through means such as ships discharging their cargoes at places other than their stated destinations, ships turning off their transponders during voyages, and pairs of ships transferring coal cargoes in the open ocean.
- Official statistics show a marked reduction in all kinds of trade from China to the DPRK in 2017 and 2018, going beyond oil products, coal, and metals, all of which are included in UNSC sanctions, to vehicles, appliances, and other commodities. It is unclear to what extent these reductions are actual reductions in trade volume, or whether some trading has shifted "off-books".
- Crude oil imports to the DPRK from China, via a pipeline across the Yalu River from the Chinese city of Dandong to the DPRK's refinery in Sinuiju (the Ponghwa Chemical Factory) appears to have been steady since 2016, and possibly slightly increased.
- DPRK labor abroad seems to have been reduced, in large part due to UNSC sanctions.
- Construction, at least in the Pyongyang area, as well as in some other areas (for example, the completion of a tourist area on the coast near Wonsan) seems to have continued, at least through early 2020.
- Some continued construction of hydroelectric power plants has been announced, albeit generally with few details around timing or capacity.

3.6. The Impact of COVID-19 on the DPRK Energy Sector in 2020

Officially, the DPRK has reported no cases of coronavirus during the current global pandemic, with the exception of one individual with a suspected case who allegedly crossed the border from the ROK.[310] [311] This report, however, appears at odds with DPRK requests for corona-virus related supplies from Medecins Sans Frontieres, UNICEF, the WHO, and others, as well as reported quarantines of foreigners and DPRK citizens, and the use of facemasks in the DPRK by most residents pictured in recent photos (with the exception of Chairman Kim Jong Un). Reports by observers outside the DPRK, including those receiving intelligence briefings, include descriptions of hundreds of covid-19 deaths among soldiers, a one-month military "lockdown",

[310] South China Morning Post (Agence France-Presse), 2020, "North Korea insists it has no coronavirus cases, thanks to shutting borders, containment", dated 3 April, 2020, available as https://www.scmp.com/news/asia/east-asia/article/3078226/north-korea-insists-it-has-no-coronavirus-cases-thanks-shutting. Later articles report that despite testing programs, the DPRK is still reporting no active COVID-19 cases. See, for example, United Press International (UPI, 2020), "WHO: North Korea says all COVID-19 test results 'negative'", *UPI*, dated October 1, 2020, and available as https://www.upi.com/Top_News/World-News/2020/10/01/WHO-North-Korea-says-all-COVID-19-test-results-negative/8711601558666/.
[311] Gabriela Bernal (2020), "North Korea Steps up Its War on COVID-19: As North Korea doubles down on COVID-19 containment measures, local sources report several outbreaks.", *The Diplomate*, dated August 06, 2020, and available as https://thediplomat.com/2020/08/north-korea-steps-up-its-war-on-covid-19/.

quarantines of thousands within and outside of the military, and other evidence of significant changes in life in the DPRK in 2020.

Whatever the actual covid-19 situation is in the DPRK, it is clear that the DPRK's response to the pandemic has changed the way that the country operates its economy, including its energy sector. Worldwide, national and local "lock-downs" and "stay-at-home" orders have resulted in vast reductions in energy demand, particularly for transportation, in part causing, among other impacts, a vast drop in oil prices, and rapidly filling oil and gas storage depots. The DPRK's energy supply situation is unlike that of other countries, particularly for oil products, due to UNSC sanctions and resulting restrictions on its oil imports. This requires the DPRK to use "unofficial" means to obtain oil supplies and export coal, strategies that are likely more difficult to carry out during the pandemic, due to the need for cooperation by outside trading partners.

The coronavirus pandemic has thus undoubtedly affected DPRK energy supply and demand. Probably the effect has been significant, as it has in other nations, but since the DPRK provides no energy statistics, and what international energy statistics there are for trade with the DPRK are unlikely to be available for 2020 for some months (and will likely show little trade anyway, due to UNSC sanctions), determining the net impact of the pandemic is a matter for analysis and estimation. Because of the lack of information coming out of the DPRK, and because some of the year 2020 lies ahead as of this writing, the estimates of DPRK energy supply and demand for 2020 presented below in the context of our overall results through 2020 are necessarily guided by a set of assumptions how the covid-19 situation is changing the DPRK economy. Below we present, first, our assumptions, based on reports, about how the DPRK is responding to the coronavirus pandemic, and second, a candidate "scenario" for how the pandemic has affected the DPRK economy in 2020, and how those impacts will have played out over the course of the year.

3.6.1. Assumed DPRK Responses to Coronavirus Pandemic

As noted above, official reports of the coronavirus situation in the DPRK are few and somewhat contradictory. Reports by those outside the DPRK, anecdotal and otherwise, therefore form the information base on which our analysis of energy supply and demand in the DPRK in 2020 must be built. Some of the reported changes in the DPRK that have (or would reasonably be expected to have) affected energy supply and demand in the DPRK include:

- Quarantines of thousands of individuals, including a recent (April 28) report that the DPRK has extended its "COVID-19 National Emergency" through the end of the year, including a strengthening of quarantine procedures.[312]
- A one-month military "lockdown" in February and March.
- Curtailing of border crossing and travel between the DPRK and China, apparently since January 26, 2020.[313] More recent news reports suggest that these restrictions will continue for some months.[314]

[312] Hyemin Son, Leejin Jun, and Eugene Whong (2020), "North Korea Extends COVID-19 National Emergency to End of Year", *Radio Free Asia*, dated 2020-04-28, and available as https://www.rfa.org/english/news/korea/national-emergency-04282020184222.html?utm_source=AM+Nukes+Roundup&utm_campaign=ba43f31c3a-EMAIL_CAMPAIGN_2018_07_25_12_19_COPY_01&utm_medium=email&utm_term=0_547ee518ec-ba43f31c3a-391728633.

- "[W]idespread stories of inflation and the hoarding of critical goods. Many schools have been closed [apparently, from at least February 20 through April 15, based on *Asia Times* reporting], social gatherings have been limited, and much tourism is suspended."[315]
- Announcement of construction of a new, modern hospital in Pyongyang.
- Shutdown of most air, rail, road, and ship travel into and out of the country
- A "huge economic loss" reported by DPRK state media.[316]
- An increase in the "price of gas", presumably gasoline.
- Issues with industrial output due to lack of inputs and spare parts from China, affecting the mining sector as well.[317]
- A crackdown on cross-border smuggling.[318]
- A demonstrable idling of the DPRK's maritime fleet, including many of the ships that have been implicated in unofficial trade in coal and oil products, starting with a recall of ships on January 22.[319] The *New York Times* summary of the situation as of late March concluded "The long-term disruptions to North Korea's revenue stream remain unclear, partly because the duration of the pandemic and its impact on maritime commerce are not yet known. But analysts said it was reasonable to assume damage has been done to North Korean agriculture, industry and the overall economy."

3.6.2. A Scenario for Drivers of 2020 Energy Supply and Demand in the DPRK

With the above as inputs, we posit the following scenario for DPRK energy supply and demand for the year 2020. We use this scenario to estimate an energy supply-demand balance for the DPRK for 2020, with the starting point our supply-demand analyses for 2018 and 2019. The scenario has the following elements:

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[313] Gabriela Bernal (2020), "North Korea's silent struggle against Covid-19: Sources inside report via smuggled cellphones that official and unofficial measures have been surprisingly effective", *Asia Times*, dated March 31, 2020, available as https://asiatimes.com/2020/03/north-koreas-silent-struggle-against-covid-19/.

[314] *Radio Free Asia* (2020), ibid.

[315] Mitchell Lerner (2020), "History Shows North Korea Will Respond to the Coronavirus by Lashing Out: Will the pattern repeat?", *National Interest*, April 1, 2020, available as https://nationalinterest.org/blog/korea-watch/history-shows-north-korea-will-respond-coronavirus-lashing-out-139732.

[316] Chad O'Carroll (2020), "COVID-19 in North Korea: an overview of the current situation: Pyongyang officially claims no infections within its territory, and has taken strict steps to stave off an outbreak", dated March 26, 2020, available as https://www.nknews.org/pro/covid-19-in-north-korea-an-overview-of-the-current-situation/?t=1585236870435.

[317] Benjamin Katzeff Silberstein (2020), "The North Korean Economy: Coronavirus Measures Causing Economic Anxiety", *38 North*, dated March 27, 2020, available as https://www.38north.org/2020/03/bkatzeffsilberstein032720/.

[318] See, for example, Bernal (2020), ibid, and NKPro (2020), "Coronavirus in North Korea: COVID-19 Tracker", updated September 9, 2020, and available as https://www.nknews.org/pro/coronavirus-in-north-korea-tracker/facts/.

[319] See Christoph Koettl (2020), "Coronavirus Is Idling North Korean Ships, Achieving what Sanctions Did Not", *New York Times*, dated March 26, 2020, available as https://www.nytimes.com/2020/03/26/video/coronavirus-north-korea.html, which also quotes Royal United Service Institute (RUSI) Project Sandstone (2020), "Rickety Anchor: North Korea Calls its Illicit Shipping Fleet Home amid Coronavirus Fears", dated 26 March 2020, and available as https://rusi.org/commentary/rickety-anchor-north-korea-calls-its-illicit-shipping-fleet-home-amid-coronavirus-fears.

1. The DPRK government will continue coronavirus protection measures, including social isolation strategies and interruption of most trade, through **December 2020**, and would thus be in place for nearly the entire year. This is consistent with the most recent reports above. It is possible that measures could have been relaxed partially in some sectors or for some geographical areas. There might, for example, have been of necessity a relaxation of movement (if not border) restrictions at harvest (particularly rice harvest) time, in order to get more hands into the field, but restrictions might have re-started after harvest, particularly if more infections were found (if not reported internationally). At any rate, we would argue that even if relaxation of isolation measures starts (or started) in late 2020, there would be a period of perhaps two months during which the economy transitions to activities at close to 2018/2019 levels, and as a result annual average energy supply and demand wouldn't be much different than if the isolation strategies were in place for the entire year (our baseline assumption).
2. An assumption that the isolation of the DPRK, in terms of closed border crossings, minimal or no cross-border plane, train, or road traffic, and idled maritime fleet, will follow the timing above, with a resulting decrease in international transportation, and a related decrease in transportation within the country. Some flow of goods from China has (and will have) continued to cross the borders, albeit with restrictive inspection and quarantine procedures, but the flow of goods will have been much slower than normal. We assume that increased military vigilance along the border has resulted in reduced successful smuggling of goods, although the economic incentive for (and thus possibly attempts at) smuggling will likely have increased.
3. The military "lockdown" is assumed to have been slowly lifted starting in June of 2020, in part due to a need to underscore an appearance of readiness, but even with some limited military exercises and maneuvers taking place, military activities will not have reached 2018/2019 levels by the end of the year, as military barracks are likely a significant breeding ground for the virus, and authorities will have been sensitive to curtailing outbreaks. Military manufacturing is assumed to have continued on a limited basis to provide spare parts for key equipment.
4. Industrial energy demand will have fallen and remained much lower than recent levels through the duration of the protection measures in 2020, both because of lack of fuel and of imports of spare parts from China, as well as lack of markets abroad (mostly China). The lack of fuel for diesel generators will have also played a role in reduced industrial energy use. Some industries, including, for example, food products, may have continued at near-normal levels of output, particularly if they use mostly domestic fuels, but many other industries will show significantly diminished output, particularly those, such as garment manufacture, relying on inputs from China.
5. Residential access to oil products will decline somewhat, although oil use by the sector is not large to begin with. Residential electricity use will likely increase modestly, as generation is mostly based on domestic resources (coal, hydro, and solar), and more electricity may be made available to residences if industries and other big users are not operating as normal. If sufficient coal was available, it is possible that residential coal use for heating will rise somewhat due to residents staying at home more, but it is likely that most residential heating use is supply-limited anyway.

6. Agricultural inputs (fertilizer and diesel oil, in particular) will have been in short supply, thanks to border restrictions (and UNSC sanctions), probably adversely affecting the 2020 harvest, and certainly decreasing fuel use, although the fertilizer industry is likely to have kept going with domestic energy inputs to the extent that it could. It is likely that military units will have been heavily mobilized to help with harvests in the fall, although perhaps less participation of labor from urban dwellers will occur during harvests than in some past years as authorities seek to avoid allowing disease transmission corridors between urban (probably particularly Pyongyang) and rural areas, and vice versa, as much as possible.
7. Fishing diesel use will also likely have declined, though one would expect fishing activity to be less affected than other sectors because it is likely to be less affected by quarantines and provides a vital protein source for North Koreans. It is, however, likely affected by diesel fuel supplies, which may have been reduced due to UNSC sanctions (despite off-books trade).
8. Public, commercial, and institutional energy demand for all fuels will have fallen significantly for the duration of the DPRK's main covid-19 measures, as shops and restaurants, as well as schools, and other public buildings are closed or operate on restricted hours. Activities at informal markets will have fallen due to both movement restrictions and restrictions on volumes of incoming goods from China.
9. There will have been little or no increase in the stock of energy-using or generation equipment during 2020, including, for example, vehicles, diesel generators, solar panels, or new industrial equipment, due to border restrictions.
10. The idling of the maritime fleet and limited road and rail traffic will have resulted in a virtual cessation of DPRK oil imports and coal exports, although some off-books trades in particular will likely have continued.
11. Coal mining will likely have continued as an essential industry, although total volumes will have decreased because of lack of coal export channels (due to border restrictions and UNSC sanctions). As much of DPRK coal extraction involves underground mining, it seems possible that mining could be significantly affected by an outbreak of covid-19 among miners, who work in enclosed spaces with recycled air (and often inadequate safety equipment).
12. The major exception to the above is crude oil imports via pipeline from China, which are assumed to have continued at recent rates, and as a result oil refining, at least at the refinery at Sinuiju, will also continue its operations at recent rates—that is, to the extent that the crude oil volumes supplied by China allowed.
13. We assume that the DPRK economy will be able to "ramp-up" to 2018/2019 levels fairly quickly once covid-19 restrictions are lifted. We assume this because of the level of social control in the society, the large influence of state enterprises, and the survival incentives that the population will face after months of isolation, which will provide a powerful push for those still able in body to work to restart, in particular, the informal economy. In addition, we assume that the DPRK's trading partners in (mostly) China will be able and willing to re-engage on cross-border trade when the opportunity presents itself. These assumptions, however, will be off the table if, as is entirely possible (and

has been the sad experience of many other countries worldwide), the lifting of restrictions results in rapid re-infection of a population that is already challenged by underlying heath issues (including, for example, malnutrition, tuberculosis, and the respiratory effects of indoor and local air pollution), and may have limited “herd immunity” due to being largely isolated from people in other nations. The implications of the potential impacts of secondary and tertiary infections of covid-19 on the DPRK will be a topic for investigation in follow-on work, but could include, for example, renewed and even more stringent restrictions on movement and commerce within the DPRK, and strict border controls applied by the DPRK’s major trading partners, China and Russia, as well as the international community.

14. We assume that ultimately the major impact on health of the covid-19 pandemic in the DPRK is likely to be not so much the number of people killed or sickened by the virus, which we assume will have been limited by the state-enforced isolation and other measures, but malnutrition due to limited food imports, limited agricultural inputs, and loss of jobs in the informal sector. It is even possible, perhaps likely, that the national lockdown actually will have reduced the incidence of diseases such as flu and tuberculosis, as well as the health impacts of outdoor air pollution as some factories, many of which are located within or close to cities, were shut down or reduced their operations.

3.7. Key Input Parameters, Sources, Assumptions and Methods Used in Estimating Energy Supply-Demand Balances for 2000, 2005, 2008 through 2010, and 2014 through 2020

Key parameters, sources, assumptions, and methods drawn upon in preparing the estimated DPRK energy supply-demand balances for selected years from 2000 through 2020 are discussed below for key energy demand sectors, fuel supply resources, and energy transformation processes. The specific parameters used, a printout of the intermediate and final results of the calculations in which they were used, and additional notes and references to data sources can be found in Attachment 1 to this Report.

3.7.1. Industrial sector activity

In the industrial sector, we assumed that year 2000 industrial output was 18 percent of 1990 levels in all subsectors except cement (30 percent), and fertilizers (7.5 percent).[320] The building

[320] WWW.koreascope.com, in "Production of Major Industrial Items and World Ranking" (visited 6/3/02), listed the ROK production of steel in 1999 as 41 million tonnes. In "Economic and Social Comparison between the Two Koreas", on the same WWW site, the ROK's steel production was listed as being 33 times that of the DPRK, implying an annual production of about 1.24 million tonnes. This figure, about 25 percent of 1990 production levels, seems plausible (though possibly high). A figure that is probably from the same ultimate source, the Korea Iron & Steel Association, suggests a value of 1.086 million tonnes in 2000, along with 1.208 million tonnes in 1996, and 1.168 million tonnes in 2005. It is unclear how these figures were derived. Based on consideration of existing estimates, observations of the overall DPRK economy, we adopt the estimate of 1.08 million tonnes in 2000. The www.koreascope.com source (which is no longer available), in the "Economic and Social…" page, listed a DPRK cement production of 4.1 million tonnes, or about 41 percent of year 1990 production, in 1999, which seems plausible. Data that are probably from the same ultimate source, the Korean National Statistical Office and the Korea Cement Industrial Association, suggest that year 2000 cement output was 4.6 million tonnes, and output in 1996 was 3.79 million tonnes. It is unclear how these numbers were derived, and though one would expect the cement industry to decline somewhat less than other industries, as it is/was not largely an export industry, the observed lack of recent construction activity in the DPRK would suggest

materials and "other minerals" sectors were assumed to have the same relative output as the cement sector.[321] We assumed, based on reports (and our own observations) of eroding industrial facilities, plus the probable impact of poor coal, oil, and electricity on industrial machinery, that the average energy intensity of industrial production was 115 percent of 1990 levels, up from our assumed 110 percent of 1990 levels in 1996. For 2005, we assumed that iron and steel production in the DPRK continued to decline (to 0.87 million tonnes, or 14.5 percent of its 1990 level), cement production increased slightly (with the overall increase in economic activity) to 32 percent of 1990 levels, fertilizer output increased slightly from 2000 (to 11 percent of 1990 levels).[322] Activity in 2005 in the building materials, pulp and paper, and other chemicals subsectors are assumed to be only modestly changed from 2000 levels, with textiles output up slightly, but output is assumed to have increased substantially in the other metals and other minerals sectors,[323] due in part to output destined for export to China. As a result of closing of some inefficient plants, improved capacity factors in some industries, and some investment in industrial infrastructure, particularly by Chinese firms,[324] the overall average energy efficiency of DPRK industrial plants is assumed to have increased slightly between 2000 and 2005, with energy intensities averaging 112 percent of 1990 levels. For 2008 we assumed that iron and steel production remained at 2005 levels, though more of the iron and steel produced was probably exported, but that output rose to the 1.2-1.3 million tonnes per year level (about 20 percent of 1990 levels) through 2014, varied between 1.1 and 1.2 million tonnes annually between 2015 and 2017, then falling somewhat in 2018 and 2019 to 17 percent of 1990

that the level of 1996 to 2000 increase that the latter source shows is not what one would expect. We assume cement output of 3.3 million tonnes in 2000, and

WWW.nis.go.kr/english/democratic/industry07.html, dated 2001, by the ROK National Intelligence Service, suggests that current supplies of fertilizer cover only 40 percent of fertilizer needs in the DPRK. *Causes and Lessons of the "North Korean Food Crisis*", by Tony Boys of Ibaraki Christian University Junior College (2000), lists total fertilizer supply in the DPRK in 1999 of 200 ktonnes of "NPK", of which 32% was produced domestically, 10% imported, and the remainder provided in aid. This would imply that about 11% of 1990 levels of fertilizer production were achieved in 1999. As an alternative source, the presentation "Agriculture and Fertilizer Situation in DPR Korea", by R.V. Misra, previously available as http://www.fertilizer.org/ifa/publicat/PDF/2006_crossroads_misra_slides.pdf (from the International Fertilizer Industry Association), presented as part of the "IFA Crossroads ASIA-PACIFIC 2006 Conference 'Growing markets, nurturing success'", Chiangmai, Thailand, 13-16 November 2006, suggests that 1999 production of fertilizer in the DPRK was 63 thousand tonnes (of nitrogen), which is roughly consistent with the level suggested in the article by Tony Boys that is quoted above. Assuming this figure is correct, we adopt Misra's 2000 fertilizer production figure of 37.5 thousand tonnes of nitrogen.

[321] With the exception of "Other Minerals" and "Building Materials", we assume that the level of activity in other industries relative to 1990 in the year 2000 is approximately the same as in the iron and steel sector. The building materials and other minerals subsectors are assumed to have activities relative to 1990 similar to the cement industry. The other minerals subsector includes magnesite (or, when processed like lime for cement, magnesia), which is a valuable export product. An industry source indicates that an 8000 tonne shipment of magnesia (although it may have been magnesite) arrived in Europe in early 2001. Japan imported $3.5 million worth of magnesia in the first half of 2000 (Korea Trade-Investment Promotion Agency data from http://www.kotra.or.kr/main/common_bbs, visited 6/3/02, "Trade Tendencies of the Major Countries"), which, if annualized and assuming a sales price of $US 100 to $200 per tonne (within the range suggested in Queensland Department of Minerals and Energy *Mineral Information Leaflet No 5: MAGNESITE*, dated January 1998, suggests exports of 35 to 70 thousand tonnes to Japan alone, which in turn suggests relatively active production of the mineral. On our trip to the DPRK in October of 2000 we saw working brick or tile production facilities, some of the very few active industrial facilities we saw during our time in the DPRK.

[322] Based on data in 2006 presentation by R.V. Misra—see reference above.

[323] Estimates for these sectors based in part on data provided by Dr. Chung Woo-jin, in his presentation entitled "Mineral Resources in DPRK", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/. Additional details of how Dr. Chung's data were interpreted for this analysis are available in Attachment 1 to this Report.

[324] See, for example, Professor Li Dunqiu's presentation entitled "DPRK's Reform & Sino-DPRK Economic Cooperation", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.

levels.[325] In 2020, we assume iron and steel output will have been about 14.5 percent of 1990 output, or about 0.9 million tonnes, as a result of border closings limited trade and of industrial plant closings related to COVID-19. Cement production is estimated to have risen to 40 percent of 1990 levels in 2008 and further to 56 percent in 2009 and 61 percent of 1990 levels in 2015 before falling to 58 percent (6.4 million tonnes) in 2018 and 2019, and 46 percent in 2020.[326] By way of comparison, reported DPRK cement imports (mostly from China) in 2010 through 2018 have averaged about 180,000 tonnes per year, or only a few percent of estimated domestic production. the but was assumed to fall slightly in 2009, possibly due to decreased electricity availability. Based on estimates from the UN Food and Agriculture Organization and World Food Program, fertilizer output was assumed to fall to 10.9 and 7.2 percent of 1990 levels in 2008 and 2009, respectively, before rising to the 21-24 percent of 1990 levels range in 2014-2016, then falling again to 16 percent of 1990 levels in 2017, 9 percent in 2018 and 2019, and 4.5 percent, as a result of COVID-19 restrictions on manufacturing, in 2020.[327] Activities in the Other Metals and Non-Metallic Minerals subsectors were assumed, again based on increasing exports to China, to be somewhat higher in 2008 and 2009 than in 2005, before falling gradually through 2019, with output further reduced in 2020 (to 35 and 37 percent of 1990 levels, respectively) due to the impacts of COVID-19 isolation measures on trade and manufacturing. Output in the Other Chemicals, Pulp and Paper, Textiles, and Building Materials subsectors were assumed to decline slightly by 2009, relative to 2005, remaining at relatively low levels through 2019, with much lower output in 2020. Energy use in "non-specified industries" was estimated to have followed a similar pattern. We assumed that, because of a combination of continued decommissioning of older, inefficient facilities, plus some investment in new or refurbished facilities, particularly by Chinese firms producing materials for export, that the relative energy intensity per unit of product fell slightly between 2005 and 2008/2009, to 110 percent of 1990 levels, remaining at roughly that level through 2020 for most industries. Major exceptions to this assumption are the energy intensities in the iron and steel and cement industries, which through a combination of plant upgrades (including with investment funds from Chinese firms) and retirement of older plants improved to an average intensity around 100 percent of 1990 levels. Even at that improved level of efficiency, however, DPRK heavy industries in general still offer a significant additional opportunity for energy efficiency improvements (see the analysis in section 4.5 of this Report, for example).

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[325] Quoting the Bank of Korea, the Website "Trading Economics" (https://tradingeconomics.com/north-korea/steel-production) provides figures for DPRK steel production for the years 2009 – 2017. In all probability, these figures are rough estimates, but we use them as figures of merit to scale energy use in the DPRK iron and steel industry. Figures for 2018 were not available from this source as of 2/2020, although a recent OECD document, again quoting the Bank of Korea, shows an estimate for 2018 steel output that is considerably lower than that for 2017 (Vincent Koen and Jinwoan Beom, *NORTH KOREA: THE LAST TRANSITION ECONOMY?*, Organization for Economic Co-operation and Development (OECD) Economics Department Working Papers No.1607, dated 12 May, 2020, and available as http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ECO/WKP%282020%2915&docLanguage=En).

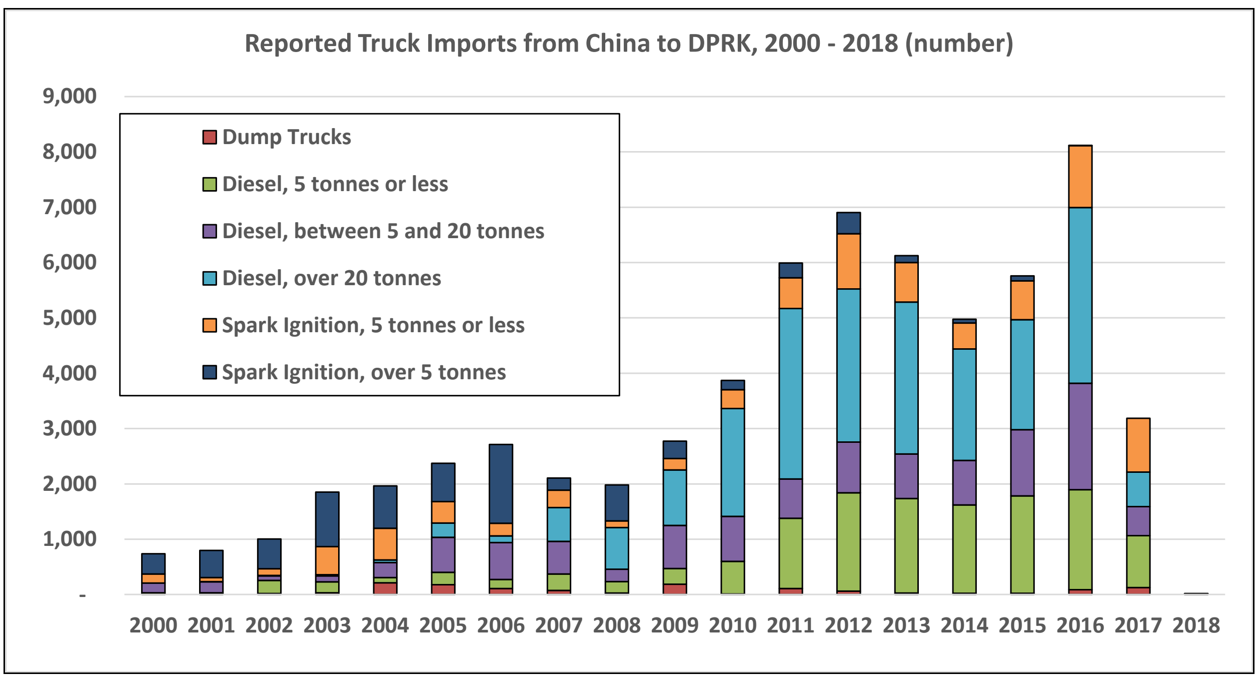
[326] Trends in DPRK cement output from 2009-on are adapted from the Website "Trading Economics" (https://tradingeconomics.com/north-korea/cement-production), which quotes the Bank of Korea. As with iron and steel production, in all probability these figures are rough estimates, but we use them as figures of merit to scale energy use in the cement subsector.

[327] Late 2000s figures for fertilizer output derived from data in UN Food and Agriculture Organization and World Food Program (2010), *Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea*, dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.pdf. Estimates are derived from data in Table 2 of that document. See section 5.3.3.1 and Figure 5-33 for additional details on assumptions regarding fertilizer production in the DPRK.

3.7.2. Transport sector activity

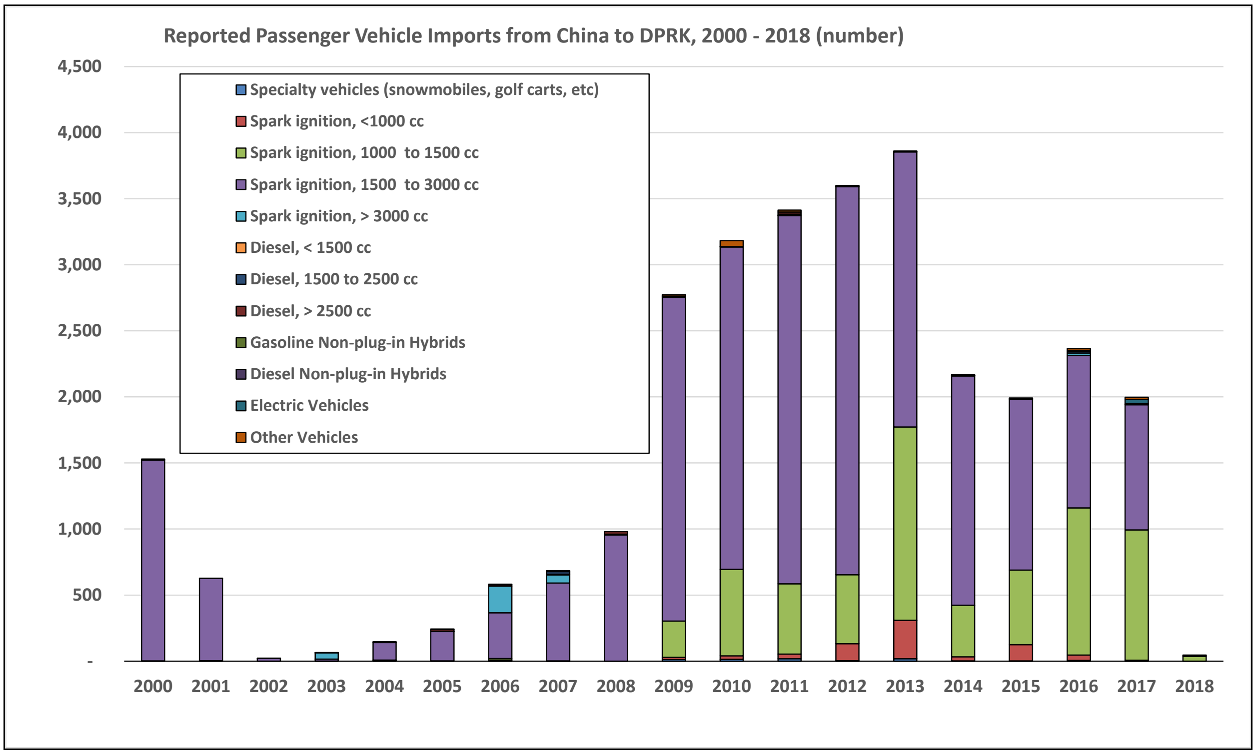
We assumed that the amount of freight to be transported by road would scale roughly with the amount of activity in most industrial sectors, and thus be about 14 percent of 1990 levels by 2000, increasing to about 23 percent in 2005 (due to somewhat increased industrial production, increased trade with China, and some increase in freight related to food aid). Road freight in 2008 was assumed to be slightly higher, at just under 24 percent of 1990 levels, in 2008, but lower in 2009 (18 percent of 1990 levels) due primarily to a reduction in the availability of motor fuels. Road freight is assumed to have climbed again to over 25 percent of 1990 levels by 2016 but fallen with the onset of UNSC sanctions to under 22 percent by 2019, then to 16 percent of 1990 levels in 2020 due to COVID-related measures. We assume that biomass (gasifier) trucks accounted for somewhat less than 10 percent of road freight in 2000 through 2016 (which is somewhat higher than in 1996), rising back to 10 percent in 2017 due to fuel supply restrictions in some areas, but that the share of freight carried by diesel trucks, including recently imported vehicles, increased to about 35 percent in 2000 and 70 percent in 2005, before decreasing to 47-55 percent in 2008 through 2020 due to the estimated relative availability of diesel fuel and gasoline (gasoline trucks carry the remainder of road freight). The pattern of truck imports to the DPRK from China is shown in Figure 3-5, with larger diesel trucks dominating imports particularly from 2010 through 2016.

Figure 3-5: Truck Imports to the DPRK from China, 2000 through 2018



"Civilian" auto transport is assumed to be decreased by 27 percent from 1996 levels in 2000, then have increased to 75 percent of 1990 levels by 2005, to 111 percent of 1990 levels by 2008, and to over 150 percent of 1990 levels by 2016, consistent with the increased in imports of private autos in recent years, before falling slightly through 2019 due to somewhat reduced fuel availability due to sanctions), and more steeply in 2020 as a result of COVID-19 restrictions. Figure 3-6 shows the trends in passenger vehicle imports to the DPRK from China since 2000, with a large increase in small and medium-sized vehicles between, especially, 2009 and 2013. To put these figures in context, however, the sum of auto imports to the DPRK from 2000 through 2018 is still less than 30,000 vehicles, or slightly more than one per thousand DPRK citizens. By way of comparison, Chinese passenger vehicle sales have been on the order of 200 million over the past decade alone, or about 140 vehicles per thousand people,[328] underscoring the relative rarity of passenger car use in the DPRK.

Figure 3-6: Passenger Vehicle Imports to the DPRK from China, 2000 through 2018



Other mechanized passenger road transport and rail transport is also assumed to have been lower in 2000 than in 1996, increasing somewhat for most conveyances in 2005 and on, with the use of diesel and gasoline buses (measured in passenger-km) decreasing in 2009 due to reduced fuel availability, but increasing thereafter (about 11,000 buses capable of carrying more than 10 passengers were reported to be imported by the DPRK from China since 2000, most of them since 2010) but the use of electric rail passenger transport increasing somewhat (to on the order of 40 percent of 1990 levels) after a decline due to limited electricity availability in 2009. Diesel rail freight is assumed to be 30 percent of 1990 levels in 2000, and electric rail freight decreased to 33 percent of 1990 levels by 2000 because of lack of availability of electricity. Diesel rail freight activity is assumed to have increased slightly by 2005, but to decrease again in

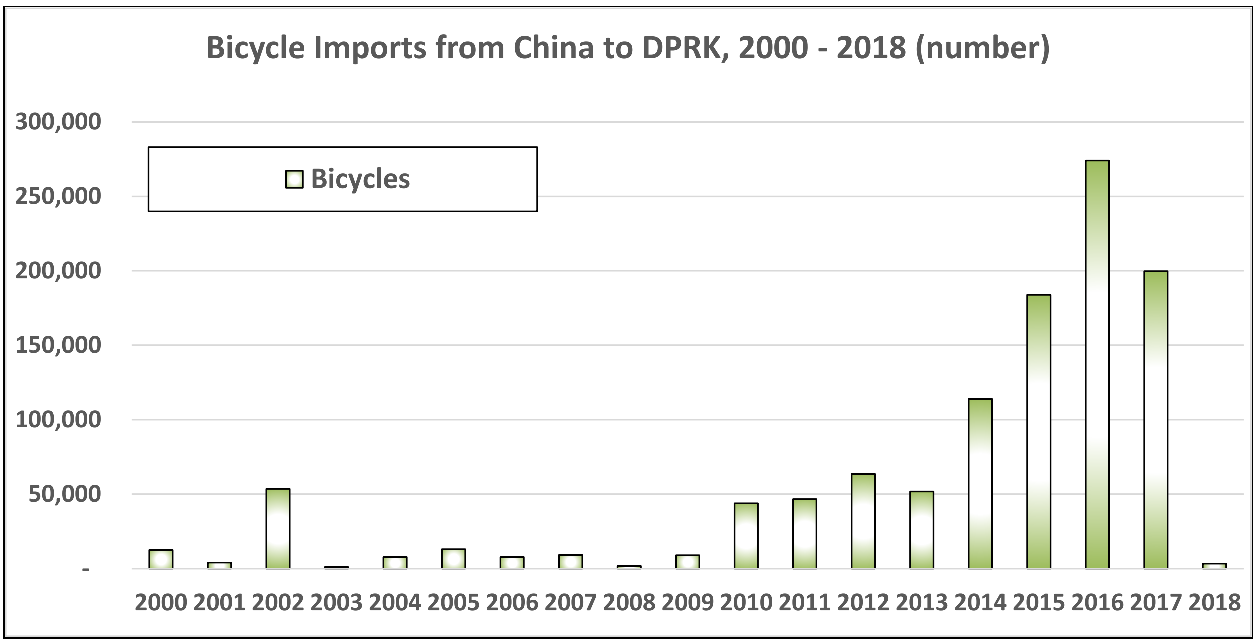
[328] See, for example, Statista (2020), "Car sales (passenger and commercial vehicles) in China from 2009 to 2019", available as https://www.statista.com/statistics/233743/vehicle-sales-in-china/.

2008 and 2009, with improvement in electric rail allowing an increase in transport of goods by that mode to 36 percent of 1990 levels by 2009, rising to 40 percent by 2016, but declining slightly thereafter.

Air travel is slightly decreased relative to 1996 by 2000 but assumed to have returned to 1996 levels by 2005 and 2008, decreasing again somewhat (back to 79 percent of 1990 levels) in 2009, but remaining at 80 to 95 percent of 1990 levels through 2019 before falling dramatically, to just over 50 percent of 1990 levels, in 2020 due to COVID-19 restrictions.

One area of DPRK transport that showed a large jump in the last decade is the use of inexpensive personal transport, notably electric bicycles and scooters (see Figure 5-41 and section 5.3.5), but also continued imports from China of large numbers of bicycles, on the order of a million of them between 2010 and 2018 alone, underscoring the degree to which DPRK citizens are taking the provision of energy services—in this case transport, into their own hands (see Figure 3-7).[329]

Figure 3-7: Bicycle Imports to the DPRK from China, 2000 through 2018



In general, no specific data were available for the transport sector for 2000 through 2020, so estimates of the parameters in the text above are rough figures based on the experiences of Nautilus staff and others in the DPRK. Visitors to the DPRK generally noted a modest increase in the use of small "private" cars and mini-vans in the years before 2000, but mainly in the Pyongyang area—thus we have assumed a small overall decrease in this activity, consistent with

[329] Note that this figure (derived by the authors, as with Figure 3-5 and Figure 3-6, from UN Comtrade data), does not include the purchases of bicycles made in the DPRK. For example, North Korean Economy Watch (2018), in "Pyongyang Bike Share", dated March 28th, 2018, and available as https://www.nkeconwatch.com/category/transportation/bicycles/, reported on a bike-share program in the DPRK using bicycles made by a joint DPRK/Chinese joint venture "called the Phyongjin Bicycle Cooperative Company".

constricted availability of fuel, between 1996 and 2000, but an increase thereafter through at least 2016. The use of other vehicles, however, seems to have stayed the same or decreased slightly between 1996 and 2000, thus the slight decrease in vehicle use by 2000 relative to 1990. Since 2000, and particularly from 2010 through at least 2017 (after which trade reports from China, at least as reflected in UN Comtrade statistics, appear to become sporadic), imports of vehicles from China have increased, and visitors have noted more vehicles on the road, though again, mostly in the Pyongyang area. The efficiency of trucks and buses and "private" vehicles was assumed to have improved somewhat between 1996 and 2019—on the order of 15 percent—with efficiency gains through the introduction of imported vehicles more than offsetting any continuing problems with the availability of spare parts and other maintenance supplies for existing vehicles. We saw many disabled trucks along the road in areas not far from Pyongyang during our visit in 2000—it is possible that the growth of imports of trucks in the 2010s allowed some of those older vehicles to be retired.

3.7.3. Parameters of residential energy use in 2000-2009

Based on the population growth rate for 1990 to 2000 that we assumed, as described in Chapter 2, was just above zero for the decade, we estimate that the year 2000 population in the DPRK was roughly 22.2 million, and that 60.4 percent of the population could be classified as "urban".[330] From the year 2000 through 2008, with some reservations, we assumed that the DPRK population increased at an average rate of 1.02 percent annually, and that a small net rural-to-urban migration continued, with the national fraction of urban households rising to 60.8 percent of the total by 2008.[331] Our reservations about using these population projections are as follows. The growth rate shown is calibrated to yield the 2008 total population reported in the landmark 2008 DPRK Census (*D P R Korea 2008 Population Census National Report*[332]) prepared under United Nations supervision. This document was welcomed as the first systematic census to be carried out on the DPRK in many years and is generally accepted by demographers as a useful picture of life in the DPRK, especially as no demonstrably superior estimate is available. Some researchers, however, have expressed doubts, privately and in some cases publicly, as to whether the 2008 population of the DPRK was likely, in fact, to be as high as the 24.05 million reported in the Census document. Inconsistencies have been noted between the size and age composition of the population reported in the 2008 Census and what had been known or imputed about population trends since 1990 in the DPRK. As of yet, however, neither we nor any other public documents we have seen have offered a definitive alternative estimate of 2008 population, so we adopt it for the estimated described here. We remain wary, however, of the fact that the 2008 population estimate that we are using could be overstated, perhaps by as much as 20 percent. From 2008 to 2010 we use an annual population growth rate of 0.536

[330] By way of comparison, the USDOE Energy Information Administration listed a year 2000 population of 21.7 million in its *North Korea Country Analysis Brief* (at www.eia.doe.gov/emeu/cabs/nkorea.html, as of 5/2002).

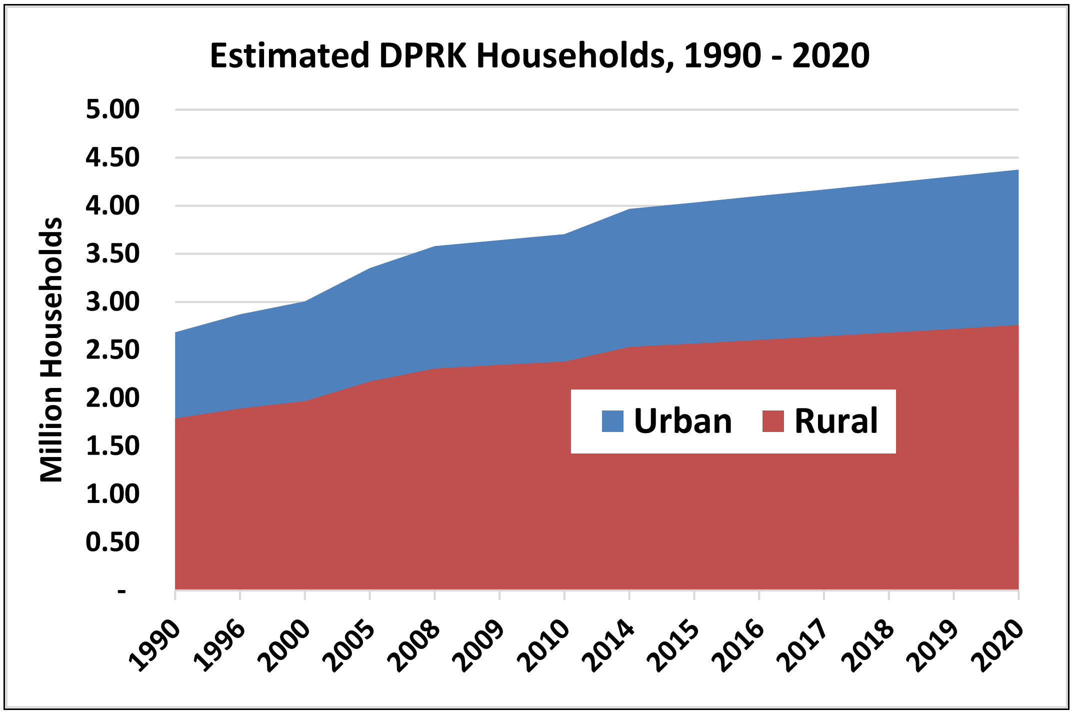
[331] Though some observers of the DPRK report a significant urban to rural migration, others suggest that the migration is largely seasonal with urban dwellers going to rural areas during the agricultural season and returning to cities at other times of the year. Depending on how "urban" is defined in allocating the DPRK's population, the fraction of the population living in urban areas may be close to 65 percent, though observers suggest that in recent years there has been a "ruralization" of urban life, with many nominally urban dwellers making their living (or much of it) from farming or raising livestock.

[332] *D P R Korea 2008 Population Census National Report*, Central Bureau of Statistics, Pyongyang, DPR Korea, 2009, available as https://unstats.un.org/unsd/demographic/sources/census/wphc/North_Korea/Final%20national%20census%20report.pdf.

percent, decreasing slightly to 0.5 percent for 2010 through 2014, and to 0.39 percent from 2014 through 2020.[333]

To estimate trends in the number of households in the DPRK, we started at our 1990 average values (4.65 persons per household in both the rural and urban sectors) and interpolated between those values and 2008 values as reported in the 2008 Census, yielding estimates of just under and just over 3.9 persons per household in the urban and rural sectors in 2009, respectively. This means that the number of DPRK households (from which "population not in households", meaning mostly those in the military, were excluded) grew faster than the rate of population growth through 2008. We assumed that the average sized of DPRK households continued to decline through 2020, with urban and rural households, respectively, averaging about 3.4 and 3.5 persons per household in 2020, and 61.3 percent of DPRK citizens living in urban areas.

Figure 3-8: Estimated DPRK Households, 1990 through 2020



Also included in the 2008 Census are data on the fraction of households using different fuels for cooking and heating, though not, unfortunately, data on the amount of those fuels used per household. Where possible, we used those data in the estimates prepared below. Again, the

[333] The 2008 Census document (ibid) lists total births in the 12 months prior to the census as 345,630 (Table 16), and total deaths in the same period as 216,616. These figures imply a rate of population increase as of 2008 of 0.536% annually. A compilation of DPRK statistics by the International Fund for Agricultural Development (IFAD), previously available as http://www.ruralpovertyportal.org/country/statistics/tags/dprkorea, estimates population growth at a slightly lower 0.50% annually as of 2014. We use this value as the estimated growth rate for population between 2010 and 2014. Population data from the United Nations (downloaded 1/28/2020 from https://population.un.org/wpp/Download/Standard/Population/) for the years 2014 through 2020 imply average population growth from 2014 through 2020 of 0.39% annually, which we take as the growth rate from 2014 through 2020.

reader is urged to consult Attachment 1 for further details and sources used for developing the inputs described below.

We assumed that the fractions of residences using coal in urban and rural settings were about 77 and 33 percent of 1990 levels, respectively, by 2000 (both having decreased somewhat further from 1996 estimates), with urban coal use continuing to fall in subsequent years, due mostly to limited availability, to about 65 percent of 1990 levels by 2009, and increasing slightly thereafter through 2020 as coal mining output improved. The fraction of rural households using coal falling to just under 19 percent by 2008, remaining at that level in 2009, but increasing to 32 percent by 2018. At the same time, we assumed a modest continued decline in the amount of coal used per household, to starting at 65 percent of 1990 levels in the urban sector in 2000 and decreasing to 50 percent by 2009 but increasing again to 63 percent of 1990 levels by 2018. In the rural household sector, per-household usage was set at 50 percent of 1990 levels in 2000, declining to 45 percent in 2005 and remaining at that level through 2009 before rising to 58 percent by 2018. The fractions of households using of wood/biomass fuels was assumed to have increased in both the urban and rural sectors, rising from 10 percent in 1996 in the urban subsector to nearly 28 percent in 2008/2009 (based on 2008 Census figures), declining slowly to 20 percent of households by 2018. In the rural sector, use of wood/biomass fuels was assumed to have risen from 60 percent of households in 1996 to over 79 percent in 2008/2009, falling to 66 percent of 1990. Average wood/biomass use per household, however, was assumed to decline slowly over time, from 80 percent of 1990 values in 2000 to 65 percent in 2008/2009 and around 52 percent of 1990 levels by 2018 for both the urban and rural sectors, due to a combination of increasing scarcity of fuel, more households in competition for fuel resources, and (relatedly) less use of heating and cooking, as well as some increase in coal availability in the 2010s.

The use of charcoal was assumed to have decreased since 1996, to 55 percent of 1990 levels in 2000 and 45 percent of 1990 levels in 2008 and 2009, rising only slightly thereafter. The fraction of households using oil products for cooking was assumed to have decreased, due to low availability of fuel, from 13 percent of urban households and 1.5 percent of rural households in 1996 to about 7 percent of urban households and less than 1 percent of rural households in 2008/2009. These values are assumed to have risen slightly, to over 9 percent in urban households and about 1.5 percent in rural households, by 2018 through 2020, as a result of improved fuel ability and possibly more disposable income in the households that could afford the convenience of LPG or kerosene stoves—that is, in households that were among the "winners" in the shift (at least in effect) to a more market-oriented DPRK economy. Per-household urban and rural use of oil products was assumed to have increased, in part due to use of kerosene as a substitute lighting fuel, through 2008, falling slightly (with reduced availability of petroleum fuels) in 2009, but thereafter remaining in the range of 70 to 80 percent of 1990 levels through 2020.

The use of electricity in residences is assumed to have been severely curtailed (by availability) relative to 1990, but improved somewhat between 2000 and 2008, declining somewhat again in 2009. Visitors to the DPRK in 2000 described electricity in Pyongyang as having been generally available, but electricity in at least major portions of other cities being largely unavailable. Based on Korea Trade-Investment Promotion Agency (KOTRA) data[334] that listed the population of Pyongyang as 3.4 million, and assuming, based roughly on a record of electrical

[334] Formerly available from http://www.kotra.or.kr/main/info/nk/eng/main.php3, visited 6/3/02.

outlet voltage collected in Pyongyang and covering most of 2000, that Pyongyang suffered from blackouts for about 20 percent of 2000, and further assuming that residents of cities other than Pyongyang had power only 14 percent of the time, we estimate that the average consumption of power per household in 2000 was about 29 percent of that in 1990 in urban areas. Nautilus Institute's rural energy survey in the village of Unhari, on the West Coast of the DPRK,[335] suggested an annual average usage of 390 kWh per household per year, fairly close to the 1990 value estimated as described earlier in this report. During our mission to Unhari in 2000, we determined that householders virtually never had electric power available in their homes during the day, especially in the winter months. As Unhari is relatively close to Pyongyang, it is our expectation that the situation there is likely, if anything, to be better than that in many other rural areas. We therefore assume that the lack of availability of power limited rural residents to 12 percent of 1990 levels of electricity consumption in the year 2000. Since 2000, visitors' observations of electricity supplies in the DPRK have varied dramatically depending on where and, to some extent, when the observations occurred. In some cities, particularly Pyongyang and areas near the Pukchang power station (the largest plant in the DPRK), close to round-the-clock supplies were reported, while only sporadic availability was reported for other areas. Overall, the electricity supply situation seems to have improved, at least marginally, since 2000 through about 2008, and our estimates of per-household usage reflect that improvement. Anecdotal evidence in late 2011/early 2012 suggested that electricity supplies were once again on the downswing, as evidenced by reports of more extensive and longer-duration blackouts, even in the Pyongyang area.[336] We assume that per-household electricity use fell in 2009 through 2014, remaining at about 26 to 28 percent of 1990 levels in urban areas, and about 7 percent in rural areas, through 2019. We estimate that household electricity use will have increase substantially in 2020, however, as COVID-19 restrictions have residents spending more time at home, and more importantly, as reduced industrial and commercial/public sector activity has left more electricity to be distributed to households.

The fraction of urban households using district heat is assumed to have decreased slightly over time since 2000, essentially because the number of households has grown but we assume that the deployment of district heating systems has not. The use of district heat per connected household is assumed to parallel the use of electricity, since the two are either co-produced or depend on the same sorts of central power plant/central heating plant fuels and infrastructure, and thus would be subject to the same sorts of constraints, on average.

3.7.4. Estimates of energy use parameters for the Agricultural and Fisheries sectors

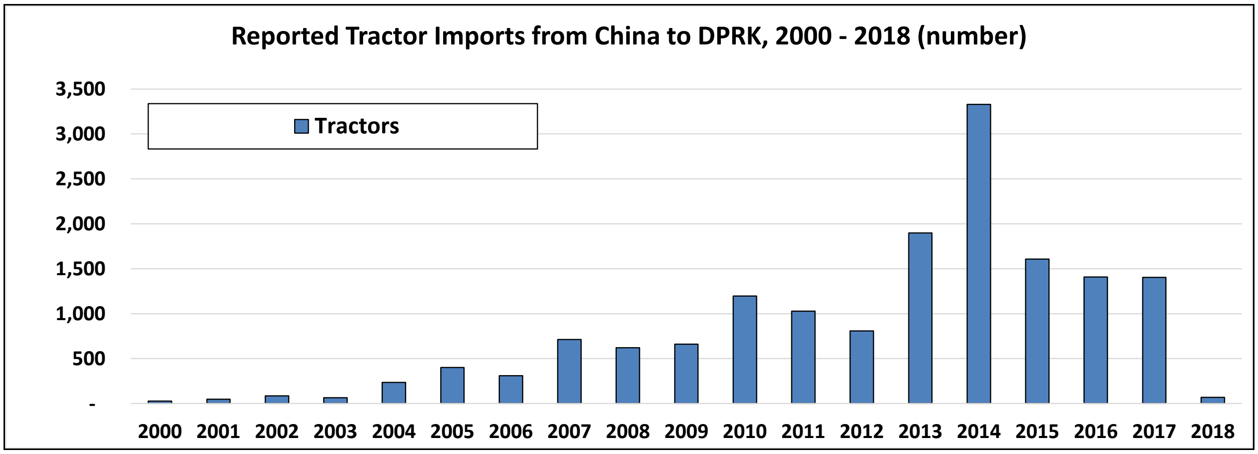
We assume that the availability of mechanized aids to agriculture continued to decrease from 1996 to 2000, increased slightly by 2005, then continued to decline slowly through 2009, resulting in the use of diesel tractors and other oil-fueled equipment in the agricultural sector decreasing to 25, 27, and 24 percent of 1990 levels in 2000, 2005, and 2008/2009, respectively,

[335] As reported on in "A Rural Energy Survey in Unhari Village, The Democratic People's Republic of Korea (DPRK): Methods, Results, And Implications", *Asian Perspectives Special Issue, 2002*, by D. von Hippel and co-authors. A longer version of this study is available as a Nautilus Report at http://nautilus.org/wp-content/uploads/2015/01/Asian-Perspectives-DPRK-fulltext.pdf.

[336] See, for example, *North Korean Economy Watch*, "Power shortage in Pyongyang prompts residents to move to older housing", providing two related stories describing electricity shortages of the winter of 2011/2012, originally dated 2012-1-13 and 2012-2-1, and available as http://www.nkeconwatch.com/2012/02/01/power-shortage-in-pyongyang-prompts-residents-to-move-to-older-housing/.

down from 30 percent in 1996. The lack of spare parts and fuel play a significant role in this reduction.[337] We assume that this situation eased somewhat in the years after, with the use of powered field machinery increasing to 29 percent of 1990 levels by 2016, in part with new imported tractors (see Figure 3-9), but fell thereafter as the impacts of UNSC sanctions on fuel availability and trade in agricultural machinery and other imports were felt.

Figure 3-9: Tractor Imports to the DPRK from China, 2000 through 2018



The use of electricity in fields (mostly for water pumping) in the agricultural sector were also assumed to decline relative to 1996 through 2009, though the total area cropped was assumed to change only modestly. Reduced electricity use "in fields" was due in part to the completion of major gravity-flow irrigation systems in the western agricultural area of the country (see, for example, Figure 3-10),[338] in addition to reduced electricity availability and probable continued degradation of pumping infrastructure. We assume that electricity use per hectare cropped remained at about 50 percent of 1990 levels from 2010 through 2020, while the area harvested falling over the period from about 82 to 69 percent. The use of coal, electricity, and biomass for crop processing are estimated to have declined from 1996 to 2000 due to a combination of lower crop output and reduced fuels availability. From 2000 to 2005, we assumed an increase in the availability (and use) of electricity for crops processing, and also an increase in biomass use (as well as coal and electricity) related to increased crop output. After 2005, use of these fuels is assumed to vary somewhat year to year, but to remain near 2005 levels through 2018, falling

[337] See, for example, Hugh Bentley, "Trends in the DPRK Agricultural Sector & Implications for Energy Use", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/. Bentley notes that ongoing post-harvest losses during threshing, drying/, and cleaning operations, early crop consumption, shortages of fertilizer, lack of timely field operations, and soil erosion caused by deforestation in the DPRK all have implications for agricultural energy use.

[338] A KCNA news item, "Power Stations Built along Kaechon-Lake Thaesong Waterway", dated December, 2004 (available as https://www.globalsecurity.org/wmd/library/news/dprk/2004/12/dprk-041223-kcna03.htm) reads in part "power stations have been built along the Kaechon-Lake Thaesong Waterway in South Phyongan Province, the Democratic People's Republic of Korea. The 150-kilometer-long natural-flow waterway has been built from Taegak-ri in Kaechon City to Lake Thaesong. It saves 140 million kWh of electricity a year." 140 million kWh, or 140 GWh, is substantially larger than the reduction in the field use of electricity we estimate which could mean that our estimate of savings is understated, the KCNA figure is overstated, some of the reduction in electricity use from the waterway has meant that more electricity is available for use in water pumping in other areas, which would tend to reduce savings—or, most likely, a combination of all three factors.

thereafter due to reduced availability of fuel and other inputs, in part due to the impacts of UNSC sanctions.

Figure 3-10: Natural-flow Irrigation Waterway in the DPRK Completed in the Early 2000s[339]

In the fisheries sector, based on data on DPRK marine catch, we assumed that fisheries effort and energy use would be 25 percent on 1990 levels in 2000, with activity increasing slightly from 2000 levels by 2005, but declining slowly through 2009 due to lack of fuel and equipment maintenance issues.[340] [341] Trade statistics show that since at least the years from 2010 the DPRK

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[339] From John Lewis, "North Korean Energy: 2005-2006 New Technologies and Construction" as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.

[340] The Korea Trade-Investment Promotion Agency (KOTRA) suggests that DPRK marine products catch decreased substantially between 1996 and 1997 but increased somewhat from that point through 2001. KOTRA data (from "Agriculture, Forestry, and Marine Products industries", available through http://www.kotra.or.kr/main/, visited 6/3/02) lists 1996 output of .876 million tonnes, and 1999 output of .664 million tonnes. A web page on "North Korea's Foreign Trade in 2000" from the same site lists the value of marine exports as having increased 9.4 percent between 1999 and 2000. If all fisheries production tracked export earnings (which is not necessarily the case, but assumed for the sake of argument here), the implied ratio of fisheries output between 1996 and 2000 is 83%. We further assume that fisheries effort (as reflected in fuel use) is proportional to fisheries output. Alternatively, end-of-1999 data based on the *Economic and Social Comparison between the Two Koreas*, published by the National Statistics Administration (December 2000) and provided as of 2005 (but not as of 2021) on http://www.koreascope.org/english/sub/1/index3-h.htm, suggest that the DPRK fish catch in 1999 was 45.7 percent of the catch in 1990. The ROK Ministry of Unification web site http://www.unikorea.go.kr/en/index.jsp (but no longer available at that address as of 2021), as of about 2007, included a listing of fisheries output suggesting that total marine products production in the DPRK had increased to 1.16 million tonnes by 2004, a significant jump from 2002 and 2003 (0.81 and 0.84 million tonnes). Much of this production increase, however, may have been in products that were relatively less energy intensive to harvest, such as seaweed.

[341] The United Nations Food and Agriculture Organization (UNFAO) global fisheries database "FishStat" (downloaded from http://www.fao.org/fishery/statistics/software/fishstatj/en on 3/28/2012) includes what appear to be estimated data for DPRK

has been exporting large quantities of fisheries products. China imports the vast bulk of these products—well over 90 percent. Most of China's imports from the DPRK are in the category "Molluscs", a category dominated by imports, specifically, of cuttlefish and squid—exports of products in this category were valued at over $100 million annually for all but one of the years from 2012 through 2017. The increased harvest of squid is due, in part, to an abundance of squid as a result of the same climatic conditions that have led to drought in the DPRK.[342] This uptick in exports of fisheries products suggests that fuel use in 2010 was higher—we assume about 39 percent of 1990 levels—and varied thereafter with the level of fisheries exports by the DPRK through 2017, ranging from about 27 to 48 percent of 1990 levels. We assume that the sum total of these trends is an increase in fishing effort in smaller boats, mostly (fishing collectives), reflected in an increase in oil use in those boats between 2010 and 2017, and a slight decrease from 2010 levels by 2015 (to 30 percent of 1990 levels) in the average use of electricity for processing of marine products, since the bulk of the processing of cuttlefish and squid, for example, seems to be being carried out by hand. Fisheries energy use in 2018 and 2019 was assumed to be lower than in previous years, due to fuel availability and trade restrictions as a result of UNSC sanctions,[343] and to be still lower in 2020 as a result of COVID-19 responses in the DPRK.

An additional potential reduction in DPRK fisheries energy use stems from a reported recent practice of DPRK organizations selling fishing licenses to Chinese fishing operators.[344] This practice apparently involved transferring DPRK fishing licenses to Chinese fishing boats and ships, which then operated in the waters off the DPRK and elsewhere. It is unclear what impact this practice might have on DPRK fishing effort, and specifically, how it might affect DPRK fuel use for fishing, but to the extent that DPRK fishing was effectively transferred to Chinese vessels, it likely that DPRK fishing effort would decrease, although it seems possible that some of the Chinese vessels fishing in DPRK waters (or in international waters near that DPRK) with DPRK licenses might be obtaining fuel in the DPRK. We make the assumption that the practice

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fisheries output from about 2000 on, often with little or no change over time, suggesting that no significant data were available on DPRK fisheries to UNFAO in recent years.

[342] As described, for example, in "North Koreans turn to squid to compensate for drought", prepared by Choi Song Min for *Daily NK*, dated July 15, 2015, and available as http://www.theguardian.com/world/2015/jul/15/north-korea-drought-squid-harvest. See also "North Korea's military orders surge in squid poaching", *Daily Telegraph*, by Mike Firn, dated 28 Nov 2014, available as http://www.telegraph.co.uk/news/worldnews/asia/northkorea/11259846/North-Koreas-military-orders-surge-in-squid-poaching.html. Similarly, "North Korean fishing industry increases output", *NK News*, February 10th, 2015, available as http://www.nknews.org/2015/02/north-korean-fishing-industry-increases-output/,also reports increased output after about 2011.

[343] There was a major change in fisheries trade reports involving the DPRK as of 2018, as China reported no imports in the fisheries category from the DPRK at all. This lack of reporting is probably due to UNSC sanctions on the DPRK, although it seems improbable that fisheries exports from the DPRK to China really dropped to zero in 2018, when imports to the DPRK from China were at $71 million, which was about 69% of 2017 imports to the DPRK from China, but hardly insignificant. With little else to go on with respect to available statistics (exports from the DPRK to other nations, mostly nations in Africa, continued at levels not very different than in 2017, although those levels were on the order of a percent of historical trade with China), we assume that fisheries effort probably did decline as a result of the combinations of sanctions on DPRK exports and on DPRK imports of diesel oil to fuel the fishing fleet, but that fishing effort did not fall to zero. We assume that 2017 fisheries effort and processing energy use was about 70% of that in 2017.

[344] The March 5, 2019 UNSC *Report of the Panel of Experts established pursuant to resolution 1874 (2009)*, includes mention of the DPRK practice of "...prohibited transfer by the Democratic People's Republic of Korea of its fishing rights, as clarified in resolution 2397 (2017), continued throughout 2018, acting as a potential source of income for the country." (P. 28 of https://www.undocs.org/S/2019/171). The same source includes a quote from a fisherman indicating "that there were around 200 Chinese fishing boats operating in the 'water of North Korea'". If these were larger fishing vessels (with engines of around 100 hp or more), this would be the equivalent of more than 10% of the DPRK fleet, but we do not really have information on the size of these vessels using DPRK licenses.

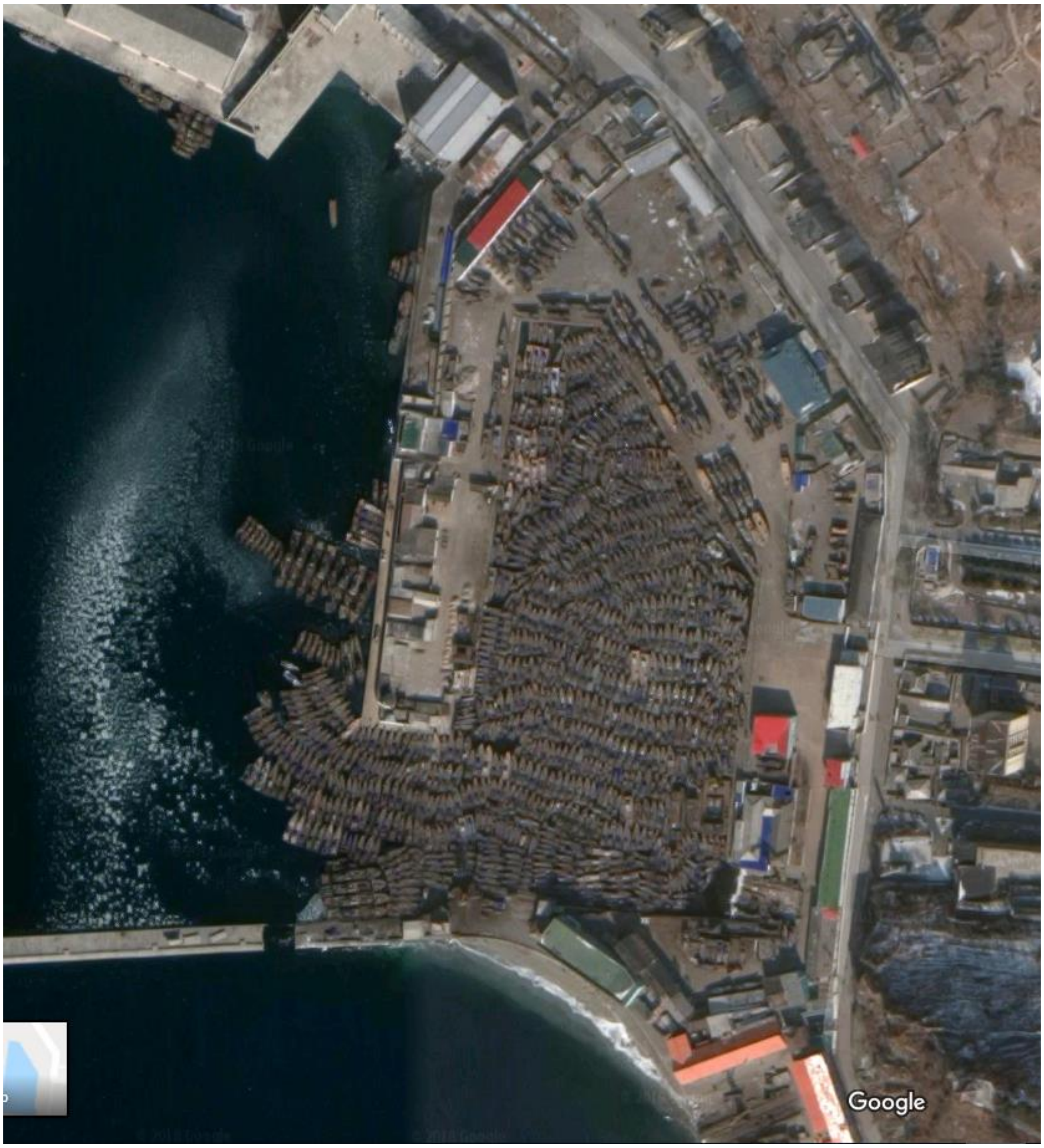
of transferring licenses further reduced DPRK fishing effort by 5 percent in 2018, although this must be considered the roughest of estimates. We assume that this estimate also holds for 2019. For 2020, we assume that the impacts of the COVID-19 virus and the impacts of the measures taken to prevent it have had a relatively small impact on fishing effort, perhaps 10 percent relative to 2019, because fishing would likely be considered a crucial occupation, given the importance of fish and seafood protein to the DPRK population, as well as the importance of seafood exports to the economy. In addition, fishing itself involves gatherings of relatively few people, though fish processing plants do typically require large numbers of people working close together.

Figure 3-11 shows a DPRK fishing vessel that drifted to Japan in late 2017, and Figure 3-12 shows an image of what appears to be a significant portion of the DPRK fishing fleet in harbor in Chongjin, probably during the winter of 2018.

Figure 3-11: DPRK Fishing Vessel[345]

[345] Image from Gareth Davies (2017), "Another North Korean 'ghost ship' washes up ashore in Japan as the bodies of three dead fishermen from Kim Jong-un's regime are also discovered", *Daily Mail.com*, dated, 4 December 2017, and available as https://www.dailymail.co.uk/news/article-5143573/Another-North-Korean-ghost-ship-washes-ashore.html.

Figure 3-12: DPRK Fishing Boats in Harbor Near Chongjin, Winter 2018[346]



[346] Google Earth image showing a harbor in Chongjin filled with on the order of a thousand of what appear to be 10-to-15-meter fishing boats and about 15 larger boats (25-30 meters). Image from Google Earth, approximate coordinates 41.778022, 129.829610, February 11, 2018. An image of another basin about 4.5 km from the first, at coordinates 41.768142, 129.777686 (see Attachment 1) appears to also show nearly 1000 10–15-meter boats. This would appear to be a significant portion of the DPRK's east coast fishing fleet. Whether they have been stored together in these basins for protection to wait out the winter and/or because they are idle for lack of fuel is an interesting question. In addition, at least one report suggests that some of these Chongjin-based vessels belong to Munitions factories that are tasked with fishing to generate foreign exchange income. See Radio Free Asia (2017), "North Korean Munitions", Reported by Jieun Kim for RFA's Korean Service, translated by Leejin Jun, and written in English by Roseanne Gerin, and available as https://www.rfa.org/english/news/korea/north-korean-munitions-factories-turn-to-fishing-to-generate-foreign-currency-08092017152812.html. Interestingly, this particular harbor appears to be filled with boats in 10 of 12 images of the area taken in 2020, with the harbor mostly empty in a 9/3/2020 image that also appears to coincide with flooding from a local river and perhaps a pollution episode, and about half full in the next (and last available, as of 11/18/20) image, taken on 9/8/20. Whether this observation says something about fishing activity in 2020 is difficult to determine.

3.7.5. Public/Commercial sector parameters

Based on visits to the DPRK in 1998, 2000, and 2009, commercial/public building space did not seem to be under construction at an unusual rate (when there was construction at all), so the ratio of residential to commercial/public space was assumed to have been 95 percent of that in 1990 (assuming, in fact, some closure of public buildings and shops since 1990), meaning, effectively, less public/commercial building space per person in the DPRK. We assume that this ratio continued to fall through 2010, to 84% of 1990 levels, before rising slowly thereafter, reflecting the resumption of commercial building as the economy improved.

We assumed a fraction of electricity use relative to 1990 in the year 2000—about 29 percent—that is a function of the same assumed average urban electricity outage rate used for the residential sector, namely that power outages in cities outside the Pyongyang area as of 2000 were by far the rule rather than the exception. For 2005 through 2010, the electricity and heat use per unit floor area was between 40 and 47 percent of the 1990 rate, which is slightly higher than the rate in urban households for those years, based on the assumption that more commercial and public buildings were on heating circuits, and had preferred access to electricity. From 2014 through 2019, due in part to limited availability of grid electricity, we assume decreased use of electricity and heat, at 33 to 35 percent of 1990 levels, but declining to under 25 percent of 1990 levels in 2020 due to reduction in activity in the sector because of COVID-19 restrictions. The fraction of 1990 coal use per unit area assumed for 2000 through 2010, 45 percent, reflects the observation that coal availability was and continued to be poor in many areas of the country, with the modest improvements assumed thereafter—to 52 percent of 1990 levels by 2018/2019, in part due to improved coal availability as exports of coal to China were constrained by UNSC sanctions. Coal use per unit commercial/public floorspace is estimated to have fallen to about 37 percent of 1990 levels in 2020, however due to measures to reduce the spread of COVID-19. Visitors to the DPRK within the last few years report that most public buildings are unheated in the winter, and many of those that have some heat are heated with biomass fuels. We have accordingly assumed that the use of wood and biomass fuels in the commercial sector, on a per unit floor area basis, increased from 10 percent of the 1990 rate of coal use in 1996 to 20 percent in 2000 to 30 percent in 2005 through 2010, but falling thereafter as coal availability increased. As in the residential sector, the change in electricity availability noted by observers varied substantially by area and by season in the DPRK, as well as varying in relation to proximity to new or existing power plants, or to priority users of power.

3.7.6. Military energy use parameters in 2000 through 2020

With the minor exception of the addition to the roster of marine vessels of some small submarines and some amphibious "Kong Bang" hovercraft, the vehicles, vessels, aircraft and armaments assumed in use for the DPRK military is much the same in 2000 (and in 2005-2020) as it was in 1996 (and 1990) .[347] [348] A photo of a group of hovercraft, assumed to be Kong Bang, at their base in Northwestern DPRK near the mouth of the Yalu river, is shown in Figure 3-13.

[347] Two ROK media reports--"North Korea Deploys Air Cushion Warships", Seoul, *The Korea Times* (Internet Version-WWW) in English, by Cho'ng Su'ng-ki, dated April 1, 2007 (and quoting the 2006 ROK Defense White Paper); and "N. Korea Develops High-Speed Military Hovercraft", Seoul, *Chosun Ilbo* WWW-Text in English, dated April 2, 2007--report the development of DPRK hovercraft, but these appear to be the same as the Kong Bang hovercraft developed deployed during the 1990s, with no

Figure 3-13: Hovercraft Based in Northwestern DPRK, November, 2019[349]

We have assumed, based on the modest information available in the open literature and on conversations with analysts, that ground forces military activity in 2000 was lower (by 20 - 25 percent) than in 1996,[350] with a smaller continued decline from 2000-2010, and a modest increase thereafter through 2016, after which oil import restrictions under UNSC sanctions

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apparent change in the number of such vessels (both of the 2007 articles give a number of 130 hovercraft) that have been present in the DPRK fleet since about 2000.

[348] A fairly recent publication covering the DPRK's overall military readiness, *North Korea's Military Threat: Pyongyang's Conventional Forces, Weapons of Mass Destruction, and Ballistic Missiles*, by Andrew Scobell and John M. Sanford, Strategic Studies Institute, U.S. Army War College, dated April 2007, and available as https://publications.armywarcollege.edu/pubs/1869.pdf, implies that DPRK production of armaments continues, but does not, based on our quick review, seem to indicate any substantial net addition of armaments to the DPRK working inventory in recent years.

[349] Image from Google Earth Pro, dated November 2019. This facility hosting amphibious vessels that are probably similar to the "Kong Bang" craft is located near the northern border of the DPRK. A review of earlier images in Google Earth indicates that this facility has been in use since at least 2010, including the structures housing the 16 vessels (one is absent in the photo). In 2010 there were a few additional vessels at the site. The hovercraft vessels are about 20 m long. Location is 39.808390, 124.412620. Just north of the hovercraft port there is what appears to be a drydock (or possibly production?) facility for small patrol craft, about 22.5 m, located at approximately 39.819, 124.413. The two facilities are located just south of the city of Yongju-gun, about 15 km south of the outlet of the Yalu river.

[350] Analysts contacted regarding the "tempo" of DPRK military exercises, and reports in the media (for example, "NK Ground Exercises Up as Navy and Air Force Decline", Yoo Yong-won, www.chosun.com, 2001- 9-10) suggest that the DPRK military exercise tempo for ground forces had increased somewhat to that point, but not substantially, and that some of the apparent increase in exercises may be an increase in the number of soldiers involved, but not necessarily the number or use of fuel-using vehicles and armaments. Accordingly, we assume that the average hours of annual use (and fuel use) by ground vehicles in 2000 was somewhat lower in 2000 than in 1996.

caused military oil use to stagnate or fall slightly, despite military uses likely being top priority. Ground forces activity is assumed to have decreased markedly in 2020 due to COVID-19 quarantine measures. Aircraft use in 2000 was substantially less than the already low levels of 1996,[351] due in part to the particularly constrained supplies of fuel in that year, but somewhat higher (close to 1996 levels) in 2005-2019, though with year-to-year variability due to fuel supplies. 2020 use of fuel by aircraft, as with ground forces, is assumed to have been significantly lower than previous years. Figure 3-14 show an array of military aircraft lined up for an airshow or inspection in late 2019 at the new Wonsan-Kalma International Airport.

Naval vessel energy use in 2000 was modestly (7-10 percent) lower, on average than the levels assumed for 1996,[352] with the assumed number of hours of use of different naval vessels and related equipment assumed to be mostly similar to 2000 levels in 2005, but slightly lower in 2008 through 2016, and lower still thereafter due to lower fuel availability under UNSC sanctions. In 2020, naval vessels are assumed to have spent more time in port due to COVID-19. The level of military manufacturing is assumed to be lower in 2000 through 2010 than was assumed for 1996, at 45 percent of the 1990 level of activity, but slightly higher from then through 2019, with activity falling to 25 percent of 1990 levels in 2020 due to the impacts of COVID-19 shut-downs in factories.

[351] The informal opinion or analysts familiar with the DPRK military situation suggests that air force activity in the DPRK is, if anything, declining slowly, perhaps due to lack of fuel, probably due to lack of spare parts, and probably due to a recognition on the part of the DPRK military command that in a real conflict, the DPRK Air Force is unlikely, given the age and condition of its aircraft, to play a substantial role. Accordingly, we have assumed that DPRK Air Force training exercises have continued to decrease slowly since 1996, as reflected in the flight-hours estimates shown.

[352] There does not appear to be any definitive information of an unclassified nature that could be used to qualitatively estimate the level of activity in the DPRK naval forces as of 2000. Analysts contacted in around 2001 in researching an update of this document, however, indicated that the DPRK Navy did not seem to be operating under any particular fuel restrictions, and that the level of incursions (from DPRK vessels) experienced in ROK waters seemed to be fairly consistent with prior years. As a result, we have assumed that DPRK naval activity (at least for patrol craft) was only somewhat lower (in average terms of activity per vessel—which would include both serviceable and inactive vessels) than in 1996.

Figure 3-14: Aircraft Lined Up for an Exhibition or Inspection at Wonsan, November, 2019[353]

Similar to the public/commercial sector, we assume that from 2000 to 2005 and thereafter the use of coal and oil in military buildings decreased somewhat, rising again slightly in the 2010s, but the use of wood fuels, for cooking and some heating, continued to increase through 2010 (falling somewhat thereafter), as soldiers were increasingly asked to produce and forage food and fuel for themselves. For 2005 and thereafter, the typically small decrease in activity levels we have assumed for in all branches of the military relative to 2000 levels is the result of energy-consuming training activities being limited by fuel supplies, lack of spare parts, and also,

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[353] Image from Google Earth Pro, dated November,13, 2019, shows the new Wonsan-Kalma International Airport, taken on November 13, 2019, shows a group of military aircraft lined up for what might have been an airshow and/or inspection. Aircraft appear to include fighters and bombers, among others. Image coordinates are approximately 39.171, 127.479. Additional military aircraft, including helicopters and transport aircraft, also appear in parts of the airport not shown in this image. The report by Peter Makowsky and Jenny Town (2019), "Military Aircraft Lined Up at the Wonsan Airport", for *38 North*, dated November 14, 2019, and available as https://www.38north.org/2019/11/wonsan111419/, lists the aircraft present as follows: “"On imagery from November 11, there were four MiG-17 fighter aircraft, six MiG-15 fighter aircraft, fourteen Su-25 close support aircraft, six MiG-29 fighter aircraft and six Il-28 bomber aircraft observed on the tarmac north of the passenger terminal. On November 13, additional MiG-15 and MiG-17 were added to the display bringing their total to eleven MiG-15s and eight MiG-17s. Several small vehicles were parked on the tarmac near the MiG-29 and Il-28 aircraft. In addition, thirteen probable MiG-21 fighter aircraft were observed on the alert apron at the south end of the airfield, and six small, either Hughes 500 or Mi-2 Hoplite light helicopters, six, possibly Mi-8 or Mi-14, medium transport helicopters, and eight An-2 Colt light transport aircraft were parked along the auxiliary runway located on the southwest side of the airfield. Further to the south of the auxiliary runway at the rail transfer point, seven additional MiG-21 were parked on an adjacent apron.". A count from the 11/13/2019 image prepared for Nautilus in May 2020 by Liam Tasa and Guy Tasa tallied 87 aircraft in similar categories. Either represents about 6 percent of the total estimated DPRK military aircraft fleet. Most of these aircraft were gone when the next available image was taken, a few weeks later (12/5/2019).

possibly, increased time spent by military personnel in economic pursuits.[354] Another possible reason for reduced military activities in some years could have been the reportedly lower physical capabilities of soldiers working on shorter rations.

3.7.7. Non-specified and non-energy commodities demand

We have included no non-specified fuels demand in the estimated balances for 2000 through 2020, with the exception of heat from the re-started Yongbyon reactor in 2005 (at the 1990 level), but not in 2008 through 2010. As the reactor was operating for at least part of the time during 2014 through 2018, we assume 67 percent of full heat output during those years, falling to 0 percent for 2019, and rising to 33 percent in 2020.[355] The image in Figure 3-15, from Google Earth Pro, shows the Yongbyon "5 MWe" reactor as of October 13, 2019, apparently not operating, as indicated by the lack of steam from the smokestack.

[354] Reviews of the literature describing DPRK military equipment stocks in the different branches of the armed forces are available on http://www.globalsecurity.org, for example, on http://www.globalsecurity.org/military/world/dprk/air-force-equipment.htm for air force equipment, http://www.globalsecurity.org/military/world/dprk/kpa-equipment.htm for ground forces equipment, and http://www.globalsecurity.org/military/world/dprk/navy.htm for the navy. These reviews find relatively little change in the DPRK's stock of energy-using military equipment in recent years but note that it is not entirely clear whether these results stem from a lack of recent insights, on the part of analysts, as to any changes in the DPRK military, or to a lack of changes in the actual equipment inventory in the DPRK.

[355] The Yongbyon reactor was not operating in 1996 or 2000. The capacity factor in 2005 was assumed to have been similar to that in 1990 (about 60 percent). According to several sources (see, for example, Nuclear Threat Initiative, "Yongbyon 5 MWe Reactor", available at https://www.nti.org/learn/facilities/766/, and GlobalSecurity.org, "Weapons of Mass Destruction (WMD): Yongbyon (Nyongbyon)", available as https://www.globalsecurity.org/wmd/world/dprk/yongbyon-5.htm), the Yongbyon plant operated at least "intermittently" from 2014 through 2018. We assume that the reactor operated somewhat less than in previous periods of activity, at an average capacity factor of about 40% percent. In 2019, several sources suggest that the reactor did not operate at all, so we assume that heat output for 2019 was 0% of full capacity. For 2020, some sources suggest that although no activity had been detected to about March of 2020, the DPRK was possibly readying the reactor for a restart. We therefore assume that heat output in 2020 will have been about 20% of capacity. Relevant references include Shim Kyu-Seok (2019), "Yongbyon reactor seems to be idle, says IAEA", *Korea JoongAng Daily*, dated September 18, 2019, and available as https://koreajoongangdaily.joins.com/news/article/article.aspx?aid=3068062; Joseph Bermudez and Victor Cha (2019) "Yongbyon Nuclear Complex: Normal Operations with Low Level Activity", *Beyond Parallel*, dated April 1, 2019, and available as https://beyondparallel.csis.org/yongbyon-nuclear-complex-normal-operations-with-low-level-activity/; *38 North* (2019), "North Korea's Yongbyon Nuclear Center: Low Level Activity and Flood Management", dated August 30, 2019, and available as https://www.38north.org/2019/08/yongbyon083019/; and Peter Makowsky, Frank V. Pabian and Jack Liu (2020), "North Korea's Yongbyon Nuclear Center: Rail Activity at the Radioisotope Production and Uranium Enrichment Plants", dated February 14, 2020, and available as https://www.38north.org/2020/02/yongbyon021420/.

Figure 3-15: "5 MWe" Reactor at Yongbyon as of October 2019

For non-energy commodities included in the balance, we have assumed that coal and oil used as feedstocks for ammonia production scaled with overall fertilizer output, and are thus 8 percent of 1990 levels in 2000, rising to 11 percent in 2005 and 2008, but falling again to 7 percent of 1990 levels in 2010. Estimated fertilizer production increased in 2014 through 2017 before falling to 9 percent of 1990 levels in 2018 and 2019, and to 4.6 percent in 2020 due to the economic impacts of COVID-19 measures. Other non-energy petroleum products use is assumed to be greater than 1996 levels at 38 percent of 1990 levels in 2000, but the increase relative to 1996 is mostly due to our estimate for the amount of asphalt required to build the Pyongyang-Nampo superhighway in that year. In 2005 through 2016, non-energy oil products use is estimated to have ranged between about 9 and 15 percent of 1990 levels, rising by a few percent to around 20 percent of 1990 levels in 2018 and 2019. Roundwood (logs) consumption is assumed to have declined to 50 percent of 1990 levels in 2000, and to have stayed at that level through 2020.

3.7.8. Energy resources, imports, and exports

We based our estimates of energy resources, imports, and exports for 2000 through 2020 on the data and assumptions described below. Note that a more detailed description of our analysis oil products supply and demand is provided in Chapter 6 for the years 2010 through 2020.

- Domestic coal and biomass resources were sufficient for any level of production that could be sustained by the DPRK infrastructure.
- In 2000, coal was imported by the DPRK from (at least) China (about 226,000 tonnes, including bituminous, coking, and unspecified coals), Russia (82,000 tonnes of coal, and

2000 tonnes of coke) and Australia (about 31,000 tonnes of coal), and exported to (at least) China (8,100 tonnes) and Japan (351,000 tonnes of anthracite).[356, 357, 358] There may have been additional off-the-records coal imports from or exports to China (and/or Russia), but we have no information about such transactions.

- In 2005, 147,000 tonnes of coal and coal products were imported from China, along with about 26,000 tonnes of coke. An additional 1.17 million tonnes of coal was imported from Russia. A significant amount of coal was exported to China—2.8 million tonnes[359]—and 277,000 tonnes of coal were exported to Japan.[360] Again, there may have been some off-the-record imports or exports.
- In 2008, the DPRK imported about 232,000 tonnes of coal from China, along with 7600 tonnes of coke. 192,000 tonnes of coal were imported from Russia. 2.54 million tonnes of coal were exported to China, but exports of coal to Japan were nil, having been discontinued by Japan after 2006.
- Coal imports to the DPRK from both Russia and China declined in 2009, to about 28,000 and 90,000 tonnes, respectively along with about 4000 tonnes of coke (from China). Exports of coal to China rose to 3.6 million tonnes, rising again to 4.6 million tonnes in 2010, and reaching a peak at over 22 million tonnes in 2016 (see Figure 3-16), before reported (and likely to some extent, actual) exports fell due to UNSC sanctions.[361]

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[356] Chinese import/export data from *China Customs Report 2000*, pp. 1483-1495 (in Chinese).

[357] Estimated roughly based on data from "Democratic People's Republic of Korea Fact Sheet", from the Australian Department of Foreign Trade (www.dfat.gov.au/geo/dprk, visited 5/17/2002), which listed Australian exports of coal to the DPRK during "2000-2001" as having a value of $AU 1.7 million.

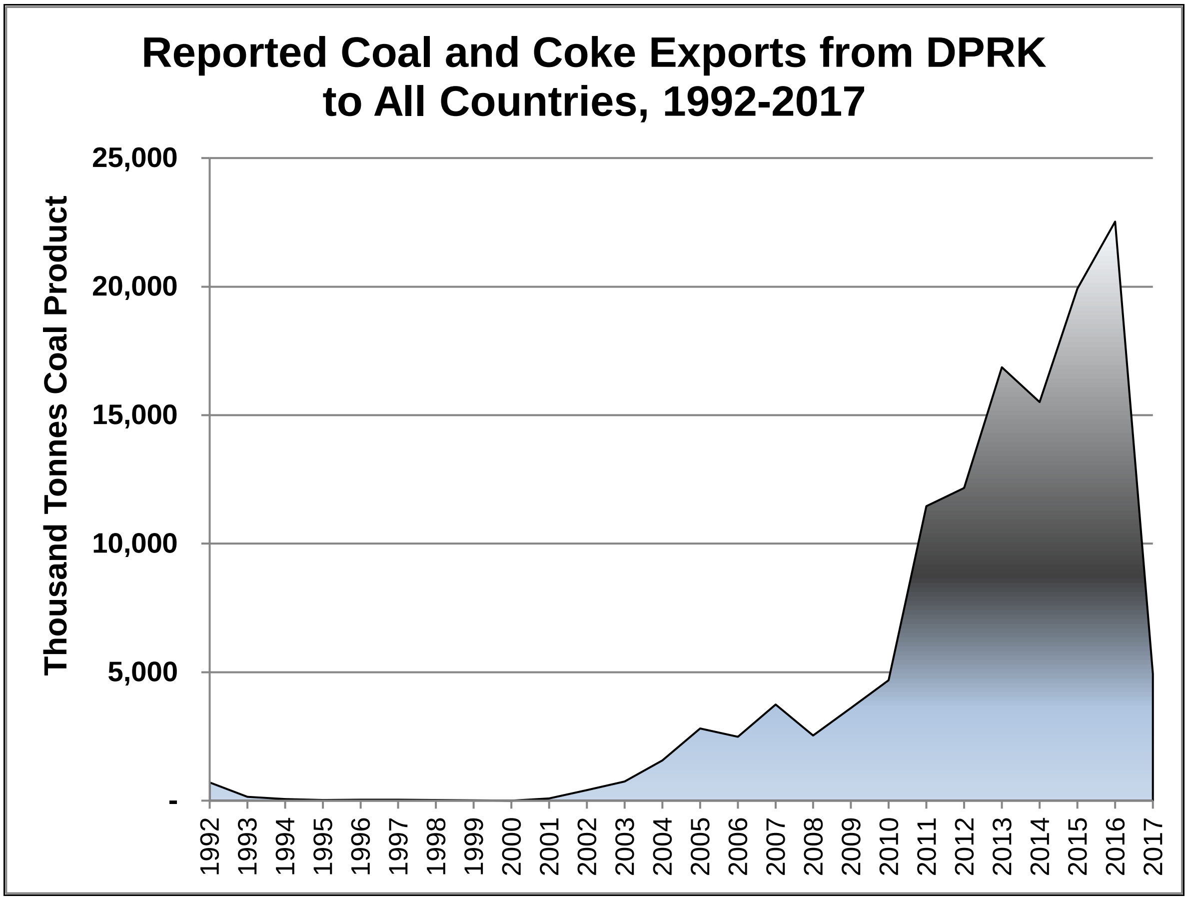
[358] From data in Japan customs statistics, http://www.customs.go.jp/toukei/info/index_e.htm.

[359] From China Customs Statistics as compiled by Nathanial Aden, 2006. For related analysis, see also N. Aden, *North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications*, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Mr. Aden's paper is available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/0679Aden1.pdf. Updated analyses prepared for Nautilus by Mr. Aden in 2008 and 2010 were drawn upon for the 2008 and2009 statistics on DPRK energy trade with China reported on here, and are summarized as http://nautilus.org/wp-content/uploads/2011/12/Aden.pdf and http://nautilus.org/wp-content/uploads/2011/12/02.-Aden.pdf.

[360] Japan customs statistics, http://www.customs.go.jp/toukei/info/index_e.htm, and formerly at http://www.customs.go.jp/toukei/download/index_d012_e.htm (the latter visited 2/2007).

[361] Data on Russia's energy trade with the DPRK, and on China's coal imports from the DPRK are taken from the United Nations "Comtrade" database (http://comtrade.un.org/db/default.aspx, accessed on several occasions).

Figure 3-16: Reported Coal and Coke Exports from the DPRK through 2017



- Crude oil imports in 2000 were limited to the 389,000 tonnes reported (in China Customs Statistics) as imported from China.[362] Imports from China in 2005 were 523,000 tonnes[363]. It is possible that a modest volume of additional crude oil was imported in one or both years, as well as in subsequent years, from an unknown location--possibly by rail from Russia or China, or by ship from Russia, China or elsewhere. Reported crude oil and oil products exports from China to the DPRK remained remarkably stable from 2005 through even 2020, as shown in Figure 6-10.[364]
- There have been reports that the DPRK "began to produce crude oil in a sea well off Sukchon County, South Pyongan Province" in 1998 (Lee Kyo Kwan, writing on www.chosun.com, "North Korea Exports Petroleum", probably sometime in 2001). This article suggests, without citing any specific figures, that DPRK production was significant enough to allow the reduction of petroleum imports. It seems clear that foreign companies have obtained the

[362] A similar quantity of crude oil imports from China was reported by KEEI in a workbook of DPRK energy statistics provided to Nautilus in April 2002.
[363] From China Customs Statistics, compiled by Nathanial Aden—see footnote above.
[364] Data for Figure 3-4 China Customs Statistics, compiled by Nathanial Aden—see footnote above, except for 2010 data, which are from the United Nations "Comtrade" database (see above).

rights to drill in DPRK territorial waters, and that some exploratory wells have been drilled (though we do not know if drilling was active during 2000). We assume based on conversations with experts in the industry (who were informed by both industry news and a knowledge of the geology of the region—which generally consists of small pockets of oil that are difficult to extract), that any production from DPRK wells, if it did occur, was minimal, and as a result have assumed that year 2000, 2005, 2008, and 2009 domestic oil production in the DPRK was 30,000 tonnes, though this figure may well be too high.[365] We further assume that this oil (or a similar quantity imported by rail or ship) was refined in the small West Coast refinery (see below).

- In 2000, refined products imports to the DPRK included products from the ROK (reported informally to be "off-spec" products,[366] probably heavy oil and diesel fuel, and in not well-known quantities, but estimated at 50,000 tonnes), Singapore (probably mostly gasoline and some diesel, totaling about 60,000 tonnes), and Japan (44,000 tonnes of heavy fuel oil, plus a minor amount of solvents and lubricants, according to customs statistics), and China (a variety of products totaling about 117,000 tonnes). According to an industry source, barter trade with Russia may have produced imports of "gas oil and light crude" from Russia at "1.5 kbbl/day or less". We have assumed an average of 1500 bbl/day. These quantities are in addition to the 395,000 tonnes of heavy fuel oil delivered by KEDO during the 2000 calendar year[367]. We also assume that the DPRK continued to receive oil product imports equal to about half of the output of a refinery on the Chinese side of the China/DPRK border. These

[365] Though our conversations with some experts in the industry have suggested that any production from DPRK wells was minimal, other sources in the literature suggest that DPRK oil production has indeed been enough to supply a significant fraction of DPRK needs. For example, Selig Harrison writes in *Toward Oil and Gas Cooperation in Northeast Asia: New Opportunities for Reducing Dependence on the Middle East* (published as Woodrow Wilson Center for International Scholars Asia Program Special Report No. 106, dated December 2002, and available as http://www.wilsoncenter.org/topics/pubs/asiarpt_106.pdf), that "an oil well [in Sukchon] began producing 2.2 million barrels annually in 1999". This is similar to a figure of 300,000 tonnes crude oil per year quoted in several publications by Keun-Wook Paik, including *Pipeline Gas Introduction to the Korean Peninsula*, published by Chatham House, January 2005, and available as http://www.chathamhouse.org.uk/pdf/research/sdp/KPJan05.pdf. In the Chatham House report, Paik wrote (p. 37) "Even though the scale of annual crude oil production from the Sook-Cheong County's Anju Basin is very small (0.3 mt/y), to the North Korean authorities it is a significant volume." In personal correspondence with Dr. Paik, he indicated that the information for this estimate came from an article in the ROK press in approximately 2001—probably the chosun.com article referenced above, and that while he had not seen the quantity of oil production confirmed, he believed that some oil production was ongoing. Dr. Harrison indicated that his figure for DPRK oil production was likely taken from the work of Dr. Paik, or from the same original source. Other experts in the field consulted on this question have expressed skepticism that DPRK domestic oil production to date, if any, has been even close to as significant as the quantity reported. Accordingly, we assume that a more reasonable figure for ongoing DPRK domestic oil production is one the order of 10 percent of the reported (300,000 tonne) value (which might also have been misreported due to an error in reporting units, as happens occasionally in the DPRK and elsewhere). Another estimate of DPRK oil production is offered in *index mundi* (http://www.indexmundi.com/g/g.aspx?c=kn&v=88), based on data from the CIA World Factbook, which suggests that DPRK oil production in 2004 to 2007 was about 140 bbl per day, declining to 118 bbl per day in 2009 (and 2010, according to the *CIA World Factbook*). The index mundi (CIA) estimate of 140 bbl/day is the equivalent of 7,000 tonnes/yr, considerably lower than the estimate we are using, but on the same order of magnitude, and perhaps equally plausible (but also equally speculative).

[366] "Off-spec" denotes products which may not have met quality or other standards for sale in the ROK or other countries. These could include, for example, fuels with higher-than-allowed levels of sulfur or other impurities, or fuels that did not meet octane or other specifications.

[367] Note that, based on KEDO flow-meter-based estimates, approximately 200,000 tonnes of heavy fuel oil remained in storage in the DPRK as of the end of calendar 2000 (Korean Peninsula Energy Development Organization *2002 Annual Report*, available as KEDO_AR_2002.PDF from www.kedo.org; page 10). As KEDO changed its practice of accounting for deliveries and estimated consumption of HFO (the definition of "HFO Years") between 2001 and 2002, it is not possible to definitively determine from KEDO annual reports how much HFO was estimated to be in storage as of the beginning of 2000, but KEDO data for months close to the end of 1999 suggest that HFO in storage at the beginning of 2000 was also close to 200,000 tonnes, meaning that consumption of HFO more or less matched HFO deliveries for the calendar year.

products are estimated to have totaled about 300,000 tonnes in 2000. For 2005, the DPRK received just under 150,000 tonnes of oil products "officially" from China, with gasoline, diesel fuel, and kerosene/jet fuel the dominant products. We assume that the DPRK also received a smaller share (a total of 150,000 tonnes) from the output of the Chinese refinery near the border, and about 60,000 tonnes of fuel (mostly diesel oil) from the ROK. 2005 imports of oil products to the DPRK from Japan were very limited (100 tonnes).

- We estimate that the total DPRK refined products imports in 2008 were about 700,000 tonnes. Of this total, 304,000 tonnes were in the form of heavy fuel oil provided to the DPRK as a part of the Six-Party Talks agreement. Most of the rest was imports from China and Russia, but trade statistics show that the DPRK also imported much smaller amounts of various products from Malaysia, Singapore, Japan (a tiny amount), the Netherlands, and (probably) India.[368]
- In 2009, we estimate that oil products imports to the DPRK were about 310,000 tonnes, with much (but not all) of the large drop related to the cessation of HFO shipments from the Six-Party Talks agreement. The largest portion (but less than half) of these imports came from China, with the rest being cobbled together from most of the same sources the DPRK received oil products from in 2008, with additional small quantities probably coming from other countries as well.
- Also listed under refined products in 2000 are the imports of about 22,000 tonnes of used tires (or fuel derived from same) from Japan (additional shipments may have originated in Taiwan) for use as a boiler fuel (for electricity generation).[369] Cargoes of tires from Europe have reportedly also been requested by the DPRK. Imports of used tires/tire-derived fuel to the DPRK from Japan in 2005 were 26,000 tonnes, with imports declining to about 8600 tonnes in 2006, the last year that such shipments were reported.
- Year 2000 exports of refined products from the DPRK include about 24,000 tonnes of mostly heavy oil exported to China. We have guessed that the DPRK traded about 48,000 tonnes of heavy oil, probably to China, receiving in exchange sufficient asphalt to construct the new (at the time) superhighway between Nampo and Pyongyang (finished in late 2000). Although there may have been similar trading of oil products in 2005, the only on-the-record exports of oil products from the DPRK to China in 2005 were about 4,400 tonnes of liquefied petroleum gases. The DPRK exported about 3000 tonnes of similar products to China in both 2008 and 2009, and also exported a tiny (just under 4 tonnes) amount of oil products to Russia in 2008.

[368] Indian trade statistics show substantial (on the order of one million tonnes, with value near a billion dollars) shipments of oil products to the DPRK in 2008 and 2009. The sizes and types of these shipments (including large amounts of naptha, typically used as an input to the plastics industry), however, have led us and other analysts to conclude that most or all of these reported trades were in fact between India and the Republic of Korea, not the DPRK, and that there were simply clerical errors in reporting the trades. India's petroleum product trade with the ROK in recent years has been very large. We have assumed that a just small fraction of the reported imports of oil products from India actually did go to the DPRK—perhaps one smaller tanker's worth (20,000 tonnes).

[369] A source from the industry reported that the DPRK likely received a total of 25,000 tonnes of used auto tires from Japan and Taiwan in 2000 for use as a supplemental boiler fuel. This estimate corresponds well with data from Japan Customs Statistics (data from files downloaded from http://www.customs.go.jp/toukei/download/index_d012_e.htm) that lists year 2000 exports from Japan to the DPRK in a category (HS # 400400000) that is defined as "Waste, parings and scrap of rubber (other than hard rubber) and powders and granules obtained therefrom" at a total level of 22,156 tonnes in 2000, and 25,599 tonnes in 2005.

3.7.9. Data and assumptions regarding energy transformation processes in 2000, 2005, 2008, and 2009

Below we present the key data and assumptions used for our estimated of year 2000/2005/2008/2009 activities in the major fuels "transformation" sectors—coal production, oil refining, and electricity generation, transmission, and distribution. For electricity generation/transmission and distribution and oil products supplies, Chapters 5 and 6, respectively, provide additional detail on our estimates from 2010 through 2020, as well as some additional information about the operation of those sectors in earlier years. (Charcoal production is assumed to be sufficient to produce the modest quantities required.)

- We generally assume that **sufficient coal mining capacity is operable** to supply the DPRK economy at the low level of demand reflected in the 2000 through 2009 energy balances. Some DPRK observers have suggested that some large coal mines have been operating since the late 2000s, which is consistent with the large increase in coal exports seen in the mid-2010s, and media reports (many of them from DPRK agencies) have mentioned the output of major mines. Other observers suggest that practically no large mines were operating as of 2000, due to electricity shortages, but that some smaller, less mechanized mines may have continued to supply residential and perhaps other users. The mines in the important Anju region, portions of which lie below the seabed, reportedly continued to be flooded and inoperable, in part due to lack of electricity for pumping. Recent investments in selected coal mines by Chinese companies have been noted, doubtless supporting the 2.8 million tonnes of coal exports from the DPRK to China recorded in 2005 (up to 22 million by 2016, as noted above). Further, the DPRK government was, at least at one point, revising ownership rules to encourage any (foreign and, presumably, domestic) groups to undertake coal mine operation, whether those groups had coal supply expertise or not.[370]
- We assume that the **East Coast (Sonbong) refinery remained largely closed**, and that the **West Coast refinery** on the Chinese border (on the DPRK side) **continued and continues to operate** with crude oil provided from China. As a consequence, the latter plant was assumed to operate at an average of 27 percent of capacity during 2000, 37 percent of capacity in 2005 and 2008, and 36 percent of capacity in 2009, increasing to about 50 percent by 2018-2020.
- There is apparently another **small** (capacity unknown) **refinery** on the DPRK's West Coast. This refinery is reportedly very basic, lacking any "cracking" capacity, and operating in batch mode as a "fractionating" unit to produce fuels, reportedly, for the military. We have "back-calculated" the output from (and input to) this plant based on assumptions about the product slate, the capacity factor of an associated 60 MW power plant that uses heavy oil from the refinery, and the efficiency of that plant. See Attachment 1 for details of these calculations.
- Conversations with industry sources indicated that the **thermal power generation** system in the DPRK was rapidly eroding as of 2000. In virtually all of the large power stations, only selected boilers and turbines are operating, if any are operating at all. The (nominal) 200

[370] For example, NK Brief No 06-12-14-1, titled *Independent Coal Mines Get Legal Backing in DPRK*, and based on a Korean Central Broadcasting Agency report dated 12/112006, describes a December 2006 law, the "Small-Medium Coal Mines Management Development Regulations", that a number of different types of foreign organization now have the "legal support", upon receiving official permission, to develop small and medium coal mines. The article also cites a recognition that coal production has decreased.

MW heavy fuel oil-fired plant near the (East Coast) Sonbong refinery—which has recently been undergoing conversion to use coal—apparently did not operate at all in 2000, and at least three other 100 MW plants also did not operate. Those plants that do operate are reportedly plagued by problems with "air heaters"—devices that extract heat from exhaust gases to heat incoming combustion air. These air heaters have in most plants been degraded to the point of inoperability by acid gases from the combustion of high sulfur fuels such as heavy oil and used tires.[371] The result was reportedly a considerable decrease in plant efficiency, quite possibly greater than the decrease in efficiency (from 28 percent in 1990 to 23 percent in 2000, before accounting for plant own-use) that we have assumed. Further, boiler tubes in many power plants have been degraded from the outside by acid gases from high-sulfur fuels, and from the inside by the use of inadequately-treated or untreated boiler feed water. The lack of spare boiler tubes—and in many cases it may be that boiler tubes to fit these generators, which were built in the 1950s and 1960s, are not available at all, anywhere—means that it is very difficult to repair the boiler tube degradation. Two power plants, however, were added to the roster of thermal generators that we previously knew about. A 60 MW plant built for operation on heavy fuel oil is located near the small West Coast refinery described above. This power plant only operates when crude oil is processed by the associated small refinery. A diesel engine-type plant with capacity totaling 9.8 MW was recently installed and operated for much of 2000 at Songlim, in association with a steel plant there. This plant generally seems to have been fueled with heavy fuel oil. In total, we estimate that less than 800 MW of thermal capacity were operable as of 2000, though it is possible that some other units were technically operable but did not operate due to lack of fuel. For those power plants that were operable, we estimate an average capacity factor in the range of 50 percent or less, due to maintenance problems and lack of fuel.

Many of the problems noted above reportedly persisted through 2009, but we have little direct evidence of significant changes in the sector since 2002 (see Chapter 5 of this Report). We have heard reports of some repairs at major power plants, including the (nominal) 1600 MW Pukchang plant, as well as reports of arrangements for importing of used power plant boilers, possibly from Eastern Europe.[372] Based on what we have heard from other observers, estimates by the (ROK) Korea Electrotechnical Research Institute (KERI) that operable thermal capacity was about 2 GW, and output 5.4 TWh, in 2005, seems reasonable, and we have adopted these estimates.[373] We estimate the output of thermal generation in 2008 at nearly the same level as 2005—5.3 TWh, but, based on consideration of the ratio of ROK overall generation estimates in 2008 and 2009, we estimate the total thermal generation in 2009 to have been lower—about 4.2 TWh.[374]

[371] Oxford Recycling Inc. (http://www.oxfordrecycling.com/product.html#5, visited 6/8/02) lists a sulfur content of 1.3 percent for fuel from shredded tires.

[372] Observers suggest that the coal mine feeding the Pukchang power plant was working at less than full capacity (as of several years ago), as the use of largely older, manual tools limited output despite the mine being in operation around the clock. The mine provides coal to other DPRK counties and provinces. Observers report that the Pukchang power plant itself appeared to be operating at near-full capacity during approximately 2005, with most or all boilers in use most of the time.

[373] J.Y. Yoon , "Analysis of Present Status and Future Supply /Demand Prospects for the DPRK Power System", presented at the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.

[374] 13 For 2009, we assume that there was a decrease in overall gross generation approximately equal to that estimated by J.Y. Yoon in his presentation for the 2010 Energy and Minerals Experts Working Group Meeting in Beijing, September 2010 (available from https://nautilus.org/projects/by-name/dprk-energy/2010-meeting/papers/, and in narrative form at http://nautilus.org/napsnet/napsnet-special-reports/the-dprk-power-sector-data-and-interconnection-options/), "Analysis on

- As a consequence of the difficulties with thermal power plants, **hydroelectric plants** had shouldered the burden of power generation in the DPRK by 2000. Information from industry sources indicated that any difficulties associated with the 1995/1996 flood damage to the shared power stations (China/DPRK) along the Chinese border has been repaired, and those plants were operating normally within a few years. Normally, however, apparently means that those plants—about 700 MW of capacity each for China and for the DPRK—are used largely in a peaking mode to conserve river water, and operate at full capacity only during the rainy mid-July to mid-August period. We have thus assumed an overall capacity factor of 17.5 percent for these units. Other hydroelectric facilities in the DPRK may in fact be operated in a similar manner, and it is clear that the country as a whole has far less power in the dry winter than at other times of the year. We have assumed, for the year 2000, that of the approximately 3900 MW of other hydroelectric plants, 75 percent of capacity was operable, and those operable hydro plants had a capacity factor in 2000 (a low water year) equaling 75 percent of the capacity factor assumed for 1996, or about 33 percent overall. This could, in fact, prove an over-estimate.
- A major "Youth Dam" including a tunnel system for carrying water, had recently been completed, but its hydroelectric capacity, if any as of 2000, was unclear. Also underway, at the time of the 2000 Nautilus visit to the DPRK, was a scheme to dam the Taedong River to provide irrigation water to rice fields on the Southwest Coast of the DPRK without the need to pump water from the Nampo barrage area. That project has since been completed (see Figure 3-10), but it is not clear to the authors whether the latter project has or is expected to have significant associated hydroelectric capacity, or whether the "Youth Dam" and the Taedong water diversion project are related.
- For 2005, we have based our estimate of hydroelectric output on data from KERI (see endnote reference above), but added 100 MW of large hydroelectric capacity, plus 86 MW of medium-sized hydroelectric capacity, to account for facilities completed (or likely completed) in 2005. The resulting estimate of hydroelectric capacity for 2005 is about 4100 MW, with output of about 11 TWh and thus an average capacity factor of a bit over 30 percent. In 2008 and 2009, hydroelectric capacity is assumed to have increased somewhat over 2005 as a result of the completion of several medium-sized (tens of MW) hydro plants. Average capacity factors for hydroelectric plants in both years were estimated at just under 32 percent, with total output of just under 12 TWh in both years.
- The above assumptions as to electricity generation imply a gross output of about 13.3 terawatt-hours in 2000, 16.5 TWh in 2005, 17.2 TWh in 2008, and 16.2 TWh in 2009. Chinese customs statistics cite export of 22.7 GWh to China from the DPRK in 2000,

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DPRK Power Industry & Interconnection Options". In the presentation, Yoon quotes ROK analysts as estimating that the DPRK's generation in 2008 was 25.5 TWh, and generation in 2009 was 23.5 TWh. We do not use these absolute generation estimates, because we believe that they are too high (Mr. Yoon agreed that a "minimum" value could be closer to 16 TWh for 2007, for which ROK analysts estimate output of 23.7 TWh), but we use the ratio of these 2009 and 2008 estimates, 92.2%, to estimate a target value for 2009 output. As another point of comparison, a recent article by the Yonhap News Agency ("N. Korea's power consumption per capita at 1970s levels", dated 8/6/2010, and available as https://en.yna.co.kr/view/AEN20120806003300315), quoting the ROK's Statistics Korea, describes per-capita consumption in the DPRK of 819 kWh per capita, which would, based on the population assumptions used in this report, equate to about 19.7 TWh of overall consumption. Whether the quoted figure is intended to be actual end-use consumption, or simply overall estimated electricity production divided by population, is unclear, as is the ultimate source used by Statistics Korea to prepare the estimate.

apparently in addition to the shared output of the plants on the border rivers.[375] No exports of power from China to the DPRK were recorded in 2000. China Customs statistics reported DPRK electricity exports to China in 2005 of 90 GWh, along with exports of 143.5 GWh in 2008 and 128.9 GWh in 2009. Imports of power to the DPRK from China had fallen to about 660 MWh in 2005, but rose again to 17.9 GWh in 2008, falling to 6.9 GWh in 2009 (and 3.3 GWh in 2010). Imports of power from China may therefore be helpful in some local areas near the border, possibly to provide power for enterprises in which Chinese firms have invested, but imports from China do not contribute much to overall DPRK electricity needs.

- We have assumed, based on reports of the continuing erosion of the transmission and distribution (T&D) grid, that T&D losses were 20 percent higher in 2000 through 2009 than in 1996, totaling over 27 percent of net generation. Although "own use" at coal-fired power plants was assumed to remain at 9 percent of gross generation, we assumed that additional "emergency losses" decreased net output at coal-fired power plants, with overall net emergency losses totaling 9.4 percent in 2000, and a slightly lower 9 percent in 2005 through 2020, reflecting some improvements in power plant maintenance (or, alternatively, the abandonment of units with worse-than-average losses).

3.8. Presentation of Estimated Year 2000, 2005, 2008 through 2010, and 2014 through 2020 DPRK Energy Balances, and Discussion of Results

In this section we present our estimated DPRK energy balances for 2000 through 2020. We provide presentations of results for all fuels, as balances focusing on the supply of and demand for electricity and of refined products in particular are presented in Chapters 5 and 6 of this Report. As with our 1990 and 1996 balances, these pictures of the DPRK energy sector in 2000 through 2020 were pieced together from information from many different sources, with many assumptions made to fill in the gaps in data. In so doing, we have attempted, however, to make the balances as internally consistent as possible. Although the balances are doubtless in error in many areas, we hope that it will provide a good starting point for those studying and discussing the current state of the energy sector in the DPRK, and we would as always welcome any additional information that reviewers of this document can provide. Additional results of our estimates of year 2000 through year 2020 energy supply and demand in the DPRK can be found in Attachments 1 and 2 to this Report.

Table 3-1 through Table 3-12 present summary versions of our estimated 2000 through 2020 energy balances for the DPRK. More detailed versions of selected balances (for 2000, 2010, 2016, 2019, and 2020) are presented as Table 3-13 through Table 3-17. Detailed balances for these and other years can be found in Attachment 1, as can detailed balances that focus on the supply of and demand for refined petroleum products and electricity. Detailed electricity and petroleum products balances for recent years are also presented in sections 5.3.1 and 0 of this Report. In the summary balances, the largest difference between 1996 and 2000 is a pronounced (and growing) increase in the fraction of the total DPRK energy budget supplied by wood and biomass (17 percent of supplies in 1996 vs. 27 percent in 2000, a slightly larger 28 percent in

[375] Apparently, the shared hydro facilities on the Tumen and Yalu rivers have turbine sets dedicated to and operated by the DPRK, and turbine sets dedicated to and operated by China. The two sets of turbines are operated at different frequencies. The water resource appears, however, to be jointly managed, so that the two sets of turbines operate with the same capacity factor.

2005, rising to 31 percent in 2010, then falling to a low of 23 percent in 2019 with better coal availability, then rising again to 27 percent in 2020 as the impacts of COVID-19 restrictions reduced activities in most non-residential sectors. Increases and decreases in the fractions of total demand met by wood and biomass use were met with changes in opposite direction in the fractions of the DPRK energy budget accounted for by other fuels, particularly coal and coal products, as shown in Figure 3-17 through Figure 3-23.

Figure 3-24 and Figure 3-25 show, respectively the breakdown in shares of overall energy use by sector from 1990 through 2020, and absolute energy use by sector in those years. Continuing the trend of 1990 to 1996 described in Chapter 2 of this Report, the residential sector uses an even larger share (over 40 percent in each year) of the overall energy budget, while the industrial sector share of total energy use shrinks to less than a third of the total through 2019, and falls even further in 2020 due to a decline in industrial activity due to DPRK measures to restrict the spread of COVID-19. This change is in general the combined result of continued reduction in fuel demand in the industrial sector, slowly rising use of wood and other biomass fuels in the residential and other sectors, and reductions in the use of other residential fuels (notably coal and electricity) that are not as severe as the reductions experienced in the industrial sector, although results vary on a year-to-year basis. Figure 3-26 shows the patterns of final fuels demand by fuel, with the share of coal use eroding in 1990s and early 2000s but increasing again slightly in the latter half of the 2010s. Figure 3-27 through Figure 3-32 show the patterns of demand for coal by sector in selected years between 2000 and 2020.

Table 3-1: Summary Estimated Supply/Demand Balance for the DPRK in 2000

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	339	17	40	38	160	0	-	(0)	594
Domestic Production	336	0	-	38	151	-		-	525
Imports	12	17	42	-	12	0		-	83
Exports	9	-	3	-	3	0		0	15
Stock Changes	-	-	(1)	-	-	-		-	(1)
ENERGY TRANSF.	(53)	(17)	(1)	(38)	(6)	2	3	31	(79)
Electricity Generation	(32)	-	(16)	(38)	-	-	2	48	(35)
Petroleum Refining	-	(17)	17	-	-	-		(0)	(0)
Coal Prod./Prep.	(16)	-	-	-	-	-		(2)	(18)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(1)		(0)				1		(1)
Own Use	-	-	(1)	-	-	-		(2)	(3)
Losses	(4)	-	-	-	-	-	(1)	(13)	(17)
FUELS FOR FINAL CONS.	286	-	39	-	154	2	3	31	515
ENERGY DEMAND	286	-	39	-	154	2	3	31	515
INDUSTRIAL	150	-	12	-	1	-	-	13	175
TRANSPORT	-	-	8	-	1	-	-	3	12
RESIDENTIAL	95	-	2	-	122	2	2	3	225
AGRICULTURAL	3	-	1	-	15	-	-	1	19
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	21	-	11	-	7	-	-	7	47
PUBLIC/COMML	16	-	0	-	3	-	1	3	23
NON-SPECIFIED			-	-					-
NON-ENERGY	1		4		6				11
Elect. Gen. (Gr. TWhe)*	2.64	-	0.15	10.47	-	-		-	13.26

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-2: Summary Estimated Supply/Demand Balance for the DPRK in 2005

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	391	23	23	44	187	(0)	-	(0)	668
Domestic Production	434	0	-	44	182	-		-	661
Imports	36	22	23	-	7	0		0	89
Exports	80	-	0	-	2	0		0	82
Stock Changes	-	-	(0)	-	-	-		-	(0)
ENERGY TRANSF.	(112)	(23)	13	(43)	(6)	2	4	38	(127)
Electricity Generation	(84)	-	(8)	(43)	-	-	4	60	(72)
Petroleum Refining	-	(23)	23	-	-	-		(0)	(0)
Coal Prod./Prep.	(21)	-	-	-	-	-		(3)	(24)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				2		(0)
Own Use	-	-	(1)	-	-	-		(4)	(5)
Losses	(5)	-	-	-	-	-	(1)	(15)	(22)
FUELS FOR FINAL CONS.	279	-	36	1	181	2	4	38	541
ENERGY DEMAND	279	-	36	-	181	2	4	38	539
INDUSTRIAL	150	-	9	-	1	-	-	15	175
TRANSPORT	-	-	11	-	1	-	-	4	16
RESIDENTIAL	85	-	2	-	135	2	2	4	230
AGRICULTURAL	5	-	1	-	26	-	-	1	34
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	20	-	11	-	8	-	-	9	47
PUBLIC/COMML	17	-	0	-	5	-	1	5	28
NON-SPECIFIED			-	-					-
NON-ENERGY	2		1		6				8
Elect. Gen. (Gr. TWhe)	5.15	-	0.26	11.15	-	-		-	16.55

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-3: Summary Estimated Supply/Demand Balance for the DPRK in 2008

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	TOTAL
ENERGY SUPPLY	379	23	26	43	204	0	-	0	675
Domestic Production	427	0	-	43	200	-		-	669
Imports	19	23	30	-	6	0		1	78
Exports	67	-	4	-	1	0		1	72
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(107)	(23)	9	(43)	(6)	2	4	40	(124)
Electricity Generation	(80)	-	(13)	(43)	-	-	4	62	(69)
Petroleum Refining	-	(23)	23	-	-	-		(0)	(0)
Coal Prod./Prep.	(20)	-	-	-	-	-		(3)	(23)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				1		(1)
Own Use	-	-	(1)	-	-	-		(3)	(5)
Losses	(5)	-	-	-	-	-	(1)	(16)	(22)
FUELS FOR FINAL CONS.	272	-	34	-	198	2	4	40	550
ENERGY DEMAND	272	-	34	-	198	2	4	40	550
INDUSTRIAL	155	-	7	-	1	-	-	15	179
TRANSPORT	-	-	12	-	1	-	-	4	17
RESIDENTIAL	74	-	2	-	153	2	3	5	239
AGRICULTURAL	5	-	1	-	25	-	-	1	32
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	18	-	10	-	7	-	-	9	45
PUBLIC/COMML	17	-	0	-	5	-	1	5	29
NON-SPECIFIED			-	-					-
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	5.12	-	0.29	11.83	-	-		-	17.23

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-4: Summary Estimated Supply/Demand Balance for the DPRK in 2009

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	TOTAL
ENERGY SUPPLY	397	22	13	43	205	0	-	0	681
Domestic Production	484	0	-	43	202	-		-	729
Imports	7	22	14	-	5	0		1	48
Exports	94	-	0	-	1	-		0	96
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(99)	(22)	14	(43)	(6)	2	4	37	(113)
Electricity Generation	(68)	-	(7)	(43)	-	-	4	58	(56)
Petroleum Refining	-	(22)	22	-	-	-		(0)	(0)
Coal Prod./Prep.	(23)	-	-	-	-	-		(3)	(26)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				1		(1)
Own Use	-	-	(1)	-	-	-		(3)	(4)
Losses	(6)	-	-	-	-	-	(1)	(15)	(22)
FUELS FOR FINAL CONS.	298	-	28	-	199	2	4	37	568
ENERGY DEMAND	298	-	28	-	199	2	4	37	568
INDUSTRIAL	181	-	5	-	1	-	-	15	202
TRANSPORT	-	-	9	-	1	-	-	4	14
RESIDENTIAL	76	-	2	-	156	2	2	4	241
AGRICULTURAL	5	-	1	-	24	-	-	1	31
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	18	-	9	-	7	-	-	8	43
PUBLIC/COMML	17	-	0	-	5	-	1	5	28
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	4.05	-	0.32	11.87	-	-		-	16.24

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-5: Summary Estimated Supply/Demand Balance for the DPRK in 2010

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	383	25	15	43	208	0	-	1	675
Domestic Production	492	0	-	43	205	-		-	739
Imports	13	25	16	-	4	0		1	60
Exports	122	-	2	-	1	0		1	124
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(89)	(25)	17	(43)	(6)	2	4	36	(105)
Electricity Generation	(58)	-	(7)	(43)	-	-	3	57	(48)
Petroleum Refining	-	(25)	25	-	-	-		(0)	(0)
Coal Prod./Prep.	(24)	-	-	-	-	-		(3)	(27)
Charcoal Production	-	-	-	-	(6)	2		-	(4)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(1)	-	-	-		(2)	(4)
Losses	(6)	-	-	-	-	-	(1)	(15)	(22)
FUELS FOR FINAL CONS.	294	-	31	-	202	2	4	37	570
ENERGY DEMAND	294	-	31	-	202	2	4	37	570
INDUSTRIAL	176	-	6	-	1	-	-	15	197
TRANSPORT	-	-	10	-	1	-	-	4	15
RESIDENTIAL	77	-	2	-	158	2	2	4	245
AGRICULTURAL	5	-	1	-	24	-	-	1	31
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	18	-	10	-	7	-	-	8	44
PUBLIC/COMML	17	-	0	-	5	-	1	4	28
NON-SPECIFIED			-						-
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	3.44	-	0.36	11.91	-	-		-	15.70

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-6: Summary Estimated Supply/Demand Balance for the DPRK in 2014

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	457	25	21	39	208	-	-	1	751
Domestic Production	851	0	-	39	205	-		-	1,096
Imports	8	25	22	-	5	-		1	60
Exports	402	-	1	-	2	-		1	406
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(153)	(25)	11	(39)	(7)	2	3	37	(171)
Electricity Generation	(100)	-	(12)	(39)	-	-	3	62	(87)
Petroleum Refining	-	(25)	25	-	-	-		(0)	(0)
Coal Prod./Prep.	(41)	-	-	-	-	-		(6)	(46)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(1)	-	-	-		(4)	(5)
Losses	(10)	-	-	-	-	-	(1)	(15)	(27)
FUELS FOR FINAL CONS.	304	-	32	-	202	2	3	37	580
ENERGY DEMAND	304	-	32	-	202	2	3	37	580
INDUSTRIAL	166	-	6	-	1	-	-	17	190
TRANSPORT	-	-	10	-	1	-	-	3	15
RESIDENTIAL	91	-	2	-	156	2	2	3	256
AGRICULTURAL	5	-	1	-	26	-	-	1	34
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	19	-	10	-	7	-	-	8	44
PUBLIC/COMML	19	-	0	-	5	-	1	4	30
NON-SPECIFIED			-						-
NON-ENERGY	3		1		6				10
Elect. Gen. (Gr. TWhe)	5.97	-	0.66	10.57	-	-		-	17.20

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-7: Summary Estimated Supply/Demand Balance for the DPRK in 2015

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	TOTAL
ENERGY SUPPLY	463	28	25	40	204	-	-	1	762
Domestic Production	950	0	-	40	202	-		-	1,192
Imports	30	27	25	-	5	-		2	89
Exports	516	-	0	-	2	-		0	519
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(159)	(28)	9	(40)	(7)	2	3	37	(182)
Electricity Generation	(100)	-	(17)	(40)	-	-	3	62	(92)
Petroleum Refining	-	(28)	28	-	-	-		(0)	(0)
Coal Prod./Prep.	(45)	-	-	-	-	-		(6)	(52)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(2)	-	-	-		(3)	(5)
Losses	(12)	-	-	-	-	-	(1)	(15)	(28)
FUELS FOR FINAL CONS.	304	-	35	-	198	2	3	38	580
ENERGY DEMAND	304	-	35	-	198	2	3	38	580
INDUSTRIAL	157	-	8	-	1	-	-	17	182
TRANSPORT	-	-	11	-	1	-	-	4	16
RESIDENTIAL	99	-	3	-	151	2	2	3	260
AGRICULTURAL	6	-	1	-	27	-	-	1	35
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	20	-	10	-	7	-	-	8	45
PUBLIC/COMML	20	-	1	-	5	-	1	4	31
NON-SPECIFIED			-						-
NON-ENERGY	3		1		6				10
Elect. Gen. (Gr. TWhe)	5.08	-	0.96	11.25	-	-		-	17.29

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-8: Summary Estimated Supply/Demand Balance for the DPRK in 2016

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	TOTAL
ENERGY SUPPLY	477	28	30	42	197	-	-	(0)	774
Domestic Production	1,020	0	-	42	194	-		-	1,257
Imports	41	28	30	-	4	-		0	104
Exports	584	-	0	-	2	-		1	586
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(155)	(28)	8	(42)	(7)	2	4	39	(180)
Electricity Generation	(91)	-	(20)	(42)	-	-	3	65	(85)
Petroleum Refining	-	(28)	29	-	-	-		(0)	0
Coal Prod./Prep.	(49)	-	-	-	-	-		(7)	(55)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(2)	-	-	-		(4)	(5)
Losses	(12)	-	-	-	-	-	(1)	(16)	(29)
FUELS FOR FINAL CONS.	322	-	37	-	190	2	4	39	594
ENERGY DEMAND	322	-	37	-	190	2	3	39	593
INDUSTRIAL	165	-	8	-	1	-	-	16	191
TRANSPORT	-	-	11	-	1	-	-	4	16
RESIDENTIAL	107	-	3	-	146	2	2	4	264
AGRICULTURAL	5	-	1	-	24	-	-	1	32
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	20	-	11	-	6	-	-	9	46
PUBLIC/COMML	21	-	1	-	5	-	1	4	33
NON-SPECIFIED			-						-
NON-ENERGY	3		1		6				10
Elect. Gen. (Gr. TWhe)	5.44	-	1.21	11.50	-	-		-	18.15

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-9: Summary Estimated Supply/Demand Balance for the DPRK in 2017

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR- COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	460	28	17	38	172	-	-	(1)	713
Domestic Production	567	0	-	38	169	-		-	774
Imports	29	27	17	-	4	-		0	77
Exports	137	-	0	-	1	-		1	139
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(126)	(28)	15	(38)	(7)	2	4	37	(142)
Electricity Generation	(90)	-	(11)	(38)	-	-	3	59	(77)
Petroleum Refining	-	(28)	28	-	-	-		(0)	(0)
Coal Prod./Prep.	(27)	-	-	-	-	-		(4)	(31)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(2)	-	-	-		(4)	(5)
Losses	(7)	-	-	-	-	-	(1)	(15)	(23)
FUELS FOR FINAL CONS.	334	-	31	-	165	2	4	36	571
ENERGY DEMAND	334	-	31	-	165	2	3	36	571
INDUSTRIAL	158	-	4	-	1	-	-	14	177
TRANSPORT	-	-	10	-	1	-	-	4	15
RESIDENTIAL	126	-	3	-	123	2	2	4	260
AGRICULTURAL	5	-	1	-	22	-	-	1	29
FISHERIES	0	-	1	-	-	-	-	0	2
MILITARY	20	-	9	-	6	-	-	9	45
PUBLIC/COMML	23	-	1	-	5	-	1	4	34
NON-SPECIFIED			-						-
NON-ENERGY	2		1		6				10
Elect. Gen. (Gr. TWhe)	5.29	-	0.67	10.37	-	-		-	16.33

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-10: Summary Estimated Supply/Demand Balance for the DPRK in 2018

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR- COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	449	31	13	39	165	-	-	(1)	697
Domestic Production	531	0	-	39	161	-		-	732
Imports	0	30	13	-	4	-		0	48
Exports	82	-	0	-	0	-		1	83
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(107)	(31)	17	(39)	(7)	2	4	35	(125)
Electricity Generation	(73)	-	(12)	(39)	-	-	4	56	(64)
Petroleum Refining	-	(31)	31	-	-	-		(0)	(0)
Coal Prod./Prep.	(25)	-	-	-	-	-		(3)	(29)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(2)	-	-	-		(3)	(5)
Losses	(7)	-	-	-	-	-	(1)	(14)	(22)
FUELS FOR FINAL CONS.	343	-	30	-	158	2	4	35	571
ENERGY DEMAND	343	-	30	-	158	2	3	35	571
INDUSTRIAL	155	-	4	-	1	-	-	13	173
TRANSPORT	-	-	10	-	1	-	-	4	14
RESIDENTIAL	137	-	3	-	117	2	2	4	266
AGRICULTURAL	4	-	1	-	21	-	-	1	27
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	21	-	9	-	7	-	-	9	45
PUBLIC/COMML	24	-	1	-	5	-	1	4	36
NON-SPECIFIED			-						-
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	4.34	-	0.67	10.55	-	-		-	15.56

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-11: Summary Estimated Supply/Demand Balance for the DPRK in 2019

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	457	31	14	38	165	-	-	(1)	704
Domestic Production	619	0	-	38	161	-		-	819
Imports	0	30	14	-	4	-		0	49
Exports	163	-	0	-	-	-		1	164
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(112)	(31)	16	(38)	(7)	2	3	35	(131)
Electricity Generation	(73)	-	(13)	(38)	-	-	3	57	(64)
Petroleum Refining	-	(31)	31	-	-	-		(0)	(0)
Coal Prod./Prep.	(30)	-	-	-	-	-		(4)	(34)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(2)	-	-	-		(3)	(5)
Losses	(8)	-	-	-	-	-	(1)	(14)	(23)
FUELS FOR FINAL CONS.	345	-	30	-	157	2	3	35	572
ENERGY DEMAND	345	-	30	-	157	2	3	35	572
INDUSTRIAL	155	-	4	-	1	-	-	13	173
TRANSPORT	-	-	10	-	1	-	-	4	14
RESIDENTIAL	139	-	3	-	119	2	2	4	269
AGRICULTURAL	4	-	1	-	19	-	-	1	24
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	21	-	9	-	7	-	-	9	46
PUBLIC/COMML	25	-	1	-	5	-	1	4	37
NON-SPECIFIED			-						-
NON-ENERGY	1		1		6				8
Elect. Gen. (Gr. TWhe)	4.34	-	0.74	10.66	-	-		-	15.74

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-12: Summary Estimated Supply/Demand Balance for the DPRK in 2020

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	HEAT	ELEC.	**TOTAL**
ENERGY SUPPLY	379	32	7	39	164	-	-	(1)	619
Domestic Production	461	0	-	39	162	-		-	662
Imports	0	32	7	-	2	-		0	41
Exports	82	-	-	-	-	-		1	83
Stock Changes	-	-	-	-	-	-		-	-
ENERGY TRANSF.	(73)	(32)	18	(39)	(7)	2	5	33	(94)
Electricity Generation	(43)	-	(13)	(39)	-	-	5	51	(40)
Petroleum Refining	-	(32)	32	-	-	-		(0)	(0)
Coal Prod./Prep.	(22)	-	-	-	-	-		(3)	(25)
Charcoal Production	-	-	-	-	(7)	2		-	(5)
District Heat Production	(2)		(0)				1		
Own Use	-	-	(2)	-	-	-		(2)	(4)
Losses	(6)	-	-	-	-	-	(1)	(13)	(20)
FUELS FOR FINAL CONS.	306	-	24	-	156	2	5	32	525
ENERGY DEMAND	306	-	24	-	156	2	4	32	525
INDUSTRIAL	125	-	4	-	1	-	-	10	140
TRANSPORT	-	-	7	-	1	-	-	4	11
RESIDENTIAL	141	-	3	-	121	2	4	6	278
AGRICULTURAL	4	-	1	-	18	-	-	1	23
FISHERIES	0	-	1	-	-	-	-	0	1
MILITARY	17	-	6	-	7	-	-	8	37
PUBLIC/COMML	18	-	1	-	4	-	1	3	26
NON-SPECIFIED			-						-
NON-ENERGY	1		1		6				7
Elect. Gen. (Gr. TWhe)	2.58	-	0.72	10.74	-	-		-	14.04

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-13: Detailed Estimated Supply/Demand Balance for the DPRK in 2000

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	338,806	16,877	40,010	37,705	160,477	3	-	(82)	593,796
Domestic Production	336,168	298		37,705	150,543				524,715
Imports	11,952	16,579	41,778		12,450	3		-	82,762
Exports	9,314		3,013		2,517	0		82	14,926
Inputs to International Marine Bunkers									-
Stock Changes			(1,245)						(1,245)
ENERGY TRANSFORMATION	(52,861)	(16,877)	(721)	(37,705)	(6,051)	1,815	2,645	30,857	(78,898)
Electricity Generation	(31,665)		(16,206)	(37,705)			2,451	47,746	(35,379)
Petroleum Refining		(16,877)	16,877					(99)	(99)
Coal Production/Preparation	(16,093)							(2,179)	(18,272)
Charcoal Production					(6,051)	1,815			(4,236)
Coke Production									-
District Heat Production	(988)		(391)				855		(524)
Other Transformation									-
Own Use			(1,001)					(1,903)	(2,904)
Losses	(4,116)						(661)	(12,708)	(17,485)
FUELS FOR FINAL CONSUMPTION	285,945	-	39,289	-	154,425	1,818	2,645	30,775	514,898
ENERGY DEMAND	285,944	-	39,290	-	154,426	1,818	2,645	30,774	514,897
INDUSTRIAL SECTOR	149,673	-	11,726	-	1,153	-		12,828	175,380
Iron and Steel	67,382							3,609	70,991
Cement	19,096		7,024					1,503	27,623
Fertilizers	2,070		343					1,629	4,042
Other Chemicals	2,325		-					1,373	3,699
Pulp and Paper	836				836			194	1,865
Other Metals	4,924							857	5,780
Other Minerals	869		3,478					137	4,484
Textiles	6,100							518	6,618
Building Materials	21,383							65	21,448
Non-specified Industry	24,689		882		317			2,942	28,831
TRANSPORT SECTOR	-	-	8,395	-	504	-	-	3,237	12,135
Road			6,548		504				7,052
Rail	-		585					3,237	3,821
Water	-		476						476
Air			786						786
Non-Specified			-					-	-
RESIDENTIAL SECTOR	95,055	-	2,079	-	121,601	1,818	1,826	2,856	225,235
Urban	73,246		1,924		19,021	1,117	1,826	2,421	99,555
Rural	21,808		156		102,580	701		435	125,680
AGRICULTURAL SECTOR	2,827	-	968	-	14,663	-	-	979	19,437
Field Operations			507					526	1,033
Processing/Other	2,827		461		14,663			452	18,404
FISHERIES SECTOR	423	-	828	-	-	-	-	196	1,447
Large Ships	-		668						668
Collectives/Processing/Other	423		161					196	779
MILITARY SECTOR	21,308	-	11,094	-	7,379	-	-	7,420	47,202
Trucks and other Transport			4,064						4,064
Armaments			148						148
Air Force			1,367						1,367
Naval Forces			5,430						5,430
Military Manufacturing	401		-					21	422
Buildings and Other	20,908		85		7,379			7,399	35,771
PUBLIC/COMMERCIAL SECTORS	15,629		78		3,126		820	3,258	22,911
NON-SPECIFIED/OTHER SECTORS			-				-		-
NON-ENERGY USE	1,029		4,121		6,000				11,150
Electricity Gen. (Gross TWhe)*	2.64		0.15	10.47					13.26

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-14: Detailed Estimated Supply/Demand Balance for the DPRK in 2010

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	383,464	25,309	14,789	42,864	208,309	0	-	507	675,242
Domestic Production	491,714	251		42,864	204,624				739,453
Imports	13,432	25,058	16,459		4,268	0		1,053	60,270
Exports	121,681		1,670		583	0		546	124,480
Inputs to International Marine Bunkers									-
Stock Changes			-						-
ENERGY TRANSFORMATION	(89,126)	(25,309)	16,676	(42,864)	(6,067)	1,820	3,517	36,023	(105,330)
Electricity Generation	(57,667)		(7,118)	(42,864)			3,353	56,540	(47,756)
Petroleum Refining		(25,309)	25,309					(149)	(149)
Coal Production/Preparation	(23,539)							(3,188)	(26,726)
Charcoal Production					(6,067)	1,820			(4,247)
Coke Production									-
District Heat Production	(1,900)		(35)				1,100		(836)
Other Transformation									-
Own Use			(1,480)					(2,395)	(3,875)
Losses	(6,020)						(935)	(14,785)	(21,740)
FUELS FOR FINAL CONSUMPTION	294,338	-	31,465	-	202,242	1,820	3,517	36,530	569,912
ENERGY DEMAND	294,337	-	31,465	-	202,242	1,821	3,517	36,530	569,912
INDUSTRIAL SECTOR	175,522	-	5,688	-	836	-	-	15,204	197,250
Iron and Steel	69,197							3,707	72,904
Cement	43,099		2,278					2,611	47,988
Fertilizers	1,950		338					1,535	3,823
Other Chemicals	1,725							1,019	2,744
Pulp and Paper	642				642			149	1,433
Other Metals	15,133							2,633	17,766
Other Minerals	4,423		2,381					214	7,018
Textiles	5,172		-					439	5,611
Building Materials	19,090		-					58	19,148
Non-specified Industry	15,090		691		194			2,839	18,814
TRANSPORT SECTOR	-	-	10,485	-	712	-	-	3,913	15,111
Road			8,720		712			0	9,432
Rail	-		526					3,913	4,439
Water	-		376						376
Air			863						863
Non-Specified			-					-	-
RESIDENTIAL SECTOR	77,012	-	2,071	-	158,248	1,821	2,294	3,849	245,295
Urban	63,513		1,894		35,291	1,127	2,294	3,366	107,486
Rural	13,499		177		122,957	694		483	137,809
AGRICULTURAL SECTOR	4,907	-	1,031	-	23,955	-	-	1,211	31,105
Field Operations			539					374	913
Processing/Other	4,907		491		23,955			838	30,192
FISHERIES SECTOR	430	-	889	-	-	-	-	183	1,502
Large Ships	-		724						724
Collectives/Processing/Other	430		165					183	778
MILITARY SECTOR	18,415	-	10,018	-	7,379	-	-	7,699	43,512
Trucks and other Transport			3,186						3,186
Armaments			103						103
Air Force			2,100						2,100
Naval Forces			4,553						4,553
Military Manufacturing	401		-					21	422
Buildings and Other	18,014		76		7,379			7,678	33,147
PUBLIC/COMMERCIAL SECTORS	17,037		417		5,111		1,224	4,469	28,258
NON-SPECIFIED/OTHER SECTORS			-				-		-
NON-ENERGY USE	1,014		866		6,000				7,879
Electricity Gen. (Gross TWhe)	3.44		0.36	11.91					15.70

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-15: Detailed Estimated Supply/Demand Balance for the DPRK in 2016

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	476,927	28,282	29,614	42,351	196,968	-	-	(295)	773,848
Domestic Production	1,019,644	251		42,351	194,495				1,256,740
Imports	41,430	28,031	29,634		4,172			307	103,574
Exports	584,146		20		1,699			602	586,466
Inputs to International Marine Bunkers									-
Stock Changes			-						-
ENERGY TRANSFORMATION	(154,503)	(28,282)	7,510	(42,351)	(7,137)	2,141	3,592	38,921	(180,109)
Electricity Generation	(91,391)		(19,615)	(42,351)			3,398	65,340	(84,619)
Petroleum Refining		(28,282)	28,840					(170)	389
Coal Production/Preparation	(48,811)							(6,610)	(55,421)
Charcoal Production					(7,137)	2,141			(4,996)
Coke Production									-
District Heat Production	(1,817)		(35)				1,148		(704)
Other Transformation									-
Own Use			(1,681)					(3,679)	(5,360)
Losses	(12,484)						(955)	(15,960)	(29,398)
FUELS FOR FINAL CONSUMPTION	322,425	-	37,124	-	189,831	2,141	3,592	38,626	593,739
ENERGY DEMAND	322,424	-	37,123	-	189,831	2,141	3,592	38,627	593,737
INDUSTRIAL SECTOR	165,190	-	8,454	-	584	-	-	16,472	190,700
Iron and Steel	65,238							3,494	68,732
Cement	44,481		4,228					2,802	51,511
Fertilizers	6,156		1,096					4,846	12,098
Other Chemicals	1,356							801	2,156
Pulp and Paper	443				443			103	988
Other Metals	13,444							2,339	15,783
Other Minerals	4,230		2,511					212	6,953
Textiles	3,879		-					330	4,208
Building Materials	14,999		-					46	15,045
Non-specified Industry	10,965		619		141			1,500	13,224
TRANSPORT SECTOR	-	-	11,020	-	881	-	-	4,375	16,276
Road			9,115		881			17	10,013
Rail	-		554					4,358	4,912
Water	-		363						363
Air			988						988
Non-Specified			-					-	-
RESIDENTIAL SECTOR	107,093	-	2,993	-	146,422	2,141	2,023	3,508	264,179
Urban	83,880		2,728		31,668	1,331	2,023	3,172	124,801
Rural	23,213		266		114,754	810		336	139,379
AGRICULTURAL SECTOR	5,004	-	1,106	-	24,428	-	-	1,163	31,702
Field Operations			579					359	938
Processing/Other	5,004		527		24,428			804	30,764
FISHERIES SECTOR	430	-	1,463	-	-	-	-	199	2,092
Large Ships	-		1,282						1,282
Collectives/Processing/Other	430		181					199	810
MILITARY SECTOR	20,106	-	10,805	-	6,401	-	-	8,609	45,921
Trucks and other Transport			3,999						3,999
Armaments			111						111
Air Force			2,567						2,567
Naval Forces			4,049						4,049
Military Manufacturing	445		-					24	469
Buildings and Other	19,660		80		6,401			8,585	34,727
PUBLIC/COMMERCIAL SECTORS	21,312		746		5,115		1,254	4,300	32,727
NON-SPECIFIED/OTHER SECTORS			-				315		315
NON-ENERGY USE	3,289		537		6,000				9,826
Electricity Gen. (Gross TWhe)	5.44		1.21	11.50					18.15

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-16: Detailed Estimated Supply/Demand Balance for the DPRK in 2019

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	TOTAL
ENERGY SUPPLY	456,851	30,705	14,048	38,392	164,524	-	-	(834)	703,686
Domestic Production	619,098	251		38,392	160,907				818,649
Imports	301	30,454	14,127		3,616			172	48,670
Exports	162,548		79		-			1,006	163,633
Inputs to International Marine Bunkers									-
Stock Changes			-						-
ENERGY TRANSFORMATION	(112,177)	(30,705)	16,178	(38,392)	(7,321)	2,196	3,359	35,428	(131,435)
Electricity Generation	(73,027)		(12,705)	(38,392)			3,030	56,674	(64,419)
Petroleum Refining		(30,705)	30,705					(179)	(179)
Coal Production/Preparation	(29,637)							(4,014)	(33,650)
Charcoal Production					(7,321)	2,196			(5,125)
Coke Production									-
District Heat Production	(1,934)		(36)				1,222		(749)
Other Transformation									-
Own Use			(1,786)					(2,937)	(4,724)
Losses	(7,580)						(893)	(14,117)	(22,589)
FUELS FOR FINAL CONSUMPTION	344,674	-	30,226	-	157,203	2,196	3,359	34,594	572,251
ENERGY DEMAND	344,674	-	30,226	-	157,203	2,196	3,359	34,593	572,251
INDUSTRIAL SECTOR	154,886	-	4,147	-	654	-	-	12,995	172,682
Iron and Steel	55,184							2,956	58,140
Cement	42,177		2,173					2,552	46,902
Fertilizers	2,359		416					1,857	4,632
Other Chemicals	1,356							801	2,156
Pulp and Paper	443				443			103	988
Other Metals	12,785							2,224	15,009
Other Minerals	4,899		1,225					192	6,316
Textiles	3,556		-					302	3,858
Building Materials	15,681		-					48	15,729
Non-specified Industry	16,447		333		211			1,960	18,952
TRANSPORT SECTOR	-	-	9,662	-	785	-	-	3,661	14,109
Road			7,988		785			55	8,828
Rail	-		496					3,606	4,103
Water	-		320						320
Air			858						858
Non-Specified			-					-	-
RESIDENTIAL SECTOR	139,060	-	3,300	-	119,048	2,196	2,037	3,659	269,300
Urban	105,137		2,998		23,621	1,368	2,037	3,308	138,469
Rural	33,924		301		95,427	828		351	130,831
AGRICULTURAL SECTOR	3,826	-	749	-	18,678	-	-	927	24,180
Field Operations			396					312	708
Processing/Other	3,826		353		18,678			615	23,472
FISHERIES SECTOR	285	-	1,032	-	-	-	-	147	1,464
Large Ships	-		910						910
Collectives/Processing/Other	285		122					147	554
MILITARY SECTOR	20,852	-	9,272	-	6,644	-	-	8,819	45,587
Trucks and other Transport			4,035						4,035
Armaments			85						85
Air Force			2,209						2,209
Naval Forces			2,867						2,867
Military Manufacturing	445		-					24	469
Buildings and Other	20,407		76		6,644			8,795	35,922
PUBLIC/COMMERCIAL SECTORS	24,515		981		5,393		1,321	4,387	36,597
NON-SPECIFIED/OTHER SECTORS			-				-		-
NON-ENERGY USE	1,248		1,083		6,000				8,331
Electricity Gen. (Gross TWhe)	4.34		0.74	10.66					15.74

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-17: Detailed Estimated Supply/Demand Balance for the DPRK in 2020

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	HEAT	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	378,623	32,196	6,629	39,155	163,652	-	-	(834)	619,421
Domestic Production	460,509	251		39,155	161,844				661,758
Imports	120	31,945	6,629		1,808			172	40,674
Exports	82,006		-		-			1,006	83,012
Inputs to International Marine Bunkers									-
Stock Changes			-						-
ENERGY TRANSFORMATION	(72,547)	(32,196)	17,511	(39,155)	(7,435)	2,231	4,639	32,846	(94,106)
Electricity Generation	(42,949)		(12,758)	(39,155)			4,650	50,560	(39,652)
Petroleum Refining		(32,196)	32,196					(188)	(188)
Coal Production/Preparation	(22,045)							(2,985)	(25,030)
Charcoal Production					(7,435)	2,231			(5,205)
Coke Production									-
District Heat Production	(1,915)		(55)				1,222		(749)
Other Transformation									-
Own Use			(1,871)					(1,796)	(3,667)
Losses	(5,638)						(1,233)	(12,745)	(19,616)
FUELS FOR FINAL CONSUMPTION	306,076	-	24,141	-	156,217	2,231	4,639	32,012	525,315
ENERGY DEMAND	306,075	-	24,141	-	156,217	2,231	4,639	32,013	525,316
INDUSTRIAL SECTOR	125,183	-	4,498	-	566	-	-	10,180	140,427
Iron and Steel	47,069							2,521	49,590
Cement	32,188		2,986					2,024	37,198
Fertilizers	1,179		208					928	2,316
Other Chemicals	986							582	1,568
Pulp and Paper	354				354			82	791
Other Metals	9,654							1,679	11,333
Other Minerals	3,810		953					150	4,912
Textiles	2,586		-					220	2,806
Building Materials	10,908		-					33	10,942
Non-specified Industry	16,447		351		211			1,960	18,970
TRANSPORT SECTOR	-	-	7,233	-	582	-	-	3,663	11,478
Road			6,111		582			57	6,750
Rail	-		374					3,606	3,980
Water	-		200						200
Air			547						547
Non-Specified			-					-	-
RESIDENTIAL SECTOR	141,394	-	3,437	-	120,823	2,231	3,528	6,406	277,818
Urban	106,977		3,127		24,009	1,390	3,528	5,796	144,827
Rural	34,417		310		96,814	840		610	132,991
AGRICULTURAL SECTOR	3,629	-	741	-	17,713	-	-	895	22,977
Field Operations			396					312	708
Processing/Other	3,629		344		17,713			583	22,269
FISHERIES SECTOR	257	-	929	-	-	-	-	132	1,318
Large Ships	-		819						819
Collectives/Processing/Other	257		110					132	499
MILITARY SECTOR	17,308	-	5,731	-	6,644	-	-	7,575	37,258
Trucks and other Transport			2,409						2,409
Armaments			47						47
Air Force			1,653						1,653
Naval Forces			1,556						1,556
Military Manufacturing	223		-					12	235
Buildings and Other	17,085		65		6,644			7,564	31,358
PUBLIC/COMMERCIAL SECTORS	17,682		707		3,890		953	3,161	26,393
NON-SPECIFIED/OTHER SECTORS			-				158		158
NON-ENERGY USE	624		866		6,000				7,490
Electricity Gen. (Gross TWhe)	2.58		0.72	10.74					14.04

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Figure 3-17: 2000 DPRK Energy Supply Shares by Fuel

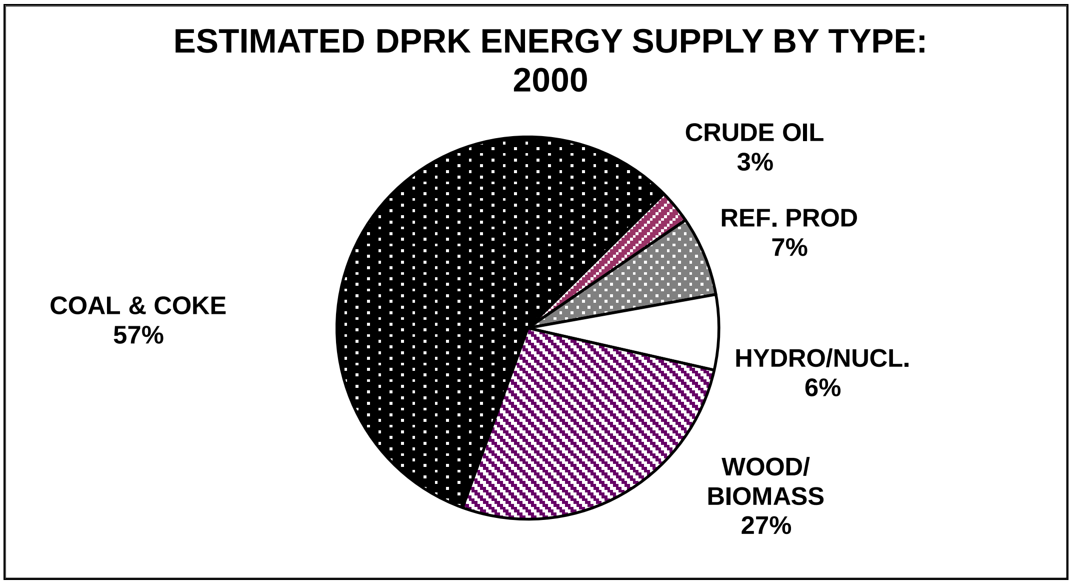


Figure 3-18: 2005 DPRK Energy Supply Shares by Fuel

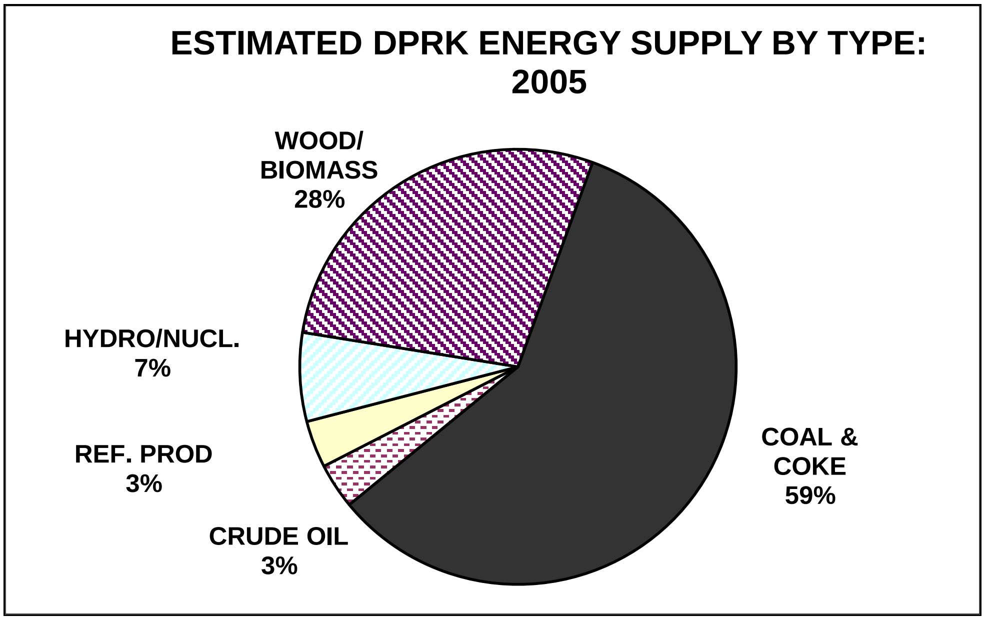


Figure 3-19: 2005 DPRK Energy Supply Shares by Fuel

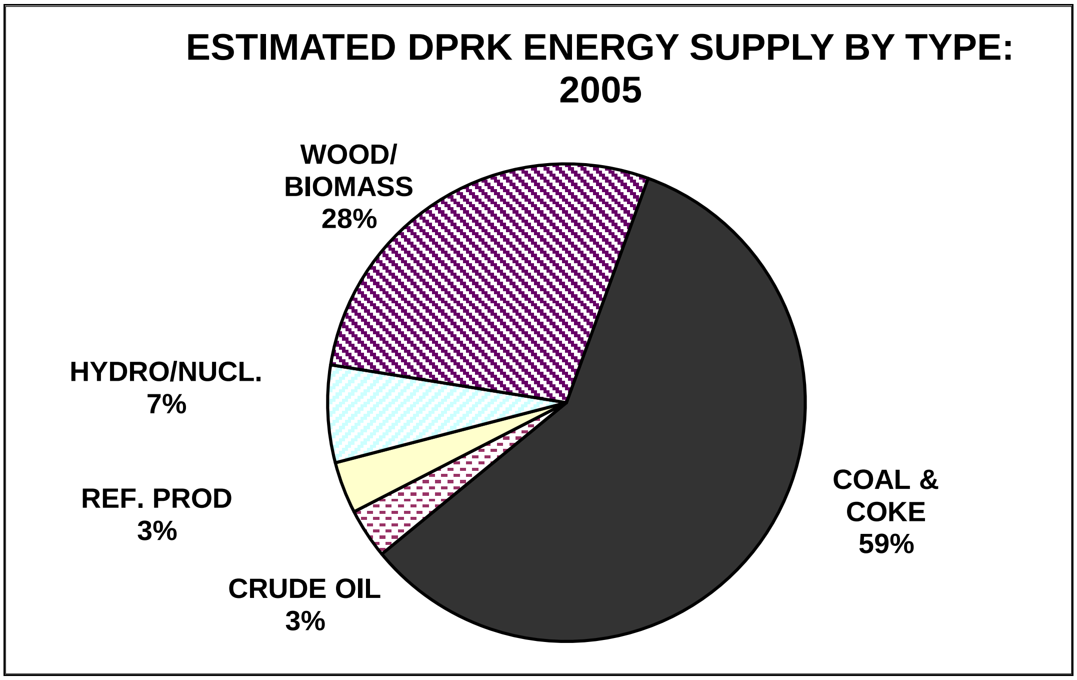


Figure 3-20: 2010 DPRK Energy Supply Shares by Fuel

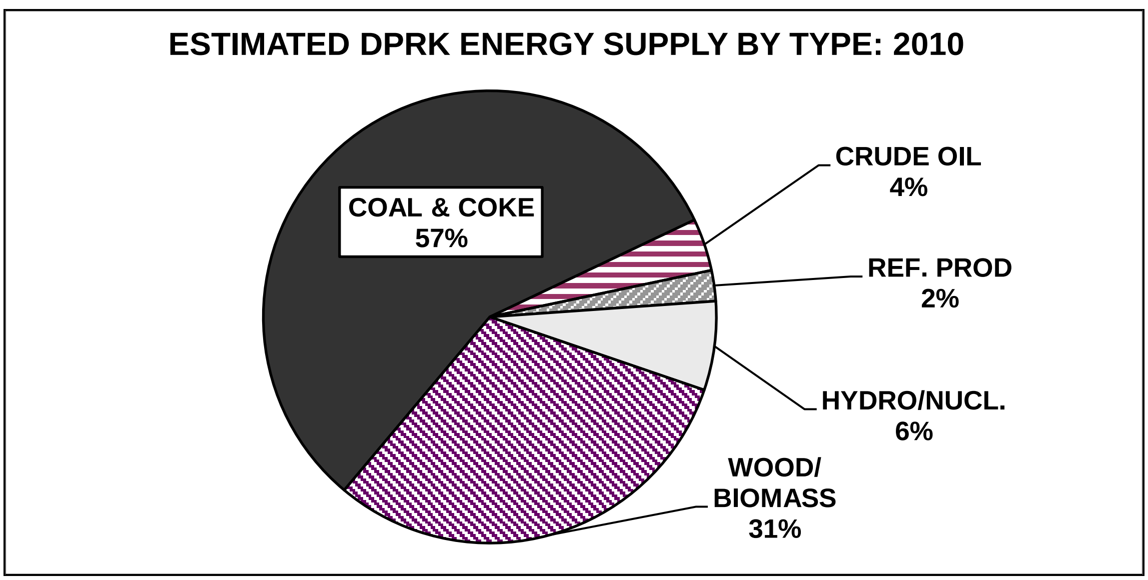


Figure 3-21: 2016 DPRK Energy Supply Shares by Fuel

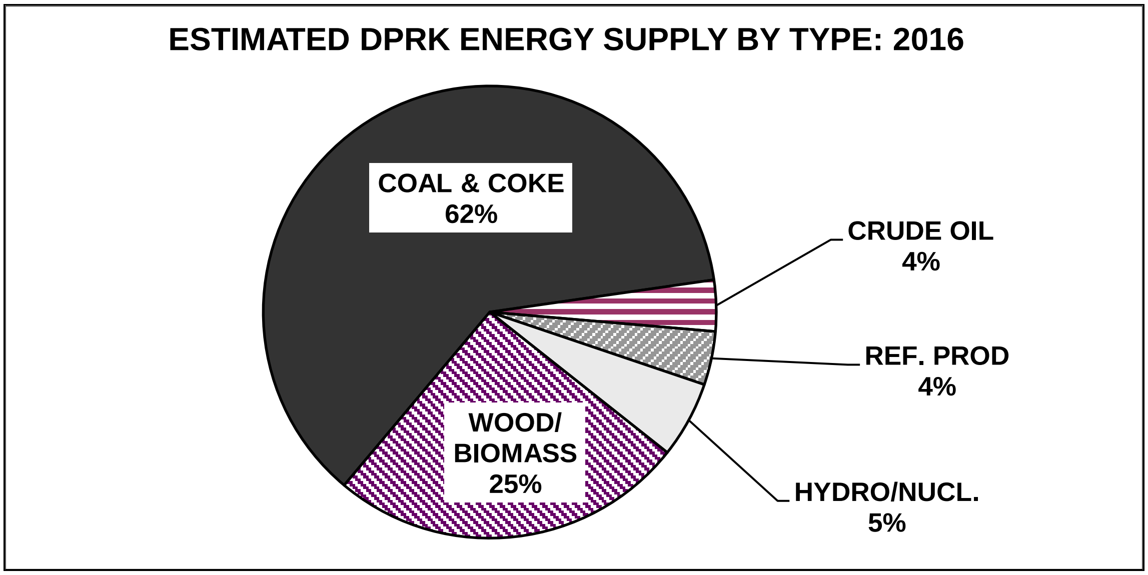


Figure 3-22: 2019 DPRK Energy Supply Shares by Fuel

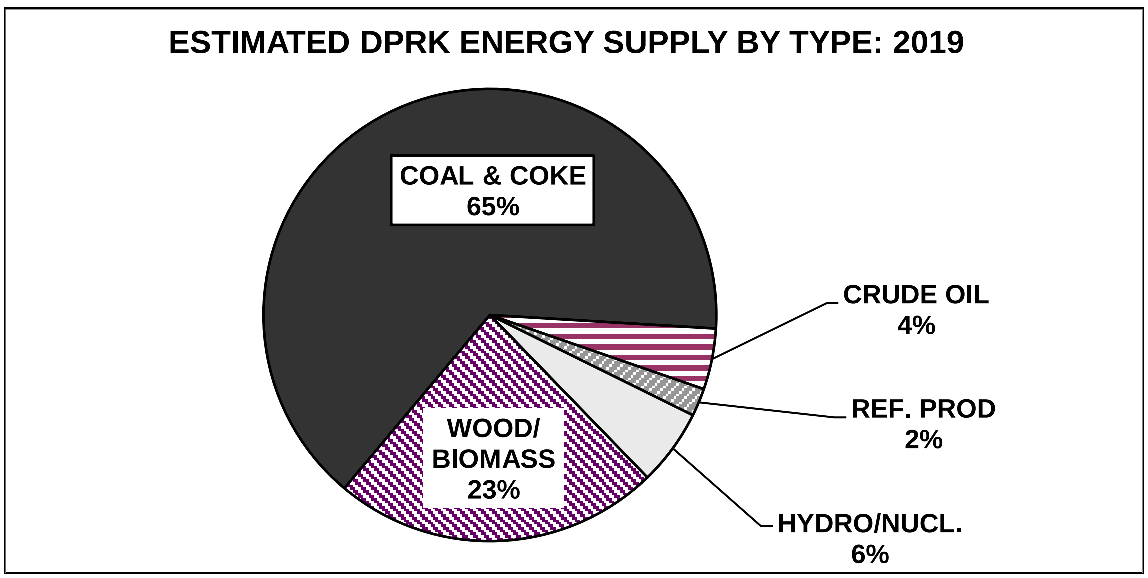


Figure 3-23: 2020 DPRK Energy Supply Shares by Fuel

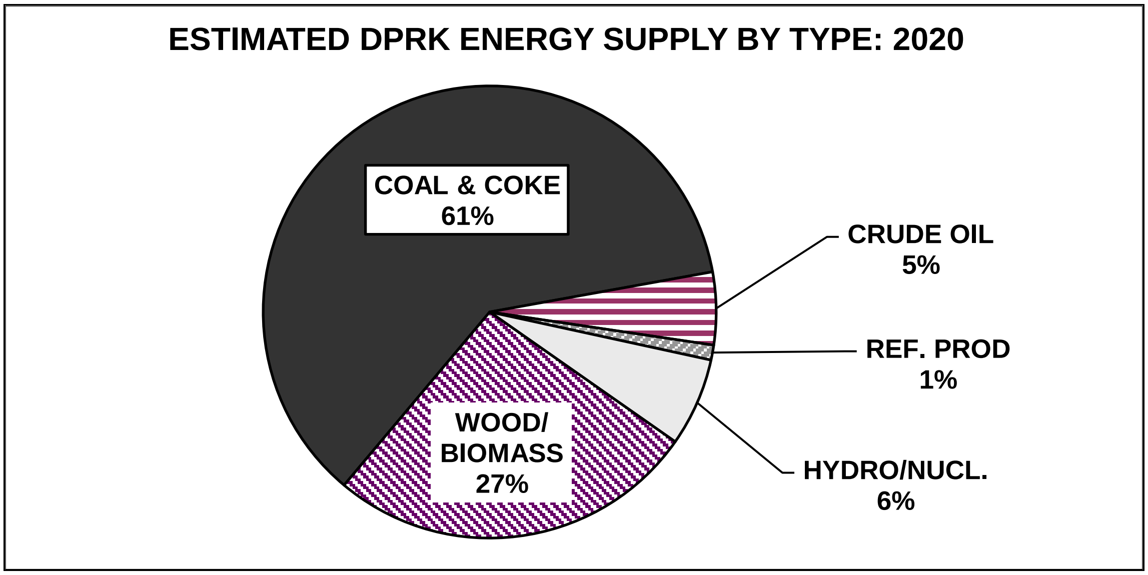


Figure 3-24: DPRK Energy Use Shares by Sector, 1990 - 2020

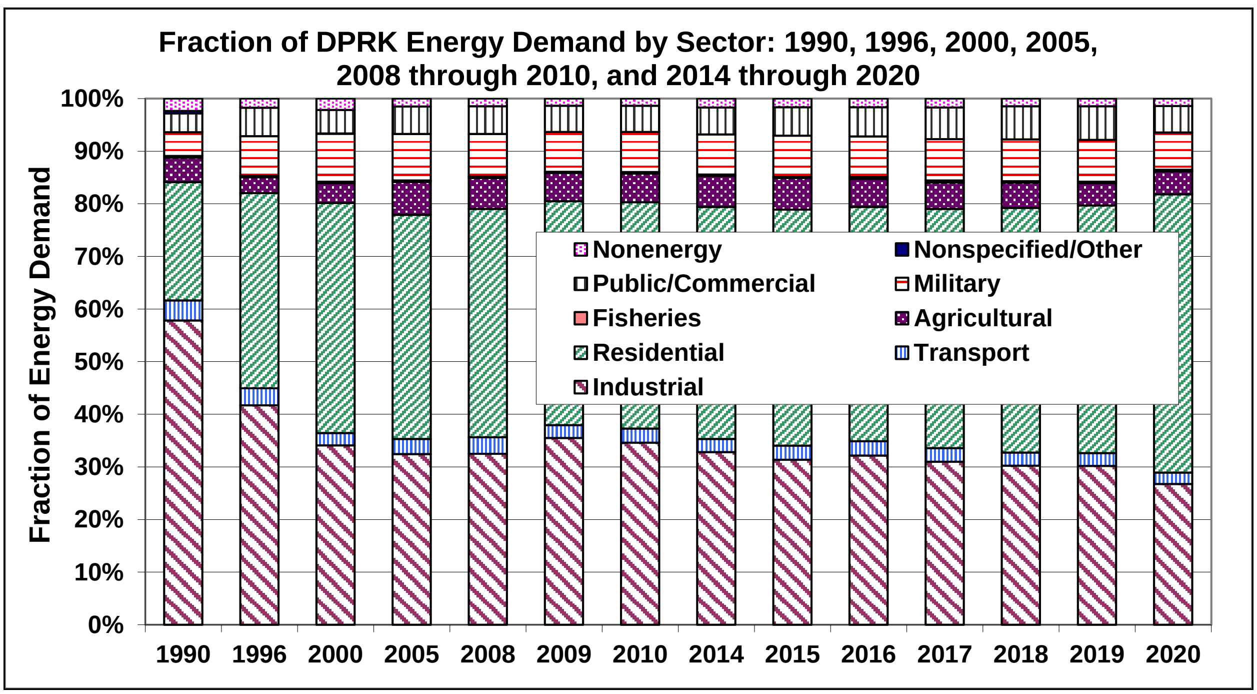


Figure 3-25: DPRK Energy Use by Sector, 1990 - 2020

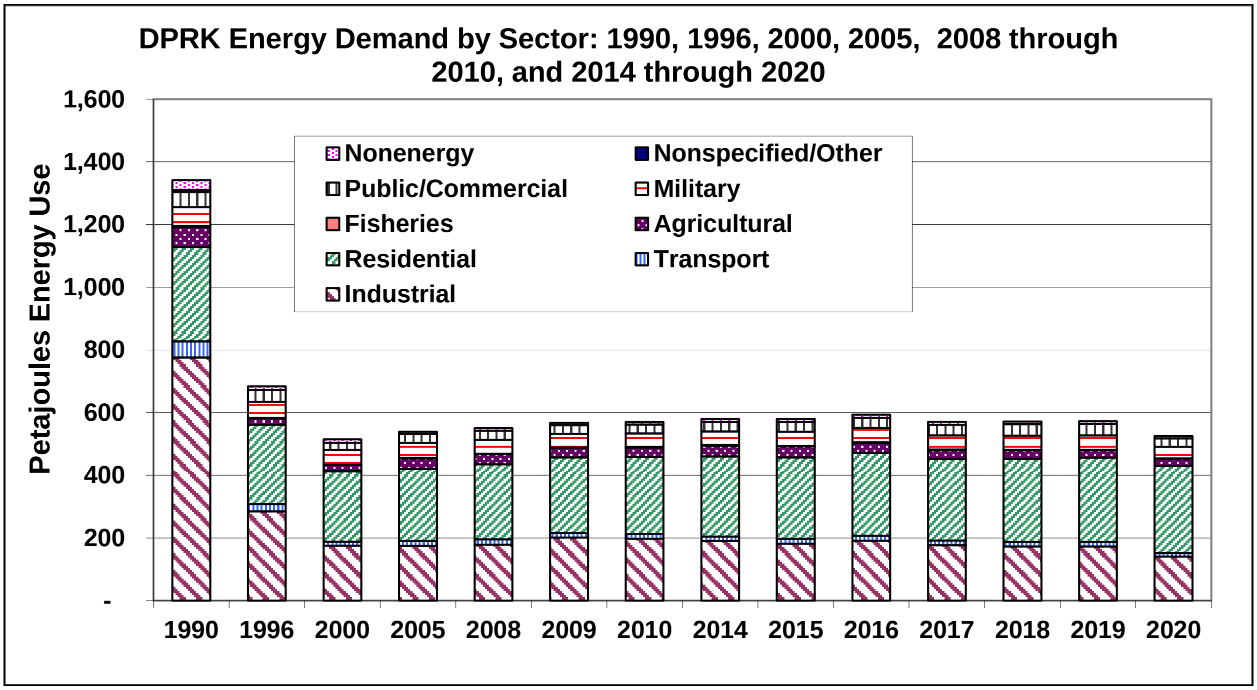


Figure 3-26: Share of DPRK Energy Use by Fuel, 1990 - 2020

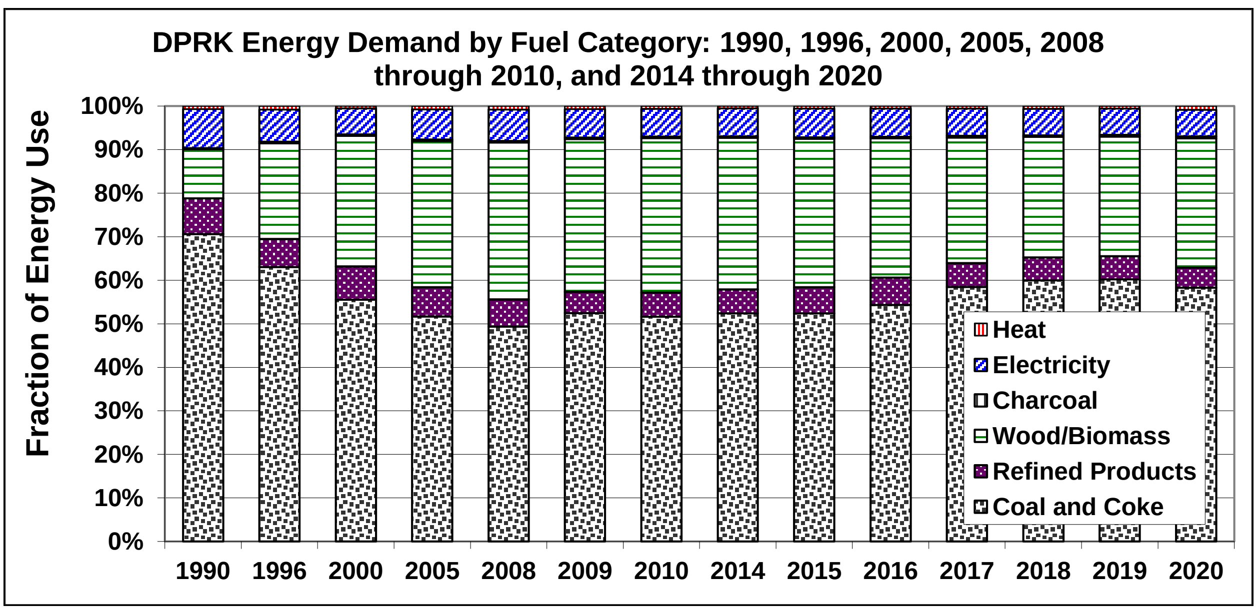


Figure 3-27: Shares of DPRK Coal Use by Fuel, 2000

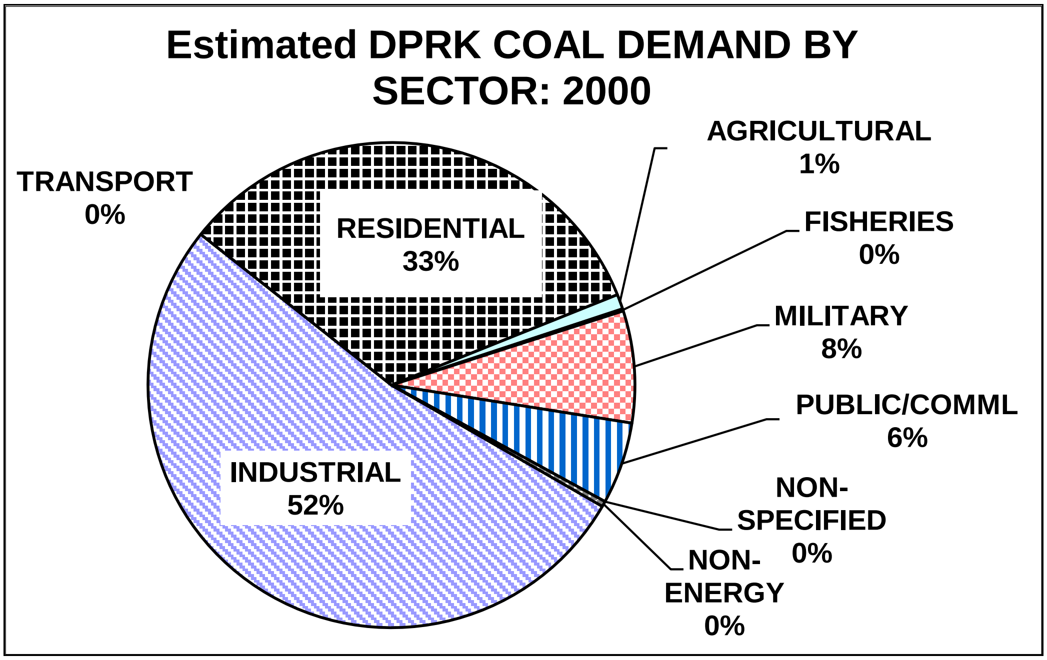


Figure 3-28: Shares of DPRK Coal Use by Fuel, 2005

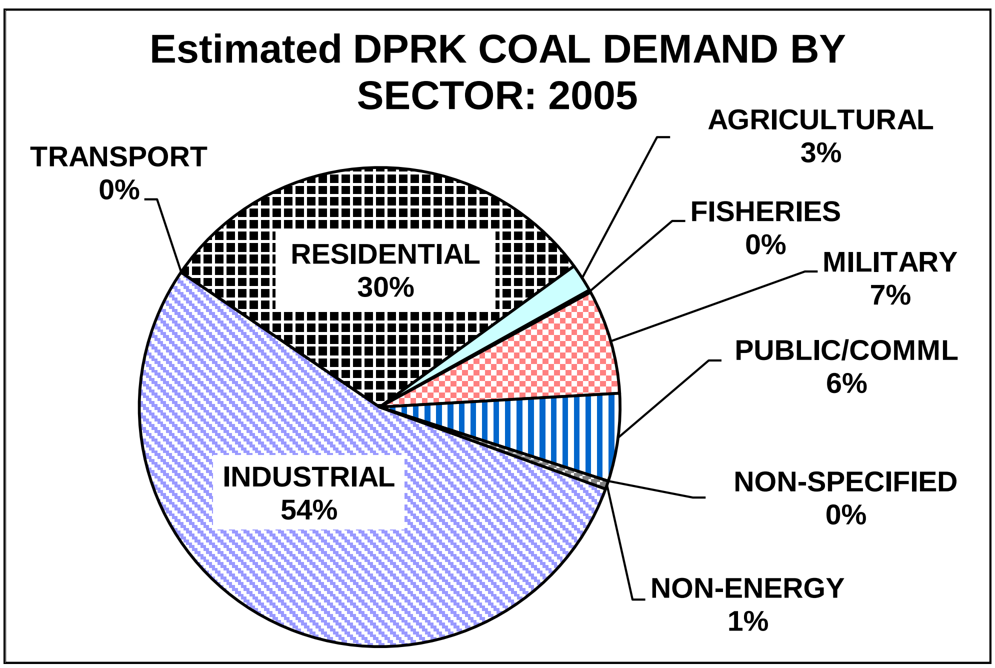


Figure 3-29: Shares of DPRK Coal Use by Fuel, 2010

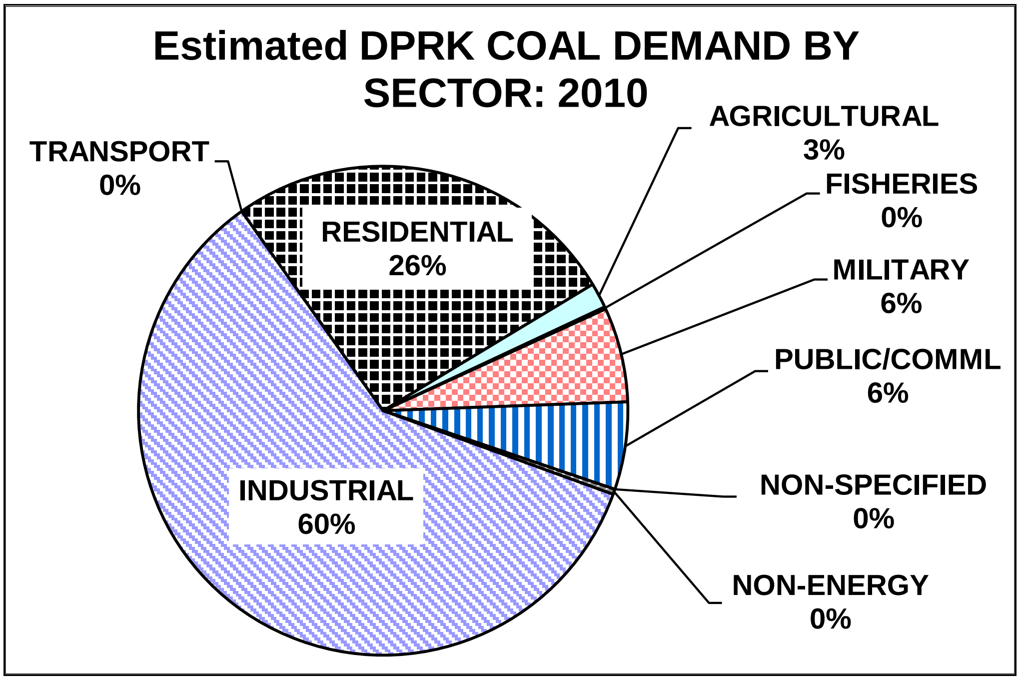


Figure 3-30: Shares of DPRK Coal Use by Fuel, 2016

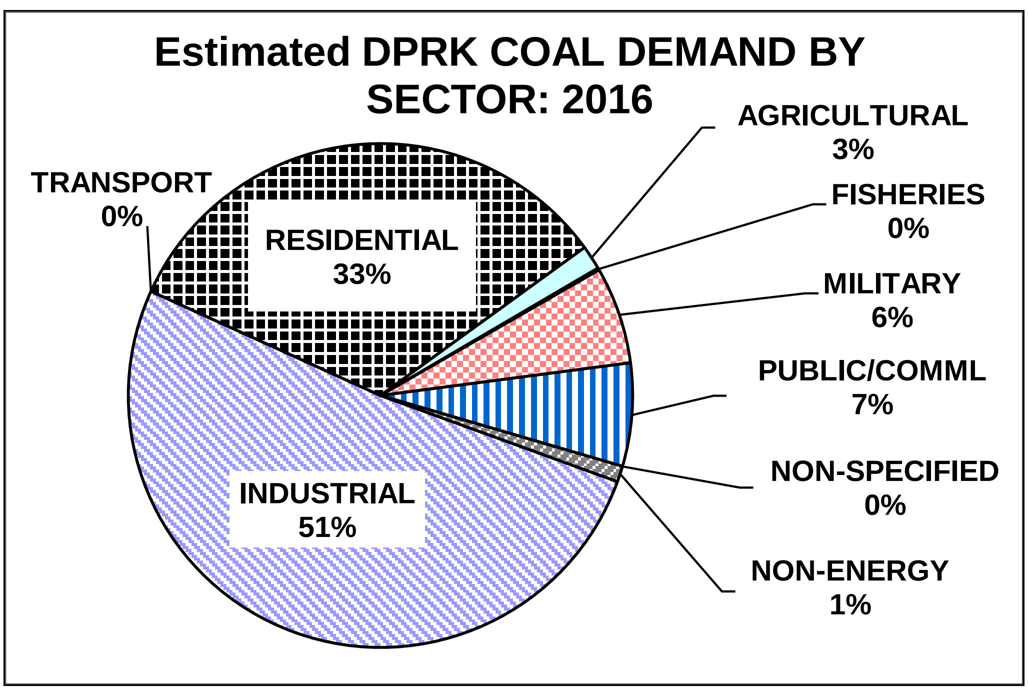


Figure 3-31: Shares of DPRK Coal Use by Fuel, 2019

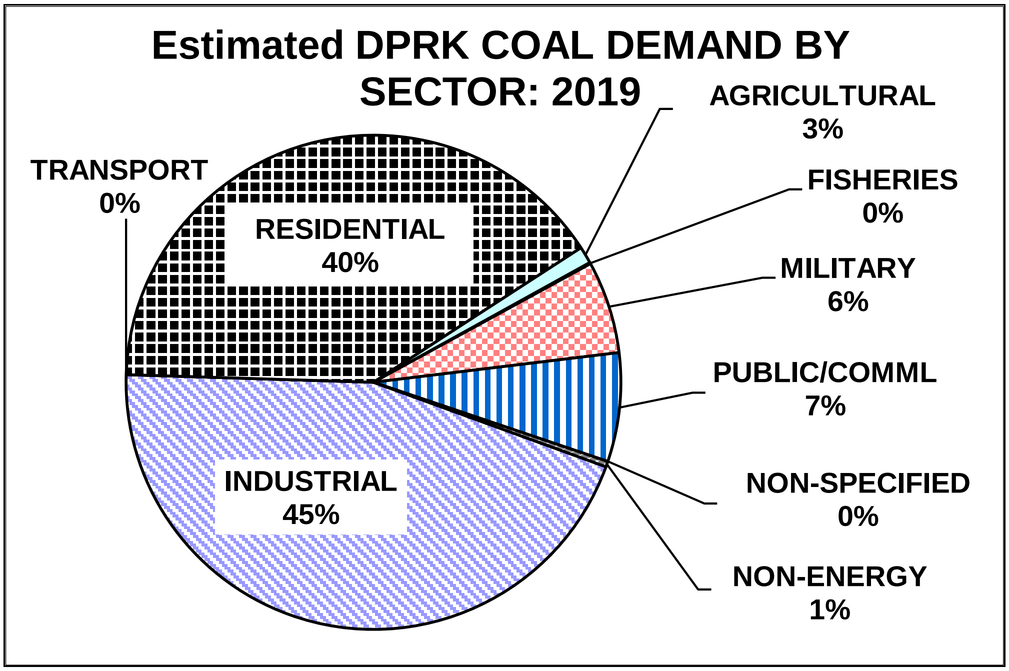
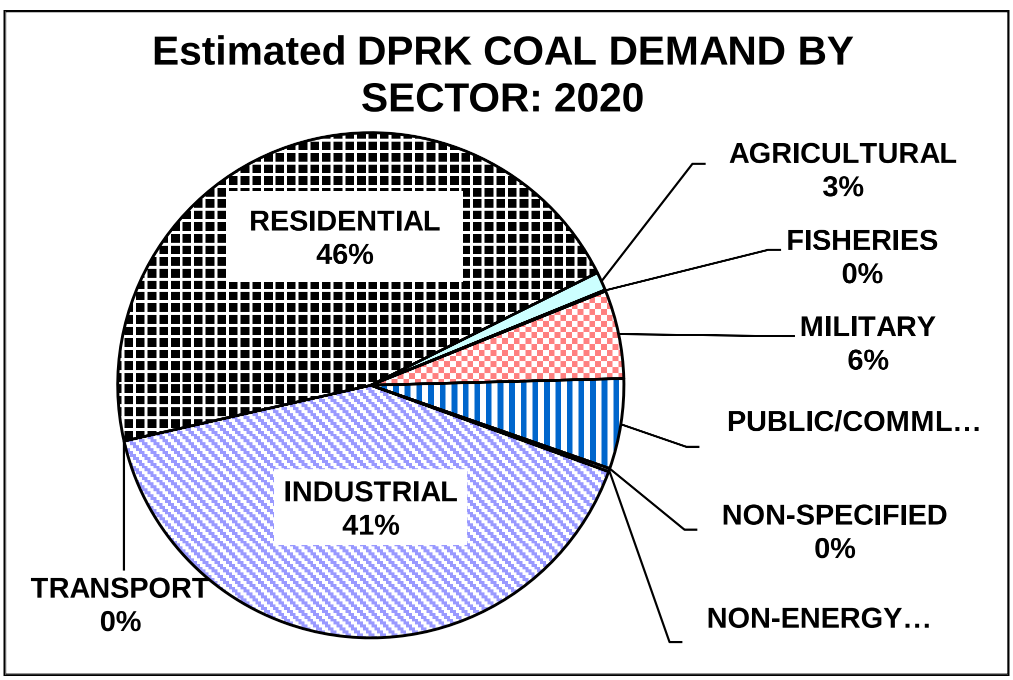


Figure 3-32: Shares of DPRK Coal Use by Fuel, 2020



4. The DPRK's Energy Resources for Fueling Redevelopment

4.1. Introduction

As with virtually any country, the key resource that the DPRK possesses to drive the redevelopment of its economy is its people. The political and other developments of the last three decades, and their effect on the DPRK economy, however, mean that the availability of dedicated workers alone will not be sufficient to assure significant economic progress in the DPRK, even assuming an improvement in the DPRK's relations with neighboring countries and the world community.

In the short and medium term, the DPRK's mineral resource endowment will likely be drawn on to provide the major source of income to fuel economic growth. As the economy improves, energy resources, but from domestic supplies and from exports, will need to be tapped in greater quantities. Coal has for more than a century been the most important fossil fuel resource for the DPRK. Oil and gas, though substantially untapped, are said to be found in the DPRK's onshore and offshore territories. Wood and other biomass contribute, as noted above, a considerable portion of the DPRK's estimated energy supplies, but forest health (and, relatedly, soil conservation) has become a major concern in the DPRK in recent years. Additional renewable resources—solar, tidal, and wind energy—are available. Finally, the relatively low efficiency with which energy is currently used in most applications in the DPRK means that there is a significant resource of energy efficiency to be tapped as the DPRK economy improves—and tapping that resource has important ramifications for the amounts of fuels, electricity, and heat ultimately needed in the DPRK. In the Chapter that follows, we review the status of the DPRK's estimated supplies of each of these potential "resources for fueling development". Note that Chapters 2, 3 and 5 also provide summary information on DPRK energy resources, the latter in the context of resources available for electricity generation.

4.2. Fossil Fuels

Coal has historically been the DPRK's only significant domestic fossil fuel resource, and the DPRK has, by all accounts, substantial coal reserves. Recent production of oil in the DPRK has been rumored, albeit at a small scale, following many years of exploration with a variety of partners. Geologic structures bearing gas have also been identified in DPPRK territory.

4.2.1. Coal

The DPRK has abundant coal resources, including deposits of anthracite coal and lignite, or "brown" coal. It substantially lacks, however, bituminous coal, which is the most common coal used worldwide as an input to coke production for steelmaking, and as a power plant fuel. Coal quality in the DPRK seems to be quite variable, with reported energy contents for different DPRK coals ranging from a very low 1000 and 2300 kilocalories (kcals) per kilogram for "low grade coal" (lignite and anthracite, respectively)[376] to a relatively high 6150 kcal/kg for high-

[376] Document in the authors' files [VO-90].

grade anthracite coal.[377] The DPRK's total coal resource or reserves have been variously estimated at levels ranging from 600 million tonnes ("proven coal reserves", and "recoverable coal reserves", as noted in international compendia of energy statistics[378]) to resources ("coal deposits") of nearly 15 billion tonnes.[379] The latter estimate was included in a fairly detailed description of coal (and other mineral) resource in the DPRK published through a Korean-language website in China.[380] Information from the latter source includes the following:

> "Coal in the DPRK is generally divided into two kinds - anthracite and lignite. The major producing area of anthracite is North and South P'yo'ngan Provinces and lignite is mainly distributed in North and South Hamgyo'ng Provinces. In terms of area, the four major coalfields are in the northern part of South P'yo'ngan Province, southern part of South P'yo'ngan Province, and northern part of North Hamgyo'ng Province, and southern part of South Hamgyo'ng Province respectively.
>
> "Of the about 100 central-level [chungang-ku'p] coal mines in the DPRK, 70 are anthracitic coal mines and 30 are lignite ones. There are about 500 local-level small- and medium-sized coal mines.
>
> "The conjoined areas in the southern part of South P'yo'ngan Province surrounding Pyongyang, 80 km east and west of [Pyongyang], are very rich in coal deposits. Coal mines that can be representative include Samsindong in Taeso'ng District, Sadong District, Ryongso'ng District, Hu'ngnyo'ng District in Kangdong County, Kangso' County, So'ngch'o'n County, and Onch'o'n County.
>
> "Anthracitic coal in the northern part of South P'yo'ngan Province is distributed in an area 668 square km wide. Major coal mines are To'kch'o'n, Hyo'ngbong, and Chenam in the City of To'kch'o'n; Choyang, Kaech'o'n, Pongch'o'n, Yo'mjo'n, Wo'lli, Sillim; Songnam and Hyo'ndong in Pukch'ang County; Sinch'ang, Ch'o'nso'ng, and Yo'ngdae in U'nsan County; Musandae and Chiktong in Sunch'o'n County; and Ryongdu'ng, Ryongmun, and Ryongch'o'l in Kujang County, North P'yo'ngan Province.
>
> "Wuguang Group, one of the five leading Chinese Coal Mining Enterprises, has obtained mining rights to Ryongdu'ng Coal Mine.
>
> "In North Hamgyo'ng Province, Pukpu Coalfield (north of Aoji-ri), Nambu Coalfield (south of Ch'o'ngjin), and Anju Coalfield in South P'yo'ngan Province have the richest coal deposit.
>
> "Among the coal mines in the Pukpu Coalfield, the largest are Aoji in U'ndo'k County and Obong and Hoeryo'ng in the City of Musan. Anju Coal Mine has seven 25-meter-

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[377] Choi Su Young, *Study of the Present State of Energy Supply in North Korea*, RINU, 1993. P. 14.
[378] For example, U.S. Department of Energy's Energy Information Administration, "EIA Country Analysis Brief", Updated February 2006, and available as https://www.eia.gov/international/analysis/country/PRK; and British Petroleum Company, "QUANTIFYING ENERGY: BP STATISTICAL REVIEW OF WORLD ENERGY JUNE 2006", more recent versions of which are available as https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/downloads.html.
[379] For example, an article in MSN Encarta, "North Korea", (now unavailable, but previously available as http://encarta.msn.com/encyclopedia_761555092_2/North_Korea.html), states "Most estimates suggest that North Korea's vast anthracite coal reserves exceed 10 billion tons." The Federation of American Scientists, in a web page entitled "other industry" and available as http://www.fas.org/nuke/guide/dprk/target/industry.htm, lists, estimated anthracite coal reserves of 1.8 billion tonnes.
[380] *Changchun Killim Sinmun* (Internet Version-WWW) in Korean 31 Aug 06 - 08 Sep 06, ""Guide to DPRK Mineral Resources".

> thick ore beds. Lignite coal with caloric value of over 5,300 kilocalories [kcal/kg] is mainly being produced in this coal mine. It is the largest coal mine in the DPRK, producing 7 million tonnes a year.
>
> "The DPRK is confirmed to have coal deposit of 14.74 billion tonnes. Of them, 11.74 billion tonnes is anthracitic coal and 3 billion tonnes of lignite coal."

As noted elsewhere in this Report, customs statistics report that the DPRK has since 2004 exported between 1.5 and 22 (the latter in 2016) million tonnes of coal annually to China in exchange for strategic materials needed by North Korea or for hard currency.[381] For example, coal produced in the Pyong-An Regional Mines has been reportedly exported to Tien-jin, Dalian and Ching-dao Cities in China from Nam-po port in the Western DPRK.

It has been reported that the Anju coalfield has produced coking coal (high heat content coal used as coking coal), which was exported to China in 2008. South Korean research papers on the topic, however, have so far denied the existence of coking-quality coal production at Anju. Annual nationwide coal production was reported by ROK soures as 38.3 million tonnes in 1989, but production of coal declined sharply after 1990 such that annual coal production was 18.6 million tonnes in 1999.[382] Estimated nationalwide coal production capacity, however, is said to have been 53.50 million tonnes in 1986.

With regard to coal quality, DPRK-produced anthracite coal from the Duck-Chon coal mine is reported by Chinese importing authorities and shipping business sources to have the following characteristics. Coal of this type has been exported to Chinese thermal power plants in Tien-jin and Dai-lian. This coal is of much better quality from a caloric value standpoint than normal coal produced by the DPRK.

Coal Specifications:

- Caloric value: 6,480 kcal/kg (min.)
- Fixed Carbon: 80.3% (max.)
- Ash contents: 12.2% (max.)
- Volatile material: 6.1% (max.)
- Sulfur: 0.2% (max.)
- Moisture (max): 6.0% (max.)
- Size: 0-30 mm (100%. min.)

Urgent Problems in the DPRK Coal Industry

There have been, over the past three decades, and are currently several urgent reported problems that the DPRK coal industry must overcome. First, the depth of mining at existing sites has grown, which means that the expense and difficulty of draining underground water has

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[381] Most of the remainder of this discussion of the DPRK coal sector is adapted from a report prepared for Nautilus by Edward Yoon, *Status and Future of the North Korean Minerals Sector*, dated January 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf.
[382] Korea Mineral Improvment Corporation Report, "Deposits of Mineral resource in DPRK and trading between South and North Koreas", 2005.

increased, and the operational effectiveness of the mines has decreased, on average. Second, a lack of power, transport equipment, mining technology and funding has held down production. Third, there is a lack of attention to mine development, as opposed to enforcement of impractical plans to promote coal production in the short term when new general managers or Labor party executive are sent to oversee the mines**.** Fourth, deterioration of mining equipment and equipment parts, as well as lack of mine support posts, limits production. Fifth, a high rate of industrial accidents and the lack of new investment in the coal mining industry reduces output. And sixth, that lack of electricity for mine operation is a cause of lack of power production due to the fact that most thermal power plants rely on coal supplied by coal mines as energy sources, resulting in a vicious circle connecting the problems of lack of power and the energy sources used to produce power in the DPRK.

Assuming future coal output on the order of 20 to 50 million tonnes annually, coal reserves would appear to be adequate for at least 20 years, and probably on the order of 100 years, of consumption.[383]

4.2.2. Oil and Gas

Whether or not oil in commercial quantities has actually been produced from wells either on- or offshore in DPRK territory is somewhat unclear. As noted above (see section 3.7.8), one media source listed production of 300,000 tonnes of crude oil per year starting in approximately 2000, but experts consulted in preparing this Report cast doubt on that estimate, though at least one expert (as of 2006) offered his opinion that ongoing oil production at some level occurred in the DPRK.

The amount of oil resource present in DPRK territories is uncertain. Explorations of potential oil-bearing structures—both onshore and offshore—in the DPRK have occurred intermittently for years. Within the past two decades, the DPRK has negotiated and/or reached agreements on exploration of its potential oil resource areas with the ROK's Korean National Oil Company, with the private firm Aminex Plc., of the United Kingdom, and with the Chinese Government, though this may not be an exhaustive list of potential DPRK oil (and gas) development partners.[384] [385] Several sources suggest that an oil resource of about 12 billion barrels lies in the Korea West Sea off of the DPRK, in the area near Anju.[386] The map shown in Figure 4-1 indicates several possible or probable oil-bearing areas in the DPRK or in its waters.[387] Figure

[383] This assumes that the DPRK will continue to use domestic coal. If its economy develops, and with the global implications of coal use on climate change, as well as the relative economics of coal production in other nations the DPRK might trade with (the United States, Indonesia, and/or Australia, for example, as the ROK has come to do as its domestic coal industry has been priced out of the market), though this is not a given, and internationally power generation in many places is trending away from the use of coal, for a variety of reasons.

[384] Keun-Wook Paik, "Challenges and Opportunities in Sino-DPRK Energy Cooperation", in *China Brief: A Journal of Analysis and Information*, Volume VI, Issue 16, August 2, 2006, published by the Jamestown Foundation. Pages 6 and 7.

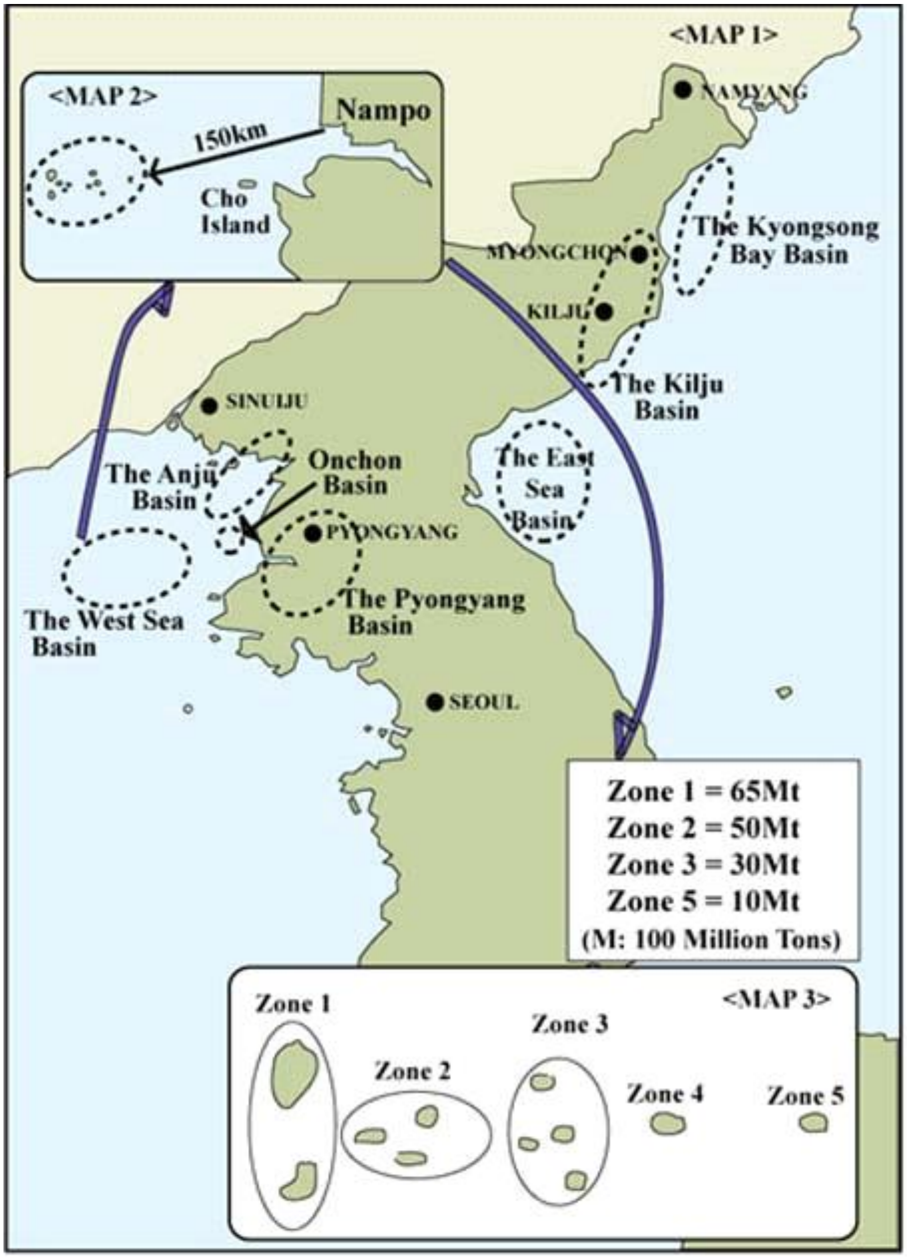
[385] Selig S. Harrison, in "Quiet Struggle in the East China Sea", (*Current History*, September 2002, page 271) identifies several other oil exploration arrangements made between the DPRK and mostly small western companies before 2000.

[386] Selig S. Harrison (2005), *Seabed Petroleum in Northeast Asia: Conflict or Cooperation?* Published by the Woodrow Wilson International Center for Scholars, Washington, D.C. Available as https://www.wilsoncenter.org/sites/default/files/media/documents/publication/Asia_petroleum.pdf.

[387] Map from *The People's Korea*, 2 December 1998, "DPRK has 12 Mil. (sic) Barrels of Oil Reserves in Western Sea: Expert", available as http://www.hartford-hwp.com/archives/55a/161.html. Note that this map provides confusing references to oil units.

4-2 provides a photo of an oil rig, provided by Romania, which was reportedly used by the DPRK to prospect for oil in the Tumen River area in the late 1990s.[388]

Figure 4-1: Location of Potential DPRK Oil Resources



The correct unit for the oil estimates by "zone" appears to be million tonnes of oil (summing to a total of 155 million tonnes, which would be on the order of 1.2 billion barrels.

[388] Photo from presentation by SOVEREIGN VENTURES PTE LTD, "Hydrocarbon Potential of Cenozoic Basins In the Tuman River Area of North Korea (DPRK)", prepared by Dr. Robert Mummery, dated 7/6/2002, and formerly available at http://sv-oil.com/oil/cspg/Sub.asp?TitleID=0 and http://sv-oil.com/oil/cspg/images/CSPG_presentation.pdf, but with a related abstract available as http://www.searchanddiscovery.com/abstracts/html/2004/annual/abstracts/Mummery.htm.

Figure 4-2: Oil Rig, Provided by Romania, in use in the Tumen River Area of the DPRK

A document from a Korean-oriented, Japan-based website includes the following reference to a long-term DPRK program of research into oil resources in its territory:[389]

> "In its report released in late 1997, the ministry [Ministry of Petroleum Industry], after 30 years of geological study and test borings in both offshore and onshore parts of the country, concluded that there exist seven oil-bearing basins. The report suggests that the West Sea Bay Basin alone contains billions of barrels of oil."

The accuracy of this estimate, as with any other assessment of DPRK oil resources, is difficult for outsiders to determine, but the proximity of the purported oil-bearing areas to similar nearby structures in, for example, China's territorial waters[390] do suggest that the presence of oil is likely, though the quantities are uncertain.[391] Still, oil extraction in onshore and offshore areas of

[389] "Oil & Gas Reserves Found in DPRK", from a Korean-oriented website based in Japan, and dated 2002, but no longer available as of 2021, http://www1.korea-np.co.jp/pk/185th_issue/2002103105.htm. A very similar (likely derivative) article appears at http://www.gasandoil.com/news/2002/11/dix24872.

[390] A report on DPRK oil explorations (Selig S. Harrison, *Asia Program Special Report No. 106, December 2002*, "Toward Oil and Gas Cooperation in Northeast Asia: New Opportunities for Reducing Dependence on the Middle East", The Woodrow Wilson International Center for Scholars), includes the following: "[The DPRK and the oil firms with which it had partnered] hopes for major discoveries on the geological linkages connecting its seabed concessions with the nearby Bo Hai Gulf, where China has already found oil. There are proved recoverable reserves of 450 million barrels in Bo Hai."

[391] Several available reports and articles summarize the DPRK's oil sector activities over the years. See for example, *NORTH KOREA AND SEABED PETROLEUM*, by Keun Wook Paik. Royal Institute of International Affairs (undated, but probably about 2005), available as https://www.wilsoncenter.org/sites/default/files/media/documents/publication/Keun_Wook_Paik.pdf. The document *Energy Scenarios for the DPRK – Report of the Working Group Convened by the United Nations: Phase I*, published by the University for Peace, New York, and dated 2005 (available as https://documents.pub/document/energy-scenarios-for-the-

the DPRK is likely to be an attractive target for investment as (and when) the redevelopment of the DPRK energy sector gets underway.

In a report prepared for Nautilus,[392] Edward Yoon includes the following descriptions of what is known about oil production, resources, and exploration activity, some of which overlaps with the information provided above:

> "Ascertaining the truth as to whether or not North Korea has petroleum deposits has not only been one of the critical issues in the geological exploration community in the DPRK, but also is a factor for central economy planning authorities. In fact, North Korean geologists and foreign engineers have found oil deposits during East Sea seabed area exploration (near Tong-Chon, Kang-won) and in West seabed area exploration (near Nam-Po) in 1985 (Private source). North Korean authorities have established a self-reliance policy for oil exploration and production since the 1960s. The DPRK set up an Oil Exploration Institute in Sook-Chon (near the West Sea) in 1968, with advanced exploration equipment imported from Russia and Sweden, in order to accelerate oil exploration within the West seabed area. In 1978, North Korea signed an agreement with China on oil exploration, under which the DPRK would receive support in the form of Chinese technology and equipment (oil drilling machines and oil prospecting ships) in the Bal-Hae-man area (the Yellow Sea) (Chinese documents, Private source, 2010).
>
> "In addition, North Korea sent experts in oil exploration to Russia in 1991 in order to gain expertise and experience from Caspian Seabed oil exploration activities. The North Korean Physical Exploration Department drilled 13 exploratory holes in the East seabed and West seabed with assistance from Sweden engineers, and found significant results in 1993. As a consequence, 350 barrels of oil were produced in 1998 at the "406" location, located 66 km from Cho-Do Island of Pyong-An province in the West Sea. Also, 450 barrels of oil were produced from an exploration well at the Nam-Po offshore drilling point, also in 1998. The Canadian oil exploring company Cantexa reported that the oil deposit in the 406 drilling area could hold 5 - 40 billion barrels (Korea Marine Institute, www.kordi.re.kr). The Microleptonics Research Laboratory of the Russian Exploration Institute has reported that massive oil deposits have been found in the West seabed and Yellow seabed (ITAR NEWs, 4/9/1999). Analysis of oil samples from these explorations revealed specific gravity of 0.854-0.887, paraffin content of 8-9%, hydrocarbon content of 70-80%, and asphaltic content of 0.2-1%, suggesting that these finds are commercially valuable oil deposits (ibid, and Private source).
>
> "The latest activities related to oil exploitation in the DPRK in partnership with overseas investors include an agreement between KOREX and KOEC (Korean Oil Exploration Company) on a PSC (production sharing contract) in the East-sea, based on a report by Channel Asia News, 2 June, 2006. KOREX was established as a subsidiary of the Irish company Aminex and the North Korean firm Cho-sun Energy (as a 50:50 shared company)."

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dprk-report-of-the-.html) includes a summary of some of the DPRK's oil exploration efforts and joint ventures with exploration firms.

[392] Edward Yoon, *Status and Future of the North Korean Minerals Sector*, dated January 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf.

Reports of the extent of natural gas resource in the DPRK are less numerous than those of oil reserves, and likely just as speculative. A 2002 report reads as follows:[393]

> "'Sovereign Ventures,' a Singaporean petroleum exploration company, announced on August 28 that it found in the DPRK reserves of at least 28.3 billion cubic meters of natural gas and 50 million barrels of petroleum. The locations are in Hoeryong and Onsong in North Hamgyong Province. The Singaporean venture stressed that the discovery is particularly significant since the survey covered only a third of the exploration zone with an area of 6,000 square kilometers."

A late 2002 presentation by the company involved in the exploration, Sovereign Ventures, echoed the above, noting:[394] [395]

> "It is unlikely that a 'Giant' oilfield will be found in the Tuman (Tumen) area of North Korea. However significant potential exists for gas reserves in excess of 1 TCF [trillion cubic feet] and smaller oil pools".

A 2015 review of DPRK oil and gas prospects included the maps shown in Figure 4-3, showing, based on geology, five potential onshore resource areas as well as offshore areas in the Korea East and West Seas.[396] This review reports "…five main onshore sedimentary basins in the DPRK …in which a total of 22 wells have been drilled, many encountering shows of oil and/or gas, with one well reporting 75 bopd [barrels of oil per day] of light sweet crude oil/condensate". Although it is unknown whether this well is still producing oil, the amount reported is equal to approximately 3700 tonnes of oil annually, well over half of the 5900 tonnes of ongoing domestic production that we have assumed for recent years.

A reported gas find in the Korea East Sea in ROK waters may increase the probability that gas will be found offshore of the DPRK as well.[397]

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[393] "Oil & Gas Reserves Found in DPRK", from a Korean-oriented website based in Japan, and dated 2002, formerly available at http://www1.korea-np.co.jp/pk/185th_issue/2002103105.htm. A very similar (likely derivative) article appears at http://www.gasandoil.com/news/2002/11/dix24872.

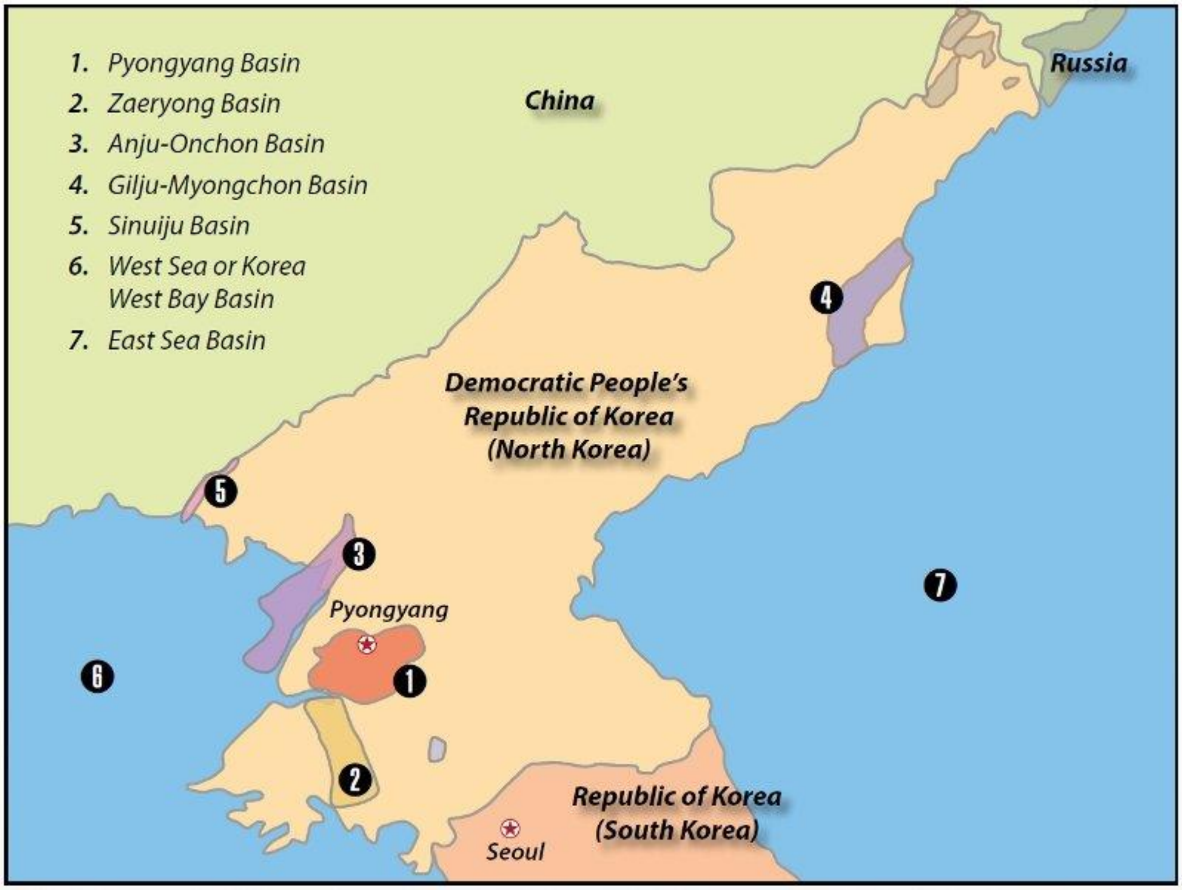
[394] SOVEREIGN VENTURES PTE LTD, *Hydrocarbon Potential of Cenozoic Basins In the Tuman River Area of North Korea (DPRK)*, prepared by Dr. Robert Mummery, dated 7/6/2002, and previously available at http://sv-oil.com/oil/cspg/Sub.asp?TitleID=0 and http://sv-oil.com/oil/cspg/images/CSPG_presentation.pdf. As of 2021, a related abstract is available as http://www.searchanddiscovery.com/abstracts/html/2004/annual/abstracts/Mummery.htm.

[395] It is unclear what the status of Sovereign Ventures' oil and explorations in the DPRK is currently. The most recent item apparently available on the company's website (formerly available as http://sv-oil.com/oil/News/default.asp), "Reuters, September 08, 2003, INTERVIEW-Politics stall Singapore firm's N. Korea oil plans"), appears to underline the difficulties of working in the DPRK energy sector in recent years.

[396] Mike Rego (2015), "North Korea - Hydrocarbon Exploration and Potential", *GeoExPro* Vol. 12, No. 4, available as https://www.geoexpro.com/articles/2015/09/north-korea-hydrocarbon-exploration-and-potential. This article was also summarized in Anthony Fensom (2019), Could North Korea Become the Next Oil and Gas Mega Producer?", *The National Interest*, dated December 28, 2019, and available as https://nationalinterest.org/blog/buzz/could-north-korea-become-next-oil-and-gas-mega-producer-109066.

[397] *The Korea Herald*, "New gas reserves found in East Sea", dated March 4, 2005, by Kim Min-hee Formerly available as http://www.nautilus.org/aesnet/2005/MAR0905/Korea_Herald_NewGAS.pdf. Also see a related article from approximately the same time period: Offshore (2006), "KNOC makes new discovery in the East Sea; Korean National Oil Corp. has discovered an economically viable natural gas deposit in the East Sea", dated February 22nd, 2006, and available as https://www.offshore-mag.com/home/article/16792973/knoc-makes-new-discovery-in-the-east-sea.

Figure 4-3: Projected Onshore and Offshore Locations of Potential Oil and Gas Basins in the DPRK



4.3. Wood and Other Biomass

The DPRK's forest resource base as of about 1990 has been estimated at somewhat less than 9 million hectares out of a total national territory of about 12 million hectares. This estimate appears to include some "unstocked forests". Table 4-1 presents a forest lands and forest stocks summary derived from a UNEP (United Nations Environment Programme) document.[398] [399] Anecdotal evidence, time series satellite photos, consideration (as discussed in previous chapters) of the increasing rate of use of wood fuels in recent years to compensate for short supplies of commercial fuels, and remote sensing data all point toward a considerable decline in DPRK forest area and forest stocks over the past two decades. As with (many) other aspects of

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[398] *DPR KOREA: STATE OF THE ENVIRONMENT 2003*, published by the United Nations Environment Programme, and available as https://wedocs.unep.org/bitstream/handle/20.500.11822/9690/-DPR_KOREA_State_of_the_Environment_Report-2003DPRK_SOEReport_2003.pdf.pdf?sequence=3&isAllowed=y. Table 3.1.

[399] Note that the shaded row and column in this table are calculated based on data in the original source table (Table 3.1 in the report *DPR KOREA: STATE OF THE ENVIRONMENT 2003*, published by the United Nations Environment Programme). The year to which the data in the table correspond is not explicitly described in the source document, but the total forest value is the same as provided in the UN FAO Forest Resource Assessment for 1990. Text in the source document indicates that the units for wood stocks shown in Table 4-4 may in fact be incorrect—it is possible that the units should be cubic meters of wood per hectare, not tonnes per hectare.

the DPRK, different sources disagree on the attributes of the DPRK's forest stocks, how they have been changing, and how they are used.

4.3.1. Forest area and forest types

As shown in Table 4-2, based on the DPRK's "State of the Environment" report, as published by UNEP, the DPRK's forests are (or were, as of about 1990) approximately 42 percent coniferous forests, 35 percent deciduous/hardwood species (referred to as "latifoliate" in the table), and 23 percent mixed conifer and deciduous forests. Pine species dominate the coniferous forests, and oaks dominate the deciduous species. A somewhat different picture of the forests, at least as of 1996, was described by Professor Seung-Ho Lee of the Remote Sensing Laboratory of the Korea (ROK) Forest Research Institute (KFRI). Based on UN FAO statistics, he estimated that about 20 percent of forests were conifers, 63 percent were hardwoods, and the rest were mixed forests (Table 4-3 and Figure 4-4).[400] Table 4-4 presents another estimate for the forest area of the DPRK during the 1990s, this estimate for the year 1997 (in comparison with 1970 stocks), and presented by province and municipality.[401] Table 4-5 presents estimates for the distribution of wood stocks by type of tree.[402]

Table 4-1: Estimated Summary of Forest Areas and Stocks in the DPRK as of 1990

Classification	**Area (1000 hectares)**	Biomass stock (ton/hectare)	Implied stock (million tonnes)
TOTAL Forested land	**8,201**	**62.3**	510.92
Forest of timber industry	5,440	74.55	405.55
Economic forest	1,436	48.3	69.36
Firewood forest	196	40.95	8.03
Protected forest	1,129	66.15	74.68
Non-timber forest land	436	3.15	1.37
Unforested area	383	-	-
Grass field	170	18	3.06
Total of Above	**9,190**	**61.16**	**562**

[400] Table and map from presentation entitled "Forest and Other Biomass Production in the DPRK: Current Situation and Recent Trends as Indicated by Remote Sensing Data - Status of Forest Resources, Degradation & Biomass in North Korea using Remote Sensing Data" by Professor Lee Seung-ho of the Remote Sensing Laboratory, Korea Forest Research Institute, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Professor Lee's paper is available as http://www.nautilus.org/DPRKEnergyMeeting/papers/Lee.ppt.
[401] Table 4-4 was adapted from "Table 1" in a MS Word document entitled *Current Status of Forest and Agricultural Land in North Korea*, authored by Park Dong kyun, Secretary General, Northeast Asian Forest Forum, Korea. The document is undated, but apparently from around the year 2000. Document downloaded via Google on 7/19/2012, apparently originally from the website http://english.kfem.or.kr/international/symposium, although direct access to that website did not seem to be available. Some of the headings in Table 4-4 have been corrected or elaborated, relative to the table in the original source, and the note following the table was added for clarity.
[402] From presentation by Professor Lee--same source as for Table 4-3 and Figure 4-4. Data for Table 4-3 originally from UN FAO Forest Resource Assessment.

***Table 4-2: Species Composition of DPRK Forests as of (approximately) 1990*[403]**

Classification	Ratio (percent)
Compositions by species of forest land	100
Coniferous forest	41.9
Latifoliate forest	35.6
Mixed forest	22.5
Coniferous forest	
Pinus	37.8
Larch	33.8
Pinus koraiensis	11.9
Kind of Deodar	14.8
3 needle-leaf Pinus	1.7
Latifoliate forest	
Oak	52.4
Lime	6.4
White birch	6.3
Acacia	3.2

[403] *DPR KOREA: STATE OF THE ENVIRONMENT 2003*, published by the United Nations Environment Programme, and available as https://wedocs.unep.org/bitstream/handle/20.500.11822/9690/-DPR_KOREA_State_of_the_Environment_Report-2003DPRK_SOEReport_2003.pdf.pdf?sequence=3&isAllowed=y. Table 3.2.

Table 4-3: Alternative Estimate of Species Composition of DPRK Forests (as of 1996)

Forest Type		**Area (1,000 ha)**	**Ratio (%)**
Total		**8,445.5**	**100**
Conifers	**Subtotal**	**1,675.5**	**19.8**
	Conifers	**955.1**	**11.3**
	Alpine Con.	**720.4**	**8.5**
Hardwoods	**Subtotal**	**5,331.9**	**63.2**
	Hardwood	**4,415.3**	**52.3**
	Oaks	**916.6**	**10.9**
Mixed wood		**1,438.1**	**17.0**

Table 4-4: Estimate of Forested Land in 1997 by Province, with Change from 1970

Province (Do)	Forest Land in 1997 (ha)			Forest Land in 1970 (ha)	Change from 1970
	Man-made	Natural	Total		Area (ha)
Pyongyang-si	7,118	93,061	100,179	-	-
Nampo-si	3,368	16,767	20,095	-	-
Pyongyang-S*	90,180	575,249	665,429	918,632	-132,929
Pyongyang-N	91,387	579,683	671,070	928,406	-257,336
Chagang	208,413	859,045	1,067,458	1,514,766	-447,308
Gaesung-si	20,287	33,007	53,294	-	-
Hwanghae-S*	80,956	150,432	231,388	420,225	-135,543
Hwanghae-N	90,071	309,447	399,518	586,360	-186,842
Gangwon	103,369	619,250	722,619	889,313	-166,694
Hamgyong-S	207,097	1,076,007	1,283,104	1,612,493	-329,389
Hamgyong-N	166,793	1,045,984	1,212,777	1,485,447	-272,670
Yanggang	141,046	983,974	1,125,020	1,417,040	-292,020
Total	1,219,025	6,341,906	7,551,931	9,772,682	-2,220,751

* Note: Totals for Pyongyang-S and Hwanghae-S in the "Forest Land in 1970" and "Change from 1970" columns apparently include data for Pyongyang-si plus Nampo-si and Gaesung-si (that is, the municipalities of Pyongyang, Nampo, and Gaesung), respectively.

Figure 4-4: Map of Forest Types in the DPRK

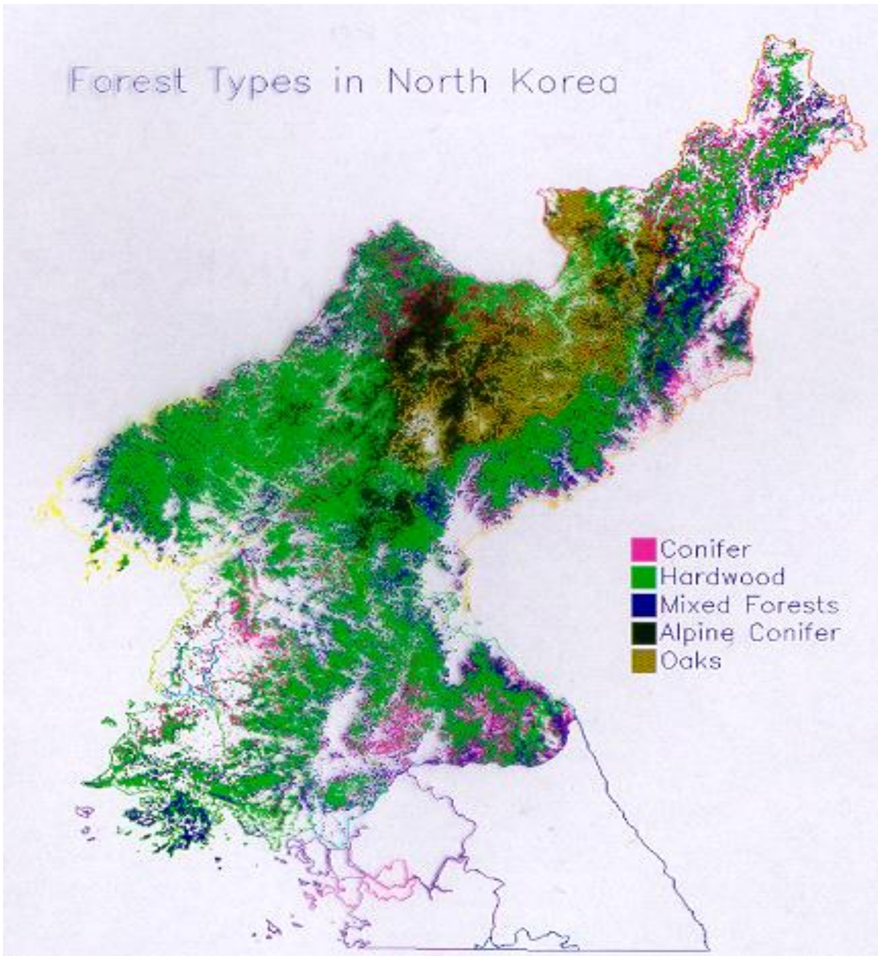


Table 4-5: Estimated Wood Stocks by Type in DPRK Forests (as of 1996)

		Growing Stock (1,000 m^3)	Ratio (%)	Volume per ha (m^3/ha)
Total		**342,864**	**100**	**40.6**
Conifers	**Subtotal**	**86,402**	**25.2**	**51.6**
	Conifers	**46,703**	**13.6**	**48.9**
	Alpine Conifers	**39,699**	**11.6**	**55.1**
Hardwood	**Subtotal**	**205,443**	**59.9**	**38.5**
	Hardwood	**163,879**	**47.8**	**37.1**
	Oaks	**41,564**	**12.1**	**45.3**
Mixed wood		**51,019**	**14.9**	**35.5**

Another source of information on DPRK forests, a set of reports by Keith Openshaw, dated 1994, suggests that the nominal DPRK forest area in 1993 was about 9 million hectares, but that only 7.8 million hectares were "in practice" forested. He applies an average standing volume for DPRK forests of 40 cubic meters per hectare, based on forests in surrounding countries, to estimate wood stocks.[404] This source suggests that softwoods make up 45 percent of total DPRK stocks, and hardwoods 55 percent.

4.3.2. Wood stocks

Despite different assumptions about the composition of DPRK forests, the sources cited above appear to converge on a reasonably consistent set of estimates for stocks of wood in the DPRK. Correcting the table from the UNEP document for what appears to be an error in units suggests a wood volume of about 370 million cubic meters in 1990. Openshaw's average standing volume estimate, depending upon whether the stock average is applied to the DPRK area forested "in practice" or the nominally forested area, yields estimated 1993 stocks of between about 310 and 360 million cubic meters. Table 4-4 yields a growing stock measurement of about 340 million cubic meters as of 1996. Using two different estimates of average cubic meters of wood per tonne, Professor Lee calculates 1996 DPRK wood stocks of between 251 and 293 million tonnes of total above-ground biomass. We use the former estimate—which is based on an average wood density that seems more reasonable for the tree species present in the DPRK, as one input in the estimation of the time series of DPRK wood resources presented below.

4.3.3. The DPRK wood resource over time

The ultimate question to be answered by an investigation into wood resources is the extent to which existing rates of resource use are sustainable. To address this question, we used Professor Lee's summary of data obtained from remote sensing techniques to estimate a trend in total DPRK forest area, and used those estimates with estimates of DPRK forest stocks to derive the amount of wood annually available in the DPRK.

Table 4-6 presents data from two "snapshots" of an area within the DPRK, derived from remote sensing images taken by the Landsat (1999) and Quickbird (2004) satellite systems. Figure 4-5 shows maps created from the two sets of data. Though this table represents only one small area of the DPRK, over only a five-year period, there is a clear increase in the amount of unstocked forest and denuded forest over the period between analyses.[405] Figure 4-6 shows false-color satellite images of an area of the DPRK, taken in 1981 and 1993, showing that "approximately 10,000 ha [of forest area] has been converted into farmland in Daeheungdan-gun County (near Yangkang and North Hamgyong Province)" in the DPRK over the 12-year period.[406]

A series of satellite analyses of the extent of DPRK forest cover were summarized by Professor Lee as follows: 9.77 Mha in 1970 (DPRK source), 8.97 Mha in 1987 (FAO source), 8.45 Mha in 1994 (KFRI Satellite Image Analysis), 7.53 Mha in 1997 (DPRK from UNDP Round Table

[404] Keith Openshaw, *DPRK/UNDP-GEF Project on Forestry Carbon Sink. Visit to DPR Korea, October 15th to 25th, 1994. Project Brief. Technical Appendix: Estimating Carbon Sequestration in North Korean Forests*.
[405] Table and map from presentation entitled "Forest and Other Biomass Production in the DPRK: Current Situation and Recent Trends as Indicated by Remote Sensing Data - Status of Forest Resources, Degradation & Biomass in North Korea using Remote Sensing Data" by Professor Lee Seung-ho, as cited above.
[406] Quote and satellite photos for Figure 4-6 from presentation by Professor Lee Seung-ho, as referenced above.

Meeting) and 7.53 Mha in 1999 (KFRI Satellite Image Analysis). An additional time-series of DPRK forest area from the UN FAO Global Forest Resource Assessment 2005 (FRA 2005)[407] shows a trend from 8.20 to 6.82 to 6.19 Mha in 1990, 2000, and 2005, respectively. A 2011 report estimated that forest area had fallen from 8.20 Mha in 1990 to 6.99 Mha in 2000 and 5.66 Mha in 2010.[408] Finally, the most recent version of the UN FAO Global Forest Assessment suggests a slower rate of decline of DPRK forest area, as shown in Table 4-7.[409]

Table 4-6: Land-type Data from Remote Sensing Studies of an Area of the DPRK, 1999 and 2004

CLASS	**Landsat TM (1999)**		**Quickbird (2004)**	
	AREA (ha)	**Ratio (%)**	**AREA (ha)**	**Ratio (%)**
Total	**35920.44**	**100**	**28594.72**	**100**
Stocked Forest	**8344.08**	**23.23**	**5124.91**	**17.93**
Unstocked Forest	**4345.11**	**12.09**	**7791.51**	**27.25**
Converted Farmland	**4186.44**	**11.65**	**2470.97**	**8.65**
Denuded Forest	**753.93**	**2.10**	**3754.73**	**13.13**
Rocky Area	**-**	**-**	**1828.37**	**6.39**
Paddy	**2834.64**	**7.89**	**4574.85**	**16.00**
Cropland	**11574.18**	**32.22**	**2921.62**	**10.22**
Others	**3882.06**	**10.81**	**127.76**	**0.45**

Table 4-7: DPRK Forest Area Trends from UN FAO 2020 FRA

Estimate (Mha)			
Forest	**Other Woodland**	**Year**	**Growth Rates, Forest**
6.912	1.864	1990	
6.455	2.172	2000	**-0.68%**
6.242	2.301	2010	**-0.33%**
6.136	2.366	2015	**-0.17%**
6.030	2.430	2020	**-0.17%**

[407] The UN FAO *Global Forest Resource Assessment 2005* (FRA) provides forest extent, forest stock, and other data over time for most nations, including the DPRK. DPRK data are available from www.fao.org/forestry/site/32086/en/prk.
[408] Korea Forest Research Institute (KFRI, 2011), "NATIONWIDE INTERNATIONAL NEWS, N. KOREA'S DEFORESTATION PROCEEDING RAPIDLY: REPORT", *Asia Pulse*, dated June 17, 2011..
[409] The *UN FAO Forest Resource Assessment (FRA) for 2020, Desk Study Democratic People's Republic of Korea*, available as http://www.fao.org/3/ca9858en/ca9858en.pdf, provides details of FAO estimates of DPRK forest area and related data. The methods and categorizations for forest area appear to be slightly different than those used in earlier versions of the FRA.

Figure 4-5: Land-type Maps Created from Satellite Images of the Kaesong Area in the DPRK, 1999 and 2004

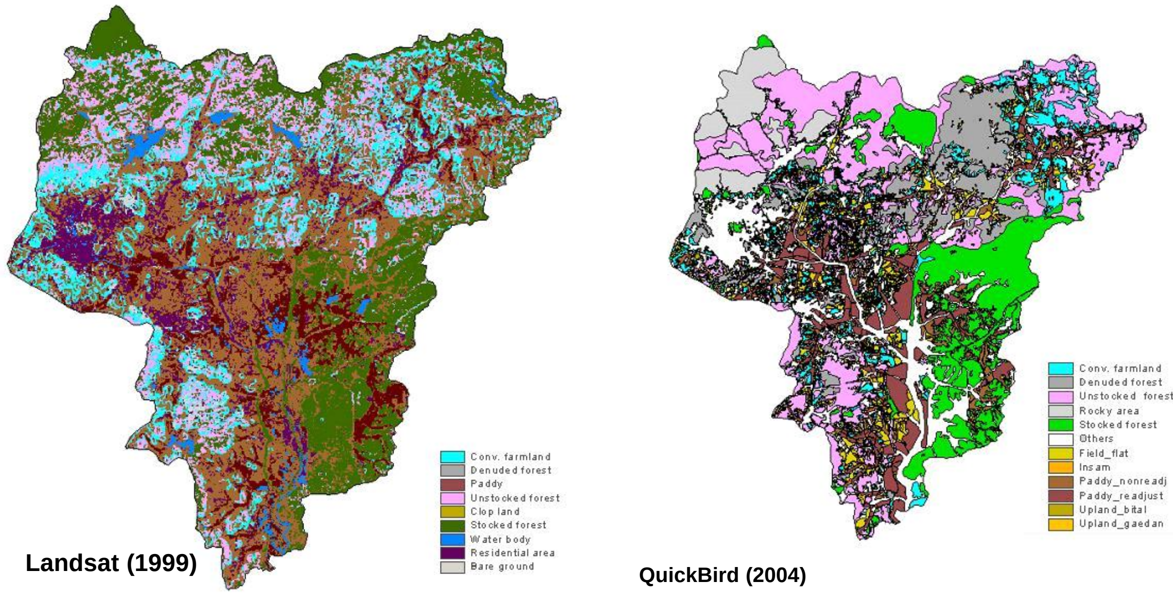
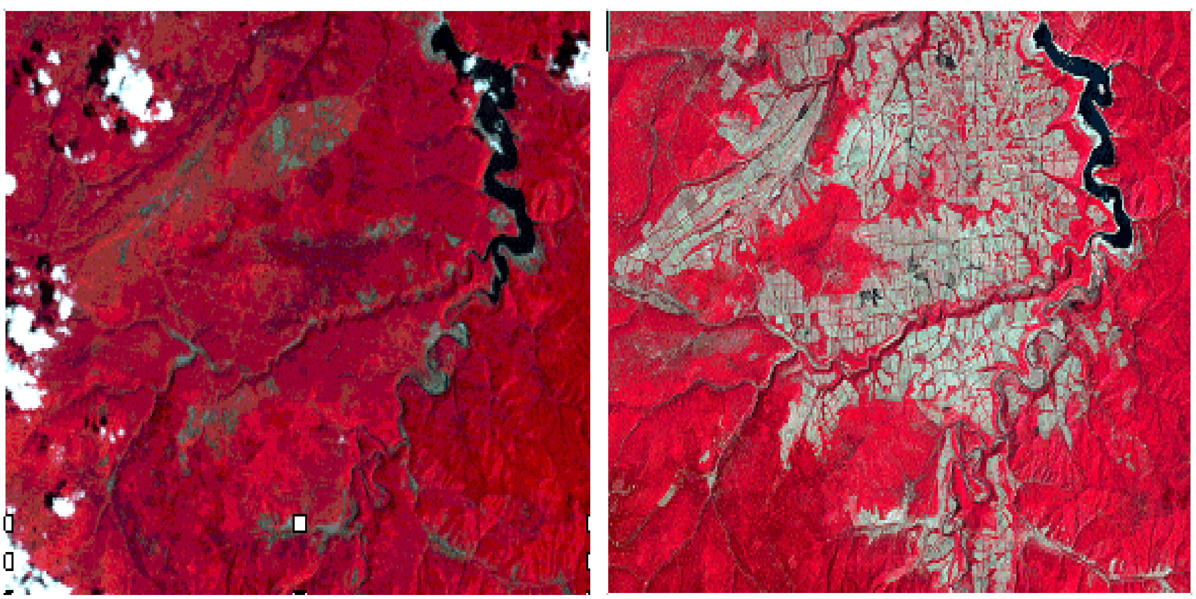


Figure 4-6: Landsat Images of an Area in the DPRK taken in 1981 (left) and 1993 (right)



Based on growth rates for forests in areas of the ROK that have forests similar to the types of forests found in the DPRK, and using data from three sources, Professor Lee calculates a weighted-average annual growth rate of 3.06 %, which implies an annual production from growing tree stocks in the DPRK of 7.68 million tonnes per year in 1996. Note that this figure includes all above-ground biomass, some of which (small twigs and leaves, for example) would likely not be used as fuel, and likely some of which would be lost during harvesting. Prof. Lee cites ratios of total above-ground biomass to tree stem volume ranging from 1.22 (for hardwoods) to 1.29 (for conifers). This implies that leaf and twig biomass might be on the order of 5 to 15 percent of total above-ground biomass.

From the forest area data above, the decline in the area of forest lands in the DPRK averaged 1.45% per year from 1987 to 1999, using the multi-survey timeline cited by Prof. Lee; average rates of forest decline using the FRA 2005 estimates were and 1.83% per year from1990 to 2000, and 1.93% per year from 2000 to 2010.

Based roughly on the information above, we make the following estimate of forest area, wood stocks, and wood production over time through 2020.

Key Assumptions and intermediate results:

- Estimate of forest area in 1990: 8.20 Million ha (DPRK State of Environment Report, 2003, and UN FAO FRA)
- Change in extent of forest lands, 1990 to 2000: -1.06% per year (average of rates in documents referenced above).
- Change in extent of forest lands, 2000 to 2005: -1.21% per year (average of 2020 FRA and KFRI estimates).
- Change in extent of forest lands, 2005 to 2010: -1.26% per year (average of 2020 FRA with average of KFRI and other estimates described above).
- Change in extent of forest lands from 2010 through 2020: -0.50% per year (estimate, and about three times 2020 UNFAO FRA estimates for the period, but which likely takes into account reported DPRK reforestation efforts and improved availability of non-biomass fuels as the DPRK economy has grown, while still resulting in estimates for the wood harvest by year consistent with demand-based estimates of wood needs as described in section 3.8, above).
- Growing wood stocks on forest lands, 1996: 251million tonnes (estimate above by Prof. Lee)
- Average annual growth on stocked forest lands: 3.06% per year (estimate above by Prof. Lee)
- Average growth per ha on forest lands: 0.94 te/ha-yr, based on estimates above.
- Total degraded forest lands as of about 1997: 1.6317 Million ha (from Prof. Lee presentation, slide 34; including "denuded forest", "unstocked forest", and "converted farmland", of which the latter is 59% of the total.
- Average fraction of annual stocked-forest growth per hectare in degraded forests: 20% (rough estimate).

The results of this analysis are presented in Table 4-8 and Figure 4-6. Overall forest lands are estimated to have decreased by over 25 percent between 1990 and 2020, with a similar decrease in the amount of annual growth in growing stocks.[410] The total annually available woody biomass decreases from over 13 million tonnes in 1990 to just under 10 million tonnes in 2010, but of those totals, about 4 to 4.5 million tonnes annually was biomass from forest areas cleared for one purpose or another. This suggests that by 2010 some 40 percent, at least, of DPRK biomass use was unsustainable—that is, cut from forest stocks, not from annual forest growth. Our estimates for total wood use in the DPRK in 2019 and 2020 are each about 6.5 million tonnes. This is already most of what we calculate as the total woody biomass available from annual growth plus wood from cleared lands, but this simple comparison does not consider the following factors:

- The estimate of total woody biomass available includes twigs and leaves, most of which would likely not be used for fuelwood (or industrial roundwood).
- There will be some harvest losses (wood left behind in the forests or fields).
- Much of the annual increment of forest growth may be in rugged terrain inaccessible for use by people.
- Not all forest clearing results in complete land conversion, meaning that the wood harvest from land clearing may be overstated.
- Both the estimated average wood stocks and the average growth rate of DPRK forests may be overstated.

Taken in combination, these factors, together with our estimates, suggest that the DPRK populace is indeed using the bulk of the nation's available supply of wood as fuel and for other uses, and underscores the observations by visitors and satellites alike of a dwindling forest and woodlands resource base. The DPRK government has undertaken massive reforestation projects, with mixed results, but clearly reforestation and related forest and soils conservation activities constitute an area where international assistance and capacity building will be both useful and a crucial step toward environmental sustainability in the DPRK. The importance of forest health and reforestation was underlined in the announcements of national DPRK efforts in late 2020 to prevent forest fires from further damaging forest stocks, and thus further exacerbating problems such as erosion and landslides.[411]

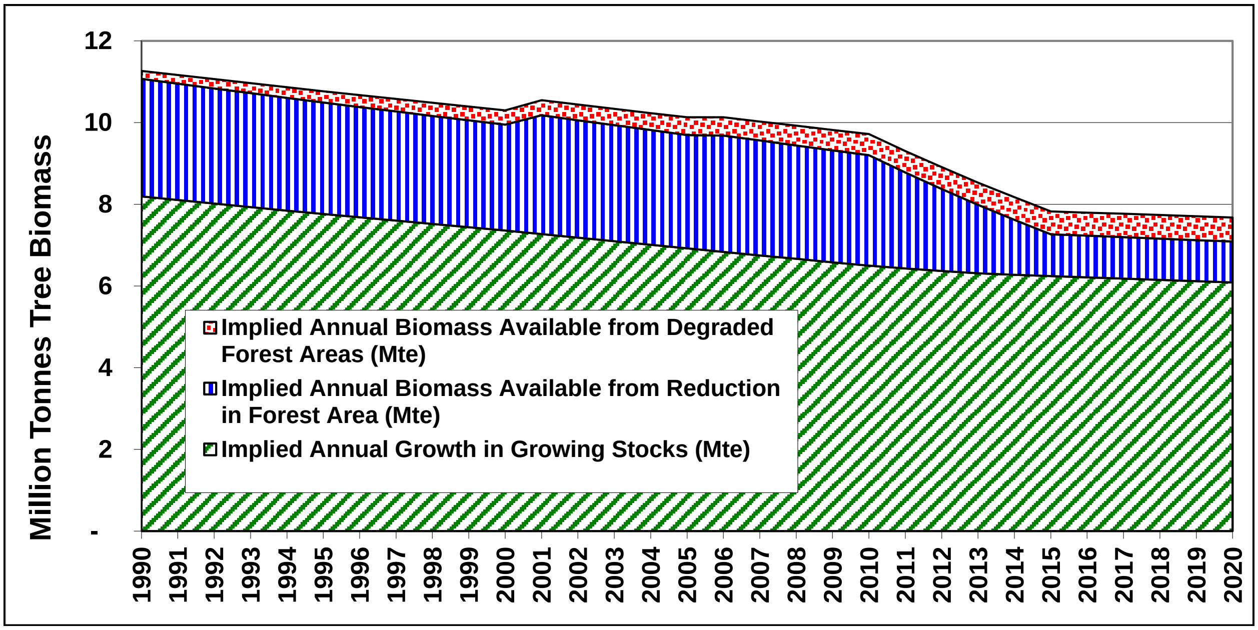
[410] The Forestry Department of the Food and Agriculture Organization (FAO) of the United Nations, in its *Global Forest Resources Assessment 2010, Country Report, The Democratic People's Republic of Korea*, dated 2010, and available as http://www.fao.org/docrep/013/al489E/al489e.pdf, presents a variety of data on the DPRK forest sector, but little of the information appears to have been updated since the 1990s. The 2020 update of this assessment (The *UN FAO Forest Resource Assessment (FRA) for 2020, Desk Study Democratic People's Republic of Korea*, available as http://www.fao.org/3/ca9858en/ca9858en.pdf), does present an estimate of forest area in 2020 that is nearly the same (6.03 million ha) as our estimate for that year.

[411] See, for example, Yonhap News Agency (2020), "N. Korea calls for efforts to prevent wildfire amid dry weather", dated November 11, 2020, and available as https://en.yna.co.kr/view/AEN20201111004400325.

Table 4-8: Estimate of Annual DPRK Woody Biomass Production, 1990 to 2020

Year	Mha Forest Lands	Growing Stocks (million te)	Implied Annual Growth in Growing Stocks (Mte)	Implied Annual Biomass Available from Reduction in Forest Area (Mte)	Implied Annual Woody Biomass Available from Forest Lands and Clearing (Mte)	Estimated Degraded Forest Lands or "Other Woodland" (Mha)	Implied Annual Biomass Available from Degraded Forest Areas (Mte)	Implied Annual Woody Biomass Available from all Stocked and Degraded Forests (Mte)
1990	8.20	268	8.19	2.88	11.07	1.04	0.19	11.27
1991	8.11	265	8.10	2.85	10.95	1.13	0.21	11.16
1992	8.03	262	8.02	2.82	10.84	1.21	0.23	11.06
1993	7.94	259	7.93	2.79	10.72	1.30	0.24	10.96
1994	7.86	256	7.85	2.76	10.61	1.38	0.26	10.87
1995	7.77	254	7.76	2.73	10.49	1.47	0.27	10.77
1996	7.69	251	7.68	2.70	10.38	1.55	0.29	10.67
1997	7.61	248	7.60	2.67	10.27	1.6317	0.31	10.58
1998	7.53	246	7.52	2.64	10.16	1.71	0.32	10.48
1999	7.45	243	7.44	2.62	10.05	1.79	0.34	10.39
2000	7.37	240	7.36	2.59	9.95	1.87	0.35	10.30
2001	7.28	238	7.27	2.91	10.18	1.96	0.37	10.55
2002	7.19	235	7.18	2.88	10.06	2.05	0.38	10.44
2003	7.10	232	7.09	2.84	9.94	2.14	0.40	10.34
2004	7.02	229	7.01	2.81	9.82	2.22	0.42	10.23
2005	6.93	226	6.92	2.77	9.70	2.31	0.43	10.13
2006	6.85	223	6.84	2.85	9.68	2.39	0.45	10.13
2007	6.76	221	6.75	2.81	9.56	2.48	0.46	10.03
2008	6.67	218	6.67	2.78	9.44	2.57	0.48	9.92
2009	6.59	215	6.58	2.74	9.32	2.65	0.50	9.82
2010	6.51	212	6.50	2.71	9.21	2.73	0.51	9.72
2011	6.44	210	6.43	2.35	8.78	2.81	0.53	9.30
2012	6.37	208	6.37	2.01	8.37	2.87	0.54	8.91
2013	6.32	206	6.31	1.67	7.99	2.92	0.55	8.53
2014	6.28	205	6.27	1.34	7.62	2.96	0.55	8.17
2015	6.25	204	6.24	1.03	7.27	2.99	0.56	7.83
2016	6.22	203	6.21	1.02	7.23	3.02	0.57	7.80
2017	6.19	202	6.18	1.01	7.19	3.05	0.57	7.77
2018	6.16	201	6.15	1.01	7.16	3.08	0.58	7.74
2019	6.13	200	6.12	1.00	7.12	3.11	0.58	7.71
2020	6.10	199	6.09	1.00	7.09	3.14	0.59	7.68

Figure 4-7: Estimated Trend in Sources and Amount of Woody Biomass Availability in the DPRK, 1990 to 2020



4.3.4. Other biomass

Crop wastes constitute the other major source of biomass for fuel in the DPRK. As of this writing, we have no detailed estimate of the DPRK's crop waste resource. A very rough estimate can be prepared for the major crops of rice and maize as follows. For rice, about one unit of straw is typically produced per unit of grain. The year 2004/2005 rice harvest was estimated at about 1.5 million tonnes, meaning that available rice straw would also have been about 1.5 million tonnes (though in fact some or much of this straw should have been used as a soil amendment).[412] The UN FAO estimated somewhat higher rice production in 2004/2005, at about 2.2 to 2.4 million tonnes, with similar output in 2009 and 2010 (and about 3 million tonnes in 2008).[413] Maize production was estimated at about 1.7 million tonnes of grain in 2004/2005, and about the same (as estimated by UN FAO—see previous footnote) in 2009 and 2010, though 2008 harvests were somewhat lower, at about 1.4 million tonnes. The amount of maize crop residues per unit grain seems to vary depending on the source of information, but most estimates seem to be in the range of 1 to 1.5 tonnes of residues (stalks, husks, and cobs) per tonne of grain. Using a value of 1.3 for this parameter suggests that maize residue production in 2005, for example, was approximately 2.2 million tonnes. Residues from other crops, including other grains, potatoes, and orchard crops, are likely in the range of 0.5 to 1 million tonnes, meaning that overall crop residue availability was about 4 to 5.5 million tonnes annually. Our estimates for non-wood biomass used for fuel in the DPRK in 2019 and in 2020 are each within this range,

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[412] Randall Ireson, *Food Security in North Korea: Designing Realistic Possibilities*, dated February 2006, published by the Walter H. Shorenstein Asia-Pacific Research Center. Freeman Spogli Institute for International Studies, Stanford University, and available as https://aparc.fsi.stanford.edu/events/food_security_in_north_korea_designing_realistic_possibilities.

[413] See Figure 1 in UN FAO, *Special Report, FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea*, dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.htm.

at about 4.0 million tonnes, which suggests, if both supply and demand estimates are close to accurate, that the vast bulk of crop residues are used for fuel in the DPRK and/or (probably and) other biomass fuels, such as grasses and other non-tree biomass, are harvested for fuel use. In either case, the lack of residues returned to the soil, and the use of non-wood vegetation for fuel, suggest an ongoing pattern of soil fertility decline, and spell trouble for soil conservation.

As the DPRK livestock population is relatively low relative to other countries with similar population, animal manure presently is unlikely to represent a sizable resource, although the DPRK does have an active program of dissemination of small biogas digestors that use human night soil, wastes from pigs raised in rural households, and other biomass materials as substrates. Based on UN FAO statistics, the DPRK in 2005 had slightly under 600,000 cattle (a very few dairy cows, with most of the rest classified as "Oxen"), 3.2 million pigs, 21 million chickens, 5.5 million ducks, 2.75 million goats, and about 170,000 sheep. Using rough estimates of 2.2 kg volatile solids (dry organic matter) per head of cattle per day, 0.3 kg per pig per day, 0.010 kg per chicken, and 0.024 kg per duck per day suggests that the DPRK's current resource of biomass in livestock manures was about 1 million tonnes per year in 2005.[414] More recent statistics suggest somewhat lower livestock numbers. The Yonhap News Agency quoted **(**in 2011**)** the World Organization for Animal Health (OIE) as saying that "North Korea has 577,000 heads of cattle, 2.2 million pigs and 3.5 million goats".[415] The lower number of pigs in the 2011 estimate suggests that the total available livestock manure would probably fall to closer to 900,000 tonnes by 2009/2010.

4.4. Other Renewable Resources

Other renewable energy resources in the DPRK include hydraulic power, wind energy, solar energy, tidal power, and geothermal energy. Summaries of these DPRK resources for electricity generation are provided below—please see section 5.2.2 of this Report for a more extensive treatment of these resources.

A number of sources suggest that the DPRK's hydraulic resource is sufficient to provide about 10 GWe of hydroelectric generation. This is consistent with what we have been told in workshop presentations by delegations from the DPRK:

> "The hydraulic generating capacity of DPRK is now over 4 million kW – but this figure only accounts for 30% of the total available resources." And "DPRK has hydraulic energy resources of 10 million kW with a favorable development condition and high effectiveness of investment."[416]

[414] Manure from goals and sheep, which are typically difficult to collect, are not included in this estimate. Animal population estimates are from UN Food and Agriculture Organization FAOSTAT, available as http://www.fao.org/faostat/en/#home. Estimates of manure production per animal are derived from data in *Rural Energy Production: Biogas Plant, a Sustainable Source of Energy for Cooperative Farms*, by Arthur Wellinger, dated December 12, 2003, and published by ADRA (Adventist Development and Relief Agency International) and Nova Energie. This report provides case studies of the application of manure-fed biogas digesters in the DPRK.
[415] Yonhap news article included in a 2011-4-20 post on North Korea Economy Watch, "Agricultural Statistics" archive, available as http://www.nkeconwatch.com/category/statistics/agriculture-statistics/.
[416] DPRK Delegation, "THE POTENTIAL IMPACT OF THE INTER-STATE ELECTRIC TIES IN NORTH EAST ASIA ON ENVIRONMENT," September 31, 2003. Paper presented at Nautilus Institute's 3rd Workshop on Grid Interconnections, held in Vladivostok, Russia, September 30 to October 3, 2003. Available as http://nautilus.org/wp-content/uploads/2011/12/K_DPRK_2_PPR.pdf.

Many, but not all, of the sites for large hydroelectric facilities have been built upon, but many sites for small and medium hydro dams remain. In addition, it has been reported that some of the DPRK hydroelectric plants—some of which were built before the Korean War, have efficiencies (electrical energy output as a fraction of energy available in falling water) that are around 60 percent, suggesting that significant additional electricity could be generated at these existing sites once plants are upgraded to modern efficiency levels (on the order of 90 percent). Table 4-9 provides one estimate of hydroelectric potential for major rivers in the DPRK. The total of the estimates shown is the equivalent of approximately 9,200 average MW of power.[417]

Table 4-9: Estimate of Hydraulic Resources in the DPRK[418]

Name	GWh	(%)
Amrok River	39,635.00	47.9
Tumen River	8,134.61	9.5
Taedon River	7,508.17	9.1
Chongchon River	4,407.00	5.3
Rimjin River (north)	2,806.10	3.4
Pukhang River (north)	3,422.10	4.1
Resong River	701.34	0.8
Songchon River	1,675.00	2.0
Kumya River	1,617.17	2.0
Tanchonnam River	1,692.40	2.0
Orangchon River	1,451.80	1.8
Kiljunam River	7,670.80	0.9
TOTAL OF ABOVE	80,721.49	88.8

Estimation of the wind resources potential in the DPRK is incomplete, and we have found existing DPRK wind data to be potentially unreliable. Significant DPRK wind resources are said to exist, however, in mountain areas and in coastal areas (including offshore areas). A DPRK delegation to a workshop organized by Nautilus and co-hosts provided an annual wind resource estimate of 1.7 TWh, which corresponds to about 550 MWe of wind power at an assumed capacity factor of about 35 percent (not atypical for wind generators). A presentation by a DPRK delegation at a subsequent Nautilus workshop included the following passage on wind power in the DPRK

> "Most of the western seashore of the country is suitable for installing large size wind turbines. The annual average wind speed is above 4.5 m/s in 18% of the territory and it is expected to have an installed capacity of more than 4,000 megawatts of wind-generated electricity."[419]

[417] That is, the total shown is the equivalent of 9200 MW of power supplied continuously, year-round. Given that the average capacity factors of DPRK hydroelectric facilities may be 50 percent or less, this implies a total potential "nameplate" hydroelectric potential on the order of 18,000 MW, though not nearly all of this potential can be taken advantage of in practice.
[418] Table from *Some Thoughts on DPRK's Natural Geological Conditions and Their Evaluation - On the Distribution and Development of Hydropower Resources and the Electric Industry*, by Professor Sagong Jun, Korea University in Japan, formerly available as http://www1.korea-np.co.jp/pk/112th_issue/99091601.htm. Units in the original source were listed as "1,000,000 kw/h", but it seems likely that the units intended are GWh.
[419] "Options For Rehabilitation Of Energy System & Energy Security & Energy Planning In The DPR Of Korea", prepared by the DPRK Delegation to the Asian Energy Security Workshop 2004, May 12th - 14th, 2004, Beijing, China. Available as

Based on our own (Nautilus') experience in installing several small wind generators in a location on the western coast of the DPRK, it seems unlikely that onshore wind resources in that area are quite as good as claimed above, though offshore areas may well prove to have a better wind regime than onshore areas. Until additional and more rigorous wind data collection is completed, the actual DPRK wind resource is uncertain, but it seems likely that the total practical level of wind turbine installations in the DPRK will be in the range of hundreds of megawatts, of which some is likely to be in near-offshore areas or on islands.

The same DPRK presentation cited above gives the following information about the DPRK solar resource: "Annual average solar irradiation is about 1200 kWh/m^2 and 55~60% of days per year are clear." The DPRK's winters are often relatively clear but cold, and summers are humid, with much of the annual rainfall in the DPRK occurring in the summer months. This weather pattern, and the solar resource data provided, suggest that the DPRK has at best a moderate solar resource, on average. At 1200 kWh/m^2-yr, the DPRK's average insolation is less than that in many cities in the United States (for example, Pittsburgh, Pennsylvania has a similar solar resource[420]), but is more favorable than the solar resource in most locations in northern and central Europe.

Tidal power is a possibility for some coastal areas of the DPRK. The 2004 presentation by DPRK delegates described above noted: "The west seashore of the DPRK is one of the well-known tidal zone in the world. The average difference between high and low tide is 4~6 m. n Tidal potential capable of the development is estimated at about 19 TWh." Generation of 19 TWh annually suggests installed capacity on the order of 4 to 6 GW. An estimate by a Russian author put the tidal power resource of the DPRK at 4700 MW (4.7 GW).[421] At least one small tidal power station exists in the DPRK—a 500 kW unit built into the Nampo barrage near the mouth of the Taedong River[422] (see Figure 4-8 and Figure 4-9). The DPRK planned, as of 2004, to build a 2 MW prototype tidal power plant in South Hwanghae province, and to investigate a site for a 20 MW tidal power plant and complete a design for that plant. In 2004, China was reportedly planning to build a 300 MW tidal power facility based on an artificial offshore lagoon approach near the mouth of the Yalu River near the DPRK border, but it is somewhat unclear whether this project has moved forward since.[423] The fact that China was planning such a project, however, probably means that such projects are also possible in nearby DPRK near-shore territory, at least from the point of view of the tidal energy resource.

Geothermal energy is also mentioned as a possible source of both heat and power for the DPRK. At present, we have no information about the extent of the DPRK's geothermal resources, though some potential geothermal sites undoubtedly are present in the DPRK.

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https://nautilus.org/supporting-documents/options-for-rehabilitation-of-energy-system-energy-security-energy-planning-in-dpr-of-korea/.

[420] See, for example, http://howto.altenergystore.com/Reference-Materials/Solar-Insolation-Data-USA-Cities/a35/.

[421] Marina Trigubenko (1991), "Industry of the DPRK". Paper presented at Korea Development Institute Symposium, Seoul, ROK (October 1991).

[422] The authors visited this installation on their 1998 Unhari wind power project mission to the DPRK. We do not know its current operational status, although in Google Earth Pro imagery through 2/27/19, the basic infrastructure of the generating station appears to be intact.

[423] See, for example, K. Steiner-Dicks, Tidal: Asia's Cinderella renewable energy", *Tidal Today*, dated July 5, 2011, and formerly available as http://social.tidaltoday.com/technology-engineering/tidal-asia%E2%80%99s-cinderella-renewable-energy; and Renewable Energy World.com, "China Endorses 300 MW Ocean Energy Project", dated November 2, 2004, and available as as https://www.renewableenergyworld.com/storage/china-endorses-300-mw-ocean-energy-project-17685/.

Figure 4-8: Photo of West Sea Barrage, Near Nampo, DPRK[424]

[424] Photo shows locks for ship passage and, in the channel in the center of the photo, spillways and structures where tidal power turbines are installed. Photo downloaded from http://www.llukasz.com/North_Korea_photos/DPRK/West_sea_barrage.JPG.

Figure 4-9: Painting of Kim Il Sung and Kim Jong Il at the Dedication of the West Sea Barrage[425]

4.5. Energy Efficiency

In the 1990 energy balance study (conducted in 1995) described in part in Chapter 31 of this report, the estimated energy balance was used as a starting point for a indicative—though admittedly very approximate and not at all exhaustive—quantitative analysis of a subset of the energy efficiency and renewable energy options that could be implemented in the DPRK. This analysis was intended to illustrate the significant potential for energy efficiency as a crucial component to energy sector development in the DPRK. Since 1990, based on the observations of the authors and others who have visited the DPRK, there have been relatively few changes in end-use equipment that would substantially affect the overall conclusions of the 1995 study.[426] An energy-efficiency analysis using substantially the same measures included in the 1995 study, but updated to take into account 2019 estimated energy consumption, is presented below. Note that the use of the 2019 energy balance as a starting point reduces both the costs and savings from the energy efficiency measures. This may in fact be an artificial reduction, as any economic improvement that also includes an improvement in the availability of electricity and other commercial fuels is likely to increase demand for energy, and thus would increase the

[425] Photo taken by D. von Hippel at the West Sea Barrage Visitors' Center, near Nampo, DPRK, in October 1998.

[426] For a more complete discussion of the analysis of the energy efficiency opportunities described in this section, as well as a more qualitative discussion of some of the additional opportunities available, see, for example, P. Hayes and D.F. Von Hippel (1997), "Engaging North Korea on Energy Efficiency", Chapter 9 in *Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula*, Young Whan Kihl and Peter Hayes, editors, M.E. Sharpe, Armonk, NY; and D.F. Von Hippel and P. Hayes (1996) "Engaging North Korea on Energy Efficiency", *The Korean Journal of Defense Analysis*, Volume VIII, No. 2, Winter 1996, pages 177 - 221.

savings potential (and absolute costs, if not costs relative to the costs of installing new standard devices and equipment) of the measures described below.[427]

4.5.1. Analytical Approach

The general approach used in preparing the analysis of energy efficiency opportunities can be described as follows:

- Use the estimated DPRK energy balance data as a guide to indicate key sectors and subsectors where fuel demand could be significantly reduced by energy efficiency measures.
- Use the energy balance results, together with data from the international energy literature and rough estimates of key parameters to estimate end-use shares for key technologies.
- Use cost and performance data on energy efficiency and renewable energy technologies data from international literature sources to estimate the potential achievable fuel savings available in key subsectors, and the investment costs required to achieve those savings.[428] In some of these cases, the cost and performance data are based on actual Chinese experience obtained during the 1980s, as the measures will pertain to DPRK equipment of that vintage (and earlier) although more recent data were used to estimate improvements for some end-uses.
- Evaluate and aggregate the potential impacts and costs of the energy efficiency and renewable energy technologies quantified, and suggest other key measures that are likely to be broadly applicable in the DPRK.
- Evaluate, briefly, the potential environmental and other impacts of implementing energy efficiency measures.

A full-fledged analysis of the achievable potential for energy efficiency measures requires a host of assumptions about the future. Population growth rates, economic growth rates, and underlying, ongoing structural changes such as changes in the housing stock, shifts in industrial output, and changing patterns of personal consumption (among many others) form the backdrop against which energy efficiency opportunities should be considered. For this analysis, however, the choice has been to let estimates of potential energy sector improvements stand for the achievable savings over the next decade. Reasons for this assumption, in addition to the paucity of reliable data, include:

- The relatively static present state of the DPRK economy, suggesting that a complete and immediate turnaround less likely than a slow recovery, and thus that a 10-year analysis based on a current year's data might not be entirely unreasonable.
- Though complete implementation of a particular energy efficiency measure in a subsector is unlikely, the pathways for technology dissemination in North Korea—if there is committed support from national leaders and enabling financial and technical support from the

[427] Democratic People's Republic of Korea, *NATIONAL REPORT on Asian Least Cost GHG Abatement Strategy (ALGAS)*, Ministry of Land and Environment Protection Pyongyang, DPR of Korea, April 2000.
[428] In many cases, this analysis has drawn upon the large body of work on energy efficiency programs in the People's Republic of China that has been published by the by the Energy Analysis Program of Lawrence Berkeley National Laboratory (LBNL or LBL) and their Chinese collaborators.

international community—have the potential to allow the rapid implementation of energy efficiency measures.

- We believe that our assumptions as to the energy savings achievable from the technologies we address (quantitatively) are more likely to prove to be under- than over-estimated. This belief is informed by the large number of anecdotal reports of extremely high energy intensities in the DPRK, even when compared with early 1980s conditions in China, and with our own (if limited) observations of end-use technologies in the DPRK. Experts with experience in "energy rationalization" projects in the DPRK during the 1990s have estimated potential for energy conservation in the DPRK ranging from 20 to 60 percent of current energy use, providing further evidence that our estimates of potential energy efficiency savings may be conservative. The results of an industrial energy audit program carried out in the DPRK found potential savings of 15 to 60 percent of current consumption, and that a combination "housekeeping" measures, with simple paybacks (time required for the value of energy savings to equal the cost of any initial investment) of less than a year, and process improvements, with paybacks of one to three years, could by themselves result in savings of up to 40 percent of current energy use.[429]

4.5.2. Overall Results for Energy Efficiency Measures Evaluated

The following set of energy efficiency and renewable energy measures have been chosen for initial analysis:

- *Electric Utility Coal-Fired Boiler Improvements*: Utility boilers in the DPRK reportedly have minimal (if any) insulation, are poorly operated, suffer from steam tube cracks and other maintenance problems, and are often antiquated. We assumed that a combination of measures that have been applied to industrial boilers in China can be applied to utility boilers in the DPRK at similar costs to obtain similar results. We have assumed that a combination of microcomputer boiler control, insulation of piping, and renovation of boilers can raise the average boiler efficiency (heat energy output divided by fuel energy input) from about 55-60 percent to 75-80 percent, reducing coal consumption by about 30 percent (total improvement in heat delivery to turbines for power generation).[430] We assumed that these measures are available for about the same cost as similar industrial boiler improvements were available in China in the 1990s—approximately $7.54 per annual GJ of coal saved (year 2019 US dollars/(GJ/yr)).[431] [432] In fact, economies of scale may make efficiency improvements for

[429] Jan Jasiewicz, presentation "Energy Efficiency Activities in the DPRK and Opportunities for Rationalization of Energy Use", and paper entitled *Energy Efficiency Activities in the DPRK and Opportunities for Rationalization of Energy Use*, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA. Both are available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/.

[430] Levine, M. and L. Xueyi (1990), *Energy Conservation Programs in the Peoples Republic of China*, Applied Science Division, Lawrence Berkeley Laboratory, Berkeley, California, USA and Energy Research Institute, Peoples Republic of China. LBL-29211. Levine, M., F. Liu, and J. Sinton (1992), "China's Energy System: Historical Evolution, Current Issues, and Prospects", in *Annual Review of Energy and the Environment 1992*, 17:405-435. Yande, D. (1992?), *An Analysis of the Potential in Investment-Cum- Energy Conservation in Chemical Industry in China*, Energy Research Institute, The State Planning Commission, The People's Republic of China.

[431] We have used a conversion rate of 4.755 1990 Chinese Yuan to the 1990 US dollar (Microsoft Encarta, 1994) to convert quoted costs for Chinese energy efficiency investments to $US. This is close to the 4.73 Yuan per dollar value for 1990 found in Macrotrends (2020), "Dollar Yuan Exchange Rate - 35 Year Historical Chart", available as https://www.macrotrends.net/2575/us-dollar-yuan-exchange-rate-historical-chart. As the Yuan was not as of 1990 a floating currency, this assumption may introduce some inaccuracy in converting Chinese costs.

utility boilers less costly, per unit of energy saved, than similar measures for the generally smaller industrial boilers.

- *Reduction in "Own Use" at Coal-Fired Electric Utility plants:* We have assumed that the in-station use of electricity at coal-fired power plants is 9 percent of gross generation. Based on cost and savings estimates from Sathaye,[433] we estimate that own use can be reduced to 4.5 percent at a cost of about $93 per GJ/yr of electricity saved.
- *Reduction in Electricity Transmission and Distribution (T&D) losses:* Official DPRK estimates place transmission and distribution losses of electricity at 16 percent of net generation (electricity leaving the power plant), although, as noted earlier, this figure may well be low. We have assumed, again based on performance and cost data cited by Sathaye, that will be possible through a combination of measures to reduce combined T&D losses to 10 percent of net generation at an average cost of 58 $/(GJ/yr). T&D improvements would include better system control facilities, improved transformers and substation equipment, the addition of capacitance to the system, and other measures to improve power factors and reduce voltage fluctuations.
- *Reduction in "Emergency Losses" at Coal-Fired Electric Utility plants:* We have assumed, based on anecdotal reports, that emergency losses of power at coal-fired power plants in the DPRK average about 7 percent of gross generation. We assume that these losses can be reduced by 90 percent through the application of measures available at a cost per unit energy saved similar to that for T&D improvements described above. It may well be, however, that the combination of boiler improvements, T&D improvements, and possibly control system improvements will by themselves reduce or eliminate emergency losses, with little or no additional efficiency investments required.
- *Wind powered Electricity Generation:* Wind power is one of the major renewable resources readily available to the DPRK, though, as noted above, the wind resources in the country remain, to our knowledge, largely unmapped at a detailed local scale, and appear to be only modest over most of the country in international compilations such as the *Global Wind Atlas*.[434] We have assumed that 500 MW of wind generation capacity (for example, 500 machines per year of 100 kW, or 250 200-kW machines per year) could be installed in the DPRK over the next 10 years (with machines manufactured in the DPRK and/or imported), and that the average installed capital costs of the machines would be about $1500/kW, though costs of wind power in China seems to be somewhat lower, and this estimate may thus be somewhat high.[435] We assumed a relatively low capacity factor of 30 percent for

[432] Unless otherwise specified, dollar figures referred to in this description of our energy efficiency analysis refer to year 2019 USD.

[433] Sathaye, J. (1992), *Economics of Improving Efficiency of China's Electricity Supply and Use: Are Efficiency Investments Cost-effective?*

[434] An official description of the wind resource in DPRK (document in the author's files, 1993 [EE1]) mentions the Chinese border area and offshore islands as the only likely sites for wind energy development, but it appears from the context of the description that this assessment considered wind-generated electricity to be primarily an off-grid resource. Our assessment that wind is probably an attractive resource for the DPRK is based on the country's rugged topography and strong seasonal (winter/summer) weather patterns—see the map in section 5.2.2.6.

[435] See, for example, https://www.alibaba.com/product-detail/wind-turbine-200kw-235kw-250kw-275kw_62007888249.html?spm=a2700.galleryofferlist.normal_offer.d_title.1717174e5FSa3r, and https://www.alibaba.com/product-detail/China-wind-turbine-100kw_60833845707.html?spm=a2700.galleryofferlist.normal_offer.d_title.1717174e5FSa3r.

machines installed in the DPRK, yielding an investment cost of $160/(GJ/yr) of electricity generated. Note that this figure does not include fixed or variable operating and maintenance costs, but variable operating and maintenance costs are included in the overall analysis of this option (at $13 per MWh of generation).

- *Solar-powered Electricity Generation:* Small solar photovoltaic (PV) panels numbering probably 100 thousand or more have been put into service by DPRK citizens since 2010, but there are relatively few large solar PV arrays in use. Assuming an average solar power resource in the DPRK of 1300 annual kWh output per peak kW of panel capacity, we assume deployment of 500 MW of solar PV systems over 10 years, although in practice a much greater amount of capacity could be put in place. We assume an average installed capital cost of $1000 per kW, although costs could soon be considerably lower,[436] and an average fixed operating and maintenance cost of $10 per kW-yr. These assumptions together yield an investment cost of about $210/(GJ/yr) of electricity generated.

Other potential energy efficiency improvements addressing the electricity generation sector that seem promising but which we have been unable to evaluate quantitatively include:

- *Coal Preparation*: Grinding and washing coal to remove ash and sulfur will improve the efficiency of coal combustion in utility boilers. Such preparation will reduce the load of ash in the bottom of boilers and provide a more homogeneous coal particle size, allowing for cleaner and more complete combustion. The environmental benefits of such measures (including reduced particulate and sulfur oxide emissions to the air) could be considerable, and byproducts of coal cleaning (inert material removed from coal, and elemental sulfur) could be used in the building and other industries. In addition, coal preparation, if done near the coal mines, should reduce coal transport costs by increasing the energy content of the coal per unit mass.
- *Expansion of Electricity Metering*: At present there is reportedly very little metering of electricity consumption in the DPRK. Metering the electricity used by industrial facilities, residences, and buildings would not only provide valuable information on the use of electricity in the DPRK, it would also, if coupled with per-unit electricity pricing, provide electricity users with an incentive to use electricity efficiently. It should be noted that the benefits of metering have apparently been taken to heart by DPRK officials, as witnessed by a trend, starting on the order of 15-20 years ago but of uncertain distribution around the country (particularly away from Pyongyang), toward the use of pre-paid card-type electricity meters in Pyongyang (see Figure 4-10), and the recent establishment in the DPRK of a factory to produce electricity meters.[437]

[436] The International Renewable Energy Agency (IRENA) document *RENEWABLE POWER GENERATION COSTS IN 2018*, dated 2019 and available as https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf, provides show total installed cost for utility scale solar photovoltaic power of less than $1000 USD per kW in 2018, with recent trends showing costs falling rapidly. Alibaba.com, as of July 2020, showed numerous vendors offering solar PV modules for as low as USD $200 per kW, so the estimate used here, $1000 per kW, may be high even for the year 2020.

[437] William B. Brown, *Changes In The North Korean Economy And Implications For The Energy Sector: Is North Korea Really Short of Energy?*, prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA. Paper and presentation available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/.

Figure 4-10: Graphic of Card-style electricity meter in use in Pyongyang[438]

- *Waste Heat Recovery and Cogeneration:* The energy literature on China and the former Soviet Union (for example, Levine and Xueyi[439]) cites examples of industrial boilers and furnaces that have very high exhaust gas temperatures, indicating the availability of a substantial amount of waste heat. Assuming that such situations are also common in North Korea, the waste heat from industrial and other large boilers could be used to generate electricity, though in all probability much of the industrial infrastructure that could support such cogeneration will need to be rebuilt or replaced as the DPRK economy is redeveloped.
- *Gasification-Combined Cycle Electricity Generation/Retrofits:* The efficiency of electricity generation from coal could be increased significantly in the DPRK by first converting the coal into a gas, combusting the gas in a turbine that turns a generator, and then routing the exhaust gasses from the turbine to a boiler to raise steam for a second cycle of electricity generation. Gasifiers could be added as "front ends" to existing (renovated) coal-fired boilers in the DPRK. The efficiency of gasification-combined cycle plants can be over 40 percent[440], a vast increase from the probable 20 to 25 percent efficiency in existing DPRK plants. There should also be substantial emissions benefits from employing this technology, though it should be noted that the IGCC (integrated gasification combined-cycle) technology is arguably still not quite at the point of commercial deployment as of 2020.[441] Coal

[438] Figure from John Lewis, “North Korean Energy: 2005-2006 New Technologies and Construction” as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/.

[439] Levine, M., and L. Xueyi (1990), *Energy Conservation Programs in the Peoples Republic of China*, Applied Science Division, Lawrence Berkeley Laboratory, Berkeley, California, USA and Energy Research Institute, Peoples Republic of China.

[440] Williams, R.H., and Larson, E.D. (1993), "Advanced Gasification-Based Biomass Power Generation". In *Renewable Energy: Sources for Fuels and Electricity*, edited by T.B. Johansson, H. Kelly, A.K.N. Reddy, and R.H. Williams. Island Press, Washington, D.C., USA.

[441] See, for example, Christian Wolfersdorf and Bernd Meyer (2017), “The current status and future prospects for IGCC systems”, Chapter 25, pages 847-889 in *Integrated Gasification Combined Cycle (IGCC) Technologies*, dated 2017, and edited

preparation may be a prerequisite for implementing this technology in North Korea. Repowering of the DPRK's oil-fired utility boilers (over 200 MW) to make them combined-cycle plants could also be a strong possibility, although, as noted in Chapter 5, recent work has already been done toward converting the major oil-fired plant, near the Northeast refinery at Sonbong, to use coal, presumably using a traditional boiler.[442] Looking further into the future, it is possible that existing coal-fired power plants in the DPRK could be merged with renewable generation (likely mostly solar) by either converting solar PV electricity to hydrogen to be used in retrofitted boilers when power is needed, or converting existing boilers to used stored heat made from excess electricity produced by renewable generators, although both types of conversion effectively assume that the DPRK energy system adds renewables fast enough that a means of longer terms (for example, days or weeks) electricity storage will need to be developed.

Industrial Sector Measures

Our quantitative analysis of efficiency and renewable energy measures in the industrial sector of the DPRK includes the following measures:

- *Improvements in Industrial Coal-Fired Boiler and Furnaces:* Like utility boilers, industrial boilers and furnaces in the DPRK reportedly have very low average efficiencies, perhaps as low as 50 percent (or less) for boilers, on average. Using the same set of improvements assumed for utility boilers (see above), we assumed that the average efficiency of boilers themselves could be raised from about 50 percent to about 65 to 70 percent, reducing coal consumption by about 37.5 percent when other boiler-related measures are also applied.[443] We assumed that these measures are available for approximately the same cost as has been estimated in the past for similar industrial boiler improvements in China--approximately $7.60 per GJ/yr saved.

- *Improvements in Industrial Electric Motors:* Electric motors in DPRK may be made domestically, imported from China, or a combination, although based on our observations some of the older motors we saw in service did seem to have been manufactured domestically. In any case, the stock of motors in the DPRK is highly likely to be both aging and inefficient. Table 5-14 provides rough estimates of the fraction of electricity use, by subsector, that is consumed in motors and drives. These estimates vary from as low as 50 percent, for subsectors where we felt electricity was likely to be used intensively in end uses other than motive power (such as electrolytic refining of metals), to as high as 95 percent for subsectors (such as the Cement industry) where we felt that motor-driven applications such as grinding and sizing of cement "clinker" would likely be the dominant use of electricity.

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by Ting Wang and Gary Stiegel. Chapter available through https://www.sciencedirect.com/science/article/pii/B978008100167700024X.

[442] Repowering existing 20- to 30-year-old oil-fired boilers to create combined-cycle plants figured prominently in the future plans, for example, of the major electricity utility in Hawaii, as of the mid-1990s.

[443] Levine, M., and L. Xueyi (1990), *Energy Conservation Programs in the Peoples Republic of China*, Applied Science Division, Lawrence Berkeley Laboratory, Berkeley, California, USA and Energy Research Institute, Peoples Republic of China. LBL-29211. Levine, M., F. Liu, and J. Sinton (1992), "China's Energy System: Historical Evolution, Current Issues, and Prospects", in *Annual Review of Energy and the Environment 1992*, 17:405-435. Yande, D. (1992?), *An Analysis of the Potential in Investment-Cum- Energy Conservation in Chemical Industry in China*, Energy Research Institute, The State Planning Commission, The People's Republic of China.

As a point of reference, note that 65 percent of the electricity used in the entire Chinese economy has been estimated to be consumed in electric motors.

Based again on Chinese experience, we have assumed that it will be possible to increase the average motor efficiency from approximately 75 percent to approximately 88 percent.[444] The latter efficiency (which corresponds to higher efficiency new motors produced in China as of 1990—and is considerably lower, in fact, than the current generation of premium motors made in the US, Japan, and Europe—and possibly in China as well) is similar to that for standard new electric motors sold in the US and Japan as of 1990, so efficiency improvements beyond what we have assumed are definitely possible.[445] We have assumed that the cost of this efficiency improvement would be on the order of $77 per GJ/yr of electricity savings.

- *Industrial Lighting Improvements:* We have assumed that lighting accounts for a relatively modest 5 percent of industrial electricity use in the DPRK. Based on the cost and performance of non-residential lighting improvements in industrialized countries, we have estimated that it will be possible to save 50 percent of the industrial lighting electricity used through a variety of measures (including improved bulbs and ballasts, more efficient fixtures, replacement of incandescent lamps—where they are used—and older fluorescent fixtures with high-efficiency fluorescent lamps and particularly LED (light-emitting diode)-based lighting, improved daylighting, and lighting controls) at a cost of about $46 per GJ/yr of electricity saved, the equivalent of about $25 per MWh of saved electricity.[446]

As in the electricity generation sector, there is a wealth of opportunities for saving energy in the industrial sector that we have not been able to quantitatively evaluate. These include:

- *Industrial Process Improvements:* It is likely that a considerable amount of electricity and coal could be saved by improvements in industrial processes. These opportunities are available in many subsectors. In the DPRK cement industry, for example, the coal consumption per unit output is 6.9 GJ per tonne of "clinker" (raw cement; data from document in authors' files [CE1]). This can be compared with an average coal use of 6.1 GJ/te in China in 1980, 5.2 GJ/te in China in 1992,[447] and 3 GJ/te in modern plants in industrialized countries, and implies that coal use in the cement subsectors could be reduced by 12 to more than 50 percent. Similar opportunities exist in the iron and steel, other metals, fertilizer, textiles, and other industrial subsectors. In the important iron and steel subsector, possible process improvements include integrating steel production and forming processes (thus eliminating the need to cool and reheat the steel), continuous casting and forming, electricity generation using top pressure in blast furnaces, use of coal gas for electricity

[444] Sathaye, J. (1992), *Economics of Improving Efficiency of China's Electricity Supply and Use: Are Efficiency Investments Cost-effective?*
[445] Note that motor efficiencies vary by size class, with larger motors (for example, 100 to 200 hp or 75 to 150 kW) having efficiencies generally a few percent higher than smaller motors of similar types. The efficiencies presented here can be thought of as rough weighted averages over the stock of electric motors in use.
[446] Von Hippel, D., and R. Verzola (1994), *Indicative Study of the Potential Economic and Environmental Impacts of Demand-Side Management in the Philippines*. Nautilus Institute Report. Nautilus Institute, San Francisco, California, USA.
[447] Sinton, J. (1995), "Physical Intensity of Selected Industrial Products". Spreadsheet printout. LBL" Lawrence Berkeley Laboratory, Berkeley, California, USA.

generation, and other technologies.[448] Generic efficiency improvements applicable to many industries include insulating product pipelines, using better refractory materials (special ceramics used as, for example, furnace linings) that last longer and have better insulating properties, using variable-speed drives to reduce the electricity used in electric motors, modifications to reduce friction in piping, valves, and conveyance systems, and using harder, longer lasting materials in cutting and grinding applications.

Note that process improvements can be geared to not only improving the efficiency of fuel use, but also in reducing materials waste. Improving chemical reactors so that there is less waste of reactants, using better-quality raw materials to improve product yield, and recycling waste materials from production processes and product refining can reduce both waste and energy consumption.[449] Product modifications that result in the reduction of raw material (and thus energy) used per unit of product are also possible.[450] Not coincidentally, these improvements also typically reduce process effluents to the environment.

Process improvements could also be directed toward the 30 percent of DPRK petroleum demand that is reportedly used in carbide manufacturing. As we know little about how this petroleum is used in carbide manufacture (if the report is in fact correct), it is impossible to say what the prospects for savings are.

Many DPRK industries use technologies that are on the order of 50 years old. In many cases, simply replacing key industrial machinery with modern equipment will result in considerable energy savings, as well as improvements in productivity, but will require significant investments.

- *Coal Processing:* As for electricity generation, coal washing and other methods of coal preparation could help to dramatically improve the combustion efficiency of coal-fired boilers and furnaces in the industrial and other sectors. It is likely that coal processing could also improve the efficiency of industrial processes where coal is used as a feedstock—including fertilizer (ammonium) and synthetic fiber manufacturing.
- *Construction Industry Modifications:* The massive scale of construction projects in the DPRK, coupled with the use of manual design and construction methods results in wastage of building material relative to more updated methods, although the use of manual design may be changing as DPRK engineers become more adept in using design software, to the extent that they have access to modern software, or have developed such software domestically. Considerable savings in steel and cement--and thus savings in the energy needed to produce these materials–are possible through the use of improved construction practices.[451]

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[448] Liu, Z. P., J. E. Sinton, F. Q. Yang, M. D. Levine, and M. K. Ting (1994), *Industrial Sector Energy Conservation Programs in the People's Republic of China during the Seventh Five-Year Plan (1986-1990)*. Lawrence Berkeley Laboratory, Berkeley, California, USA and Energy Research Institute, Peoples Republic of China. LBL-36395.

[449] For example, valuable metals such as gold, zinc, and cadmium can be recovered from the flue gases and liquid effluents of metal smelting industries, and sulfuric acid could be recovered from steel and non-ferrous metal plants. The latter modification would not only remove SO_x from flue gases but would also serve as a source of sulfuric acid for the chemical industry, reducing energy use in that subsector.

[450] As an example of reduction in materials use per unit product (though one unlikely to be directly germane to North Korean industry at present), by carefully controlling the aluminum rolling and forming process, US manufacturers have been able to markedly reduce the thickness and weight of aluminum cans.

[451] Document in the authors' files [ER1].

Residential and Public/Commercial/Military Sector Measures

Our quantitative analysis included four efficiency measures for the residential sector:

- *Boiler Improvements:* For small and medium-sized space heating (and possibly water heating, in some instances) boilers of the type found in urban residential and other buildings, we assumed, based roughly on the same sources we used for our industrial boiler measure estimates, that a 15 percent improvement in efficiency (starting from an average boiler efficiency of 50 percent; thus a 23 percent reduction in coal use) is available for approximately $4.2/(GJ/yr) of coal saved. Note that the boiler improvements included here are unlikely to exhaust the opportunities for improving boiler energy efficiency (and delivery of heat to end-users) through equipment upgrades and improved operations and maintenance.

- *Building Envelope Improvements:* We have included two simple building envelope improvement measures in our estimate of possible energy efficiency savings. A combination of A) application of a 30 mm coat of concrete containing perlite--a lightweight mineral with insulating properties--to the inside of the typical concrete slab walls of residential and other buildings, and B) double glazing of windows are together estimated, based on simulations for Chinese buildings, to save 20 percent of heating energy.[452] The assumption of the use of a perlite/concrete coating for insulation is limiting, in that there are much better insulation materials (rigid foam board, for example) that might as easily be applied to existing buildings, but the DPRK at present, so far as we know, lacks the technology to make these insulation products, so we have focused on insulation materials that could be produced domestically. The costs of these savings are estimated at slightly under $8 per GJ/yr. Note that in applying this measure to coal use in buildings, we have assumed that boiler improvements take place before (or at the same time as) building envelope improvements, that is, the savings fraction for building envelope improvements was applied to the total energy use <u>after</u> boiler efficiency improvements had been factored in.

  The two building envelope improvements above can be considered a minimal simple start to the list of potential measures of this type. Other measures include caulking and weatherstripping to reduce air infiltration, insulation of water and steam piping, improved radiator controls (in fact, visitors to the DPRK report that the only heat control measure available to residents of typical North Korean apartment buildings is the opening and closing of windows and doors), interior and exterior wall and roof insulation, roof coatings, and other improvements. Actual savings from building envelope measures will vary by building type and with the current condition of the buildings, but savings of much more than 20 percent of current energy use are quite possible, at costs possibly not significantly higher than those above. Proposals to undertake pilot building efficiency projects in the DPRK were developed by United Nations agencies in the late 1990s, but have not, to the authors' knowledge, been implemented as of yet. Colleagues from the DPRK that the authors have interacted with have shown a very keen interest in promoting building energy efficiency measures in their country and understand very well the potential benefits of those measures to the DPRK, but lack the combination of materials, technical know-how, and funding to implement them.

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[452] Lang, S., Y.J. Huang, and M. Levine (1992), *Energy Conservation Standards for Space Heating in Chinese Urban Residential Buildings*. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA.

- *Rural Residential Coal Stove/heater Improvements:* We have assumed that the average residential stove/heater can be improved from an average of 30 percent efficiency to 40 percent efficiency, thus saving 25 percent of initial coal use. This is a rough estimate on our part. The estimates that we have found of coal stove efficiency in the DPRK and China range from 20 to 50 percent; 30 percent was cited as an estimate for DPRK by an informed visitor to the country.[453] We have assumed that this efficiency improvement is available for the same cost cited for coal stove improvements in China,[454] namely $1.4/(GJ/yr).

- *Electric Motor Improvements in Urban Residential and Non-residential Buildings:* Electric motors are typically used in multi-family apartment buildings and in non-residential buildings for a variety of uses, including ventilation, refrigeration, and water pumping (for heating and potable water). We have assumed that 10 percent of the electricity used in the urban residential subsector, and 30 percent of that used in the Public/Commercial and Military sectors, is used in electric motors. These estimates are admittedly rough guesses at best but are lower than the fraction of electricity used in motors in similar sectors in many other countries. We have assumed that the average cost and performance of measures that increase the efficiency of these motors is roughly the same as in the industrial sector.

- *Improvements in residential and non-residential lighting:* We have assumed that the fraction of residential electricity used in lighting end-uses is 50 percent. This figure is somewhat higher than lighting electricity fractions quoted for Thailand and the former Soviet Union (28 and 33 percent, respectively), but both of those societies use electricity for end uses—including air conditioning and water heating—that reportedly are little used in DPRK residences. We have assumed that 30 percent of lighting electricity use in residences in DPRK powers incandescent bulbs, 30 percent goes to fluorescent bulbs, and 40 percent is used in LED bulbs, the use of which has accompanied the widespread use of solar PV panel. These are rough assumptions, and it is quite possible that LED and fluorescent lighting use is less prevalent nationwide, particularly outside of Pyongyang. We assume that LED bulbs can save 85 percent of the electricity used by incandescent bulbs (while providing similar or enhanced light output), and that LED bulbs can provide the same lighting as the different types of fluorescent bulbs in use (compact fluorescent bulbs and tube-type fluorescents) with 50 percent less electricity input. Taken together, these three assumptions result in a 40 percent reduction in electricity use in residential lighting. If, as has been suggested, tube-type fluorescent lamps are in wider use than we have assumed, these savings may be somewhat overstated, but a combination of luminaire, lamp ballast, and bulb improvements for tube-type fluorescent lamps can yield savings that are nearly as significant, even without replacing tube-type lamps with LED bulbs in the same form factors. As an estimate of costs, we have estimated that the two types of measures above (LED replacement of incandescent and fluorescent bulbs) would provide electricity savings at an average cost of saved energy of $11 per lifetime MWh saved, or an investment cost of about $20 per GJ/yr saved. We should note that the lifetime of most CFLs is shortened if they are operated on a grid with fluctuating voltage and low power factors, and LEDs may have similar issues, thus unless LEDs are specifically designed for such conditions, and/or power conditioning is used,

[453] Document in the authors' files [R1].
[454] Levine, M., F. Liu, and J. Sinton (1992), "China's Energy System: Historical Evolution, Current Issues, and Prospects", in *Annual Review of Energy and the Environment 1992*, 17:405-435.

transmission and distribution improvements would probably have to go hand in hand with major on-grid introduction of LEDs in the DPRK. This is likely less of an issue with LEDs operated, for example, from home solar PV systems or from solar PV mini-grids, as both would have battery (or other) storage of electricity, which would dramatically reduce power quality issues at the bulb.

In 2005, we were told by a DPRK delegation to a Nautilus workshop that CFLs had in fact been implemented in residences in the DPRK, using Phillips brand bulbs and also bulbs made in the DPRK. This implementation was reportedly fairly extensive, but we do not have independent feedback on how extensive or effective, on a long-term basis, it will prove to be. We therefore leave this measure in the list of potential improvements for the time being. While in Pyongyang in 2009 one of the authors estimated, based on observation (from outside) of a limited number of residential buildings in the city, that perhaps 40 percent of apartments were using CFLs.[455] As the penetration of CFLs in other cities and in rural areas is likely to be lower than in Pyongyang, and since then, LEDs have probably also arrived in Pyongyang first, we roughly estimate that 40 percent of residential electric lighting energy use was, as of 2019, consumed in LEDs. Although it is likely that other improvements in residential lighting, at similar cost per unit savings, can be identified to replace the savings ascribed to LED introduction, any estimate of the potential benefits of lighting efficiency improvements in the DPRK, in a scenario where the DPRK economy is redeveloped, should, realistically, take into account that existing lighting levels in DPRK residences are, on average, very low by the standards of most industrialized nations, and thus as the DPRK economy is rebuilt, residents will probably choose to install much more lighting than is currently (typically one bulb per room) present in most dwelling units.

Our assumption for non-residential buildings is that 50 percent of the electricity consumed is used in lighting. As for industrial lighting, we assume that 50 percent of this amount can be saved by a package of lighting energy efficiency measures, at a cost of about $46 per GJ/yr. Since these costs and savings estimates are based on figures for industrialized countries, our guess is that similar improvement will cost less and save more in the DPRK, particularly if production of quality lighting components can be done with a substantial contribution of domestic (versus imported) labor and materials.

Other possible energy efficiency measures for the residential and non-residential buildings sectors include:

- *Improvements in Electric Appliances:* The fraction of residences in the DPRK with refrigerators is unknown, but likely to be small. What refrigerators are in use in the DPRK—and we found relatively few households with refrigerators in our one-village survey of rural energy use in 1998 and 2000[456]—are likely to be mostly older models imported from Japan or China, or cheaper Chinese models, and thus up to 50 percent less efficient than those manufactured in industrialized countries, or the best refrigerators currently

[455] This extremely rough survey was done simply by looking around the city at the lights visible inside residential buildings at night, observing that apartments lit with CFLs showed a more bluish light than apartments lit by incandescent bulbs, and estimating the fraction of dwellings in which each type of bulb was present.

[456] See, for example, D. von Hippel et al (2001), *Rural Energy Survey In Unhari Village, The Democratic People's Republic of Korea (DPRK): Methods, Results, and Implications*, Nautilus Institute Special Report dated May 20, 2001, and available as http://nautilus.org/wp-content/uploads/2011/12/Unhari_Survey.pdf.

manufactured in China, China made great improvements in refrigerator efficiency starting in the early 2000s, a process that has likely continued through recent years as China has produced progressively more of the world's appliance).[457] Liu et al[458] reported that Chinese refrigerators in the 200-liter size range consumed 365 kWh per year as of approximately 1990, while South Korean models of similar capacity used 240 kWh per year. To the extent that refrigeration is used in buildings other than private residences (for example, in communal kitchen facilities), similar savings may be possible. Improvement of the efficiency of refrigerators manufactured in or available to DPRK could be increasingly important, as a refrigerator is probably one of the first appliances that households will invest in if economic conditions in North Korea begin to markedly improve.

- A substantial fraction of households in DPRK have either television or radio, or both. Recent improvements in electronics technology that the DPRK does not currently have access to have reduced the hourly energy consumption of these devices markedly, though the aggregate amount of electricity saved by such improvements may be small due to the limited power consumption of radios and small televisions. When we visited the DPRK in 1998 and 2000, most televisions were of an older design, but that situation seems highly likely to have changed in recent years thanks to imports from China. From 2014 through 2018, based on UN Comtrade statistics, The DPRK imported nearly 3.3 million televisions (HS Category 8528) from China, at an average cost of about $85 (USD) per unit, or a total of $280 million over the five years. Based on 2020 Alibaba.com prices, this average cost suggests that the average imported TV was in the 24- to 32-inch-class (60 to 80 cm) range, although the HS 8528 class also includes devices that include both screens and devices such as DVD players, which may reduce the average screen size.[459] The number of units sold suggests an average of about 0.5 new televisions per household during this five-year period alone, with another 930,000 units imported from 2008 through 2013. These imports suggest that efficiency improvements may be modest, or not available until some years in the future as the Chinese units purchased through 2018 are retired. Other improvements in appliance efficiency in North Korea may well be possible, but their evaluation must await better information on the stock of electricity-using appliances in the household and other sectors. Microwave ovens, for example, accomplish many cooking tasks more efficiently than simple electric resistance stoves and heaters, but based in UN Comtrade data on exports of microwaves from China to the DPRK (about 2900 total reported over the decade from 2008 through 2018), penetration of the latter in the DPRK residential housing stock appears likely to be low. On the other hand, UN Comtrade data suggests that on the order of 2.2 million rice cookers (or similar devices—HS 851660) were exported from China to the DPRK during 2008 through 2018, an average of one for every 3 or so DPRK households, at a cost averaging about $14.[460]

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[457] See, for example, China Daily.com (2012), "China produces most home appliances: report", dated 10/3/2012 and available as https://www.chinadaily.com.cn/business/2012-10/03/content_15958806.htm.

[458] Liu, F., W.B. Davis, and M.D. Levine (1992), *An Overview of Energy Supply and Demand in China*. Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL- 32275 UC-350.

[459] Alibaba.com included (as of about 2020) advertisements for a variety of small DVD players with screens at wholesale costs in the $40 to $60 range, including, for example, a unit with a 15.4 inch (about 40 cm) screen that plays from DVDs, HDMI, or via USB drives, and uses on the order of 27 watts. See, for example, https://www.alibaba.com/product-detail/manufacture-new-16-inch-digital-multimedia_60283354579.html?spm=a2700.galleryofferlist.normal_offer.d_title.5c84560dvD3LoJ.

[460] This appears to be a fairly typical wholesale price for a rice cooker made in China. See, for example, https://www.alibaba.com/product-detail/Rice-Cooker-Ricecooker-National-Electric-Rice_1600076813302.html?spm=a2700.galleryofferlist.normal_offer.d_title.3d135ba8xfB9cv&s=p. For reasons unclear to us,

- *Improvements in Cooking Efficiency (Non-coal fuels):* Urban households in the DPRK reportedly use charcoal, LPG, and kerosene stoves for cooking in addition to coal stoves. Rural households use wood and other types of biomass for cooking and heating. Efficiency improvements in all of these technologies are possible, though the percentage improvements (and the aggregate amount of fuel savings) are likely considerably higher for devices using solid fuels. Reduction in the use of wood and biomass fuels using more efficient stoves and heaters would help to make wood and biomass available for other applications and/or to reduce harvest pressures on forests.
- *District Heating:* District heating of homes and other buildings using heat from power plants, industrial facilities, and stand-alone central steam plants is apparently practiced in North Korea (as it is throughout Eastern Europe), but the full extent to which it is practiced is not entirely clear (but see our estimates in earlier chapters of this Report). Switching to an efficient district heating network from a system of dispersed small boilers and stoves can result in substantial coal savings, and there are quite likely extensive opportunities for improvements to existing district heating systems that can markedly increase the efficiency with which those systems deliver heat (and thus, possibly, increase the number of households that the district heating systems serve, especially when combined with weatherization of residential and commercial/institutional buildings, boiler and other improvements in district heating plants, and other upgrades).
- *Building Shell Improvements in Rural homes:* Potential improvements include caulking and weatherstripping, insulation, and glazing (in some cases, in our limited experience in the DPRK, many windows use plastic or wood coverings, or are cracked, so any reasonable glazing would be an improvement), but any definitive list of measures will have to wait until a better description of the rural housing stock in the DPRK is in hand.
- *Use of Biogas:* Biogas—produced via anaerobic fermentation of human night soil, animal manures, and agricultural wastes—could be used as a clean cooking fuel in rural areas, or could contribute to small-scale power production (with cogenerated heat for agricultural processing or other applications).[461] The biogas production process also has the potential to yield important by-products such as animal bedding, soil amendments, and organic fertilizer, as well as potentially (depending on the average current status of rural waste disposal practices) reducing environmental issues associated with sewage and manure disposal.

Transport and Other Sector Measures

We have evaluated only one energy efficiency measure in the transport sector in a quantitative manner:

- *Replacement of Medium-duty trucks:* Two and one-half tonne trucks have been the workhorses of the military ground transport fleet in the DPRK and are reportedly (as well as by the author's observations) widely used in civilian goods (and civilian passenger, as shown

the cost of the average unit exported in the HS code category 851660 in 2017 was markedly higher, at about $65, than in years during 2008 through 2016, when it ranged from about $6 to $13 per unit. This suggests either a reporting error in 2017 or the inclusion in exports for that year or devices that were unusual for the HS category.

[461] See, for example, *Rural Energy Production: Biogas Plant, a Sustainable Source of Energy for Cooperative Farms*, by Arthur Wellinger, dated December 12, 2003, and published by ADRA (Adventist Development and Relief Agency International) and Nova Energie. This report provides case studies of the application of manure-fed biogas digesters in the DPRK.

in Figure 4-11) transport as well—often with military and civilian cargoes and passengers combined. We have assumed that all of the gasoline used for civilian freight transport by road in the DPRK is used in such trucks, and assuming that the freight transport provided by each vehicle is on the order of 15,000 tonne-km per year, we very roughly estimate that there are about 16,000 civilian 2 1/2 tonne trucks in the DPRK fleet, to go along with about 38,000 military trucks in active service. If the most heavily used two-thirds of these trucks (which we assumed to use 90 percent of the fuel) were replaced with new vehicles similar to the Isuzu FRR (mid-1990s) model or similar trucks available from China,[462] a fuel savings of about 43 percent would result. We have assumed that these vehicles could be imported or manufactured in the DPRK (probably, especially in the first few years, from imported parts, as has been the practice in recent automobile production joint ventures in the DPRK) at a cost of $14,000 each.[463] At this cost, however, replacement of the truck fleet is not likely to be cost-effective. Note, however, that we have assumed that the existing trucks will be replaced whether they are at the end of their useful life or not. If one assumes only an incremental cost for the trucks (the difference between the costs of producing a standard DPRK truck and one like the Isuzu model), and/or if one assumed a substantially heavier usage (in te-km/yr) for the new trucks, which is probably reasonable, this measure would appear more cost-effective. Whether these changes would make this measure sufficiently cost-effective to pursue is not possible, with the data at hand, to ascertain.

[462] See, for example, the diesel "Dongfeng" trucks described on Alibaba here https://www.alibaba.com/product-detail/4X2-wheel-drive-3-5-tons_60714507616.html?spm=a2700.7724838.2017115.93.28d138f2PRkKGF, and gasoline-fueled "FOTON" brand units here https://www.alibaba.com/product-detail/New-China-5-ton-mini-truck_60642742600.html?spm=a2700.7724838.2017115.84.287b43a48AOfyp. Note, however, but note that trucks come in many configurations, sizes, and thus costs.

[463] Approximate cost of new truck from China, including roughly estimated taxes and shipping costs. By way of comparison, the Isuzu truck model cited was available in the US for roughly $30,000 (retail) as of 1995. The cost is probably at least double that by 2020. Assuming A) that a large portion of this cost is dealer profit, profit for Isuzu, import costs and duties, and other non-product costs, and B) such trucks could be built in the DPRK at DPRK labor rates, but with Japanese technology (presumably under license), at perhaps a cost per truck of $24,000 US (2020 dollars). This may well be too high for the DPRK, however, as the average value of spark-ignition trucks of under 5 tonnes capacity imported to the DPRK from China in 2016 was under $10,000 (though some or many of these units may well have been used).

Figure 4-11: Military Truck in Use by Military Personnel and Civilians near Nampo[464]

Other potential improvements in the transport and other sectors might include:

- *Electric Motor and Drive improvements for Electric Locomotives:* Electrified rail is the backbone of the DPRK transit system. Though we have no data on the efficiency of electric locomotives in North Korea, potential efficiency improvements on the order of those described above for industrial motors seem plausible.
- Substantial improvements in electric rail efficiency may come about simply through *transmission and distribution improvements on the electric grid as a whole*. Other options for increasing rail efficiency might include updated rail control and scheduling systems, track improvements to reduce friction (and forced halts) and optimizing freight loads.
- *Updating Other Transport Fleets:* Updating the road passenger transport, water transport (including the fishing fleet), and air transport fleets may as much as double their efficiency, but any fuel savings is highly likely to be offset by increased use of these transport modes as they become more efficient and reliable. Improvements in transport infrastructure, ranging from roads to harbor and lock facilities, can also increase the efficiency of transportation by reducing transit times.
- *Biofuels for Transport:* The DPRK government has expressed an interest, in various documents, in increasing self-reliance by replacing petroleum-based transport fuels with

[464] Figure from David Von Hippel and Jungmin Kang, “Updated DPRK Energy Balance (Draft) and Work to Be Done” as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA).

liquid fuels derived from biomass. While the GHG and pollutant-reduction benefits of such a program are important, we are reluctant to enthusiastically endorse this idea at present because 1) all DPRK agricultural land appears to be needed and fully employed just to feed people, thus production of motor fuels from agricultural crops such as corn would appear to be ruled out; and 2) there appears to be relatively little extra wood or crop wastes available for use (see discussion of biomass resources above) as cellulosic feedstocks for biofuels production (via either fermentation or thermal liquefaction). If the biomass resource situation changes in the future, however, biofuels would become a more attractive option.

- *Improving agricultural tractors:* Specific fuel consumption in tractors in China, reported to be 195 grams/hp-hr in the 1980s was some 10 percent greater than for similar tractors in industrialized countries.[465] Tractors in the DPRK are unlikely to be more efficient than the average for these older Chinese units, and are likely to be worse, particularly in recent years, as spare parts and other maintenance supplies have become increasingly difficult to obtain.

- *Reducing fertilizer use:* Fertilizer application in North Korea is reported to be excessive for some crops. On rice, for example, it has been suggested that the typical-practice nitrogen fertilizer application in the DPRK could be reduced by 25 percent.[466] If so, significant reductions in energy use in the energy-intensive ammonia manufacturing industry in DPRK should be possible (and/or an expansion of the amount of crops that could be fertilized from fertilizer produced domestic plus the limited available imports), as well as (probably minor) reductions in the need for tractor fuel for fertilizer application.

Additional details of the process used in estimating the impacts and costs of these measures are provided in studies referenced previously in this paper,[467] as well as in the section of Attachment 1 providing printouts of the worksheets used for energy efficiency measure analysis.

Table 4-10 shows the overall results of our evaluation of these measures. It has been assumed that under an aggressive program with both strong leadership commitment inside the DPRK and technical and financial cooperation from other countries, these measures (or some of these measures and others with similar per-unit costs and impacts) could be implemented over the next 10 years.[468] In total (that is, in year 10 of an aggressive program), they annually save approximately 150 Petajoules (one Petajoule, or PJ, is equal to 1000 terajoules or 1 million gigajoules) of coal (about 33 percent of estimated 2019 DPRK coal supplies) at a cost of about $US 1200 million (2019 dollars), plus 23 PJ/yr (about 40 percent of 2019 generation) of electricity supply (electricity saved plus 500 MW each of new wind-powered and solar generation) at a total cost of approximately $2.3 billion. Note that more than half ($1250

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[465] Liu, F., W.B. Davis, and M.D. Levine (1992), *An Overview of Energy Supply and Demand in China*. Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL- 32275 UC-350.

[466] Personal communications with UN agricultural sector expert with experience in the DPRK, but note that this assessment probably refers to a time when DPRK fertilizer use was on average much higher than ongoing fertilizer shortages have allowed in recent years.

[467] von Hippel, D. F., and P. Hayes (1995), *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*. Nautilus Institute for Security and Sustainability, USA, December 1995. P. Hayes and D.F. von Hippel (1997), "Engaging North Korea on Energy Efficiency". Chapter 9 in *Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula*, Young Whan Kihl and Peter Hayes, editors. M.E. Sharpe, Armonk, NY. Von Hippel, D.F., and P. Hayes (1996) "Engaging North Korea on Energy Efficiency". *The Korean Journal of Defense Analysis*, Volume VIII, No. 2, Winter 1996. Pages 177 - 221.

[468] Note that figures in Table 4-10 have been rounded for presentation and are likely to be accurate to only one or two significant digits.

million) of this total cost for electricity-related measures is for wind and solar power deployment, which accounts for just 31 percent of the total 23 PJ/yr impacts on generation requirements. If the package of measures included were reconfigured to include less wind power but more energy efficiency, the average cost per unit electricity supply impacts could be reduced significantly—illustrating the fact that this illustrative package of measures is NOT by any means cost-optimized. Replacement of the DPRK fleet of 2 1/2 tonne trucks, as it has been modeled, is unlikely to be cost effective with respect to saving energy alone but would save approximately 1.9 PJ of refined products annually, which is somewhat over 6 percent of total estimated national petroleum use in 2019, and nearly a quarter of road transport petroleum use, at an investment cost of $440 million.

A key assumption made in estimating the costs and performance of most of the coal- or electricity-saving energy efficiency measures is that the costs and performance of these measures, when implemented in the DPRK, will be similar to the cost and performance of the measures as experienced in the People's Republic of China during energy efficiency programs carried out there in the late 1980s. It could be argued that the costs of the measures in China might be lower than in the DPRK, due to lower labor rates in China at that time and a larger manufacturing base in China. It could, however, equally be argued that the opportunities for savings with the measures we have evaluated are likely to be greater in the DPRK than they were in China, due to the, on average, older capital stock in the DPRK.

The environmental benefits of measures such as those described above would be substantial. The measures to save coal would avoid the emissions of approximately 69 thousand tonnes of sulfur oxides, 43 thousand tonnes of nitrogen oxides, and nearly 11 million tonnes of carbon dioxide. Using the year 2019 ratio of thermal to hydroelectric generation, the electricity-saving measures described above (including the wind power generation) would avoid emissions of another 19 thousand tonnes of sulfur oxides, 12 thousand tonnes of nitrogen oxides, and 3.2 million tonnes of carbon dioxide. These emissions reductions represent 28 to 31 percent of our estimates of total national emissions of each pollutant in 2019.

Together, the energy savings and environmental benefits of these few energy efficiency measures, as evaluated, underscore the key role that energy efficiency can, and indeed, must play in any DPRK energy sector development/redevelopment effort. By way of comparison, the electricity savings from the limited package of measures described above (excluding wind power systems) amounts to about the same amount of electricity that would be produced by a 400 to 500 MW thermal power plant at approximately the same capital cost, but with no fuel costs, arguably higher reliability, and far fewer environmental impacts. Plus, each individual investment in energy efficiency measures is smaller, and thus arguably more manageable and sustainable, than investments for the larger capital investments (such as power plants) that are avoided by energy-efficiency investments.

Table 4-10: Results of Energy-Efficiency Analyses for the DPRK

MEASURES TO SAVE COAL:

Measure	Estimated Energy Energy Savings Potential, TJ/yr		Total Estimated Investment Cost, $US 2019
Industrial Boiler and Furnace Improvements	45,526		$ 408,164,600
Residential and Public/Commercial/Military Boiler Impr.	32,095		$ 160,654,656
Building Envelope Improvements	22,902		$ 210,008,992
Solar Water Heating	11,560		$ 142,307,337
Domestic Stove/Heater Improvements	11,109		$ 18,536,092
Electric Utility Boiler Improvements	25,445		$ 229,333,411
TOTALS	148,638	TJ/yr	$ 1,169,005,088
Avoided Losses of Coal During Transport:	1,486	TJ/yr	
TOTAL COAL SUPPLY SAVINGS	150,124	TJ/yr	
Fraction of 2019 Total Coal Supply	32.9%		
Investment required, $ per GJ/yr of Coal Supply Savings			**$ 7.79**
Investment required, $ per tce/yr of Coal Supply Savings			**$ 228**

MEASURES TO SAVE/GENERATE ELECTRICITY:

Measure	Estimated Energy Energy Savings Potential, TJ/yr		Total Estimated Investment Cost, $US 2019
Industrial Motors and Drives	1,777		$ 160,913,054
Motors and Drives in other Sectors	643		$ 58,193,405
Residential Lighting	741		$ 17,759,933
Non-residential Lighting	3,620		$ 197,774,930
Own Use reduction in Power Plants	708		$ 152,393,105
Reduction of Emergency Use in Power Plants	1,266		$ 86,394,231
Transmission and Distribution Improvements	5,294		$ 361,344,118
Wind-powered Electricity Generation	4,730		$ 750,000,000
Solar-powered Electricity Generation	2,340		$ 500,000,000
TOTALS	21,120	TJ/yr	$ 2,284,772,776
Additional Avoided T&D Losses (based on 2019 Rates)	1,880	TJ/yr	
TOTAL ELECTRICITY SUPPLY SAVINGS/GENERATION	22,999	TJ/yr	
Fraction of 2019 Total Electricity Generation	40.6%		
Investment required, $ per GJ/yr of Electricity Supply Savings/Generation			**$ 99.34**
Investment required, $ per MWh/yr of Electricity Supply Savings/Generation			**$ 358**

MEASURE TO SAVE PETROLEUM PRODUCTS:

Measure	Estimated Energy Energy Savings Potential, TJ/yr		Total Estimated Investment Cost, $US 2019
Improvements in 2 1/2 tonne truck fleet	1,889		437,594,151
Fraction of 2019 Total Refined Products Use	6.2%		
Fract. of 2019 Total Refined Prod. Use in Road Transport	23.6%		
Investment required, $ per GJ/yr of refined products Savings			**$ 231.67**
Investment required, $ per toe/yr of petroleum products Savings			**$ 9,693**

5. DPRK Electricity Supply, Demand, and Options

5.1. Introduction

During the decade of the 1990s, and continuing into this third decade of the 21st century, a number of issues have focused international attention on the DPRK. As noted earlier in this report, most of these issues—including nuclear weapons proliferation, military transgressions, concern over missile (or satellite launch) tests, provocations, and posturing, economic collapse, food shortages, floods, droughts, tidal waves, and the death of DPRK leader Kim Jong Il and the passing of the leadership mantle to the third generation of the Kim dynasty in Kim Jong Un—have their roots in a complex mixture of Korean and Northeast Asian history, ongoing global economic power shifts, environmental events, international sanctions on DPRK imports and exports, and as-yet unresolved internal structural dilemmas in the DPRK economy. Energy demand and supply in general—and, arguably, demand for and supply of electricity in particular—have played a key role in many of these high-profile issues involving the DPRK, and have played and will play (and arguably are playing, as of late 2020) a central role in the resolution of the ongoing confrontation between the DPRK and much of the international community over the DPRK's nuclear weapons programs. The DPRK's electricity supply and demand situation is also highly likely to play, or have the potential to play, a key role in the rapprochement and engagement between the DPRK and the Republic of Korea (ROK), if engagement results from recent or future overtures of peace.[469] Electricity-related aid may well be a key inducement for the ROK to offer in its negotiations with the North, but such aid will need to be carefully designed and targeted if it is to be effective in building engagement between the Koreas.

Whether through ROK-DPRK bilateral discussions, through some reinvigorated international negotiations, perhaps involving most of the participants in the earlier Six-Party Talks process, or via some new multilateral forum for addressing the DPRK nuclear weapons and related issues, it is clear that energy sector issues will continue to be central to engagement of the North. Carefully-designed energy sector—and in particular, given its importance to the economy, electricity sector—assistance projects of modest scale, particularly those that combine economic development and humanitarian focus, should be sought out, designed, and, as soon as conditions permit, undertaken. The ROK is in a unique position to develop and deliver such projects, and it stands to gain considerably if such projects are successful. For the ROK, engagement with the DPRK on energy issues, and particularly electricity issues, offers many possible benefits, including an opportunity to improve its relationship with and understand its neighbor, a chance to potentially clean up the environment that the two nations share, an opening for the ROK to invest in and benefit from the development of the North's economy, opportunities to potentially link its energy system with potential resource suppliers, most notably the Russian Far East, China, and even (via Russia or China) Mongolia, and an opportunity to improve the ROK's security by promoting peace on the Korean Peninsula.

[469] As of this writing (October 2020), the administration of President Moon Jae-in in the ROK continues to press for a formal end to the Korean War, but recent DPRK announcements and actions, ranging from the killing of a South Korean fisheries official (and an apology by Chairman Kim Jong Un for same), destruction of a liaison office at Kaesong, parading of new missiles, and both angry and appeasing rhetoric suggest that little concrete action on engagement is likely before the United States elections in November 2020. See, for example, Hae Won Jeong (2020), "What's Next for Moon's North Korea Policy?", *The Diplomat*, dated October 19, 2020, and available as https://thediplomat.com/2020/10/whats-next-for-moons-north-korea-policy/.

It is critically in the interest of the Republic of Korea and its international allies to know as much as is possible to know about the electricity sector resources and needs of the DPRK, so as to be ready, when the opportunities arise, to assist the people of the DPRK in energy and economic redevelopment. Such redevelopment will most certainly not be either easy, straightforward, or inexpensive, but every effort should be made to assure that is as smooth and as sustainable as possible to reduce both the economic and human costs associated with the DPRK's transition and, ultimately, of de-facto economic or full political reunification of the two Koreas. To that end, this chapter of this Report provides an updated summary of what is known and/or inferred about the status of the DPRK electricity sector, including the DPRK's electricity supply and demand.

In the remainder of this introductory section, we provide a an overview of DPRK electricity policies, to the extent that they are known (or, indeed, exist), offer a brief summary of the DPRK's electricity supply infrastructure, outline some of the challenges facing the electricity industry in the DPRK, and provide a brief "roadmap" to Sections 5.2 through 5.4 of this chapter.

5.1.1. Overview of North Korean Electricity Policies

The DPRK's electricity policies—insofar as can be determined from a combination of announcements, news reports, and direct contact with DPRK delegations at workshops organized by Nautilus and others—has been to attempt to embrace virtually all available power sources, nominally under the self-sufficiency philosophy of *juche*. This broadly stated desire to pursue a variety of sources of power, ranging from medium-to-large-scale hydroelectric development, nuclear energy, and coal-fired power to solar, wind, and tidal energy, as well as energy efficiency, is tempered by the realities of the technologies available to the DPRK under current international economic sanctions and (relatedly) under the limits imposed by what it can afford. As such, rather than a broad, concerted, and coordinated electricity policy, the DPRK's actions in the electricity sector seem increasingly reactive to whatever the current energy sector and, indeed, international conditions appear to require.[470] In recent years, it can be argued, DPRK electricity policy is being devolved more and more to the local and even individual level, with regions, counties, businesses, and even households essentially being left to fend for themselves to secure electricity supplies, and sometimes even being encouraged to do so by the central government.

Some of the hallmarks, or perhaps more accurately, symptoms of recent DPRK electricity policy include:[471]

- Increasing adoption of distributed generation—notably diesel and gasoline-fueled, but also, especially in recent years, solar photovoltaic and some wind power systems—by

[470] In fairness, the DPRK is hardly the only country that lacks a set of fully consistent and coordinated electricity policies. In many countries, the United States and, one would argue, the Republic of Korea among them, stated national goals for the future, for example, regarding climate change mitigation and green growth, are frequently not as consistent as they might be with electricity and fuels pricing practices, environmental regulations, and other considerations. Differing motivations among public and private sector energy sector actors and interest groups, as well as the need to maintain energy supplies today to existing consumers and infrastructure while planning for tomorrow, partly explain these disconnects within electricity policies. This is not to say that such disconnects are unreasonable, only that it should be kept in mind when considering DPRK electricity policy that in general fully coherent national energy policy is the exception, rather than the rule, in the global community.

[471] Please see section 5.2 for additional information about these policies and initiatives.

households, businesses, and other organizations, as electricity supplies have become more unreliable and the DPRK government has failed to maintain electricity supplies.[472]

- Increasing emphasis on the rapid, almost frantic construction of medium and large (on the order of 10s to in very few cases 100s of megawatts—MW) power plants, particularly hydro plants, in an attempt to rapidly improve electricity supplies, particularly supplies to Pyongyang. Thus far, these efforts, with the Huichon #2 hydroelectric plant being a case in point—have had limited or transient impact, in part, reportedly, because the haste with which plants have been constructed has sometimes led to technical defects that, combined with low water levels caused by recent droughts, have limited the output of the plants.[473]
- Development of a small light water nuclear reactor (LWR) at the Yongbyon nuclear complex after the cessation of construction of the two reactors at Simpo that were to be built under the auspices of the Korean Peninsula Economic Development Organization (KEDO) with international support. As of late 2020, however, while this "experimental" reactor appears (from satellite photos) to have its major components installed, its operational status seems uncertain. The overall goal of developing this small LWR was to eventually deploy similar units elsewhere in the DPRK, in part in recognition that larger LWR units, such as the 1000 (and larger) MW units that are most common in modern installation the ROK and other nations, cannot be built without international assistance, and, in fact, could not be reliably operated on the DPRK grid even if the DPRK grid were intact and in perfect repair (which it is not). This small LWR will not help much with the DPRK's electricity shortages but is intended by the DPRK as an experimental endeavor that could lead to the production of more small reactors around the country.[474] Meanwhile, the older, nominally "5 MW electric" (though probably not, in fact, electricity-producing) gas-cooled reactor has shown intermittent signs of activity in the last few years, indicating that it has at least periodically been operated. The older reactor was, and presumably still is, used for producing plutonium, and has been the source of plutonium for the DPRK's nuclear weapons program.
- Stated encouragement by the central government to provinces and counties to look to develop local power plant options, especially small hydro power plants.
- Ongoing discussions on international power interconnections (Russia-DPRK-ROK, for example), and more modest initiatives to supply key economic assets with power from Russia or China, with an earlier Russian plan to connect the Rason port area to the Russian grid in early 2016 (although this connection has apparently not yet, as of late 2020, been established) a particular case in point.[475]

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[472] See, for example, James Pearson (2015), "In North Korea, solar panel boom gives power to the people", *Reuters*, dated April 21, 2015, and available as http://www.reuters.com/article/northkorea-solar-idUSL4N0XC2O620150421.
[473] See, for example, Eric Talmage (2015), "North Korea in rush to boost electricity supply", *Boston Globe*, dated June 3, 2015, available as https://www.bostonglobe.com/news/world/2015/06/03/north-korea-rush-boost-electricity-supply/iNmQzZISrNlSmvTpeZcg6O/story.html.
[474] See David von Hippel and Peter Hayes (2010), *Engaging the DPRK Enrichment and Small LWR Program: What Would It Take?*. NAPSnet Special Report, dated December 23, 2010, and available as http://nautilus.org/napsnet/napsnet-special-reports/engaging-the-dprk-enrichment-and-small-lwr-program-what-would-it-take/.
[475] See, for example, Liudmila Zakharova (2016), "Economic cooperation between Russia and North Korea: New goals and new approaches", *Journal of Eurasian Studies* 7 (2016) 151–161, available as https://www.sciencedirect.com/science/article/pii/S1879366516300124. See also Scott A. Snyder (2019), "Where Does the

More generally, as presented by delegations to Nautilus events (in non-official settings), stated emphases in DPRK electricity policy have included the upgrading of large thermal and hydroelectric plants, and have stressed the national goal of acquiring nuclear power, but have also expressed sincere desires for assistance and training in areas such as improving building energy efficiency (and energy efficiency more generally throughout the economy), and small- and medium-scale renewable energy technologies (solar, wind, hydro, production of methane gas from waste). A key focus stressed by DPRK energy delegations attending international meetings have always been building human and institutional capacity, including acquisition of technical materials, receiving instruction in basic energy concepts and in the use of design and analysis tools and software, and, generally learning how to bring DPRK capabilities up to speed with those in other countries. These capacity-building foci apply to electricity sector technologies and methods in addition to other technologies in the energy sector more generally. By way of illustration, the passages below, excerpted from presentations made by DPRK delegations over the past decade and more, include the following statements on electricity-related priorities, which are assumedly reflective of national electricity sector policies at the time when the presentations were delivered.

For example, in a 2008 presentation entitled "The Status of the Building Energy Sector in DPR Korea",[476] some of the national priorities expressed in the area of electricity supply and demand included:

- Replacing incandescent light bulbs with compact fluorescent bulbs (problems including lack of investment capital in production facilities and poor power quality were noted).
- The introduction of mini- and micro-combined heat and power plants, including those fueled with agricultural residues, to help provide power for agriculture and electricity and hot water for rural communities.
- The development of solar energy, including passive solar building design, solar water heaters, and solar photovoltaic systems. The delegation recognized the challenges of the North's relatively cloudy climate, and the importance of combining implementation of solar energy in buildings with good insulation practices.
- The presentation concluded by recognizing the importance of building energy efficiency in relieving energy supply deficits, as well as its consistency with the "needs for sustainable development" and achieving DPRK social, economic, and environmental goals.

A pair of presentations delivered in 2006 echo many of the goals above.[477] The 2006 presentations included the following passages (which have been lightly edited for clarity):

Russia-North Korea Relationship Stand?", *Council on Foreign Relations*, dated April 29, 2019 and available as https://www.cfr.org/in-brief/where-does-russia-north-korea-relationship-stand.

[476] DPRK Delegation (2008), "The Status of the Building Energy Sector in DPR Korea". Prepared for the Building Energy Efficiency Technology Training Workshop, Beijing, China, March 9th, 2008.

[477] DPRK Delegation (2006a), "Renewable Energy Policy and Wind Energy Development in DPRK", prepared by the DPRK delegation to the 2006 Asian Energy Security Workshop, "Energy Futures and Energy Cooperation in the Northeast Asia Region" November 6th and 7th, 2006, Beijing China, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRKwind.pdf; and DPRK Delegation (2006b), ""Energy Futures and Energy Cooperation in the Northeast Asia Region", prepared by the DPRK delegation to the 2006 Asian Energy Security Workshop, "Energy Futures and Energy Cooperation in the Northeast Asia Region" November 6th and 7th, 2006, Beijing China, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK.pdf.

"The main path for the long-term energy security of the country is to realize diverse utilization of energy resources and to enhance their use by improving demand side management. For this purpose, the DPRK government emphasizes oil exploration, nuclear power generation, introduction of advanced energy-efficiency technology and renewable energy development. Here renewable energy is relatively the most feasible and reliable in consideration of its technology and its abundant resources.

"The DPRK government always attaches great importance to the development and improvement of renewable energy for the sustainable development of the national economy. Renewable energy development has been taken as part of energy, environment, and ecology construction in the DPRK. For the security of the development and utilization of the renewable energy, the DPRK government has taken several relevant measures. To develop renewable energy as the main energy source of the economy, first of all, it was necessary to establish an appropriate organization that could mobilize and concentrate all related efforts for renewable energy."

The presentation from which the above is excerpted goes on to describe recent DPRK institutions created to assist in renewable energy development, outlines the DPRK's wind energy program, and concludes, in part:

"The DPRK is now framing a new strategy of national wind energy development. According to this strategy the total installed capacity of wind turbines is expected to reach 500 MW by 2020. The large-sized wind turbines are designed to be installed primarily in an intensive manner in tidal land and dikes of the west coastal region.

"The plan for wind farm construction is set in three stages. At the first stage in the period 2006-2010, the DPRK is planning to construct a prototype wind farm with a capacity of 10 MW, which will consist of individual wind turbines with capacity of over 600 kW. During this period, the DPRK will be acquiring the knowledge and experiences on design, construction, operation and management of large wind farms. At the second stage for the period of 2011-2015, three main wind farm projects will be implemented with a total capacity of 100 MW. The DPRK is planning to implement those projects with the cooperation of the international organizations and other NGO groups and communities. At the third stage for the period of 2015-2020, the construction of onshore and offshore wind farms throughout the country will be actively driven. Meanwhile, the manufacturing process for 5 kW small wind turbines will be arranged within a few years to supply electricity to remote villages and stand-alone wind energy systems for household use will be established in the isolated rural areas and islands. The wind resource including offshore will be re-explored and the national wind atlas will be completed by the end of 2008."

In a companion presentation, the following points were made:

"To cope with this situation [a shortage of electricity in the DPRK, exacerbated by what is described as the United States' failure to follow through on the LWR project agreement], the DPRK began to increase the government investment in the construction of hydraulic power stations which are free from the ecological environment pollution, while pushing ahead with the technological upgrading of the existing thermal power stations. As a result of putting emphasis on building large-sized hydraulic power stations, the ration of hydraulic power in electricity production has further increased at present.

"Our Future direction for securing energy is the technological upgrading of the existing thermal power plants to increase the energy conversion efficiency, further construction of hydraulic power stations to raise its proportion, and taking positive measures to develop and utilize the renewable energy including wind power. We are going to confine ourselves to the existing thermal power plants, no longer building new plants for the time being. As for hydraulic power plants, we plan to raise the turbine efficiency of the existing plants, implement several technological reconstruction works, and continue with the construction of new power plants, thereby constantly improving their generating capacity."

The presentation goes on to describe additional wind power initiatives, and concludes, in part, as follows on electricity-related topics:

"We are also consistently pushing ahead with the work of introducing energy saving technologies in time in economic, social, and all other fields. Last and this year we have replaced incandescent lamps with compact lamps as one of our energy saving measures, which has enabled us to save large quantity of electricity.

"It is very important in the development of national and local energy systems to increase the efficiency in energy transmission as well as energy production, saving and transformation efficiency. In order to ensure balanced development of the area and increase energy supply efficiency, we are making no small investment in the work of rationalizing the electricity transmission system, raising transmission voltage and unifying distribution voltage.

"The tense situation in coal production and demand urgently requires us to introduce urban heating in a modern and efficient way. Given the tense electricity situation and lack of natural gas in our country, we are going to improve the heat insulation of buildings so as to reduce the heat loss coefficient. This will ensure sufficient urban heating without increasing carbon dioxide emissions. At the same time, while raising the effectiveness of central urban heating systems, we are also paying attention to the construction of modern sample buildings supplying energy for household use through the comprehensive use of solar energy, and its introduction throughout the country.

"We are making efforts for all-round technological rehabilitation of the energy sector in order to realize the great goal of building a powerful nation and to ensure a clean living environment for the future."

Presentations by a DPRK delegation attending the meeting of Nautilus' Regional Energy Security Project in Ulaanbaatar, Mongolia, during December 2019, described a variety of research and development projects in renewable energy, ranging from biogas and ground-source heat pumps to wind and solar photovoltaic power systems.[478] One of these presentations also focused on the DPRK's interest in renewable energy-powered mini-grid systems, which appear to be a good candidate for the "bottom-up" revitalization and reconstruction of the DPRK grid (see below). Within that presentation ("The Renewable Energy Mini-grid Development in the DPR Korea", priorities for mini-grid development were listed as "The regions with rich resources of developable renewable energy resources", "Rural and mountain areas with little provision of energy", and "The regions and units with a lot of interest in using the natural

[478] "Renewable Energy Development in the DPR Korea", and "The Renewable Energy Mini-grid Development in the DPR Korea", both presented at the Regional Energy Security Project Second Working Group Meeting, Ulaanbaatar, Mongolia, December 9th and 10th, 2019.

resources", all of which are consistent with a national mandate to pursue local power generation options. Among the conclusions of that presentation were "The dissemination of the renewable energy technology should be done in diversified ways and forms on regular basis. Through media, training courses, exchanging the experiences.", showing DPRK interest in collaborating with those from outside in gaining experience with these local generation technologies, and in disseminating the technologies broadly within the DPRK.

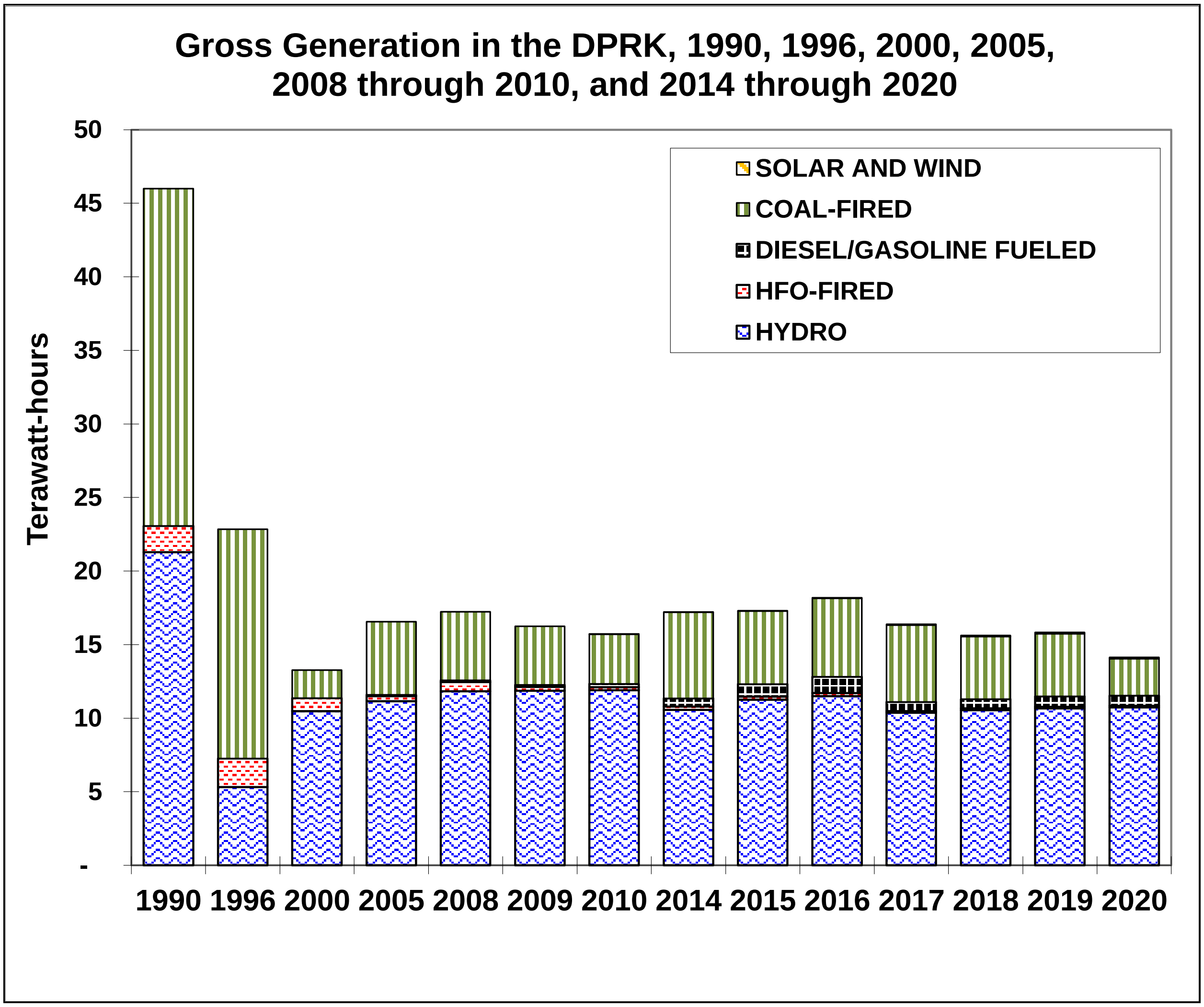
Overall, then, both the policy announcements from the DPRK government and more informal presentations by DPRK delegations paint a picture of a nation looking to diversify and modernize its electricity sector, and to work in elements of efficiency, sustainability, and environmental consideration into its electricity sector choices. The realities of the DPRK's isolation from much of the world economic system, however—particularly in the last few year during which United Nations Security Council sanctions have been in effect, mean that it is difficult for the DPRK to obtain and/or afford some of the necessary equipment that would help to rehabilitate or replace key existing electricity sector infrastructure—such as power plant and electrical substation equipment that cannot or can no longer be made domestically—or to effectively pursue many of its other "energy security" goals. The result in practice is that the need for electricity supplies are dealt with on a basically ad hoc basis, with actions ranging from DPRK engineers doing their creative best to keep systems running with the materials at hand, to rushed programs to build new power plants (often with suboptimal results), to organizations and households taking electricity supplies into their own hands by purchasing and operating their own generation equipment.

5.1.2. Overview of Power Supply Infrastructure in the DPRK

Electricity generation in the DPRK as of 1990 was primarily hydroelectric and coal-fired, in approximately equal proportions, with a small amount of oil-fired electricity generation capacity associated with the oil refinery at Sonbong and in two other plants. Total generation as of 1990 was reported to be in the range of 8 to 10 GW (gigawatts, or thousand megawatts--MW). More than 6000 MW of this nominal capacity is accounted for by less than 30 larger thermal and hydroelectric plants. Much of the generation capacity was installed in the 1970s and 1980s, although a significant portion of generation facilities—particularly hydroelectric facilities—date back to the era of Japanese occupation before World War II.[479] Many of the hydroelectric facilities in the DPRK are reported to be of the "run-of-river" variety, which means that their output is more subject to variations in stream flow than plants that rely on larger impoundments with greater water storage. Since 1990, the ratios of hydro to "thermal" power production have varied from year to year, based on the availability of hydro power (including low output in the mid-1990s following plant damage due to flooding) and on the condition of and fuel supply for coal-fired power plants. Figure 5-1 presents our estimates of electricity output by fuel type in the DPRK over the last three decades.

[479] Many of the hydroelectric facilities built during the Japanese occupation were reportedly disabled or dismantled by the Japanese (during retreat from the Peninsula) or by the USSR but were later refurbished with technical assistance and equipment from the USSR.

Figure 5-1: Estimates of Historical Gross Electricity Generation in the DPRK



The DPRK has the coal resources necessary to expand thermal power generation, but it is not clear that the coal mining or transport infrastructure is routinely capable of supplying coal to power stations at a rate much greater than that prevailing in 1990. In fact, given problems in the coal industry, only a fraction of this rate of coal supply is likely currently achievable. In a series of vicious spirals, electricity and coal infrastructure problems feed back on each other and link to problems throughout the economy. For example:

- No or sporadic electricity availability means that lights and pumps in coal mines don't stay on, reducing coal output;
- No or sporadic electricity means difficulties with coal (and other goods) transport, meaning less coal is made available for power plants and industry;[480]

[480] Transport difficulties for coal are highlighted by a 2016 article quoting DPRK officials on the need to upgrade coal transport infrastructure: Leo Byrne (2016), "N. Korea says it will upgrade rail to handle increasing coal", *NK News*, dated January 19,

- Lack of power and coal for industry limits production of spare parts for transport, generation and mining infrastructure;
- Lack of power makes outside investment in mining, manufacturing more difficult/less attractive; and so on.

Since about 2010, investments by (mostly) Chinese enterprises in coal mines focusing on the production of coal for export to China may have made the coal supply situation somewhat better, and the impact of UNSC sanctions targeting DPRK coal exports may have made the output of those mines more available for domestic use—including direct use for heating by households and enterprises and use for power generation. Sanctions, plus the effect of movement restrictions caused by the measures taken by the DPRK and its trading partners (especially China) to combat the 2020 COVID-19 pandemic, have reportedly, however, at least in the first half of 2020, made it more difficult for these mines to obtain supplies of the materials and equipment needed to maintain full operation, which may have restricted the degree to which formerly exported coal supplies have been available for domestic use.

As noted in the previous chapter of this Report, given weather patterns in the subregion, the DPRK probably has a modest wind power resource overall, as yet largely untapped (and largely unmapped), but it is far from equally distributed throughout the nation, with average winds in many of the most populous onshore areas (including the western coastal plains) being relatively light. The DPRK also has some remaining undeveloped hydroelectric sites and is working on a number of hydro plant additions, most of them likely in the megawatts-to-tens-of-megawatts range in terms of capacity (though public and definitive announcements of power generation capacity have been few).

Power generation and transmission and distribution facilities are reported to be in generally poor, and often failing, condition and sometimes, because they are based on technologies adopted from China or the Former Soviet Union, not well adapted to the coal types with which they are fired or other fuels, such as heavy fuel oil and fuel derived from waste tires, that have intermittently been used to supplement coal supplies. As a consequence, the generation efficiency of the thermal power stations in the DPRK is reportedly low on average. Thermal power plants generally lack all but the most rudimentary pollution control equipment, and also, in almost all cases, lack any kind of computerized combustion control facilities. In-station use of power is reportedly fairly high, and "emergency losses" of power have been reported at major stations.

The system of electricity dispatching is inefficient, minimally or not at all automated, and prone to failure. Estimates of transmission and distribution (T&D) losses vary from an official 16 percent up to more than 50 percent, but any estimates of T&D losses are difficult to confirm, as there is minimal end-use metering in the DPRK.[481]

As described in Chapter 2 of this Report, the DPRK's aging and often unreliable centralized and regional power grids are increasingly being supplemented by distributed generation adopted by businesses and households developing their own access to electricity. As reported by visitors to

2016, and available as https://www.nknews.org/pro/n-korea-says-it-will-upgrade-rail-to-handle-increasing-coal/. The rail transport subsector has been discussed as a potential subject for economic cooperation with Russia (Zakharova 2016, ibid), although it is not clear that substantial work on improving the DPRK rail system has taken place as of this writing (late 2020).

[481] That is, for the most part, power was and is reportedly simply provided to consumers largely without metering, so "sales records" as such generally do not exist.

the DPRK and supported by analysis of customs statistics from the DPRK's trading partners (mostly China), North Koreans have been purchasing and deploying diesel and gasoline-fired generating sets and solar photovoltaic panel/battery kits in increasing volumes in recent years. In many places, these systems likely provide North Koreans with their principal access to electric energy services, albeit probably for a limited number of high-value end-uses.

5.1.3. Electricity Industry Challenges in North Korea

The DPRK is facing a number of challenges in its electricity industry with regard to providing sufficient power for its current economy and for economic development.

Key electricity-sector problems in the DPRK include:

- *Inefficient and/or decaying infrastructure*: Much of the energy-using infrastructure in the DPRK in general, and electricity supply and demand infrastructure in particular, is reportedly (and visibly, to visitors to the country) antiquated and/or poorly maintained, although poor maintenance likely stems more from lack of materials, parts, and tools than from lack of attention by technicians and engineers. On the demand side, for example, buildings apparently lack significant, and often any, insulation, and the heating circuits in residential and other buildings for the most part apparently cannot be controlled by residents. Although some efficient lighting has been introduced in the last 15 years or so—for example, compact fluorescent bulbs and, more recently, LED (light-emitting diode) bulbs, the latter often in combination with the use of small solar photovoltaic panels for household use—inefficient, though rugged, incandescent bulbs continue to be used. Electric motors are typically old, and often not properly sized for the loads they bear. Industrial facilities, where still in use, are likewise either aging or based on outdated technology, and often (particularly in recent years) are operated at less-than-optimal capacities (from an energy-efficiency point of view).

- *Suppressed and latent demand for energy services*: Lack of fuels in many sectors of the DPRK economy has apparently caused demand for energy services to go unmet. Electricity outages in particular are an obvious source of unmet demand, but there are also reports, for example, that portions of the DPRK fishing fleet have been idled for lack of diesel fuel. Residential heating is reportedly restricted in the winter (and some observers report that some public-sector and residential buildings have not received heat at all in recent years) to conserve fuel, resulting in uncomfortably cool inside temperatures.

  The problem posed by suppressed and latent demand for energy services is that when and if supply constraints—particularly electricity supply constraints—are removed, there is likely to be a surge in energy (probably particularly electricity) use, as residents, industries, and other consumers of fuels increase their use of energy services toward desired levels. This is a further argument, as elaborated later in this report, for making every effort to improve the efficiency of electricity (and all energy) use in all sectors of the DPRK economy as restraints on energy supplies are reduced and as economic redevelopment takes hold.

- *Lack of energy product markets*: Compounding the risk of a surge in the use of energy services is the virtual lack of energy product markets in the DPRK. With the exception of consumer-owned generation—the solar photovoltaic and fossil-fueled generation described later in this chapter—virtually all electricity and substantial amounts of other fuels have traditionally been not so much marketed as allocated. Without electricity (and fuel) pricing reforms, there will be few incentives for households and other energy users to adopt energy efficiency measures or otherwise control their consumption. Recent years have seen limited attempts by the DPRK government to reform markets for energy products. Some private markets exist for local products like firewood, some commercial fuels have in recent years reportedly been traded "unofficially" (on the black market), and a prepaid card electricity metering system was used on a limited basis in some areas of Pyongyang, at least for a while in the 2000s, but for the most part, energy commodity markets in the DPRK essentially do not exist.[482] Energy consumers are also unlikely, without a massive and well-coordinated program of education about energy use and energy efficiency, to have the technical know-how to choose and make good use of energy efficiency technologies, even when and if such technologies are made available.

The DPRK's energy sector needs are vast, and at the same time, as indicated by the only partial listing of problems above, many of these needs are sufficiently interconnected as to be particularly daunting to address. The DPRK's energy sector needs include rebuilding/replacement of many of its power generation and almost all of its substation equipment, repair, replacement, and/or improvement of coal mine production equipment and safety systems, updating of oil refineries, improvement or replacement of most if its energy-using equipment, including coal-fired boilers, electric motors and drives, transport systems, and many other items, modernization of energy use throughout the country, rebuilding of the DPRK forest stocks, and a host of other measures to address serious electricity sector issues. As one example of the interrelations of energy problems in the DPRK, renovating the DPRK's coal mining sector is made more difficult because coal mines lack electricity due to electricity sector problems, and electricity generators in some cases have insufficient coal to supply power demand because of coal mine problems and problems with transporting coal to power plants. In addition, without products to sell or markets for those products, it will be very difficult for the DPRK to pay for the needed infrastructure improvements in the electricity and other energy sectors, at least without substantial support from outside the country.

5.1.4. Guide to the Remainder of this Chapter

The remainder of this Chapter is organized as follows:

- **Section 5.2** presents a description of electricity supply in the DPRK, including resources for electricity generation, what is known about DPRK electricity supply infrastructure,

[482] In his paper and presentation "Changes In The North Korean Economy And Implications For The Energy Sector: Is North Korea Really Short of Energy?", as prepared for the Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, William B. Brown discussed the state of DPRK energy markets, and noted that by one measure of electricity cost, the ratio of the price of rice to the price of a kilowatt-hour of electricity, power was one hundred times as expensive in the United States in 2006 than it was in the DPRK. See https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/. Brown also highlighted the lack of properly-functioning electricity and other energy markets in his 2018 paper: William B. Brown (2018), "North Korea's Economic Strategy, 2018", *Joint U.S.-Korea Academic Studies*, 2018, Vol 9, pages 326 – 343, Korea Economic Institute of America, available as http://www.keia.org/sites/default/files/publications/jukas_4.3_north_koreas_economic_strategy.pdf, as well as in other publications, such as William B. Brown, *SPECIAL REPORT: North Korea's Shackled Economy, 2018*, published by The National Committee on North Korea, dated March, 2018, and available as https://www.ncnk.org/sites/default/files/issue-briefs/NCNK_William_Brown_NK_Shackled_Economy_Report.pdf .

and our estimates of electricity generation by type of plant in selected years.

- **Section 5.3** provides our assessment of electricity demand in the DPRK, with descriptions of current demand sectors, and estimates of overall electricity use (which is not quite the same as demand, because actual use of electricity in the DPRK is largely limited by electricity availability) and electricity use by end-use.
- **Section 5.4** provides brief conclusions to this Report, including a summary of results, a discussion of the implication of the results for engaging the DPRK on electricity sector issues, and possible "next steps" on elaborating research into DPRK energy issues and in planning and implementing engagement projects.

5.2. Electricity Supply in the DPRK

5.2.1. Introduction

The DPRK electricity sector supply and demand estimates summarized in this Report build upon and have as their foundation Nautilus research in compiling and analyzing data on the DPRK energy sector that started in 1994. Early Nautilus research, funded by the W. Alton Jones Foundation, culminated in a 1995 report entitled *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*, and further research in 1997, funded by the Northeast Asia Economic Forum/East-West Center, produced *Demand and Supply of Electricity and Other Fuels in the Democratic Peoples' Republic of Korean (DPRK)*. In our 1995 work, we prepared an estimated energy supply/demand balance for the DPRK for the year 1990 that synthesized the information available to us on the North Korean economy and energy sector. In the 1995 report, the energy balance results were used to estimate the (by any measure, considerable) potential for energy-efficiency improvements in the DPRK, which in turn allows us to estimate electricity demand (or more accurately, electricity use) in the DPRK by end use, as presented in Chapter 3 of this Report. Our 1997 work produced an estimated energy balance for 1996 and used it as the starting point for quantitative energy "scenarios" for the DPRK for 2000 and 2005. Our 2002/2003 report, *The DPRK Energy Sector: Estimated Year 2000 Energy Balance and Suggested Approaches to Sectoral Redevelopment*, prepared with funding from and in collaboration with the Korea Energy Economics Institute, updated our analysis to a 2000 "base year", and our 2007 report, *Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths,* provided a further update to a 2005 base year. Finally, our report *Foundations of Energy Security for the DPRK: 1990-2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment* updated our assessment to provide energy balances for the years 2008 and 2009.[483] In 2013, with funding from a Korean institute, we updated our energy balance further to incorporate 2010 data, as described in *An Updated Summary of Energy Supply and Demand in the Democratic People's Republic of Korea*

[483] David von Hippel and Peter Hayes (2012), *Foundations of Energy Security for the DPRK: 1990-2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Redevelopment*, dated 18 December 2012, and available as http://nautilus.org/napsnet/napsnet-special-reports/foundations-of-energy-security-for-the-dprk-1990-2009-energy-balances-engagement-options-and-future-paths-for-energy-and-economic-redevelopment/.

(DPRK).[484] And in 2016, also with funding from a Korean institute, we prepared a study focusing on the DPRK electricity sector, with updates to the analysis through the year 2014. This chapter is based on that 2016 study, with updates through 2020.

Although the process that we followed in evaluating energy supply and demand, and electricity supply and demand in particular, in the DPRK is bound to produce energy balances and electricity sector estimates that "fit" the DPRK poorly in some areas, it is our hope that in future collaboration with DPRK energy experts we will be able to use the electricity supply/demand results described and presented below as a starting point to develop better information for use by both the international community and by the DPRK itself. Moreover, as our analysis is built up from many independent observations, estimates, and assumptions, we feel that the probability is reduced that any one off-base assumption or erroneous piece of data has considerably altered the overall accuracy of the assessment. We have, on occasion over the years, showed the results of our work to DPRK delegations that we have worked with. Those delegations have generally accepted our work as reasonably accurate portrayals of the DPRK energy system.

It should be noted that other estimates of DPRK energy supply demand balances have been developed over the years, and we have consulted those estimates available to us, and in some cases, collaborated with other researchers developing balances. Notable among other estimates of DPRK energy balances are those developed by our colleagues at the Korea Energy Economics Institute (KEEI), as described in a presentation to the 2006 DPRK Energy Experts Working Group Meeting by Dr. Kyung-Sool Kim of KEEI. The International Energy Agency (IEA) also maintains some energy statistics, including an estimated energy balance, for the DPRK.

The key assumptions and data used in preparing our estimated supply and demand balances for electricity and other fuels are presented below by fuel group (for supply) in this section, and by sector (for demand) in section 5.3. Finally, it must be emphasized that the results provided below, though based on the best data we have available, must still be called **estimates**, because information on the DPRK energy system is at best sparse, irregular, and uncertain, and at worst entirely missing. Still, we feel that the process of assembling what is known about the DPRK energy sector in a systematic and well-documented format is a key to building better understanding of the sector. We welcome the input of others in improving these estimates.

In the remainder of this section, we describe the various resources available for generating electricity in the DPRK, then provide a summary of what is known about the DPRK's electricity infrastructure, as well as our estimates of electricity generation in the DPRK, by source, in selected years.

5.2.2. Resources for Electricity Generation

5.2.2.1. Coal Resources

As noted in the previous chapter of this Report, the DPRK has abundant coal resources, including deposits of anthracite coal and lignite, or "brown" coal. It substantially lacks,

[484] David F. von Hippel and Peter Hayes (2013), *An Updated Summary of Energy Supply and Demand in the Democratic People's Republic of Korea (DPRK)*, dated February, 2013, Working Paper 2014-2, prepared for Hanyang University Center for Energy Governance and Security, and available from http://www.egs-korea.org/en/egs/egs02.php.

however, bituminous coal, which is the most common coal used worldwide as an input to coke production for steelmaking, and as a power plant fuel. Coal quality in the DPRK seems to be quite variable, with reported energy contents for different North Korean coals ranging from a very low 1000 and 2300 kilocalories (kcals) per kilogram for "low grade coal" (lignite and anthracite, respectively)[485] to a relatively high 6150 kcal/kg for high-grade anthracite coal[486]. The DPRK's total coal resource or reserves have been variously estimated at levels ranging from 600 million tonnes ("proven coal reserves", and "recoverable coal reserves", as noted in international compendia of energy statistics[487]) to resources ("coal deposits") of nearly 15 billion tonnes. The latter estimate is included in a fairly detailed description of coal (and other mineral) resource in the DPRK published through a Korean-language website in China[488]. Given the DPRK's recent coal exports to China—over 10 million tonnes annually since 2011, and over 15 million tonnes in 2013 and 2014—and the above reports of reserves, it is clear that coal could serve as a major fuel for electricity generation if supply-chain and thermal generation infrastructure difficulties are overcome. From an ROK perspective that worries about the health of the environment on the Korean Peninsula, however, and given recent climate agreements, fostering continued reliance on coal by the DPRK may not be prudent for the ROK in the long run.

5.2.2.2.Oil and Gas Resources

Although the DPRK reportedly has oil and gas resources, most prominently in offshore areas, these resources remain essentially untapped due to lack of access to technologies and investment capital, as well as restrictions on international ventures posed, effectively when not directly, by international economic sanctions on the DPRK.[489] The DPRK has essentially no infrastructure for natural gas distribution, or import sources for natural gas in more than small quantities (for example, in shipping container-sized cylinders), and its crude oil, refined mostly at a refinery in the DPRK's Northwest fed by a pipeline from China, is all imported. Diesel fuel and gasoline, refined domestically and imported, are used in limited quantities for generation. Heavy fuel oil is produced as a part of the refining of crude oil but has limited uses in DPRK electricity generation because there are essentially only one large and one small plant designed to use it. Heavy fuel oil is used in coal-fired plants to a limited extent as a starter fuel and, when supplies were available, as a substitute fuel for coal, albeit with some problems.[490]

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[485] Document in the authors' files [VO-90].
[486] Choi Su Young, *Study of the Present State of Energy Supply in North Korea*, RINU, 1993. P. 14.
[487] For example, U.S. Department of Energy's Energy Information Administration, EIA Country Analysis Brief, Updated February 2006, with an updated (2018) version available as https://www.eia.gov/international/analysis/country/PRK; and British Petroleum Company (2012), *BP Statistical Review of World Energy June 2012*, "Coal", available as https://www.laohamutuk.org/DVD/docs/BPWER2012report.pdf.
[488] *Changchun Killim Sinmun* (Internet Version-WWW) in Korean 31 Aug 06 - 08 Sep 06, "Guide to DPRK Mineral Resources".
[489] DPRK sources place estimates of total oil reserves at 6 to 10 billion tonnes. Although we have been told by independent sources that oil and gas deposits do indeed exist beneath the DPRK and its offshore territory, we have been unable to confirm the extent of those deposits. In an article entitled "Could North Korea Be the Next Energy Superpower?", dated December 1, 2015, Anthony Fensom suggests that there are several areas of the DPRK, both onshore and offshore, with good potential resources, and notes that a Mongolia company, HBOil JSC, has looked into oil resources in the DPRK. The article cites unconfirmed reports of a "1-trillion-cubic-foot (tcf) discovery in 2002" See http://nationalinterest.org/feature/could-north-korea-be-the-next-energy-superpower-14471. See also *The Maritime Executive* (2015), "North Korea has 'Excellent' Oil and Gas Potential", dated November 19, 2015, and available as http://maritime-executive.com/article/north-korea-has-excellent-oil-and-gas-potential.
[490] It has been reported that the use of high-sulfur heavy fuel oil (HFO) purchased and delivered to the DPRK as a part of and subsequent to the Agreed Framework negotiated between the DPRK and the United States and its partners in 1994 was a poor

5.2.2.3.Biomass Resources

The DPRK has biomass resources—crop wastes and forest biomass—that could in theory be used to fuel biomass-fired generation. In practice, however, the other pressures on biomass resources, that is, as fodder for animals, as a soil amendment, and as fuel for cooking and heating, coupled with the poor and in many places stressed state of the DPRK's forest resources, means that biomass-fired power is unlikely to play a large role in future DPRK electricity supplies. That said, some biomass-fired plants could be developed, including perhaps combined heat and power plants where suitable biomass supplies exist, and biogas plants fed with animal or human wastes may also have attractive ancillary benefits such as reducing water pollution. The overall likely available fuel resource for biomass-fired plants is, however, unlikely to provide more than a few hundred megawatts of power for the DPRK without severely competing with other uses for biomass.

5.2.2.4.Hydraulic Resources

Several sources suggest that the DPRK's hydraulic resource is sufficient to provide about 10 GWe (gigawatt electric) of hydroelectric generation. This is consistent with what we have been told in workshop presentations by delegations from the DPRK.[491]

Many, but not all, of the sites for large hydroelectric facilities have been built upon, but many sites for small and medium hydro dams remain. In addition, it has been reported that some of the DPRK hydroelectric plants—some of which were built before the Korean War—have efficiencies (electrical energy output as a fraction of energy available in falling water) that are around 60 percent, suggesting that significant additional electricity could be generated at these existing sites once plants are upgraded to modern efficiency levels (on the order of 90 percent). The total of one estimate of hydroelectric potential for major rivers in the DPRK is the equivalent of approximately 9,200 average MW of power.[492]

5.2.2.5.Geothermal Resources

Geothermal energy is also mentioned as a possible source of both heat and power for the DPRK. At present, we have no information about the extent of the DPRK's geothermal resources, though some potential geothermal sites undoubtedly are present in the DPRK. Recent news articles indicate an ongoing and expanding interest in the DPRK regarding geothermal energy, including a recent study tour, funded by a German foundation, by a DPRK delegation to geothermal-related sites in Germany, with a reciprocal visit by a representative of the foundation

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match to the steel used in the boiler tubes of the nominally coal-fired power plants in which it was used as a substitute fuel, and its use resulted in significantly accelerated degradation of boiler tubes, air preheaters, and other power plant facilities.

[491] DPRK Delegation, "THE POTENTIAL IMPACT OF THE INTER-STATE ELECTRIC TIES IN NORTH EAST ASIA ON ENVIRONMENT," September 31, 2003. Paper presented at Nautilus Institute's 3rd Workshop on Grid Interconnections, held in Vladivostok, Russia, September 30 to October 3, 2003. Available as http://nautilus.org/wp-content/uploads/2011/12/K_DPRK_2_PPR.pdf.

[492] That is, the total shown is the equivalent of 9200 MW of power supplied continuously, year-round. Given that the average capacity factors of DPRK hydroelectric facilities may be 50 percent or less, this implies a total potential "nameplate" hydroelectric potential on the order of 18,000 MW, though not even close to all of this potential can be taken advantage of in practice.

to Pyongyang,[493] and agreements to cooperate with China on renewable energy development, including geothermal energy.[494] A number (over 120, according to various articles quoting unnamed DPRK sources) of hot springs exist in the DPRK, many of which are in use as spas or resorts (for example, the Ryonggang resort in the Nampo area). Our guess is that the DPRK's usable resource for geothermal electricity generation is probably moderate, in the range of tens or hundreds of megawatts, but that is no better than a guess, pending further information.

5.2.2.6.Wind Energy Resources

Estimation of the wind resources potential in the DPRK is incomplete, and we have found existing DPRK wind data to be potentially unreliable. Significant DPRK wind resources are said to exist, however, in mountain areas and in coastal areas (including offshore areas). A North Korean delegation to a workshop organized by Nautilus and co-hosts provided an annual wind resource estimate of 1.7 TWh (terawatt hours, or billion kilowatt-hours), which corresponds to about 550 MWe (megawatts electric) of wind power at an assumed capacity factor of about 35 percent (not atypical for wind generators, though possibly a bit high for the DPRK).

Based on our own (Nautilus') experience in installing several small wind generators in a location on the western coast of the DPRK, it seems unlikely that onshore wind resources in that area are quite as good as claimed in the quote above, though offshore areas may well prove to have a better wind regime than onshore areas. Until additional and more rigorous wind data collection is completed, the actual DPRK wind resource is uncertain, but it seems likely that the total practical level of wind turbine installations in the DPRK will be in the range of hundreds of megawatts, of which some is likely to be in near-offshore areas or on islands. An extract of a Global Wind Atlas (see Figure 5-2) indicates that the most favorable areas for wind projects in the DPRK are likely to be the north coastal areas of North Hamhyung Province, particularly near the border with China and Russia,[495] in some of the mountainous areas of North Hamgyong, South Hamgyong, and Ryanggang Provinces (including the Mount Paektu area), and, though to a significantly lesser extent, along the West coast of the DPRK.[496] Note that this graph shows estimated average wind speeds at a height of 100 meters, meaning that megawatt-scale wind turbines would be needed to take advantage of the resource. Global Wind Atlas images at lower heights show much smaller areas of high wind speeds. There appears to be large areas of medium (Class II) winds not far off the DPRK coast in several locations, and as technologies for offshore wind, including large floating units, continue to improve, this resource may become

[493] Friedrich Naumann Foundation (2011), "Geothermal Energy – Energy Source for the DPR Korea?", available as https://www.freiheit.org/seoul/geothermal-energy-energy-source-dpr-korea, and "North Korea: Hope for Economic Revival" (undated, but apparently 2011 or 2012), available as https://www.freiheit.org/seoul/north-korea-hope-economic-revival.

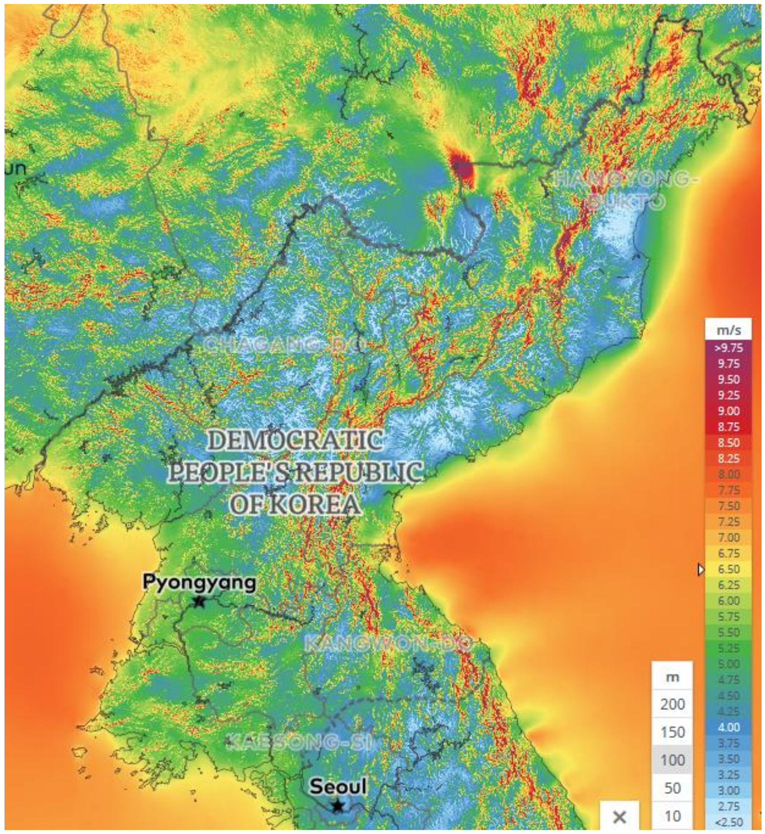
[494] People's Daily Online (2011), "China, DPRK to boost renewable energy cooperation", available as http://english.peopledaily.com.cn/90001/90776/90883/7433273.html. In this article, "Thae Jong Su, alternate member of the Political Bureau of the Korean Workers Party (KWP) and member of the Secretariat from the Democratic People's Republic of Korea" is quoted as saying "[t]he DPRK hopes to use geothermal energy in its efforts to develop its economy and build a strong and prosperous country".

[495] Krahun Company, A group described as a Christian "mission business" (see Justin Rohrlich and Chad O'Carroll (2013), Spreading the gospel in North Korea", *NK News* and *The Telegraph*, dated 15 November 2013, and available as was at one time interested in setting up a wind power farm in the Rason area, in the far Northeast of the DPRK where the wind regime is reportedly favorable. We do not know the current status of this project.

[496] Based on information from the "Global Windspeed at 80 m" map by the company 3TIER, available as https://www.3tier.com/en/support/wind-online-tools/what-wind-speeds-are-shown-map/. The map is based on a combination of satellite data and the results of "mesoscale numerical weather prediction (NWP) atmospheric simulations" done by the company.

important in a scenario where relations with the international community improve and DPRK grid redevelopment begins in earnest.

Figure 5-2: Wind Speed Map for the DPRK (100 meters)[497]

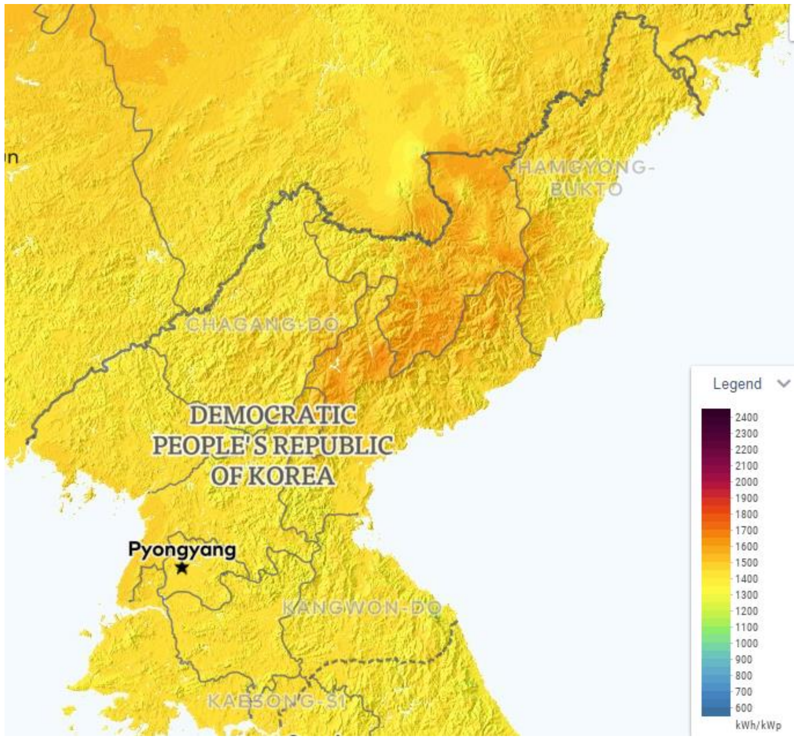


5.2.2.7.Solar Energy Resources

A DPRK presentation to a Nautilus workshop provided the following information about the DPRK solar resource: "Annual average solar irradiation is about 1200 kWh/m^2 and 55~60% of days per year are clear."[498] The DPRK's winters are often relatively clear but cold, and summers are humid, with much of the annual rainfall in the DPRK occurring in the summer months. This weather pattern, and the solar resource data provided, suggests that the DPRK has at best, on average, a moderate solar resource. At 1200 kWh/m^2-yr, the DPRK's average insolation is less than that in many cities in the United States (for example, Pittsburgh, Pennsylvania, locations in New Jersey, and Western Oregon all have a similar solar resource[499]) but is greater than the solar resource in the Northern parts of Europe (most of France and Germany, for example). These data are consistent with the values shown in Figure 5-3, which shows annual values of 1200 to 1500 kWh per peak kilowatt (kWp), a unit effectively similar to kWh/m^2-yr.

[497] Image extracted from the *Global Wind Atlas*, accessed 10-27-2020, available as https://globalwindatlas.info/.
[498] DPRK Delegation (2004), *Policy Forum 04-27A: Options For Rehabilitation of Energy System & Energy Security & Energy Planning in DPRK of Korea*, dated May 14, 2004, and available as https://nautilus.org/supporting-documents/options-for-rehabilitation-of-energy-system-energy-security-energy-planning-in-dpr-of-korea/.
[499] See, for example, http://howto.altenergystore.com/Reference-Materials/Solar-Insolation-Data-USA-Cities/a35/.

Figure 5-3: Solar Resource Map for the DPRK[500]



5.2.2.8.Tidal Power Resources

Tidal power is a possibility for some coastal areas of the DPRK. The 2004 presentation by DPRK delegates cited above noted: "The west seashore of the DPRK is one of the well-known tidal zone in the world. The average difference between high and low tide is 4~6 m. Tidal potential capable of the development is estimated at about 19 TWh." Generation of 19 TWh annually suggests installed capacity on the order of 4 to 6 GW. An estimate by a Russian author put the tidal power resource of the DPRK at 4700 MW (4.7 GW).[501] At least one small tidal power station exists in the DPRK—a 500 kW unit built into the Nampo barrage near the mouth of the Taedong River[502] (see Figure 5-4). In 2004, China was reportedly planning to build a 300 MW tidal power facility based on an artificial offshore lagoon design near the mouth of the Yalu River near the DPRK border, but it is somewhat unclear whether this project has moved forward since—no such facility is evident in recent satellite photos.[503] The fact that China was planning such a project, however, probably means that tidal energy projects are also possible in nearby

[500] Image extracted from the *Global Solar Atlas*, accessed 10-27-2020, available as https://globalsolaratlas.info/map?c=40.805494,121.278076,7.

[501] Marina Trigubenko (1991), "Industry of the DPRK". Paper presented at Korea Development Institute Symposium, Seoul, ROK (October 1991).

[502] The authors visited this installation on their 1998 visit to the DPRK. We do not know its current status.

[503] See, for example, K. Steiner-Dicks, Tidal: Asia's Cinderella renewable energy", *Tidal Today*, dated July 5, 2011, and formerly available as http://social.tidaltoday.com/technology-engineering/tidal-asia%E2%80%99s-cinderella-renewable-energy; Renewable Energy World.com, "China Endorses 300 MW Ocean Energy Project", dated November 2, 2004, and formerly available as http://www.renewableenergyworld.com/rea/news/article/2004/11/china-endorses-300-mw-ocean-energy-project-17685.

DPRK near-shore territory, at least from the point of view of the tidal energy resource (that is, large differences between high and low tides).

Figure 5-4: Painting of Kim Il Sung and Kim Jong Il at the Dedication of the West Sea Barrage[504]

5.2.2.9. Uranium Resources

Figures on the DPRK's reserves of uranium and the quality of its ore are difficult to obtain, and their accuracy is unknown. It has been reported that uranium has been mined to supply the North's domestic nuclear industry from mines located in various areas around the country, including Pyongsan, Pakchon, Hongnam, Jusong, Ungki, Sunchon, Hamheung, Hekumkang, and Najin. Two sources suggest that the DPRK's uranium deposits "are estimated at 26 million tons".[505, 506] One of the sources describes these deposits as "high grade ore", so it seems virtually

[504] Photo taken by D. von Hippel at the West Sea Barrage Visitors' Center, near Nampo, NP, in October 1998.

[505] Larry A. Niksch, United States Congressional Research Service (CRS), *CRS Issue Brief for Congress: North Korea's Nuclear Weapons Program*, updated January 17, 2006. The same figure is also quoted in Yo-Taik Song, "IN OUR TIMES SERIES, PART 6, The North Korean Nuclear Program: Technical and Policy Issues", formerly available as http://www.phy.duke.edu/~myhan/ot6-song.html.

[506] The DPRK has been highly reluctant to reveal the extent of its deposits of Uranium ore and its annual production capacity to the outside world. This same estimate of reserves (26 million tonnes of ore), however, was provided in information from private sources in China and DPRK business contacts compiled by E. Yoon (see, for example, E Yoon (2011), *Status and Future of the North Korean Minerals Sector*, available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf).

certain that the references are to tonnes of ore, not tonnes of uranium metal (or uranium oxides).[507]

Another source states:

> "It has been estimated that, at its peak in the early 1990s, North Korea was able to produce about 300 tonnes of yellow cake [U_3O_8] annually, equal to approximately 30,000 tonnes of uranium ore".[508]

The information from this source implies that the DPRK's uranium ore has (or had) an average U content of about 0.9 percent, which is quite high—most uranium ore in the Northeast Asia region has an average U content of closer to 0.2 percent or less[509]—so this estimate may be in error. Other analysts of the subject have reported estimates of 3 and 4 million tonnes of "reasonably assured resources", based on older OECD and ROK estimates, respectively. Still another source cites a figure of 4.5 million tonnes of uranium ore, and quotes "Russian scientists who have visited North Korea" as saying that the DPRK's "mining and milling capabilities produce 2000 tons of natural uranium, per year".[510] A 2004 Nautilus report described DPRK deposits as "uraniferous black shale occurrences (perhaps similar to that at Ok´chon in South Korea) occurring at a depth about 200 meters. The ore grades are about 0.2%".[511]

The DPRK is reported to have exported significant amounts of uranium ore over the years, starting in (at least) the 1947-1950 period, with the export of "over 9,000 tons of uranium [possibly ore?] and an unknown amount of monazite to the USSR", and continuing with a reported "$6 billion worth of uranium ore" to the USSR in 1985, "1,500 tons of monazite[512] annually" in the 1990s to "China, Japan, Spain, and Hong Kong"[513]. More recently, an advertisement by the DPRK's International Chemical Joint Venture Corporation was published in an English-language North Korean trade journal in 2001 and 2002, offered ammonium diuranate (ADU), a processed form of yellowcake (U_3O_8), for sale on the international market.

Unlike other mining industries in the DPRK, uranium mines have been targets of heavy investment, and its high grade engineers and skilled workers receive preferential treatment in

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[507] For additional details, see David F. von Hippel (2019), "Methods for Refining Estimates of Cumulative DRPK Uranium Production", *Journal for Peace and Nuclear Disarmament* Volume 2, 2019 - Issue 2. Pages 555-585, available as https://www.tandfonline.com/doi/full/10.1080/25751654.2019.1660522, from which some of the text here is drawn.

[508] International Institute for Strategic Studies (2006). *North Korea's Nuclear Weapons Programme*.

[509] As just two anecdotal example, an undated (but probably late 1990s) article available on the International Atomic Energy Agency (IAEA) website describing uranium mining in Benxi, in the Northeast province of Liaoning, China (about 150 km from the DPRK border) lists an ore U content of 0.34% U (Zhang Rong (no date, but probably c. 1997) "New Development Stage of China's Uranium Industry", available as https://inis.iaea.org/collection/NCLCollectionStore/_Public/33/003/33003339.pdf). The World Nuclear Association lists Russian mines with ore U contents ranging from 0.05 % to 0.2% uranium, albeit the mines listed are not particularly close to the DPRK (World Nuclear Association (2020) "Russia's Nuclear Fuel Cycle" available as http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-fuel-cycle.aspx).

[510] Paul Vos Benkowski (2006), "North Korean Hullabaloo", *Nukewatch Pathfinder*, Winter, 2006-2007, page 6.

[511] Hayes, P. (2004). "North Korea's Uranium Exports: Much Ado About Something." May 25, 2004, available as http://nautilus.org/wp-content/uploads/2011/12/Hayes-DPRKuranium.txt.

[512] Monazite is a name for a group of rare earth phosphate minerals, the most common form of which (Monazite-(Ce)) contains Cerium, Lanthanum, Thorium, Neodymium, and Yttrium. Monazite is radioactive, and it seems likely to have been exported in this instance primarily as a source of Thorium, though that is just the authors' conjecture. A description of Monazite can be found at Amethyst Galleries "THE MINERAL MONAZITE", http://www.galleries.com/minerals/phosphat/monazite/monazite.htm.

[513] "North Korea Profile, Nuclear Exports", prepared for the Nuclear Threat Initiative by the by the Center for Nonproliferation Studies at the Monterey Institute of International Studies, 2003, available as https://www.nti.org/learn/countries/north-korea/nuclear/.

terms of food, salary and social status. Funds invested in the mines have been used for mining equipment and facilities. In particular, instead of freight railway shipping of ore, sophisticated trucks, imported from Sweden and Japan, are operating to support production activities.

The Nuclear Threat Initiative (NTI) lists the uranium ore extracted from the "Kŭmch'ŏn Uranium Mine" as being reported by a defector as having "a uranium content of 0.8 percent, a vanadium content of 1.4%, and other rare metals such as nickel, molybdenum and radium". The same uranium content is listed by NTI for the Pyongsan mine, although the figures in the quote above from the NTI reference, 290 tons yellowcake from 200,000 tonnes ore, would seem to imply a U content of more like 0.2 percent, assuming about 20 percent losses in processing. The Nuclear Threat Initiative lists the Hamhung Uranium Deposit as having "approximately 4 million tons of uranium deposits". Lewis (2015)[514] includes a 1979 quote from a telegram from the Hungarian ambassador to the DPRK, in turn quoting a Soviet source, and giving the average ore quality at the two main North Korean uranium mines at the time as "0.26 percent, while in the other it is 0.086 percent".[515] Lewis goes on to say "[b]ased on other information released by the Soviet Union, it appears these mines are near Pakchon and Pyongsan, with Pyongsan likely having the higher quality ore." These values are considerably lower than the 0.8 to 0.9 percent estimates described above, but closer to international averages.

Reports on a pair of missions (1987 and 1990) undertaken by International Atomic Energy Agency (IAEA) experts at the request of the DPRK government,[516] indicate that at the time DPRK engineers were working with fairly rudimentary uranium prospecting equipment, often of Russian origin and decades old, although DPRK government news releases in the last few years have praised progress in uranium processing technology.[517]

5.2.3. Electricity Generation Infrastructure in the DPRK

With a relatively few exceptions, the energy infrastructure in the DPRK in general was installed prior to 1990, with some infrastructure—notably large hydroelectric power plants near the border with China—dating back to the period in which Japan occupied Korea in the 1920s and 1930s. Other infrastructure, including thermal power plants and oil refineries (some with associated

[514] Lewis, J. (2015). "Recent Imagery Suggests Increased Uranium Production in North Korea, Probably for Expanding Nuclear Weapons Stockpile and Reactor Fuel." *38 North*, August 12, 2015, available as https://www.38north.org/2015/08/jlewis081215/.
[515] These same values are also quoted in B. Szalontai and S. Radchenko (2006), *North Korea's Efforts to Acquire Nuclear Technology and Nuclear Weapons: Evidence from Russian and Hungarian Archives. Cold War International History Project*, Working Paper #53, Washington DC: Woodrow Wilson International Center for Scholars, available as https://www.wilsoncenter.org/sites/default/files/media/documents/publication/WP53_web_final1.pdf.
[516] See M. Matolin and M. Tauchid (1987), *Report to the Government of the Democratic People's Republic of Korea: Uranium Prospecting DRK/3/003 Evaluation Mission*, available as http://oldsite.nautilus.org/DPRKBriefingBook/nuclearweapons/DPRKUraniumProspectingMission-1987.pdf, and M. Matolin (1990), *Report to the Government of the Democratic People's Republic of Korea: Uranium Prospecting DRK/3/003-04 Laboratory Gamma Ray Spectrometry*, available as http://oldsite.nautilus.org/DPRKBriefingBook/nuclearweapons/DPRKUraniumProspectingMission-1990.pdf. In personal communication, Professor Matolin indicated that his mission did not have access to data on ore quality, but he did measure the uranium content of "0.1 percent and up" in uranium ores, though these measurements were made for the purposes of training as part of the mission, and thus do not reflect a DPRK average or even the average for the deposit where the sample was taken.
[517] See, for example, Berger, A. (2014), "What lies beneath: North Korea's uranium deposits: All signs point to Pyongyang regime's ongoing nuclear program development." *NK News*, August 28, 2014, available as https://www.nknews.org/2014/08/what-lies-beneath-north-koreas-uranium-deposits/.

generation facilities), were built with substantial technical assistance and/or material from the former Soviet Union or from China.

Below we describe the major elements of electricity supply infrastructure in the DPRK, including power plants, and electricity transmission and distribution systems, and also summarize the status of the coal mines that provide fuel for almost all thermal generation in North Korea.

There were reportedly over 500 electricity generation facilities in the DPRK as of the mid-1990s. Of these, however, only 62 major power plants were operated as part of the (nominally) interconnected transmission and distribution grid, with the remaining plants being primarily small, isolated hydroelectric facilities and/or facilities associated with industrial installations. One estimate suggests that 85 percent of total national generation took place in the 62 major power plants in the 1990s; other, unofficial reports suggest generation at smaller plants was and is insignificant. The 62 "major" plants reportedly included 42 hydroelectric plants and 20 thermal plants. Of the thermal plants, 18 were reportedly fired primarily with coal. The power generation system in general suffered even in the 1990s from a lack of spare parts (particularly for plants built with USSR assistance, for which the Soviet factories that produced the parts were not producing those items, even if the factories were still in business), as well as a lack of testing equipment for use in maintenance activities.

5.2.3.1.Existing Thermal Generating Facilities

Although there are discrepancies between the various estimates of the installed capacity of thermal electricity generating capacity in the DPRK[518], we have assumed that the total installed and potentially usable[519] coal-fired generating capacity as of 1990 was approximately 3,200 megawatts, with an additional 200 MW of oil-fired capacity. A list of the largest thermal plants in the DPRK as of 1990 (1992 for the East Pyongyang plant), and still today, to the extent we can determine, is provided in Table 5-1, and these constituted the bulk of the DPRK's 1990 thermal capacity, but we assume that there may as of that time have been up to 500 MW in total capacity of operable smaller thermal plants (thus the total estimate of 3400 MW, including oil-fired plants).

[518] Choi (1993), for example, cites a total capacity for coal-fired generating stations of 2,850 MW in 1991, while the United Nations (United Nations (1994) *1992 Energy Statistical Yearbook*, Table 32, page 386)) lists 4,500 MW of thermal capacity for 1989 through 1992 (along with 5000 MW of hydroelectric capacity), but a notation in the *Yearbook* indicates that the capacity figures are estimates by "the Statistical Division" of the UN. We feel that the UN estimates are likely to have been too high. Other documents in our files list a total of 2,900 MW of capacity as of 1990 in the largest seven thermal plants alone, and still others list "official figures" of up 6,000 MW of thermal capacity in 1990. We have adopted an overall estimate of 3400 MW of operable thermal capacity in 1990 as a reasonable figure between the sum of capacities of the plants that were identified and clearly in operation in 1990 and the higher estimates that must include some plants not explicitly named or identified in plant-by-plant rosters as of 1990.

[519] It has been reported that a large number of the smaller power plants reportedly included in official estimates of overall generation capacity were essentially built as "shams" (inoperable models) to satisfy authorities and have actually never been capable of generating power.

Table 5-1: Major Thermal Generating Facilities in the DPRK[520]

#	Name		Capacity (MW)	Fuel	Year Completed
1	Pyongyang		500	Coal	1968
2	Bukchang		1600	Coal	1985
3	Chongjin		150	Coal	1984
4	Chonchonang		200	Coal	1979
5	Oungi		200	Oil	1973
6	Sunchon		200	Coal	1988
7	East Pyongyang		50	Coal	1992
TOTAL OF LISTED PLANTS			**2900**		

In order to calculate the fuel used by thermal power plants, we have assumed that coal-fired plants use heavy fuel oil primarily as a start-up fuel in 1990, with HFO constituting about 2.0 percent of the total heat value of input fuel. Using figures for electricity generation by fuel type derived as indicated above, we then calculated the fuel requirements for thermal electricity generation using gross generation efficiencies in 1990 of 29.5 percent for oil-fired plants[521] and 28 percent for coal-fired plants. The efficiency figure we have assumed coal-fired plants is somewhat lower than the average heat rate (30 percent) reported in the Chongjin plant in the Sonbong area but is comparable to Chinese electricity generation efficiencies for thermal plants of late-1970s vintage.[522, 523]

The "own use" of electricity in oil-fired and coal-fired plants was assumed to be 8 and 9 percent of gross generation, respectively. These own use values are those quoted for the Oungi and Chongjin plants, respectively,[524] and are relatively high compared to typical thermal power plants. For coal-fired plants, we assumed an additional "emergency loss" rate in 1990 of 5 percent (accounted for in the "own use" row of the electricity balances presented in section 5.3), which is a bold extrapolation from experience at the Pyongyang power station,[525] and may be indicative of poor operating conditions in all DPRK coal-fired power plants. For 1996, we increased this rate to 7.5 percent of gross generation in coal-fired plants to reflect the reported increasing difficulties with power plant maintenance and in obtaining parts to repair and maintain thermal power plants.

520 Please see von Hippel and Hayes, 2012 (ibid), for a listing of the sources used in developing this table.
521 This value is substantially lower than an official (we assume) figure of 35 percent quoted in UNDP (1994) (*Studies in Support of Tumen River Area Development Programme*, as prepared by KIEP, Seoul, ROK for the UNDP, July 1994). An efficiency of 35 percent seems too high oil-fired generation in the DPRK, given reports about the condition of the oil-fired plant at Sonbong. The 29.5 percent efficiency we have used is consistent with information we have received about the Sonbong plant's recent operations.
522 Sinton, J., editor (1996), *China Energy Databook 1996 Edition*, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.
523 It should be remembered that most of the thermal power plants in the DPRK were built with assistance from the USSR—the example of efficiencies in Chinese plants is used here only as a benchmark.
524 UNDP (1994), *Studies in Support of Tumen River Area Development Programme*. Prepared by KIEP, Seoul, ROK for the UNDP, July 1994.
525 Confidential document in authors' files.

5.2.3.2.Thermal Power Generation in 2000 and Beyond

Conversations with industry sources indicated that the thermal power generation system in the DPRK was rapidly eroding even as of 2000. In virtually all of the large power stations, only some boilers and turbines are operating, if any are operating at all. The (nominally) 200 MW heavy fuel oil-fired plant near the (East Coast) Sonbong refinery (see satellite photo in Figure 5-5) apparently did not operate at all in 2000. We assume that it operated little in subsequent years. Several sources suggest that the 200 MW oil-fired power plant associated with the oil refinery at Sonbong has operated relatively little since, as the oil refinery has been off-line due to lack of crude oil to process (possibly compounded with maintenance issues). The oil-fired power plant generated power when heavy fuel oil was available from KEDO and, we assume probably also operated when HFO was shipped to the DPRK as a part of the Six-Party Talks agreements, but absent those inputs, has probably operated little, if at all. The website NK Economy Watch, in a posting dated November 7, 2011, under "Choson Exchange October trip findings" (available as part of http://www.nkeconwatch.com/category/energy/oil/), include the following: “Sonbong Power: This power plant was originally designed to take fuel oil from Victory Petrochemical as feedstock and generate power to feed back to Victory. Since the refinery has been offline, Sonbong Power has at times provided electricity to the region, but with fuel oil prices close to $700/metric ton and current electricity prices at 6.5 eurocents/kwh, the economics of running the plant do not work leaving the 800 workers employed here largely idle." By 2016 was apparently in the process of being converted into a coal-fired power plant, although it does not seem that it has operated as such as of 2020.

Figure 5-5: Satellite Photo of Unggi Power Plant, Near Sonbong and the Seungri Oil Refinery, as of early 2020 (Source, Google Earth Pro)[526]

Our understanding is that at least three other 100 MW thermal plants also did not operate as of 2000-2010. Those plants that have operated are reportedly plagued by problems with "air heaters"—devices that extract heat from exhaust gases to heat incoming combustion air. These air heaters have in most plants been degraded to the point of inoperability by acid gases from the combustion of high sulfur fuels such as heavy oil and used tires.[527] The result is reportedly a considerable decrease in plant efficiency, quite possibly greater than the decrease in efficiency (from 28 percent in 1990 to 21 percent in 2000 and subsequent years, before accounting for plant own-use) that we have assumed. Further, boiler tubes in many power plants have been degraded from the outside by acid gases from high-sulfur fuels, and from the inside by inadequately-treated or untreated boiler feed waters. The lack of spare boiler tubes—and in many cases it may be that boiler tubes to fit these generators, which were built in the 1950s and 1960s, are not available at all, anywhere—means that it is very difficult to repair the boiler tube degradation. Two heavy oil-fired power plants, however, have been added to the roster of thermal generators

[526] This image is from Google Maps, coordinates 42.3279749,130.3795243, and dated March 29,2020. It shows the formerly HFO-fired plant with new coal storage and coal feed buildings and equipment in place, as well as new roofs on nearby administration buildings. There is no smoke coming out of the stack, so it is not clear whether the plant is operating, and it is not clear whether coal was being handled in the storage facility as yet. In earlier images there are smaller piles of coal visible to the east of the plant, near a wharf (and outside of the image below), but they may be for a different purpose (for example, local use for households or other buildings). Historical Google Earth Pro images show that coal handling facilities were added to the site in about 2015-2016.

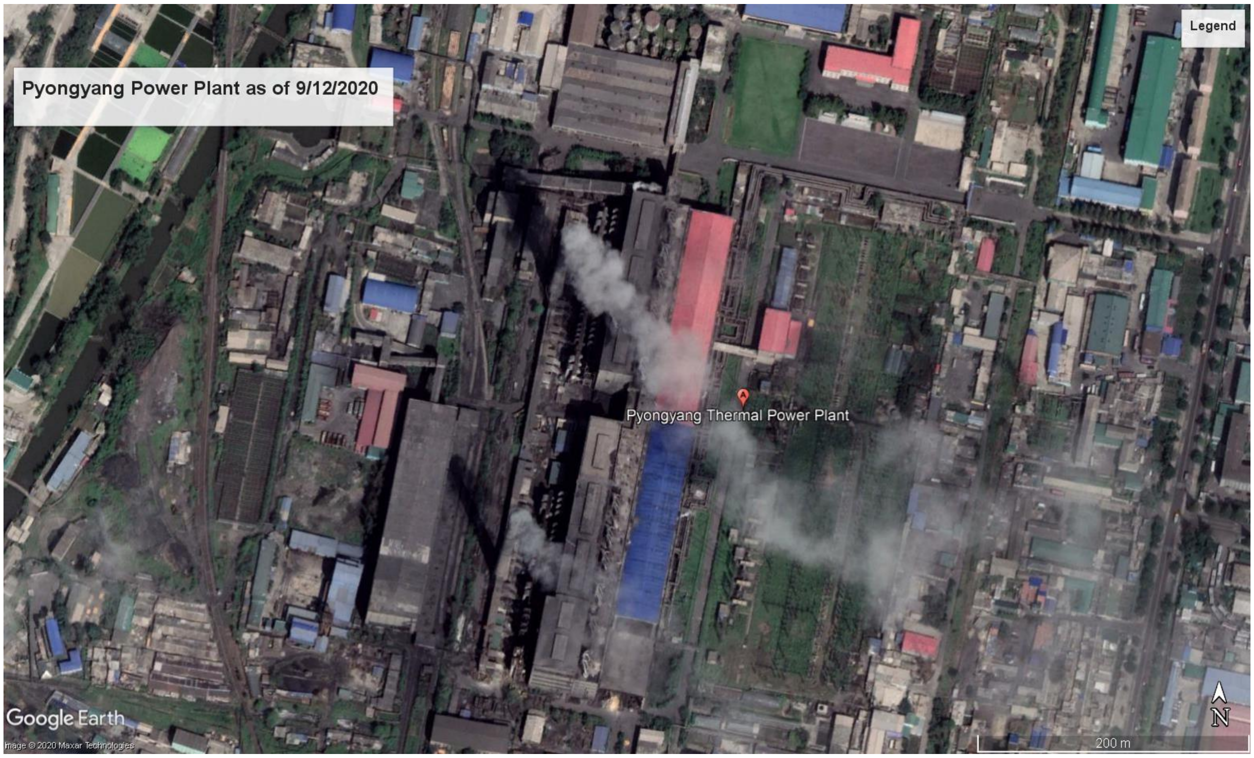
[527] Oxford Recycling Inc. (http://www.oxfordrecycling.com/product.html#5, visited 6/8/02) lists a sulfur content of 1.3 percent for fuel from shredded tires.

that we previously knew about. A 60 MW plant built for operation on heavy fuel oil is located near the small West Coast refinery described below. This power plant reportedly only operates when crude oil is processed by the associated small refinery. A diesel engine-type plant with capacity totaling 9.8 MW was installed and operated for much of 2000 at Songlim, in association with a steel plant there. This plant generally seems to have been fueled with heavy fuel oil.

We also assume that, by 2000, an additional 100 MW of coal-fired capacity was completed, possibly representing two additional 50 MW units at the East Pyongyang power plant shown in Figure 5-6. The other large power plant serving the DPRK capital, the Pyongyang Power Plant (with a nominal capacity of 500 MW) is shown in Figure 5-7.

Figure 5-6: Satellite Photo of East Pyongyang Power Plant in Operation as of Spring, 2020 (Source, Google Earth Pro)

Figure 5-7: Satellite Photo of Pyongyang Power Plant in Operation as of September, 2020 (Source, Google Earth Pro)



In total, we estimate that less than 800 MW of the total nominal thermal capacity was operable as of 2000, meaning that less than 800 MW of thermal capacity both were technically capable of operation and had the fuel supplies that enabled them to actually run some of the time. It is possible that some other units were technically operable but did not operate due to lack of fuel. For those power plants that were operable, we estimate an average capacity factor in the range of 50 percent or less, due to maintenance problems and lack of fuel. These assumptions help to inform our overall estimate of a total of about 2.8 TWhe of generation from thermal (nominally coal- and oil-fired) generation in the year 2000. It should be noted, however, that the nominal total capacity that we estimate and the technically operable capacity are two different things, as the nominal total capacity counts plants that (we believe) actually exist and did at one time operate or could at one time operate at the listed capacity, some of which may have at various times over the years been inoperable due to technical difficulties with generation units, technical problems with associated T&D facilities (such as transformers or substations), and/or lack of fuel. For the most part, we factored in the estimated operability of power plants, as well as fuel supplies (or, in the case of hydroelectric plants, hydraulic resources) by adjusting annual estimated capacity factors. In years after 2000, we assumed that some repairs to generation units and possibly better fuel supply increased the effective generation capacity, with total capacity factors for all coal-fired power plants varying from about 18 to 24 percent from 2005 through 2019. In 2020, due to COVID-19, we assume that generation was/is (as of this writing, in late 2020) substantially lower than in previous years (about 10 percent) due to restrictions on coal supply and on economic activity in general resulting from the national effort to reduce the spread of the pandemic. For 2000 through 2020 we assumed that "emergency losses" amounted to an additional 9 to 9.4 percent of coal-fired generation, in addition 9 percent of generation as own-use in coal-fired power plants.

Many of the problems noted above reportedly persisted through 2014, and continue to the date of this writing, but we have little direct evidence of significant changes in thermal power generation capacity in relatively large plants since 2002. We have heard reports of some repairs at major power plants, including the (nominal) 1600 MW Pukchang plant—shown in operation in late early 2018 in the satellite photo provided in Figure 5-8, as well as reports of arrangements for importing of used power plant boilers, possibly from Eastern Europe.[528] Based on what we have heard from other observers, estimates by the (ROK) Korea Electrotechnical Research Institute (KERI) that operable thermal capacity was about 2 GW, and output 5.4 TWh, in 2005, seems reasonable, and we have adopted values close to these estimates.[529] We estimate the output of thermal generation in 2008 at nearly the same level as 2005—5.4 TWh, but, based on consideration of the ratio of ROK overall generation estimates in 2008 and 2009, we estimate the total thermal generation in 2009 and 2010 to have been lower—about 4.4 TWh and 3.8 TWh, respectively.[530] For 2015, we assumed that the combination of the persistent drought (2013-2015) in the DPRK, which assumedly would have induced operators to produce as much thermal power as possible, coupled with possible expanded coal availability due to the domestic benefits investments in coal infrastructure for coal export, would allow thermal power generation at coal-fired plants to be expanded significantly, relative to 2010. This would put total coal-fired generation in 2014 at about 6.0 TWh, and total thermal power generation (excluding engine-driven generators, which we discuss separately) at 6.6 TWh. For 2015, we estimate similar thermal output—about 5.9 TWh, with output in recent years falling in part due to UNSC sanctions—the trend being 6.6 TWh in 2016, 6.0 TWh in 2017, 5.0 TWh I 2018, and 5.1 TWh in 2019. In 2020, as a result of the measures taken by the DPRK to address the COVID-19 pandemic, we estimate the DPRK thermal electricity output will be lower, about 3.3 TWh.

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[528] Observers suggest that the coal mine feeding the Pukchang power plant was working at less than full capacity (as of around 2010), as the use of largely older, manual tools limited output despite the mine being in operation around the clock. The mine provides coal to other DPRK counties and provinces. Observers reported that the Pukchang power plant itself appeared to be operating at near-full capacity during approximately 2005, with most or all boilers in use most of the time.

[529] J.Y. Yoon, "Analysis of Present Status and Future Supply /Demand Prospects for the DPRK Power System", presented at the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Yoon.ppt.

[530] For 2009, we assume that there was a decrease in overall gross generation approximately equal to that estimated by J.Y. Yoon in his presentation for the 2010 Energy and Minerals Experts Working Group Meeting in Beijing, September 2010 (available as http://nautilus.org/wp-content/uploads/2011/12/01.-Yoon.ppt, and in narrative form at http://nautilus.org/napsnet/napsnet-special-reports/the-dprk-power-sector-data-and-interconnection-options/), "Analysis on DPRK Power Industry & Interconnection Options". In the presentation, Yoon quotes ROK analysts as estimating that the DPRK's generation in 2008 was 25.5 TWh, and generation in 2009 was 23.5 TWh. We do not use these absolute generation estimates, because we believe that they are too high (Mr. Yoon agreed that a "minimum" value could be closer to 16 TWh for 2007, for which ROK analysts estimate output of 23.7 TWh), but we use the ratio of these 2009 and 2008 estimates, 92.2%, to estimate a target value for 2009 output. We assume relatively little change in hydroelectric output between 2008 and 2009, so the difference in generation between 2008 and 2009 was estimated to affect mainly thermal power output, hence the decline in thermal output from 5.4 to 4.4 TWh between 2008 and 2009. As another point of comparison, a 2012 article by the Yonhap News Agency ("N. Korea's power consumption per capita at 1970s levels", dated 8/6/2012, and available as https://en.yna.co.kr/view/AEN20120806003300315), quoting the ROK's Statistics Korea, describes per-capita consumption in the DPRK of 819 kWh per capita, which would, based on the population assumptions used in this report, equate to about 19.7 TWh of overall consumption. Whether the quoted figure is intended to be actual end-use consumption, or simply overall estimated electricity production divided by population, is unclear, as is the ultimate source used by Statistics Korea to prepare the estimate.

Apart from the capacity additions at the Pukchang Thermal Power Complex and the conversion of the Sonbong Heavy Fuel Oil plant to coal use—both of which may or may not be operational as of 2020—the only other reported major thermal power plant construction has been the Kangdong plant, which reportedly is to have a capacity of 300 MW, located near Pyongyang (see Figure 5-9). Construction at this site has been ongoing since at least 2011, but a review of historical satellite images suggests that progress between 2015 and 2019 has been limited. The possible location of the conversion of the Sonbong HFO plant (at the Seungri Chemical Complex Refinery) to use coal is shown in Figure 5-10, including a blue-roofed building of approximately 2000 square meters, constructed between April and September of 2020, with a rail line entering it, which will possibly be used for storing coal. The location of the image is approximately 40.32, 130.35.

Figure 5-8: Satellite Photo of the Pukchang (or Bukchang) Thermal Power Complex in Operation as of Spring 2019 (Source, Google Earth Pro)[531]

[531] The Pukchang (or Bukchang) Thermal Power Complex, location approximately 39.587368°, 126.307439°. This image shows what appears to be a new generating unit (buildings with blue roofs at right), put in place between late 2015 and early 2018, though the unit does not appear to have been operating as of the time the image was taken. News articles about the improvement at this power plant include Chad O'Carroll (2018), "North Korea expands capacity at nation's biggest electric plant: KCTV—Completion of project may be linked to Kim Jong Un's New Year's Speech", *NK News*, dated December 14, 2018, and available as https://www.nknews.org/2018/12/north-korea-expands-capacity-at-nations-biggest-electric-plant-kctv/, and IEA Clean Coal Center (2020), "North Korea: Pak Pong Ju Inspects Pukchang Thermal Power Complex and Namyang Coal Mine", dated 19 October 2020 and available as https://www.iea-coal.org/north-korea-pak-pong-ju-inspects-pukchang-thermal-power-complex-and-namyang-coal-mine/. Neither reference suggests how much capacity has been (or is being) added to the plant, although 100 to a few hundred MW seems like a fair guess, based on this image and the images in these articles.

Figure 5-9: Satellite Photo of the Under-construction "Kangdong" Thermal Power Complex in as of Spring 2019 (Source, Google Earth Pro)[532]

[532] Image source, Google Earth Pro. The construction of this plant was reported by Curtis Melvin for *38 North*, in "Pyongyang's Perpetual Power Problems", dated 25 November 2014, and available as http://38north.org/2014/11/cmelvin112514/. This article shows satellite imagery of "a new coal-powered thermal power plant in Samdung-ri, Kangdong County, in eastern Pyongyang", that was mostly finished (but apparently not yet operational) even as of late-2014. The article estimates the size of the power plant, which it refers to as the Kangdong plant, as between 100 and 300 MW, though no capacity figures have apparently been announced by the DPRK. Our guess, based on comparison of photos of the plant (see below) with photos of the 50 MW (but possibly designed to be 100 or 150 MW) East Pyongyang power plant, is that the actual capacity is/will be toward the lower end of that range, although the Global Energy Monitor (2019) indicates that the " Kangdong power station is a 300-megawatt (MW) coal plant under construction near Pyongyang, North Korea. ", but suggests that little progress has been made in construction between 2013 and 2018 and lists the plant as "canceled". Global Energy Monitor (2019), "Kangdong power station", dated December 25, 2019, and available as https://www.gem.wiki/Kangdong_power_station. In fact, in the 2019 Google Earth Pro image shown, the site looks as though it has not been kept up much in the last few years, judging from what appear to be drifts of sand in some places, although a set of what may be vehicles, trailers, or storage containers at the northwestern edge of the site may indicate pending activity.

Figure 5-10: Satellite Photo of the Possible Ongoing Conversion of the HFO-fired Power Plant at Sonbong as of September 2020 (Source, Google Earth Pro)

Another type of thermal power generation that seems to have become more significant in recent years in the DPRK are engine-generator sets used when grid power is not available, either because power plants are not running or due to T&D outages (see below) or both. Nathanial Aden's reports on DPRK-China trade in energy and related commodities, first commissioned by Nautilus in 2006 and updated in 2008 and 2010,[533] and data from the UN (United Nations) Comtrade database[534] show that the DPRK has since 2000 imported many hundreds (and in 2012 through 2017, several thousand) small, medium, and larger diesel-fueled generator units, along with, particularly starting in 2008, tens of thousands (a total of nearly 200,000 since 2004 alone) of small spark-ignition (meaning gasoline-fueled) generator sets. Our guess is that the diesel generators were likely imported to provide power, when grid power was not available, for businesses, institutions, small industrial plants, and agricultural processing, but the spark-ignition generators probably have been purchased by wealthier DPRK residential households to provide

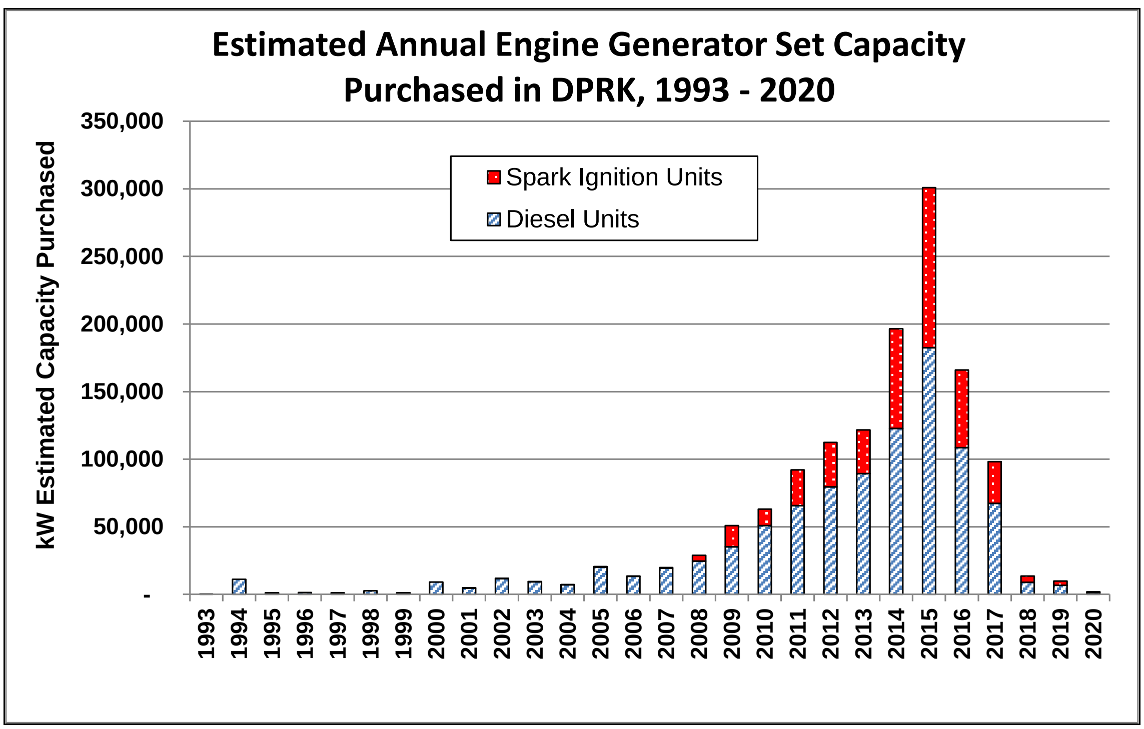
[533] See, for example, Nathaniel Aden (2011), North Korean Trade with China as Reported in Chinese Customs Statistics: 1995-2009 Energy and Minerals Trends and Implications", Nautilus Special Report, dated June 7, 2011, and available as http://nautilus.org/napsnet/napsnet-special-reports/dprk-prc-trade-aden/.

[534] United Nations (2020) Comtrade Database, queried through 2020 via http://comtrade.un.org/data/,

power in their homes, by small businesses—for example, vendors at informal markets, and/or even by units of the military.[535]

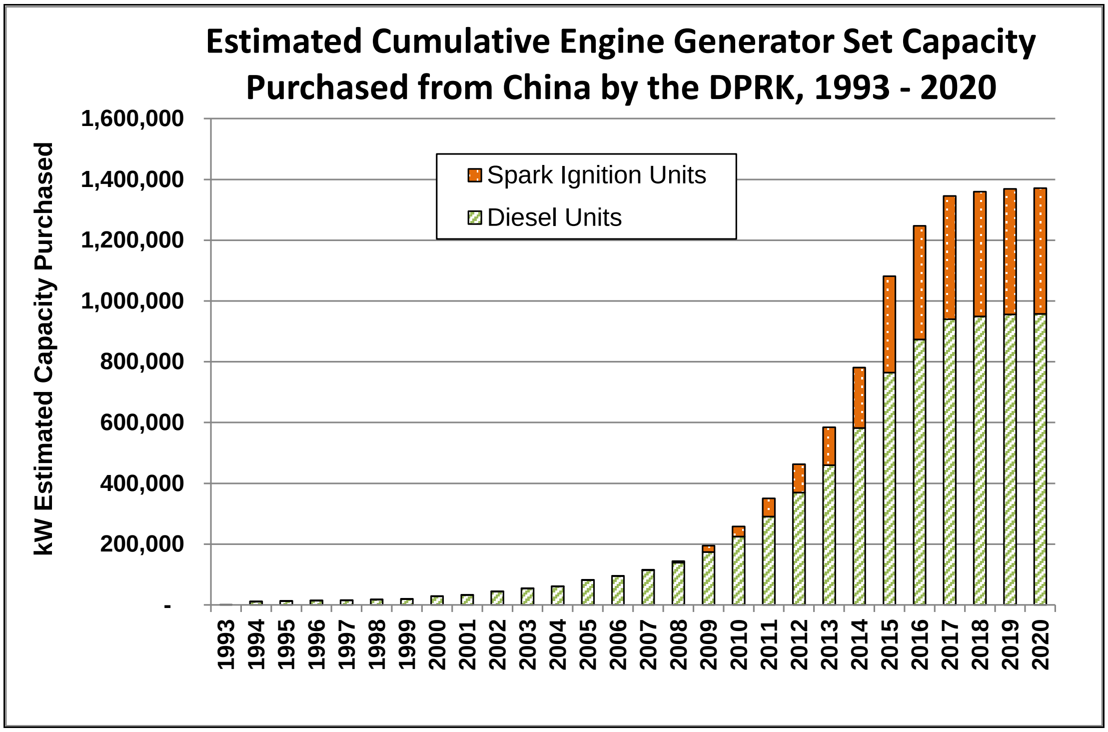
It is very difficult to estimate exactly the total generation capacity represented by these units, since the trade statistics are categorized only by three ranges of capacity for the diesel generators, and provide no direct guidance for the spark-ignition units, but considering the reported value of the trades, and the prices of generators on the open market, we estimate that the diesel generators imported from China trade from 1994 on summed to a total capacity of about 225 MW by 2010 and over 950 MW by the end of 2020 (see Figure 5-11 and Figure 5-12), with spark-ignition generators representing a total of over 30 MW of capacity by 2010, and over 400 MW by 2020. Pending more information about these trades (for example, information on the types of generators shipped from Chinese exporters, and whether those generators were mostly new or used), these capacity estimates should probably be considered accurate to within a factor of two or so. In addition, the official reports of trade in diesel generators, probably as a result of UNSC sanction, have been sparse since 2017 (as indicated by the small amount of imports shown in Figure 5-11 for the year 2018), and it is thus difficult to know to what extent DPRK imports of generators have continued, although it seems likely that they have, at least at some level.

Figure 5-11: Estimated Annual Diesel and Gasoline Generator Capacity Imported



[535] For additional discussion on this topic, see David von Hippel and Peter Hayes, *DPRK Imports of Generators in Recent Years: An Indication of Growing Consumer Choice and Influence on Energy Supply Decisions?*, NAPSNet Special Reports, dated November 02, 2018, and available as https://nautilus.org/napsnet/napsnet-special-reports/dprk-imports-of-generators-in-recent-years-an-indication-of-growing-consumer-choice-and-influence-on-energy-supply-decisions/.

Figure 5-12: Cumulative Estimated Diesel and Gasoline Generator Capacity



We have assumed, primarily due to restrictions on the availability of diesel fuel and gasoline, that the diesel generators were used relatively lightly, at average capacity factors of 8 to 10 percent in the years from 2005 through 2010,[536] but slightly less heavily at a 9.5 percent capacity factor, in 2014, due to somewhat reduced availability of diesel fuel and better availability of grid electricity. The average capacity factor for diesel generators is assumed to have increased through 2016, to 12.6%, due to better availability of fuel and more economic activity, but then to fall to about 6 percent from 2017 through 2020 because of diesel availability restrictions due to UNSC sanctions. Gasoline generators were assumed to be used even more sparingly, at average capacity factors of 1.5 to 2.0 percent in 2008 through 2014 but rising to 3.5 to 4 percent in later years with more demand for household electricity use and greater gasoline availability, and to 4.5 percent in 2020 as COVID-19 increases activity in households.

An additional type of thermal electricity generation that has reportedly begun to be used in the DPRK in the past decade, particularly for is installations such as remote mines that need reliable power, is small (100s of kW to MW-sized) gasifier-driven generation units, fueled with coal, and burning the produced coal gas in an engine-generator or a boiler. These units are available from

[536] In 2005, the first year in which we separately account for fuel used by diesel generators (in previous years, some oil accounted in the energy balances presented in our previous studies as used in specific sectors was undoubtedly used in generators), we have assumed that the total capacity of diesel generators in the DPRK was about 100 MW, which would include both generators officially recorded as imported from China and some stock of existing generators and/or generators imported from elsewhere. Note, however, that UN Comtrade statistics on imports of generators to the DPRK from countries other than China indicate very few such trades, which is not surprising given international economic sanctions imposed on the DPRK, and the dominance and nearby location of China as a trading partner.

Chinese vendors.[537] We do not know how many of these units are currently in service in the DPRK, but we assume it is on the order of tens to low hundreds. Pending more information about how many of these units might be in service, we have not estimated the output of these units in the current version of our energy analysis.

5.2.3.3.Hydroelectric Facilities

North Korea is a mountainous country with substantial rainfall. As such, it has fairly extensive total potential for hydroelectric development. The DPRK's ability to mobilize massive work forces for public works projects such as dams has helped the country to tap this potential, and as of 1990 approximately 4,500 of an estimated 10,000 to 14,000 MW of hydroelectric potential had been developed. Table 5-2 provides a listing of those major hydroelectric facilities about which we have capacity information. The 20 plants on this list built prior to 1990 account for approximately 3,100 of the 4,500 MW of hydroelectric capacity reportedly in service as of 1990, and probably comprise about half (numerically) of the larger grid-connected hydroelectric plants. Electricity from several plants on this list (Supung, Ounbong, T'aep'enmang, and Weewong) is exported to China, or, more accurately, shared with China, with the output from individual generating units in some dams going separately to the DPRK and to China. Note that the capacities listed in Table 5-2 exclude the portions of power generated in those four plants that is sent to China. Including that portion of the capacity reportedly delivered to China (700 MW) raises the total 1990 capacity accounted for by the facilities in Table 5-2 to about 4,000 MW, over 85 percent of the total hydro capacity reported.

[537] See, for example, a vendor advertisement on Alibaba, "300kw Coal gas gasifier plant gasification power plant generator ", available as https://www.alibaba.com/product-detail/300kw-Coal-gas-gasifier-plant-gasification_60058806591.html?spm=a2700.galleryofferlist.normal_offer.d_title.3d3f2655ILVn8b.

Table 5-2: Major Hydroelectric Generating Facilities in the DPRK[538]

#	Name	Capacity (MW)	Year Completed	Year Refurbished
1	Supung	400		
2	Kymgansang cascade	13.5	1930	1958
3	Puren cascade	28.5	1932	
4	Puch'on-gang	260	1932	1956
5	Chanjin-gang	390	1936	1958
6	Hoch'on-gang	394	1942	1958
7	Tonno-gang	90	1959	
8	Kangae	246	1965	
9	Ounbong	200	1970	
10	Sodusu-1	180	1974	
11	Sodusu-2	230	1978	
12	Sodusu-3	45	1982	
13	Taedong-gang	200	1982	
14	Mirim	32	1980	
15	Ponhwa	32	1983	
16	Hwan-gang	20	198?	
17	Tonhwa	20	198?	
18	T'aep'enmang	90	1989	
19	Weewong	200	1989	
20	Nam-gang	200	1994	
21	Dokro river	36		
TOTAL OF LISTED PLANTS		**3,307**		

Many of the smaller hydroelectric facilities in operation in the DPRK, are reportedly of the "run-of-river" type, meaning that relatively little water is impounded behind the dams. Although this would tend to suggest that electric output from the DPRK's hydro plants may be more likely to be subject to the vagaries of the weather—poor rainfall months or years resulting in lower-than average electricity production—than systems with more impoundment-type dams, it has been suggested that the larger plants, including those initially designed and built during the Japanese colonial era, reportedly combine impoundment and run-of-river elements, resulting in relatively high capacity factors.[539]

Given the location and extent of the flooding in the DPRK during 1995 and 1996, it always seemed probable to us that the North Korean hydroelectric system had sustained significant damage. We have modeled this reduction in usable hydroelectric capacity by assuming that available hydro capacity at existing facilities fell by about 3250 MW from 1990 values by 1996 as a result of flood damage[540] offset slightly by additions to capacity.[541]

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[538] Please see the volume of detailed calculations provided as an Attachment to this Report, 2009, for a listing of the sources used in developing this table.

[539] As an example of the potential of the combined impoundment/run-of-river design to produce power consistently, Prof. Y.S. Jang (personal communication, 1996) reports that the capacity factor of hydroelectric plants in North Korea was over 70 percent during 1943.

[540] Several sources that have been to the DPRK recently said they had no knowledge of major damage to large hydroelectric facilities. Another source had heard of damage to "one or two" "small to medium-sized" (less than 10 MW) plants.

Our estimate for the supply of hydroelectric power in 1990 starts with the figure of 46 TWhe described above, of which slightly less than half (46 percent) is assumed to be generated in hydro plants.[542] These two figures, taken together, imply an overall capacity factor for hydroelectric facilities of about 54 percent. We counted the hydro input energy to electricity generation assuming an efficiency conversion of 100 percent output electricity to input energy, as is done in United Nations statistics[543]. The "own use" of electricity in hydro plants was assumed to be 0.3 percent of gross generation, which corresponds to ROK conditions in 1970,[544] and is also similar to values for Chinese plants.

As a consequence of the difficulties with thermal power plants, hydroelectric plants had shouldered the burden of power generation in the DPRK by 2000. Information from industry sources indicate that any difficulties associated with the 1995/1996 flood damage to the shared power stations (China/DPRK) along the Chinese border has been repaired, and those plants are operating normally. Normally, however, apparently means that those plants—about 700 MW of capacity each for China and for the DPRK—are used largely in a peaking mode to conserve river water, and operate at full capacity only during the rainy mid-July to mid-August period. We have thus assumed an overall capacity factor of 17.5 percent for these units. Other hydroelectric facilities in the DPRK may in fact be operated in a similar manner, and it is clear that the country as a whole has far less power in the dry winter than at other times of the year. We have assumed, for the year 2000, that of the approximately 3900 MW of other hydroelectric plants, 75 percent of capacity was operable, and those operable hydro plants had a capacity factor in 2000 (a low water year) equaling 75 percent of the capacity factor assumed for 1996, or about 38 percent overall in 2000. This could, in fact, prove an over-estimate.

News reports from the DPRK regularly include items on hydroelectric dams under construction and, more rarely, commissioned. In addition, North Korean delegations to Nautilus events and DPRK contacts with ROK colleagues have suggested that many smaller hydroelectric facilities have been planned and built in the DPRK since about the mid-1990s. What remains very unclear, however, is the total capacity that these units represent, the amount of power they generate on average (in all likelihood, their average capacity factors are relatively low), and how many of the units are connected to a power grid, or, in fact, operate at all. Anecdotal reports suggest that the reportedly thousands of small hydro facilities (with average capacities of a few tens of kilowatts to a megawatt) installed by the end of 2004[545] (and, we assume, subsequently), have in fact, due to limitations on hydraulic resources, poor workmanship and/or operation, or a combination of factors, produced relatively little power.

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[541] KEEI (Korean Energy Economics Institute, 1996; personal communication from Mr. Roh Dongseok, Electricity Policy Division) cites an 800 MW increase in capacity from the newly opened Kumgang Mountain plant. Earlier ROK estimates had also placed the (expected) capacity of this plant at 800 MW, although its current capacity under the phases now completed and/or considering existing reservoir levels is probably in the range of 100 - 150 hundred megawatts. The Kumgang mountain plant was also referred to in announcements in the DPRK press, but without reference to plant capacity.

[542] Confidential document in authors' files.

[543] Note that the actual conversion efficiency of energy in falling water to electricity in hydro plants is typically less than 100%, on the order of 70 to 90 percent.

[544] Kim, E.-W., H. Kim, H.-K. Lim, C. Nahm, M.-C. Shin, and Y. Kim (1983), The Electric Future of Korea. Resource Systems Institute, Honolulu, Hawaii, USA. Research Materials RM-83-8.

[545] See table in J.Y. Yoon, "Analysis of Present Status and Future Supply /Demand Prospects for the DPRK Power System", presented at the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Yoon.ppt.

A major "Youth Dam" including a tunnel system for carrying water, had recently been completed, but its hydroelectric capacity, if any as of 2000, was unclear. Also underway, at the time of the 2000 Nautilus visit to the DPRK, was a scheme to dam the Taedong River to provide irrigation water to rice fields on the Southwest Coast of the DPRK without the need to pump water from the Nampo barrage area. That project has since been completed (see Figure 3-3), but it is not clear to the authors whether the latter project has or is expected to have significant associated hydroelectric capacity, or whether the "Youth Dam" and the Taedong water diversion project are related.

For 2005, we have based our estimate of hydroelectric output on data from KERI (see reference to presentation by J.Y. Yoon, above), but added 100 MW of large hydroelectric capacity, plus 86 MW of medium-sized hydroelectric capacity, to account for facilities completed (or likely completed) in 2005. The resulting estimate of hydroelectric capacity for 2005 is about 4100 MW, with output of about 11 TWh and thus an average capacity factor of a bit over 30 percent. In 2008 through 2010, hydroelectric capacity is assumed to have increased somewhat over 2005 as a result of the completion of several medium-sized (tens of MW) hydro plants. Average capacity factors for hydroelectric plants in all three years were estimated at just under 32 percent, with total output of just under 12 TWh in each year.

A number of under-construction medium-sized hydroelectric plants have been put forward by the DPRK in recent years as possible projects for international investment in greenhouse gas emissions reduction under the “Clean Development Mechanisms” (CDM) of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC). Particularly notable in this list of projects is the recently completed (at least one unit) “Heecheon” (or, as more commonly referred to, Huichon #2) Youth Power Station hydro power plant, designed to provide power for Pyongyang. Recent news reports suggest that as a result of the opening of this plant, the DPRK authorities had intended to retire the aging and polluting Pyongyang Thermal power plant[546], but uncertainty as to the actual reliable output of the Huichon plant, coupled, at least we would surmise, with the fact that the Pyongyang plant provides both heat to residents in the older part of the metropolis, as well as power, and the Huichon plant could not provide district heat to those existing buildings the Pyongyang plant now serves (except through installation of electric resistance heaters, which would dramatically increase Pyongyang’s electricity consumption if done on a large scale). The DPRK has reported to the UNFCCC quite detailed output and capacity data for six plants included in their CDM program, sufficient to estimate capacity factors for these six medium-sized hydro plants as ranging from 38 to 44 percent in 2014-2017, as shown in Table 5-3.[547]

[546] Choi Song Min (2012), “Iconic Pyongyang Power Plant Could Go”, *DailyNK*, dated 2012-05-08, available as http://www.dailynk.com/english/read.php?cataId=nk01500&num=9207.

[547] Data describing the size and output of six hydroelectric plants registered with the United Nations Framework Convention on Climate Change (UNFCCC) as DPRK CDM projects obtained from documents on the UNFCCC CDM website, https://cdm.unfccc.int/Projects/projsearch.html.

Table 5-3: DPRK Hydroelectric Plants Included in CDM Reporting to UNFCCC

			MWh Annual Net Generation							
Plant	First Operation	Capacity (MW)	2012	2013	2014	2015	2016	2017	Location	
Hamhung Hydro Power Plant #1	Dec-2013	10	-	50	24,855	25,392	29,875	30,472	39°39′ 25′ N	127°15′ 01″ E
Kumya Hydropower Plant	Dec-2013	7.5		48	16,256	17,394	19,462	14,909	39°34′ 22″N	127°07′ 08″E
Paekdusan Songun Youth 14 MW Hydropower Project No.2	10/1/2015	14	-	-	-	8,675	52,680	52,263	41°43′ 18″ N	128°50′ 15′ E
Ryesonggang Hydropower Plant No.4	11/28/2014	5	-	-	1,303	26,251	24,747	19,100	38°18′ 02″ N	126°31′ 42″ E
Ryesonggang Hydropower Plant No.5	11/30/2013	7.5	-	2,646	31,246	32,335	31,645	30,243	38º15′ 35″ N	126º29′ 41′ E
Ryesonggang Hydropower Plant No.3	10/11/2013	5	-	1,868	26,397	26,911	29,209	18,924	38°19′ 42″ N	126°34′ 03″ E
Totals		**49**	**-**	**4,612**	**100,056**	**136,958**	**187,617**	**165,911**		
Implied aggregate annual capacity factor (for plants while on line)				**29.77 %**	**37.55%**	**40.61%**	**43.71%**	**38.65%**		

The Huichon power plant, which has a reported capacity of 300 MW, was reported to have been brought on line in April of 2012. The plant is one of several to be developed on the Chongchon River in Northern DPRK, and reportedly improved power supplies in Pyongyang in some periods in 2012 and 2013.[548] Numerous other articles about this plant exist, but few provide much information about its generation capacity. One internet post states "[t]he dam is reported to be more than 300 [feet] [91 meters] high and 1,800 [feet] [550 meters] wide and capable of storing 850 million cubic metres of water.", but also suggests that it has a serious structural defect, apparently a crack or similar problem, allegedly stemming from its rapid construction and/or the use of inappropriate grades of cement/concrete.[549] Figure 5-13 shows a satellite photo of the Huichon #2 hydroelectric dam as of late 2015 or early 2016.

[548] See, for example, "N. Korea completes new power plant to tackle energy shortage", Yonghap news agency, dated 2012/04/06, available as https://en.yna.co.kr/view/AEN20120406001900315. Rainer Dormels (2014), "Profiles of the cities of DPR Korea – Huichon", also lists the capacity of the Huichon #2 power plant at 300 MW. See http://www.univie.ac.at/koreanologie/fileadmin/user_upload/DigitalNK/Forschungsarbeit/Huichon.pdf.
[549] See, for example, (Rich Lennon, May 24, 2013, available as https://www.facebook.com/DragonsParadox/posts/4975149101259, though many other articles make the same point regarding the dam having a structural defect that limits its capacity and may potentially be dangerous.

Figure 5-13: Satellite Photo of Huichon #2 Hydroelectric Power Plant, Apparently in Operation as of Late 2015 or Early 2016 (Source, Google Maps)

Multiple sources indicate that the drought in 2014 (and 2015) had a significant impact on hydroelectric output, but few sources offer numerical estimates as to the impact of the drought on hydroelectric output. One story, "North Korea Newsletter 368 (June 25, 2015) " by Yonghap News Agency, referencing a Reuters report, indicates that hydroelectric output in 2015 was affected as follows "Reuters reported on May 30 that many hydro power plants in North Korea have suspended operation, reducing the nation's power generation by half."[550] We assume that the drought resulted in a significant decrease in 2014 hydroelectric output. We assume that relative to 2008, hydro output in existing dams shared with China (along the Yalu river) decreased by 20 percent, and that hydro output in other large and medium hydro plants was reduced by 25 percent relative to 2008. For the new Huichon #2 plant, we assume a capacity factor for 2014 of 25 percent, which is designed to consider the impacts of the combination of the drought plus reported structural problems in reducing what would be an average 45-50 percent capacity factor for a DPRK hydroelectric plant. We also assume that a "normal year" capacity factor for the medium-sized hydro plants added in 2006 through 2010, many of which are "run of river" type and thus quite sensitive to seasonal water flows, was about 25 percent in 2014. Overall, we estimate that 2014 gross hydro generation in the DPRK was just over 10 TWh, about 13 percent lower than our hydroelectric generation estimate for 2010. In 2015 and 2016, we estimate that hydro generation was in the 11 to 11.5 TWh/yr range, falling again to about 10.2 to 10.7 TWh in 2017 through 2020.

News releases by the DPRK in 2015 claimed the completion of 10 more hydroelectric facilities, mostly (apparently) on 80 km of the Chongchon River, in 2015.[551] Our examination of available

[550] Source, http://english.yonhapnews.co.kr/full/2015/06/24/49/1200000000AEN20150624007300325F.html.

[551] See, for example, Leo Byrne (2015), N. Korea completes 10 hydro plants", NK News, dated November 18th, 2015, and available as http://www.nknews.org/2015/11/n-korea-completes-10-hydro-plants/.

satellite images (Google Maps) of the Chongchon River suggest that there are several sites where some hydroelectric development could arguably have taken place, but that the claim that 10 plants had been completed, and that the plants would provide a significant amount of power (hundreds of megawatts), seems likely to be overstated. For example, one probable hydroelectric site on the Chongchon downriver from the Huichon #2 plant described above appears quite small, and with its limited head (apparently only a few meters) probably only produces a few MW of electric power, if that (see Figure 5-14).

Figure 5-14: Satellite Photo of Probably Small Hydroelectric Plant (name unknown) Downstream from Huichon #2 Hydroelectric Power Plant, Apparently in Operation as of Late 2015 or Early 2016 (Source, Google Maps)

An under-construction hydroelectric plant frequently mentioned in the media is the hydroelectric facility at Mount Paekdu", or the "Mount Paekdu Songun Youth Power Station". According to a 2015 report, the first two units were to have been completed in late 2015, in time for the 70th anniversary of the Korean Workers Party, while a third unit was reportedly to have been completed in May of 2016, based on a report quoting an article in the Pyongyang Times,[552] Figure 5-15 shows a photo of the Mount Paektu dam at its dedication ceremony in October of 2015. Interestingly, one source claims that the completion of this plant, which it lists as having a capacity of 50 MW, was delayed due to damage to its concrete spillway caused by the DPRK's underground nuclear weapons tests at a location nearby.[553]

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[552] See Leo Byrne (2015), "North Korea adding to electricity grid", *NK News.org*, dated July 13th, 2015, and available as https://www.nknews.org/2015/07/north-korea-adding-to-electricity-grid/, and Leo Byrne (2015b), "Third Paekdu power plant to be completed by May – DPRK media", *NK News.org*, dated December 24th, 2015, and available as https://www.nknews.org/pro/third-paekdu-power-plant-to-be-completed-by-may-dprk-media/.

[553] Sung Hui Moon (2013; translated by Doeun Han, written in English by Joshua Lipes), "North Korea Struggles for 20 Years to Complete Hydropower Plant", *Radio Free Asia* Korean Service, dated September 27, 2013, and available as http://www.rfa.org/english/news/korea/hydroplant-09272013161417.html.

Figure 5-15: Mount Paektu Power Station Dam at Dedication Ceremony in October, 2015[554]

Overall, based on news reports that typically lack specificity, we assume that total hydroelectric capacity was growing by an average of about 50 to 70 MW annually in the 2014 through 2019 time period, falling to 33 MW by 2020, as construction would have slowed due to COVID-19 restrictions on gatherings and on trade with China, the latter potentially limiting imports of plant components. Some of these additions reflect the plants detailed in the DPRK's CDM project listing, but most are assumed to be plants with capacity in the MW to low tens-of-MW scale, including those listed in media reports (but typically without any mention of capacity). For example, there appeared to be a number of power stations completed or under construction on the Chongchon river as of mid-2019. An example, from Google Earth, at coordinates 40.0290466,126.1781053, appears in Figure 5-16, and includes what appears to be a skating rink laid out the river ice, presumably for use by the residents of the adjacent city of Kuwollim. In an article entitled "Progress in North Korea's renewable energy production", dated February 15th, 2016, NK Economy Watch quoted the Institute for Far Eastern Studies as saying "...the recently constructed Chongchon power plant which took three years to complete and has a total output of 430,000 kW". Looking at the hydro plants on the Chongchon river, which seem to have modest head and relatively limited impoundments (therefore more "run-of-river" type plants), our guess is that even assuming this figure is intended to be a total for all 11 (or so) or the plants on the

[554] Source, *The Telegraph*, dated October 5, 2015, available as http://www.telegraph.co.uk/news/picturegalleries/picturesoftheday/11911342/Pictures-of-the-day-5-October-2015.html?frame=3463526.

river, the estimate of capacity is likely to be an order of magnitude or so too high, perhaps as a result of a units reporting error. But as noted above, we have no solid data on the capacity of these plants.

Figure 5-16: Hydroelectric Plant on the Chongchon River[555]

5.2.4. Wind Power Facilities

Wind power development in the DPRK, despite being very much of interest to both the government and renewable energy experts there, remains minimal. The seven small wind turbines (totaling slightly over 11 kW) installed by Nautilus during its 1998 and 2000 missions to the village of Unhari, north of Nampo in the DPRK, have reportedly been taken down due to maintenance problems that Nautilus and its North Korean counterparts could not solve within the constraints of the long-distance communication modes available at the time. The wind turbines and related equipment are in storage in Pyongyang.[556] Within a few km of the Unhari site, two grid-connected Vestas wind turbines with capacity on the order of 100 kW or so each, were installed in the late 1990s, but reportedly operated very little, if at all, due mostly (probably) to the unstable electric grid in the area. On Nautilus' 1998 and 2000 missions to the DPRK, we saw small DPRK-made, perhaps in some instances home-made, wind turbines with capacities in the range of a few hundred Watts, often using automobile alternators as generators, but these did

[555] Image from Google Earth Pro, coordinates approximately 40.0290466, 126.1781053, dated 12/23/2018.
[556] See, for example, Jim Williams et al, "Wind Farm in the Cabbage Patch", Bulletin of the Atomic Scientists May 1999 vol. 55 no. 3 40-48, doi: 10.2968/055003014; and David F. Von Hippel, Peter Hayes, James H. Williams, Chris Greacen, Mick Sagrillo, and Timothy Savage (2001), *RURAL ENERGY SURVEY IN UNHARI VILLAGE, THE DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA (DPRK): METHODS, RESULTS, AND IMPLICATIONS, dated* May 20, 2001, and available as http://nautilus.org/wp-content/uploads/2011/12/Unhari_Survey1.pdf.

not seem to be working much.[557] At that time, Nautilus engineers also inspected wind power equipment being produced (in unknown but likely small quantities) in a factory in Pyongyang. The opinion of the Nautilus engineers was that the wind power units being produced were unlikely to be operable, due to the shape of the blades and the design of the inverters used to process power from the units.

A more recent report, the original source of which was the *Pyongyang Times*, claims that low-cost "small wind turbines made by the Aeguk Magnet Factory" have been attracting an increasing domestic market in the DPRK since mid-2015, with units rated from 100 to 300 Watts. We assume that relatively few of these were in active service by 2014.[558]

A short video is available online of the Korean People's Army installing one of a pair of relatively large (by DPRK standards) wind generators—with rated power probably on the order of one hundred or so kilowatts each, based on a rough measurement of the rotor size—on a ridge in the Southern DPRK near the town of Onjin.[559] A Google Maps image of these generators as they looked in probably mid-2019 or mid-2020 is provided in see Figure 5-17), A generator of this size would need to be tied into a stable local (if not regional) electricity grid, meaning (to us) that either it is backed up by local diesel or hydro power sources, or it does not operate properly. The year of installation of these units, which appear to be imported (not made in the DPRK), is unclear, but was probably 2008 or 2009, since they appear on Google Earth photos in 2009, but not in 2006. An additional report from 2015 shows three wind generators, possibly about the same size (blade diameter of about 20 meters) as those shown in the video referenced above and an array of photovoltaic panels probably totaling in the tens of kilowatts of capacity.[560] It was unclear from the available photos, or from current Google Earth images, whether these generators were tied to the local power grid. Interestingly, the Google Earth images of the site available as of February 2016, which appeared to have been taken in late summer of 2015, appeared to show the mounts or mounting holes for the solar PV arrays shown in the state media photos of Kim Jong Un's visit to the site provided in the March 2015 *North Korea Tech* article, but the panels themselves appear to be missing, suggesting that they had been removed sometime between March and late-summer 2015 for use elsewhere.

Photos of wind turbine installations provided in a presentation by a DPRK delegation to Nautilus Institute's Regional Energy Security Workshop in 2019, showed two larger wind generators, reportedly 100 and 250 kW units (see Figure 5-18).[561] As these units appear to have been installed at the same location (at different times), we assume that they are test or demonstration units used in a DPRK research and development program, and do not represent permanent wind power installations.

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[557] See, for example, *NK Economy Watch* (2012), "UNDP wind power project", dated 2012-9-24, and available as https://www.nkeconwatch.com/2012/09/24/undp-wind-power-project/.

[558] *NK Economy Watch* (2015), "DPRK's domestic sales of wind turbines", dated October 28, 2015, and available as http://www.nkeconwatch.com/2015/10/28/dprks-domestic-sales-of-wind-turbines/.

[559] Youtube, "North Korean military (KPA) installing wind power turbines", at coordinates 37.945745°, 125.411339°. Available at http://www.youtube.com/watch?v=JYG_SOHZ_fA. Turbine size is our rough estimate based on measurements made from Google Earth satellite imagery.

[560] Martyn Williams (2015), "State media shows off solar and wind power plant", North Korea Tech, dated March 14, 2015, and available as http://www.northkoreatech.org/2015/03/14/state-media-shows-off-solar-and-wind-power-plant/.

[561] "Renewable Energy Development in the DPR Korea" presented by the DPRK delegation to the Regional Energy Security Project Second Working Group Meeting, Ulaanbaatar, Mongolia, December 9th and 10th, 2019.

Figure 5-17: DPRK Wind Generators Installed in South Hwanghae, DPRK (image from Google Maps)

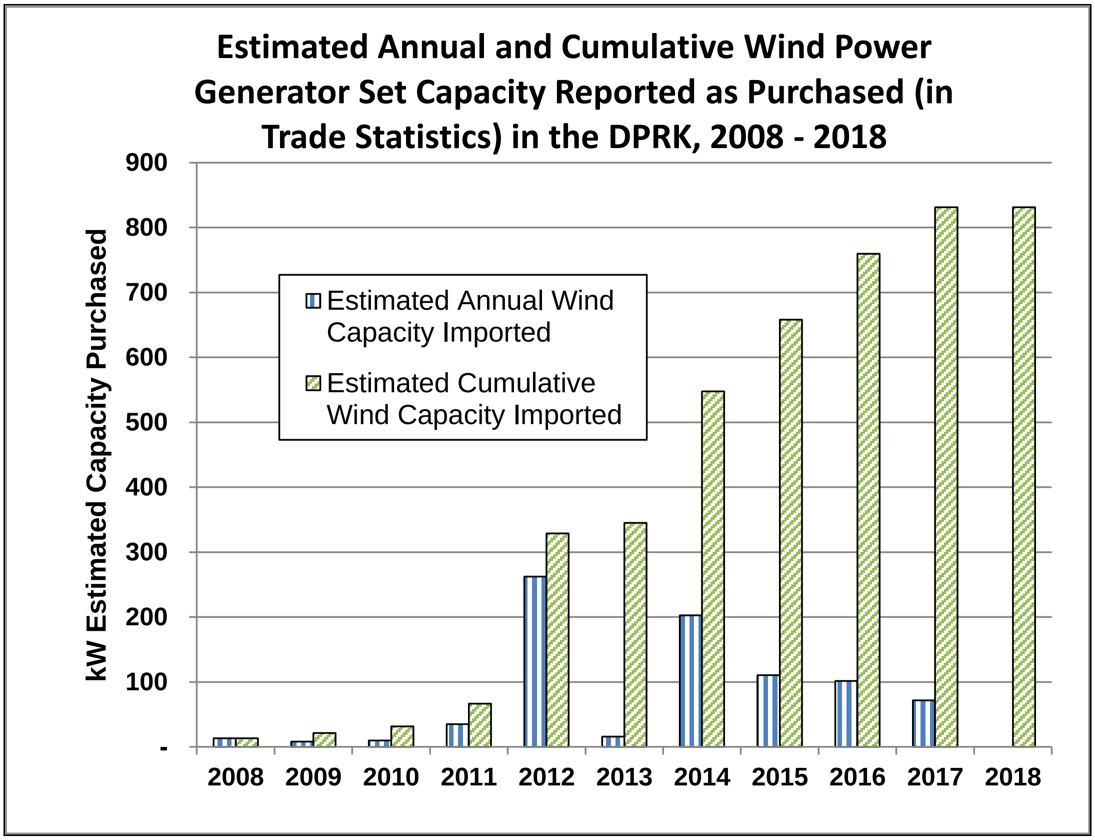
Figure 5-18: Wind Turbine R&D Units in the DPRK

The DPRK has been importing wind power systems from China in small quantities since 2008.[562] By the end of 2014, we estimate the total capacity of these imported systems were on the order of 500 kW, rising to over 800 kW by 2017. We assume that most or all of these systems—which, based on the number of units and the import value, must be relatively small (a few kilowatts on average)—were likely used in stand-alone (not grid connected) modes, with battery systems for electricity storage. Figure 5-19 shows a graph of annual and cumulative wind power capacity in the DPRK, as per our estimates. As with diesel and gasoline generators, customs data on wind power systems exports from China to the DPRK does not appear for 2018, so we do not know whether imports have in fact continued or have been interrupted by UNSC sanctions on imports to the DPRK.

We have assumed that in addition to the deployment of the wind generators imported from China, there has been some production of domestic DPRK wind power turbines. Including both domestic and imported wind power systems, we assume that a total of about 790 kW of capacity were operating in 2015, rising to about 1.6 MW by 2020. Considering the generally modest DPRK wind resource, we assume average capacity factors were 25 percent, whereas commercial wind installations elsewhere typically see capacity factors closer to 35 percent. It is likely that some fraction of the total wind power included in this estimate was not grid-connected, but included units, many likely small, used to charge batteries, including in rural locations.

[562] A very few units were also reported in China Customs Statistics to have been imported from China into the DPRK in 1998 (3 units) and 2002 (1 unit).

Figure 5-19: Estimated Imports of Wind Power Generators to the DPRK



It has been reported that Russia plans a joint venture with the DPRK in which Russia "is planning to build wind farms on both sides of the Russian-North Korean border during the next two years."[563] A reported 40 MW of wind power systems are planned to be developed in 2016 and 2017, with investments totaling "$55-62 million". What is unclear is whether these plants are to be connected to the DPRK grid or the Russian grid. Our guess is that in order for the wind turbines to be operated in a stable manner, they will need to be connected to the Russian grid, with power then exported to the DPRK grid via an intertie.

5.2.5. Solar Power Facilities

Although there are probably some small-scale solar electricity systems (photovoltaic and/or solar thermal) installed for research or demonstration purposes in the DPRK—an example of what sounds like a 10 kW pilot facility on a government building (Research Institute of the Ministry of Posts and Telecommunications) in Pyongyang was cited in 2015 *Pyongyang Times* article[564]—the vast bulk of the adoption of solar power in the DPRK has certainly been by private

[563] Eugene Gerden (2015), "Russian plan to sell wind power to North Korea", *Wind Power Monthly*, dated 29 June 2015, and available as http://www.windpowermonthly.com/article/1353670/russian-plan-sell-wind-power-north-korea.
[564] Kim Hyon Uk (2015), "Solar energy brought into wider use", *Pyongyang Times*, dated December 8, 2015, and formerly available as http://naenara.com.kp/en/order/pytimes/?page=Economy&no=21253.

households and businesses purchasing solar photovoltaic (PV) units, batteries, LED lighting, and small electronic devices for lighting and entertainment use during the frequent periods when grid power is not available.[565]

We estimate, based on data on DPRK imports of solar PV and related devices from the UN Comtrade database, that there were over 10 MW of PV systems purchased from China between 2008 and 2014 in operation in the DPRK as of the end of 2014, and nearly 30 MW by 2017.[566] At an assumed average annual output of 1200 kWh per kW of capacity, with an assumed 80 percent of panels unshaded (that is, panels harvesting on average 80 percent of the sun available to a completely unshaded panel), these panels are estimated to have provided about 10 GWh (gigawatt-hours) of electricity in the DPRK in 2014. This is obviously a small fraction of total electricity supplies, but these devices provide power for very highly valued end-uses in homes and businesses. Figure 5-20 provides a summary of our estimate of annual and cumulative capacity of solar PV systems imported into the DPRK from China from 2009 through 2018. Although the categories used for Comtrade statistics make it difficult to determine for certain, recorded trades (as opposed to trades in goods that do not appear on the Customs ledgers, which may also be substantial in the case of the DPRK) in PV systems could have been on the order of many (perhaps 3 to 8) megawatts annually, meaning that perhaps 200,000 or more DPRK households have adopted small PV systems to date.

As with import data for diesel and gasoline generators and for wind power units, official information on exports of solar units from China to the DPRK have been lacking for 2018, possibly due to UNSC sanctions on exports to the DPRK. These considerations may have affected 2017 import statistics as well. We assume, based on media reports of continuing deployment of small solar PV panels in the DPRK, that panels continue to be deployed in the DPRK, sourced either from "off-books" trades with China, or manufactured in the DPRK,[567] presumably from photovoltaic and other electronic components imported from China, in quantities representing aggregate capacities of nearly 60,000 kW over the five years of 2016 through 2020, with perhaps some slowdown in 2020 due to COVID-19 restrictions on movement and trade.

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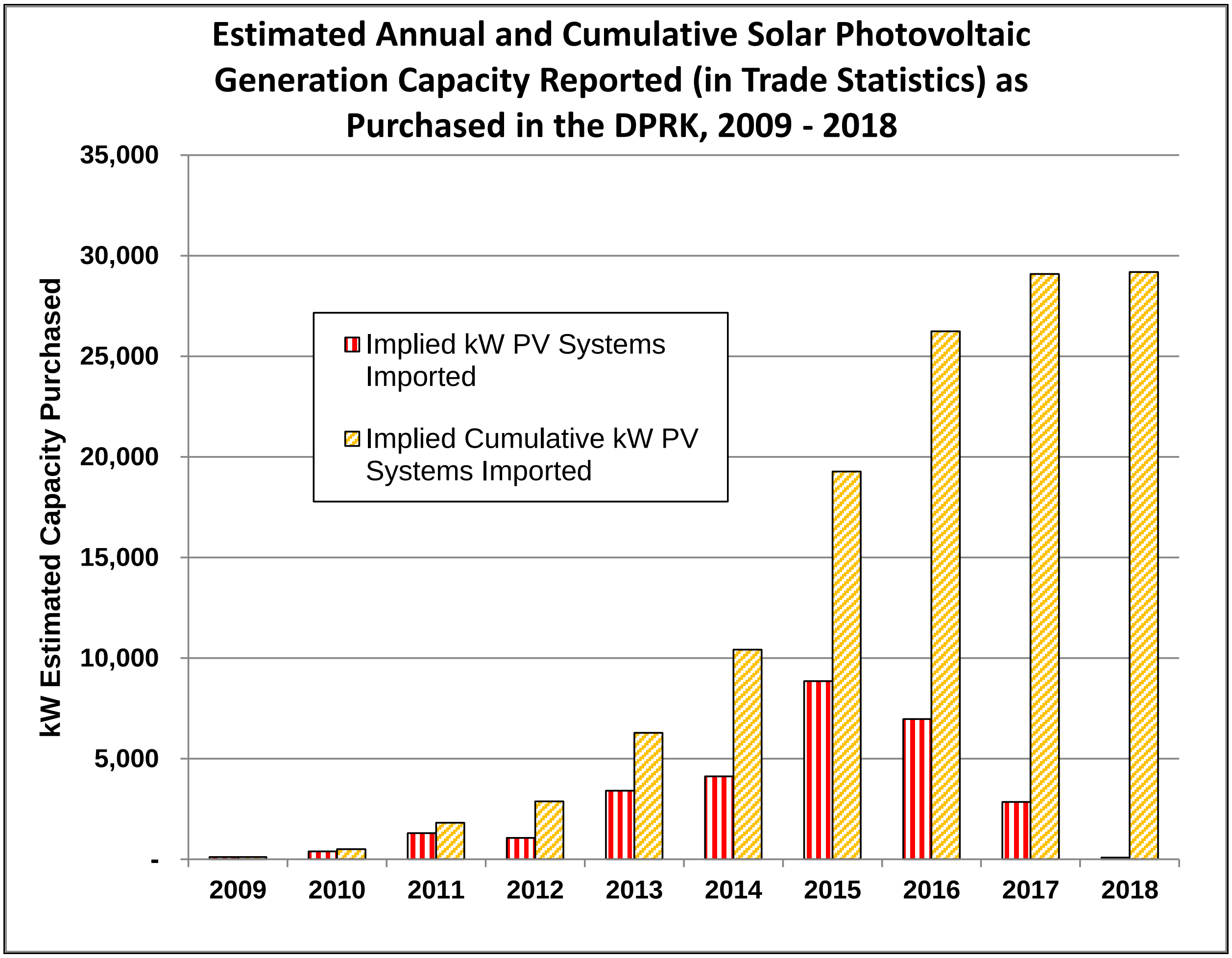
[565] See, for example, Hyonhee Shin (2017), "Cheap solar panels power consumer appliance boom in North Korea", *Reuters*, dated April 17, 2019, and available as https://www.reuters.com/article/us-northkorea-solar-feature/cheap-solar-panels-power-consumer-appliance-boom-in-north-korea-idUSKCN1RT2P1. See also David Von Hippel and Peter Hayes (2015), "Private Purchases of Solar Photovoltaic Panels in the DPRK: Signs of Green Growth on the Way?", *NAPSNet Policy Forum*, dated January 13, 2015, available as https://nautilus.org/napsnet/napsnet-policy-forum/private-purchases-of-solar-photovoltaic-panels-in-the-dprk-signs-of-green-growth-on-the-way/.

[566] Based on UN Comtrade database information regarding trades in solar photovoltaic equipment from China to the DPRK since 2009 in as reported in trade category (HS) "854140" = "Name: Photosensitive/photovoltaic/LED semiconductor devices; Description: Photosensitive semiconductor devices, including photovoltaic cells whether or not assembled in modules or made up into panels; light emitting diodes". We use these data to estimate the implied volume of imported solar photovoltaic panels into the DPRK. UN Comtrade data do not provide the capacity of solar PV systems. Our capacity estimates are based on applying reported costs of solar PV panels on the DPRK market, consistent with internet prices for Chinese solar PV systems, to calculate capacity from the value of trade in the category listed. This approach provides is an imperfect, estimate of solar PV capacity, but one that should be reasonably accurate.

[567] A solar PV factory in Pyongyang is mentioned in Voice of America (2015), "Solar Panel Boom Helping to Power N. Korean Homes", dated April 22, 2015, and available as https://www.voanews.com/east-asia/solar-panel-boom-helping-power-n-korean-homes. What appeared to be a solar PV panel assembly panel facility was at one time shown in an available video clip, presumably from a DPRK news outlet, although the video itself no longer appears to be available. See John Parnell (2016), "Is this factory driving North Korea's solar boom?", dated March 14, 2016, and available as https://www.pv-tech.org/news/is-this-factory-driving-north-koreas-solar-boom.

Figure 5-20: Solar PV Generation Capacity Imported to the DPRK



An indication of the emphasis on the use of renewable energy by DPRK authorities is provided in a 2019 story by the Korean Friendship Association USA about a factory fitted with "over a thousand solar panels on the roof of the factory building to generate several hundred kW of electricity", as well as solar thermal panels for water heating.[568] Interestingly, the article reports that "[t]he electric power generated at the factory is supplied through the private distribution network to the workshops, sci-tech learning space, mess hall and other units of the factory, and the surplus electricity is transmitted to the national power network", suggesting that the emphasis is on providing power to the facility via a mini-grid, rather than simply providing power to the main grid. An image of the PV array provided in the article (see Figure 5-21) does in fact suggest capacity on the order of 150 kW or more.

[568] Korea Friendship Association USA (2019), "The DPRK is Benefitting from Renewable Energy Sources", dated July 2, 2019, and available as https://www.kfausa.org/the-dprk-is-benefitting-from-renewable-energy-sources/.

Figure 5-21: Solar PV System Installed on Ryuwon Footwear Factory in Mangyongdae District, Pyongyang (Source: Korea Friendship Association USA)

A calculation of the cost of electricity from solar PV panels underscores the value of this source of energy to DPRK residents. As of about 2015, DPRK citizens in many cities are reportedly spending the equivalent of several months of household income to buy solar PV systems to power small electronics (the most common being combination DVD/CD/media players with 9-inch screens) as well as, probably, some light-emitting diode (LED) lighting and other small electric devices. The most common system purchased as of about 2015 included a PV panel with a rated capacity of 30 Watts (W), and a sealed lead-acid automotive-type battery with a capacity of 28 Amp-hours. Wealthier households purchased larger panels and batteries, and larger electronic devices. Households purchased the systems because electricity supplies from the DPRK central grid were (and are) in many places unreliable at best, and at worst, rarely available. Although these systems provide households with consistent access to entertainment and (probably) some lighting and other services, and do so without pollutant emissions, the cost of providing electricity via the solar PV systems is relatively high. The reason for this was not so much the cost of the PV panel in the DPRK—PV costs have been declining rapidly for years, and the in-DPRK retail cost quoted by *Daily NK*, about \$1.30 on a per-Watt-capacity basis, is similar to the high end of current bulk pricing for 30 W PV panel kits as quoted in Alibaba (the dominant Chinese internet market). Taking just the cost of the panel into account, and assuming a lifetime of 20 years, the cost per kWh of delivered electricity in the system comes to about

$0.22 per kWh.[569] The system cost becomes much more expensive, however, when the cost of batteries is included. The reason here is that the batteries used in the system, 12-volt lead-acid batteries of the type used in small vehicles (for example, electric scooters), have a finite lifetime (perhaps 5 or 6 years) even under the best of circumstances, but when continuously discharged to a low level, as they likely would be when used as North Korean households are likely to use them, the battery lifetime could be much shorter, even though some of the batteries sold with PV systems may be nominally designed for deep-cycle use. As a result, the batteries needed to accompany PV panels must be replaced many times over the life of the panels. Factoring in battery lifetimes of 5 years (a best-case scenario, although the lifetimes of lithium-ion batteries, especially for transport applications, continue to improve), the cost of usable energy from the PV/battery systems rises to $0.49 per kWh. If the batteries last only an average of 2 years, the cost per unit of energy rises to $0.78 per kWh. By 2020, with both reductions in cost for PV panels and cost reductions and improvements in lithium-ion battery technologies, the costs of energy for a solar PV system of the type that might be available to a DPRK household (assuming access to imported goods from China) has continued to fall. As an example, a recent listing on Alibaba.com offers a system with solar panels rated at 30 W with battery with a capacity of 144 Watt-hours for a wholesale cost on the order of $40 (USD).[570] If such a system sold for $60 in the DPRK, if the equivalent of half of the battery's capacity were used each evening, and if the battery lasted five years, then the cost of the system would equate to less than $0.50 per kWh, including the cost of LED bulbs, a fan, and the solar panel itself, which would presumably outlive the battery. As the size of these systems increase, the cost per Watt decreases significantly. For example, a 1 kW system including a battery and inverter was advertised on Alibaba as of late 2020 at $0.21 to 0.29 per Watt, which even with a five-year lifetime assumed for the full system would equate to about $0.20 per lifetime kWh even assuming a mark-up 100 percent from wholesale to retail costs.[571] By way of comparison, the average retail price of electricity in the ROK was about $0.11 (121 ROK Won) per kWh as of July 2020.[572]

The actual cost of electricity from PV systems underscores the high value that DPRK households place on access to even small amounts of electricity, and probably even significantly understates it. Based also on UN Comtrade data, the DPRK imported from China on the order of 4 to 5 million flashlights and other lamps in each of the years 2014 through 2017, and 60 million small batteries (likely for electronics) per year in 2012 and 2013 (and 22 million in 2017). The effective cost of electricity from these small batteries is on the order of $20 per kWh.

5.2.6. Nuclear Power

No commercial nuclear power plants are currently operating in the DPRK. An Experimental Light Water Reactor (ELWR), however, remains under construction at the nuclear weapons

[569] Calculated using a real (not including inflation) discount rate of 15%/year, which is probably appropriate, if not low, for household consumers, an assumed output of 1200 W-hours per W of PV capacity, and an average charge/discharge efficiency of 80 percent for the PV/battery system.

[570] See, for example, https://www.alibaba.com/product-detail/30W-Solar-Power-System-Home_60734588898.html?spm=a2700.galleryofferlist.normal_offer.d_title.6a386adc6WCWV4/.

[571] See, for example, https://www.alibaba.com/product-detail/High-quality-low-price-solar-system_62283944000.html?spm=a2700.galleryofferlist.normal_offer.d_title.6a386adc6WCWV4. Note that this example likely overstates the cost per delivered kWh from Solar PV systems, as the life of the solar panel and inverter in this case are likely closer to 20 years than to five years.

[572] Korea Energy Economics Institute (2020), *Monthly Energy Statistics, Volume 36-10* (October 2020), available as http://www.keei.re.kr/keei/download/MES2010.pdf.

complex at Yongbyon. Satellite images suggest that the major buildings associated with the experimental LWR at Yongbyon appear complete, but the reactor is not yet operating. The ELWR, with a reported thermal capacity of 100 MW and an estimated electricity generation capacity of about 25 MW, has been built adjacent to the site of the Yongbyon uranium enrichment facilities and the DPRK's older reactor and plutonium separation facilities.

A 2015 report by the Institute for Science and International Security indicates that "recent imagery does not show any evidence that the LWR has started operation".[573] There have been some small indications of changes on the site in recent images, including recent additions of landscaping, new buildings, and modifications to the berms and dam in the adjacent river in the last few years. Although it appears complete, the ELWR apparently has not run yet as of early 2020.[574] It is possible that the ELWR is being readied for operation in the near future, but we assume that it will not operate, or at least will not provide electricity to the grid, in 2020. Figure 5-22 show a satellite image of the experimental LWR. The small LWR, when and if it is completed, will not help much with the DPRK's electricity shortages, but is intended by the DPRK as an experimental endeavor that could lead to the production of more small reactors around the country.[575]

Meanwhile, the older, nominally 5 MW electric (though probably not, in fact, electricity-producing) gas-cooled reactor has shown intermittent signs of activity in recent months, possibly indicating that testing or low-power operations have been underway. The older reactor was, and presumably still is, used for producing plutonium, and has been the source of plutonium for the DPRK's nuclear weapons program. The construction of the two large (1000 MW) reactors being built at Sinpo under the auspices of the Korean Peninsula Energy Development Organization (KEDO) on the DPRK's east coast as a part of the provisions of the 1994 Agreed Framework has been suspended for over 15 years (the project was terminated by KEDO's board in 2006).[576] It is not clear at this point whether construction (which was being and would be carried out by the ROK and/or the international community, with DPRK workers involved) could in fact be restarted, or if the infrastructure installed at the time that construction ceased has now degraded sufficiently that construction would essentially have to begin all over again.

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[573] David Albright and Serena Kelleher-Vergantini (2015), Y*ongbyon: A Better Insight into the Status of the 5 MWe Reactor*, Institute for Science and International Security (ISIS) Imagery Brief, dated April 29, 2015, and available as http://isis-online.org/uploads/isis-reports/documents/Yongbyon_April_29_2015_Final.pdf. A Google Earth image of the area around the experimental LWR, available as https://www.google.com/maps/place/Yongbyon+Nuclear+Scientific+Research+Center/@39.7955895,125.7551529,294m/data=!3m1!1e3!4m2!3m1!1s0x0:0x47e303bb5423c566, shows the experimental LWR, and as of May 1, 2015 seemed to have been taken in mid-to-late April, similar to the image shown in Figure 1 of the ISIS report, with some minor differences.

[574] See, for example, "North Korea's Yongbyon Nuclear Center: Rail Activity at the Radioisotope Production and Uranium Enrichment Plants", dated February 14, 2020, and available as https://www.38north.org/2020/02/yongbyon021420/.

[575] See David von Hippel and Peter Hayes (2010), *Engaging the DPRK Enrichment and Small LWR Program: What Would It Take?*, NAPSnet Special Report, dated December 23, 2010, and available as http://nautilus.org/napsnet/napsnet-special-reports/engaging-the-dprk-enrichment-and-small-lwr-program-what-would-it-take/.

[576] Nuclear Threat Initiative (NTI, 2011), "Geumho-Jigu Light Water Reactor Site", last updated September 30, 2011, and available as https://www.nti.org/learn/facilities/768/.

Figure 5-22: Satellite Photo of Experimental LWR (white domed building) Under Construction at Yongbyon as of Late 2019 (Source, Google Maps)[577]

5.2.7. Total Power Generation, Imports, and Exports

The above assumptions as to electricity generation imply a gross output of about 13.3 terawatt-hours in 2000, 16.5 TWh in 2005, 17.2 TWh in 2008, 16.2 TWh in 2009, 15.7 TWh in 2010, and 17.2 TWh in 2014, rising to 18.2 TWh in 2016 before falling to 15.7 TWh in 2019, and 14.0 TWh in 2020 (see Figure 5-1).

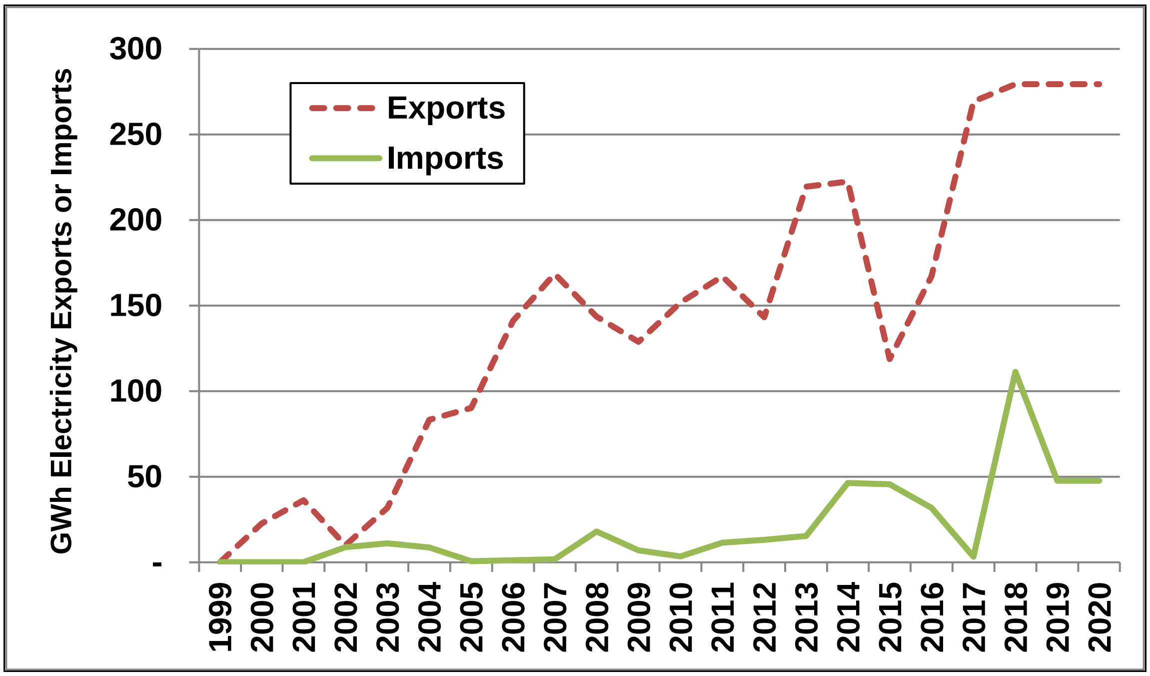
The DPRK's electrical transmission interconnection with neighboring countries are very local in nature at present, and electricity imports and exports do not contribute significantly to the DPRK's overall electricity balance. Power exports have been on the order of one percent the DPRK's total generation in recent years, totaling 222 GWh in 2014 and to an estimated 279 GWh in 2018, the last year for which such exports are reported in customs statistics.[578] Exports have, however, varied considerably on a year-to-year basis, ranging to as low as 119 GWh during the last decade (2010 to 2020). Imports of power to the DPRK from China have also varied on an annual basis, but also are generally in the tens of GWh, and thus about a tenth of a

[577] Image from Google Earth Pro, showing the Yongbyon ELWR as of October 13, 2019, apparently not operating, as indicated by the lack of steam from the smokestack. Some stains on the dome of the reactor have appeared in recent years, but we do not know what their significance is, if any.

[578] Export electricity volumes for the DPRK-China trade are not reported in 2018 statistics on Comtrade.un.org, thus we have estimated the volume of electricity traded based on the average price paid per MWh paid by China in 2017. As noted above, the hydro facilities on the Tumen and Yalu rivers shared by China and the DPRK have turbine sets dedicated to and operated by the DPRK, and turbine sets dedicated to and operated by China. The two sets of turbines are operated at different frequencies. The water resource appears, however, to be jointly managed, so that the two sets of turbines operate with the same capacity factor.

percent or less of our estimates for DPRK total generation. Exports to the DPRK from China were considerably higher in 2018 than previous years, at 111 GWh. We have assumed that exports from the DPRK to China continued at the 2018 rate through 2020, and that imports into the DPRK from China were at the average rate of 2014 through 2018 during 2019 and 2020. The trends in DPRK exports to and imports from China are shown in Figure 5-23.

Figure 5-23: Electricity Exports from and Imports to the DPRK Based on Chinese Customs Statistics



Interestingly, trade statistics indicate that China paid the DPRK on the order of 32 to 41 USD per MWh of power it imported during 2010 through 2017 but charged the DPRK 100 to 122 USD per MWh it exported to the DPRK during 2010 through 2016. Presumably, this difference reflects China's market power relative to the DPRK, though there could be other explanations, such as a higher local cost of providing power at the location where the exports from China to the DPRK originate. The last two years of data on electricity exports to the DPRK from China show markedly lower prices per unit than previous years. We do not know whether to ascribe this change to an entry error in the statistics, concessional pricing by China, or some other explanation.

Additional imports into the DPRK occurred from the ROK, as part of the Kaesong Industrial Complex located just north of the Demilitarized Zone (DMZ) from the ROK. We estimate that ROK power exports to the DPRK were about 73 GWh in 2005, 225 GWH in 2008, 230 GWh in 2009, 290 GWh in 2010, 350 GWh in 2014, and 440 GWh in 2015, though these are only our estimates and presumably can be specified precisely by ROK engineers involved or familiar with the operation of the power line providing electricity to Kaesong. In the Spring of 2013, the

DPRK unilaterally brought a halt to joint industrial activities at Kaesong,[579] but the infrastructure for power supply from the ROK was not affected, and was restored quickly when an agreement between the DPRK and ROK to restart Kaesong was reached in September of that year.[580] In February 2016, in response to the DPRK's most recent nuclear weapons test and rocket launch, the ROK unilaterally shut down the Kaesong Industrial District "indefinitely".[581] As a result, we estimate that exports of electricity from the ROK into the DPRK were about 50 GWh in 2016, but have been zero in the years since.

Table 5-4 summarizes our estimates and assumptions regarding electricity generation capacity by fuel or energy type, capacity factors, and generation in the DPRK from 1990 through 2020. Note that in this table we have treated hydroelectric and thermal capacity somewhat differently in terms of definitions of capacity. Reported hydroelectric capacity is reduced significantly in 1996 and 2000, and by smaller amounts after that, to account for the damage to hydro facilities done by the floods of the early-mid 1990s. Reports as of the late 1990s indicated that flood damage to hydro facilities was significant—for example, floodwaters were such that turbines at some plants were forced to run backwards. As such, for (especially) 1996 and 2000, there was more hydro capacity actually present at that time, but some of it was under repair and inoperable. For thermal plants, on the other hand, the capacity shown is the total capacity that we estimate exists of units that are or were once operable, which is somewhat different to the approach taken for hydroelectric power. By the late 2000s, we assume that most of the damage done to hydroelectric plants by the floods of the 1990s had been repaired, and from that point on we define hydroelectric and thermal capacity essentially the same as for thermal capacity—if the capacity exists and was at one time operable, it is counted in the capacity total. But the reader should understand that not all of the capacity we list is actually operable, either due to damage, lack of spare parts, or inoperable transformers and other substation equipment. We use the capacity factors listed in the table to adjust output to take into account considerations of inoperability, as well as constraints on output due to lack of fuel or low river flows.

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[579] See, for example, Alexandre Mansourov (2013), "Fear Prevails Over Greed: The Kaesong Shutdown" (available as http://38north.org/2013/05/amansourov052113/), and Curtis Melvin (2013), "Whither the Kaesong Industrial Complex?" (available as http://38north.org/2013/05/cmelvin052113/), both in *38 North*, and both dated, 21 May 2013.

[580] See, for example, Andrew Salmon (2013), "Inside North Korea: Could the Kaesong complex give hope for the future?", *The Telegraph*, dated 24 Dec 2013, and available as http://www.telegraph.co.uk/news/worldnews/asia/northkorea/10535828/Inside-North-Korea-Could-the-Kaesong-complex-give-hope-for-the-future.html.

[581] See, for example, Elsie Hu (2016), "South Korea Shutting Down Joint Industrial Park In North Korea", *National Public Radio*, available as http://www.npr.org/sections/thetwo-way/2016/02/10/466254605/south-korea-shutting-down-joint-industrial-park-in-north-korea. We assume that the ROK has, as a part of the Kaesong closure, cut off the power supplies from the ROK to the Kaesong region as well.

Table 5-4: Summary of Capacity and Generation by Generator Type

Supply Summary for Electricity Nominal (Operable and Previously Operable) Capacity (MW), Estimated Capacity Factors, and Generation in Gigawatt-hours of Gross Generation

	YEAR						
CAPACITY (MW)	**1990**	**1996**	**2000**	**2005**	**2008**	**2009**	**2010**
HYDRO	4,500	1,250	3,100	4,116	4,245	4,283	4,321
HFO-FIRED	200	200	270	270	270	270	270
DIESEL/GASOLINE FUELED*	-	-	-	100	161	222	282
COAL-FIRED	3,200	3,250	3,350	3,350	3,350	3,350	3,350
SOLAR, WIND, AND TIDAL*							1
NUCLEAR	-	-	-	-	-	-	-
TOTAL	**7,900**	**4,700**	**6,720**	**7,836**	**8,025**	**8,125**	**8,224**
ESTIMATED CAPACITY FACTORS (%)							
HYDRO	54.0%	48.6%	38.6%	30.9%	31.8%	31.6%	31.5%
HFO-FIRED	73.1%	52.0%	6.3%	7.3%	7.3%	7.3%	5.8%
DIESEL/GASOLINE FUELED*				9.7%	8.3%	7.6%	9.0%
COAL-FIRED	83.6%	58.3%	9.0%	17.6%	17.4%	13.8%	11.7%
SOLAR, WIND, AND TIDAL*							6.2%
NUCLEAR							
GENERATION (GWH)							
HYDRO	21,289	5,322	10,474	11,146	11,826	11,866	11,907
HFO-FIRED**	1,772	1,941	897	357	629	255	207
DIESEL/GASOLINE FUELED*	-	-	-	85	116	148	223
COAL-FIRED**	22,939	15,580	1,892	4,966	4,661	3,968	3,368
SOLAR, WIND, AND TIDAL*	-	-	-	-	-	-	1
NUCLEAR	-	-	-	-	-	-	-
TOTAL **	**46,000**	**22,844**	**13,263**	**16,555**	**17,232**	**16,237**	**15,705**

	YEAR						
CAPACITY (MW)	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
HYDRO	4,716	4,781	4,846	4,921	4,961	4,991	5,011
HFO-FIRED	270	270	70	70	70	70	70
DIESEL/GASOLINE FUELED*	805	1,105	1,272	1,370	1,383	1,393	1,395
COAL-FIRED	3,350	3,350	3,350	3,350	3,350	3,350	3,350
SOLAR, WIND, AND TIDAL*	12	21	33	48	64	80	88
NUCLEAR	-	-	-	-	-	-	-
TOTAL	**9,152**	**9,527**	**9,570**	**9,758**	**9,828**	**9,884**	**9,914**
ESTIMATED CAPACITY FACTORS (%)							
HYDRO	25.6%	26.8%	27.0%	23.9%	24.1%	24.2%	24.3%
HFO-FIRED	5.1%	5.1%	18.3%	5.8%	5.8%	5.8%	5.8%
DIESEL/GASOLINE FUELED*	7.7%	8.6%	9.9%	5.3%	5.2%	5.8%	5.6%
COAL-FIRED	20.3%	17.3%	18.5%	18.0%	14.8%	14.8%	8.8%
SOLAR, WIND, AND TIDAL*	11.5%	11.3%	11.3%	11.2%	11.2%	11.2%	11.2%
NUCLEAR							
GENERATION (GWH)							
HYDRO	10,568	11,250	11,499	10,370	10,548	10,664	10,744
HFO-FIRED**	230	219	216	101	117	116	108
DIESEL/GASOLINE FUELED*	540	837	1,103	632	632	702	688
COAL-FIRED**	5,858	4,982	5,333	5,227	4,259	4,260	2,505
SOLAR, WIND, AND TIDAL*	12	20	32	47	63	79	86
NUCLEAR	-	-	-	-	-	-	-
TOTAL **	**17,207**	**17,309**	**18,182**	**16,377**	**15,619**	**15,821**	**14,131**

* Some generation probably occurred in these categries prior to the first years in which they are reported, but capacity and output for previous years have not been estimated.

** HFO-fired generation includes, and coal-fired generation excludes, generation in coal-fired units fueled with HFO, usually (but not exclusively) as a starter fuel.

One consideration to keep in mind when looking at time-series estimates of DPRK electricity supply is that the changes in power supplies have not been uniform over the entire country. Some areas, most notably in the northern part of the DPRK and rural areas, appear based both on anecdotal information and satellite images of the DPRK lights at night (such as those shown in Chapter 1 of this Report) to have borne more of the burden of electricity supply shortages than, for example, Pyongyang. One researcher attempted to statistically link the impact of international economic sanctions on the DPRK with the distribution of lights from satellite images and found a small impact of sanctions on the relative luminosity of lights in urban versus rural areas, with rural areas more adversely affected.[582]

According to at least one report, the overall lack of power in the DPRK is recognized as a key factor in impeding economic development. Quoting an unnamed "engineer, from North Hamgyong province" in the context of failed negotiations on importing power from China, a 2013 *Radio Free Asia* article suggests that the DPRK generated only "3.6 million kilowatts per year on average", or about 20 percent of the "20 million kilowatts" it needs.[583] It is difficult to interpret these figures directly, since "kilowatts per year" is not a unit that makes sense. If we interpret the statement as "3.6 average gigawatts", implied generation is about 30 TWh, or about twice our estimate of 2010/2014 generation. If, as seems more likely, the 3.6 GW refers to operable capacity, then at capacity factors of about 50 percent (in the range of likely capacity factors for the DPRK's thermal and hydroelectric plants) the quoted capacity would be very close to our estimate of total DPRK generation in 2014.

5.2.7.1.Electricity Transmission and Distribution

The unified electrical grid in the DPRK apparently dates to 1958.[584] The DPRK T&D system must nominally manage a fairly complex grid of 62 power plants, 58 substations, and 11 regional transmission and dispatching centers. A general map of the electricity transmission system in the DPRK is provided as Figure 5-24. The main transmission lines in the DPRK are rated at 220 and 110 kV (kilovolts).

As of early 1992, the DPRK had plans to build 200 km of 220 kV power lines, 60 km of 110 kV lines, and 500 km of 66 kV lines per year through the year 2000.[585] Although we do not know the status of these construction projects, we assume that progress has not achieved targeted levels. Also, as of 1992, the DPRK had plans to build a 330 kV transmission system, with implementation to start within 2 years, and planned, in the long term, to build a 500 kV

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[582] See Martyn Williams (2015), "North Korea's lights tell story of economic redistribution", *North Korea Tech Watch*, dated May 18, 2015, and available as http://www.northkoreatech.org/2015/05/18/north-koreas-lights-tell-story-of-economic-redistribution/#more-6564.

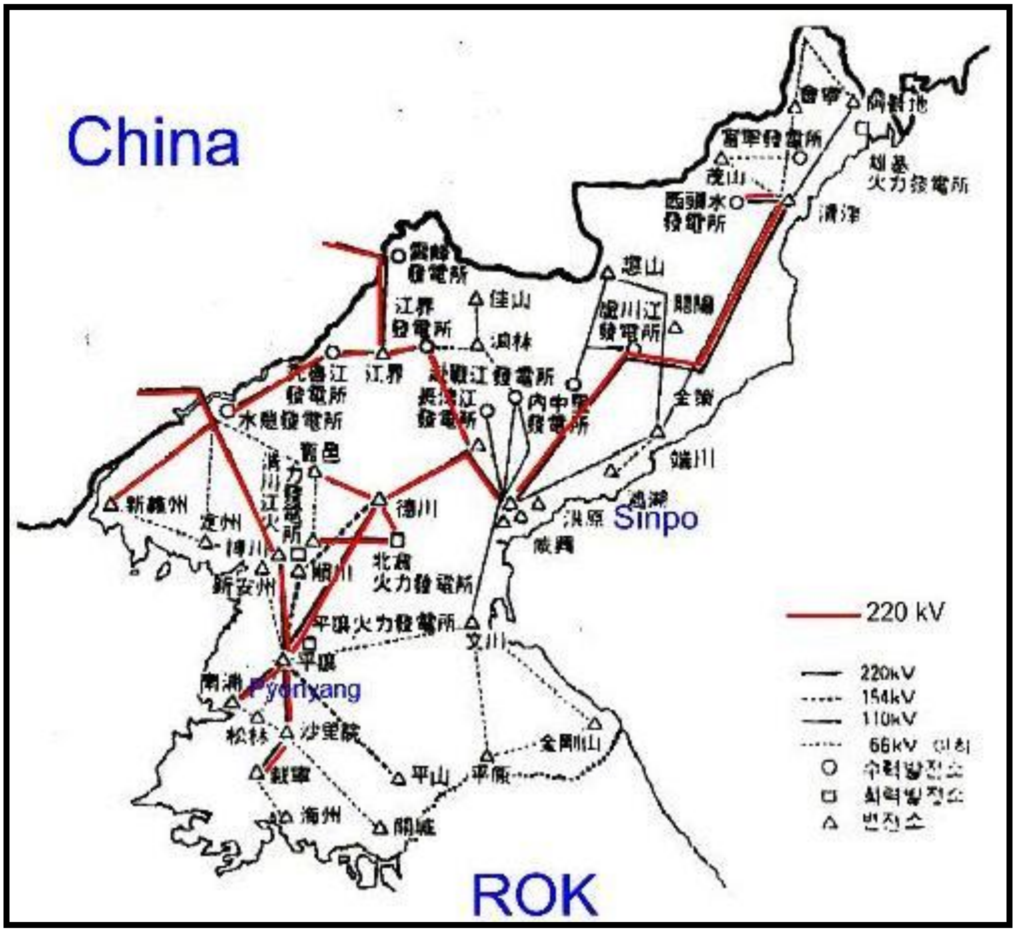
[583] Sung Hui Moon (2013, translated by Doeun Han, and written in English by Joshua Lipes), "North Korea Seeking Electricity Supply from China", *Radio Free Asia* Korean Service, dated 2013-10-21, available as http://www.rfa.org/english/news/korea/electricity-10212013160033.html.

[584] Moiseyev, V. (1996), The Electric Energy Sector of the DPRK Paper presented at the workshop on "Security on the Korean Peninsula," November 21, 1996, Diplomatic Academy, Moscow, sponsored by the Center for Nonproliferation Studies at the Monterey Institute of International Studies (with funding from the Rockefeller Foundation).

[585] Kilometers of line here probably refers to conductor-kilometers.

transmission system. We assume that little progress has been made on either of these higher-voltage systems.

Figure 5-24: Overall Map of the DPRK Electric Power Grid



There were, as of about 1990, reportedly 58 substations on the DPRK grid at the highest transmission voltage levels[586]. We have capacity information about only four of these,[587] and names for others. The substations in the DPRK are reportedly antiquated—based on obsolete Russian and Chinese technology—and also poorly maintained due largely to lack of parts and materiel.   Our assumption is that most or all of the substations would need to be replaced, or at least substantially refurbished, to bring the North Korean grid up to modern standards.

The T&D system is nominally controlled by the Electric Power Production and Dispatching and Control Centre (EPPDCC) in Pyongyang and by 11 regional dispatching centers.

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[586] More recent estimates provided by experts suggest that there may be somewhat under 80 transmission substations in the DPRK designed to operate with nominally 220 kV inputs, with perhaps another 200 transmission substations operating at the 66 kV/11 kV levels, 2500 11 kV distribution substations, and about 15,000 transformers to distribute power to consumers.

[587] Capacity is supplied in units of million volt-amps (MVA).

5.2.7.2. Technical Parameters of the T&D System, and Technical Challenges to Integration with Systems in Other Countries

The power grid in the DPRK operates at a nominal frequency of 60 Hz (Hertz, or cycles per second). Frequency control is poor, however, and the actual frequency on the system often reportedly falls to 57 to 59 Hz, and sometimes as low as 54 to 55 Hz (based on reports as of 1990).[588] [589] Our own experience in the DPRK in 1998 and 2000 showed even more radical departures from 60 Hz; on several occasions we measured grid frequencies of 50 Hz and below. It seems likely that these large excursions from the nominal frequency have for the most part continued through 2020.

Of the neighboring countries, both China and Russia have electricity systems that operate at 50 Hz, while the grid in the Republic of Korea operates at 60 Hz. This difference means that in order to interconnect the DPRK grid with the Chinese and/or Russian grid, as has been contemplated under the Tumen River Area Development Programme (TRADP), it will either be necessary to convert from 60 Hz to 50 Hz or from 50 Hz to 60 Hz at the intersection of the power grids. Interchange costs can in theory be offset, however, by reductions in required reserve capacity in one or both interconnected systems. That is, the interconnected systems (in aggregate) need not build as many power plants, thus there is significant capital cost savings.

Although the ROK power grid operates at nominally the same frequency as the DPRK grid[590] it is virtually certain that interconnection of the grids, in their present form, will require substantial power conditioning at the point of interconnection to assure that the power entering the ROK meets ROK standards for frequency and other attributes, and that the load on the DPRK side is not sufficiently unstable as to disrupt the ROK grid. The best way to achieve this outcome (short of wholesale refurbishment/replacement of the DPRK grid to ROK standards) is probably to add a station near the DPRK/ROK border that converts the AC (alternating current) power from the DPRK to DC (direct current) power, then back to AC power synchronized with the ROK system for export to the south. This conversion process would be carried out using a series of solid-state devices. Power losses through these types of AC-DC-AC system are minimal, typically much less than one percent. The cost of AC-DC-AC a system of the size that would be required was estimated to be on the order of US $125 million per GW of capacity[591] as of the late 1990s but may or may not be similar (in current dollar terms) today.[592]

[588] The historically poor control of frequency, and frequent loss of power, on the DPRK grid has reportedly figured in determining the efficiency of industrial equipment in an interesting way. In order to make sure that the USSR-built industrial equipment installed in the DPRK would hold up under the prevailing conditions of poor power quality, Soviet engineers typically augmented (usually older) USSR designs to make the DPRK plants extra-rugged. These more rugged plants were thus probably more electricity-intensive, on the whole, than typical Soviet plants of the same types and vintages.

[589] Our own power measurements in the DPRK in 1998 and 2000, in fact, showed a much wider range of frequency variation—with frequencies dropping at times to the 45 Hz range.

[590] The fact that the power grids in the Koreas operate at a different frequency than most of the rest of continental Asia (and virtually all of Europe) is probably a legacy of the Japanese colonial period (and possibly of US influence in the ROK). Japan uses both 50- and 60-cycle grids ("List of Voltages & Frequencies (Hz) Around the World", provided by *Generator Source* on https://www.generatorsource.com/Voltages_and_Hz_by_Country.aspx). (Note that the *Generator Source* website lists the DPRK as having a (nominal) grid frequency of 50 Hz, which is inconsistent with other sources.)

[591] Order-of-magnitude cost estimate obtained in conversation (1997) with G. Jutte of Siemens Power Transmission and Distribution, Limited. Indications at that time were that per-unit costs for these systems were declining. There are a number of technical issues that will have to be considered when and if AC-DC-AC converters are to be used in Korea, including the line voltage on the North Korean side, the distance over which the power must be transferred, and many others. A 2014 ETSAP study listed the cost of converters at $230,000 million per MW of capacity, or nearly twice the estimate above, but we do not know what sized converters were used to compute the figure given in the ETSAP study, and it is highly likely that unit costs for

5.2.7.3. The T&D System in 2000 and Beyond

We have assumed, based on reports of the continuing erosion of the transmission and distribution grid, that T&D losses were 20 percent higher in 2000 through 2020 than in 1996, totaling over 27 percent of net generation. This level is quite high, but hardly unprecedented—as of 2014 the World Bank lists India as having T&D losses of 19 percent, and a number of other nations have higher reported losses.[593] Although "own use" at coal-fired power plants was assumed to remain at 9 percent of gross generation, we assumed that additional "emergency losses" decreased net output at coal-fired power plants, with overall net emergency losses totaling 9.4 percent in 2000, and a slightly lower 9 percent in 2005 through 2020, reflecting some improvements in power plant maintenance (or, alternatively, the abandonment of units with worse-than-average losses). We have been told that almost all of the transformers in the major substations of the DPRK are in very poor condition, and that many of the transformers that are operating (many units are not) are working at all because North Korean technicians have applied heroic and often inventive measures to keep the units in service.[594] It is unclear, without supplies of replacement parts (or new transformers, which would be better) for substations, whether key equipment at substations can continue to operate for much longer, even though the equipment is for the most part already well beyond what would normally be considered its rated lifetime.

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these converters fall for GW-sized installations. See International Energy Agency, Energy Technology Assistance Programme (IEA ETSAP, 2014), *Electricity Transmission and Distribution*, IEA ETSAP Technology Brief E12, dated April, 2014, and available as https://iea-etsap.org/E-TechDS/PDF/E12_el-t&d_KV_Apr2014_GSOK.pdf. Two other references more recent also suggest that the older Siemens estimates are still reasonably accurate. The first is: Black and Veatch (2012), *Recommendations for WECC Transmission Expansion Planning [the US Western Electricity Coordinating Council]*, dated October, 2012, available as https://www.wecc.org/reliability/1210_bv_wecc_transcostreport_final.pdf, and the second is a 2018 document, presumably for application in Saudi Arabia, available as https://static1.squarespace.com/static/5a573aade45a7c861137d973/t/5a8413409140b75ef98b4ec5/1518605140613/EE623_Assignment_1.pdf.

[592] For example, the article "Analysing the costs of High Voltage Direct Current (HVDC) transmission", posted on *Electrical Engineering Portal*, dated August 6, 2014, and available as http://electrical-engineering-portal.com/analysing-the-costs-of-high-voltage-direct-current-hvdc-transmission, gives an sample cost for converter stations on a 2000 MW HVDC line of 250 M USD.

[593] World Bank (2020), "Electric power transmission and distribution losses (% of output)", available as https://data.worldbank.org/indicator/EG.ELC.LOSS.ZS. These data are based on statistics compiled by the International Energy Agency (IEA) as of 2018. For 2014, the World Bank list the DPRK's T&D losses at 16 percent, the same as our estimate for pre-degradation conditions in 1990, though it is not clear what the basis of that figure is.

[594] This is also consistent with our own personal observations of the capabilities of DPRK engineers and technicians—they are well-trained and very capable, particularly in adapting what materials and tools are at hand to the task of keeping machines running.

5.3. Electricity Demand in the DPRK

5.3.1. Electricity Balances

Table 5-5 through Table 5-12 present, respectively, estimated electricity supply/demand balances for the DPRK for the years 2010 and 2014 through 2020. The top part of each of these tables show the estimated sources of electricity for the DPRK (hydro, fossil, wind, solar, and other fuels), presenting the amount of generation provided by each type of plant, and the estimated amount of fuel or energy resource consumed in generation. The bottom part of each table provides our estimate of electricity use in each demand sector and subsector by end-use. Here "Motors and Drives" means electricity used in electric motors and their mechanical or electronic drive systems. Most industrial electricity use, and a much of electricity use in other sectors (in fans, pumps, and other devices) is ultimately consumed in electric motors, so we have found it convenient to categorize industrial end uses (mainly) with motors and drives as a key category, because most energy efficiency improvements to motor and drive systems can span industries, and sometimes other sectors. "Process Energy" is general category for electricity use in the industrial sector that is not in motors and drives or in lighting. An example might be electrolytic processes in the electronics or metallurgy sectors, or the use of electricity to provide process heat. "Other End Uses" appear mostly in the residential and public/commercial sectors, and include, for example, electricity used in electronic equipment, cooking (because it is not separately reported), and refrigerators and other appliances (except air conditioning and water/space heating). The end-use divisions presented in these tables are based on our research in the past, and thus may not be fully consistent with compilations in other countries. In addition, the reader is urged to remember that the division of electricity consumption in the DPRK into individual end uses is very much an exercise in applied assumptions based on experience in other places (including, for example, China in the 1990s), as there are essentially no quantitative data on electricity end uses in the DPRK currently available. As such, to prefigure one of the conclusions of this report, one of the key collaborative activities that should be undertaken, as a part of any energy sector project with the DPRK, is to undertake energy/electricity end-use surveys. These will serve as to inform the design of and act as the baseline for evaluation of any cooperative engagement activities undertaken in the electricity sector.

Additionally, the reader is urged to remember that although we refer to electricity "demand", what we really mean here is electricity use, because in virtually all areas of the DPRK the use of electricity is constrained by available supplies. In its compilation of access to electricity by country for 2012, the World Bank estimated that less than 30 percent of North Koreans had access to electricity.[595] Although it is not clear exactly how World Bank researchers derived this figure, it is quite plausible, and it is striking to remember that virtually all North Korean residences are, or were as of 1990, grid connected, so the World Bank's 30 percent access figures is, in effect, an estimate of average electricity availability, that is, the fraction of households that received electricity supplies.

[595] World Bank (2016), "Data: Access to Electricity (% of Population), available as http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS.

Moreover, the division between how much electricity would be consumed if supplies were routinely available and how much is actually consumed varies considerably from place to place. One researcher has suggested, based on an analysis of satellite photos of lights in the DPRK, that international economic sanctions on the DPRK have caused economic activity in the DPRK to shift, by one to a few percent, from rural areas to urban areas and to the centers of cities.[596]

These supply/demand balance tables do, however, in addition to providing first estimates of electricity end uses in the DPRK, offer a structure for improved end-use estimates, ideally in the context of collaborative survey work with DPRK (and ROK) colleagues.

[596] Yong Suk Lee (2014), Countering Sanctions: The Unequal Geographic Impact of Economic Sanctions in North Korea, dated August 26, 2014, and available as https://siepr.stanford.edu/sites/default/files/publications/519wp.pdf. We have not fully evaluated this author's analysis of the relationship between sanctions and luminosity, but feel that technical, as well as economic or policy, factors may well also be strongly involved in the shift of power availability (and thus the availability of grid electricity for lighting) away from rural areas and toward urban areas, as we have directly observed (in 1998 and 2000) and as anecdotes from travelers to different areas of the DPRK suggest.

Table 5-5: Estimated Electricity Supply/Demand Balance for the DPRK, 2010

UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	END USES: MOTORS AND DRIVES	PROCESS ELECTRICITY	LIGHTING	SPACE AND WATER HEATING	AIR CONDITIONING	OTHER END USES	TOTAL ELECTRICITY (GWh)	TOTAL ELECTRICITY (TJ)	GENERATION FUEL/ ENERGY INPUTS (TJ)
ENERGY SUPPLY							141	507	
Imports							292	1,053	
Exports							152	546	
ENERGY TRANSFORMATION	-	-	-	-	-	-	10,006	36,023	107,711
Electricity Generation, of which:							**15,706**	**56,540**	**107,711**
--Coal-fired							3,367	12,123	57,727
--Heavy Fuel Oil-fired							207	745	3,546
--Diesel-fueled							219	788	3,428
--Gasoline-fueled							4	16	135
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							1	2	10
--Hydroelectric Power							11,907	42,864	42,864
--Solar Power							0.5	1.8	2
--Wind Power							0.1	0.3	0
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(41)	(149)	
Coal Production/Preparation							(885)	(3,188)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(665)	(2,395)	
Losses							(4,107)	(14,785)	
ELECTRICITY FOR FINAL CONSUMPTION							10,147	36,530	
ELECTRICITY DEMAND	4,955	1,449	2,469	152	129	993	10,147	36,530	
INDUSTRIAL SECTOR	2,562.7	1,449.4	211.2	-	-	-	4,223	15,204	
Iron and Steel	514.8	463.3	51.5				1,030	3,707	
Cement	689.0	-	36.3				725	2,611	
Fertilizers	213.2	191.9	21.3				426	1,535	
Other Chemicals	141.5	127.4	14.2				283	1,019	
Pulp and Paper	39.2	0.0	2.1				41	149	
Other Metals	146.3	548.5	36.6				731	2,633	
Other Minerals	56.4	-	3.0				59	214	
Textiles	116.0	0.0	6.1				122	439	
Building Materials	15.4	0.0	0.8				16	58	
Non-specified Industry	630.9	118.3	39.4				789	2,839	
TRANSPORT SECTOR	1,032.7	-	27.2	-	-	27.2	1,087	3,913	
Road	0.0						0	0	
Rail	1,032.7		27.2			27.2	1,087	3,913	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	93.5	-	534.6	27.9	4.8	408.4	1,069	3,849	
Urban	93.5		467.6	27.6	4.8	341.7	935	3,366	
Rural	-		67.0	0.3	-	66.7	134	483	
AGRICULTURAL SECTOR	324.9	-	7.0	-	-	4.7	337	1,211	
Field Operations	103.8		-			-	104	374	
Processing/Other	221.1		7.0			4.7	233	838	
FISHERIES SECTOR	48.4	-	1.5	-	-	1.0	51	183	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	48.4		1.5			1.0	51	183	
MILITARY SECTOR	644.6	-	1,066.7	-	-	427.4	2,139	7,699	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	4.8		0.3			0.9	6	21	
Buildings and Other	639.8		1,066.4			426.6	2,133	7,678	
PUBLIC/COMMERCIAL SECTORS	248.3		620.7	124.1	124.1	124.1	1,241	4,469	

Table 5-6: Estimated Electricity Supply/Demand Balance for the DPRK, 2014

UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	END USES								
	MOTORS AND DRIVES	PROCESS ELECTRICITY	LIGHTING	SPACE AND WATER HEATING	AIR CONDITIONING	OTHER END USES	TOTAL ELECTRICITY (GWh)	TOTAL ELECTRICITY (TJ)	GENERATION FUEL/ ENERGY INPUTS (TJ)
ENERGY SUPPLY							174	628	
Imports							397	1,429	
Exports							222	801	
ENERGY TRANSFORMATION	-	-	-	-	-	-	10,202	36,726	150,645
Electricity Generation, of which:							**17,196**	**61,904**	**150,645**
--Coal-fired							5,854	21,073	100,347
--Heavy Fuel Oil-fired							230	829	3,949
--Diesel-fueled							505	1,820	7,279
--Gasoline-fueled							35	124	957
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							4	15	69
--Hydroelectric Power							10,556	38,002	38,002
--Solar Power							10.0	36.0	36
--Wind Power							1.4	5.2	5
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(41)	(146)	
Coal Production/Preparation							(1,533)	(5,520)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(1,115)	(4,016)	
Losses							(4,305)	(15,496)	
ELECTRICITY FOR FINAL CONSUMPTION							10,376	37,354	
ELECTRICITY DEMAND	5,100	1,716	2,389	134	114	924	10,377	37,356	
INDUSTRIAL SECTOR	2,836.9	1,715.6	239.6	-	-	-	4,792	17,252	
Iron and Steel	491.1	441.9	49.1				982	3,536	
Cement	711.5	0.0	37.4				749	2,696	
Fertilizers	638.7	574.8	63.9				1,277	4,599	
Other Chemicals	111.2	100.1	11.1				222	801	
Pulp and Paper	27.1	-	1.4				28	103	
Other Metals	131.1	491.7	32.8				656	2,360	
Other Minerals	56.4	-	3.0				59	214	
Textiles	87.0	0.0	4.6				92	330	
Building Materials	12.1	0.0	0.6				13	46	
Non-specified Industry	570.8	107.0	35.7				714	2,569	
TRANSPORT SECTOR	909.2	-	23.9	-	-	23.9	957	3,445	
Road	1.1						1	4	
Rail	908.2		23.9			23.9	956	3,442	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	78.9	-	439.6	23.5	4.0	333.3	879	3,165	
Urban	78.9		394.3	23.2	4.0	288.2	789	2,839	
Rural	-		45.3	0.2	-	45.1	91	326	
AGRICULTURAL SECTOR	328.4	-	7.2	-	-	4.8	341	1,226	
Field Operations	99.0		-			-	99	357	
Processing/Other	229.4		7.2			4.8	241	869	
FISHERIES SECTOR	45.7	-	1.4	-	-	1.0	48	173	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	45.7		1.4			1.0	48	173	
MILITARY SECTOR	679.8	-	1,124.9	-	-	450.8	2,255	8,120	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	5.1		0.3			1.0	6	23	
Buildings and Other	674.7		1,124.6			449.8	2,249	8,097	
PUBLIC/COMMERCIAL SECTORS	220.8		552.0	110.4	110.4	110.4	1,104	3,975	

Table 5-7: Estimated Electricity Supply/Demand Balance for the DPRK, 2015

UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	END USES: MOTORS AND DRIVES	PROCESS ELECTRICITY	LIGHTING	SPACE AND WATER HEATING	AIR CONDITIONING	OTHER END USES	TOTAL ELECTRICITY (GWh)	TOTAL ELECTRICITY (TJ)	GENERATION FUEL/ ENERGY INPUTS (TJ)
ENERGY SUPPLY							365	1,314	
Imports							484	1,741	
Exports							119	427	
ENERGY TRANSFORMATION	-	-	-	-	-	-	10,286	37,028	157,522
Electricity Generation, of which:							**17,288**	**62,238**	**157,522**
--Coal-fired							4,981	17,932	100,347
--Heavy Fuel Oil-fired							219	790	3,762
--Diesel-fueled							727	2,616	10,060
--Gasoline-fueled							111	398	2,844
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							0	2	8
--Hydroelectric Power							11,230	40,428	40,428
--Solar Power							18.5	66.6	67
--Wind Power							1.7	6.2	6
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(45)	(163)	
Coal Production/Preparation							(1,711)	(6,158)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(958)	(3,448)	
Losses							(4,289)	(15,441)	
ELECTRICITY FOR FINAL CONSUMPTION							10,651	38,342	
ELECTRICITY DEMAND	5,311	1,637	2,475	140	119	968	10,651	38,343	
INDUSTRIAL SECTOR	2,807.6	1,637.2	233.9	-	-	-	4,679	16,844	
Iron and Steel	434.3	390.9	43.4				869	3,127	
Cement	713.8	0.0	37.6				751	2,705	
Fertilizers	593.7	534.4	59.4				1,187	4,275	
Other Chemicals	111.2	100.1	11.1				222	801	
Pulp and Paper	27.1	-	1.4				28	103	
Other Metals	131.1	491.7	32.8				656	2,360	
Other Minerals	56.4	-	3.0				59	214	
Textiles	87.0	0.0	4.6				92	330	
Building Materials	12.1	0.0	0.6				13	46	
Non-specified Industry	640.9	120.2	40.1				801	2,884	
TRANSPORT SECTOR	1,109.2	-	29.1	-	-	29.1	1,167	4,203	
Road	1.8						2	6	
Rail	1,107.4		29.1			29.1	1,166	4,196	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	83.7	-	464.3	24.9	4.3	351.5	929	3,343	
Urban	83.7		418.3	24.6	4.3	305.7	837	3,012	
Rural	-		46.0	0.2	-	45.8	92	331	
AGRICULTURAL SECTOR	335.8	-	7.5	-	-	5.0	348	1,254	
Field Operations	99.1		-			-	99	357	
Processing/Other	236.6		7.5			5.0	249	897	
FISHERIES SECTOR	41.5	-	1.3	-	-	0.9	44	157	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	41.5		1.3			0.9	44	157	
MILITARY SECTOR	703.2	-	1,163.7	-	-	466.3	2,333	8,399	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	5.2		0.3			1.0	6	23	
Buildings and Other	698.0		1,163.3			465.3	2,327	8,376	
PUBLIC/COMMERCIAL SECTORS	230.2		575.5	115.1	115.1	115.1	1,151	4,143	

Table 5-8: Estimated Electricity Supply/Demand Balance for the DPRK, 2016

	END USES								
UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	MOTORS AND DRIVES	PROCESS ELECTRICITY	LIGHTING	SPACE AND WATER HEATING	AIR CONDITIONING	OTHER END USES	TOTAL ELECTRICITY (GWh)	TOTAL ELECTRICITY (TJ)	GENERATION FUEL/ ENERGY INPUTS (TJ)
ENERGY SUPPLY							(82)	(295)	
Imports							85	307	
Exports							167	602	
ENERGY TRANSFORMATION	-	-	-	-	-	-	10,811	38,921	152,401
Electricity Generation, of which:							**18,150**	**65,340**	**152,401**
--Coal-fired							5,331	19,192	91,391
--Heavy Fuel Oil-fired							216	777	3,699
--Diesel-fueled							992	3,570	13,221
--Gasoline-fueled							111	400	2,667
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							2	6	27
--Hydroelectric Power							11,466	41,279	41,279
--Solar Power							30.0	108.0	108
--Wind Power							2.1	7.7	8
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(47)	(170)	
Coal Production/Preparation							(1,836)	(6,610)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(1,022)	(3,679)	
Losses							(4,433)	(15,960)	
ELECTRICITY FOR FINAL CONSUMPTION							10,730	38,626	
ELECTRICITY DEMAND	5,222	1,692	2,545	146	124	1,002	10,730	38,627	
INDUSTRIAL SECTOR	2,654.4	1,692.4	228.8	-	-	-	4,576	16,472	
Iron and Steel	485.3	436.8	48.5				971	3,494	
Cement	739.5	-	38.9				778	2,802	
Fertilizers	673.1	605.8	67.3				1,346	4,846	
Other Chemicals	111.2	100.1	11.1				222	801	
Pulp and Paper	27.1	-	1.4				28	103	
Other Metals	129.9	487.3	32.5				650	2,339	
Other Minerals	55.9	-	2.9				59	212	
Textiles	87.0	0.0	4.6				92	330	
Building Materials	12.1	0.0	0.6				13	46	
Non-specified Industry	333.2	62.5	20.8				417	1,500	
TRANSPORT SECTOR	1,154.9	-	30.3	-	-	30.3	1,215	4,375	
Road	4.8						5	17	
Rail	1,150.1		30.3			30.3	1,211	4,358	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	88.1	-	487.2	26.2	4.5	368.4	974	3,508	
Urban	88.1		440.5	26.0	4.5	322.0	881	3,172	
Rural	-		46.7	0.2	-	46.4	93	336	
AGRICULTURAL SECTOR	312.0	-	6.7	-	-	4.5	323	1,163	
Field Operations	99.8		-			-	100	359	
Processing/Other	212.2		6.7			4.5	223	804	
FISHERIES SECTOR	52.6	-	1.7	-	-	1.1	55	199	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	52.6		1.7			1.1	55	199	
MILITARY SECTOR	720.7	-	1,192.7	-	-	478.0	2,391	8,609	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	5.3		0.3			1.0	7	24	
Buildings and Other	715.5		1,192.4			477.0	2,385	8,585	
PUBLIC/COMMERCIAL SECTORS	238.9		597.2	119.4	119.4	119.4	1,194	4,300	

Table 5-9: Estimated Electricity Supply/Demand Balance for the DPRK, 2017

UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	END USES								
	MOTORS AND DRIVES	PROCESS ELECTRICITY	LIGHTING	SPACE AND WATER HEATING	AIR CONDITIONING	OTHER END USES	TOTAL ELECTRICITY (GWh)	TOTAL ELECTRICITY (TJ)	GENERATION FUEL/ ENERGY INPUTS (TJ)
ENERGY SUPPLY							(249)	(898)	
Imports							20	72	
Exports							269	969	
ENERGY TRANSFORMATION	-	-	-	-	-	-	10,213	36,767	138,424
Electricity Generation, of which:							**16,330**	**58,789**	**138,424**
--Coal-fired							5,226	18,814	89,592
--Heavy Fuel Oil-fired							101	364	1,735
--Diesel-fueled							508	1,827	6,768
--Gasoline-fueled							124	447	2,982
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							1	3	14
--Hydroelectric Power							10,323	37,164	37,164
--Solar Power							44.3	159.3	159
--Wind Power							2.5	9.1	9
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(45)	(162)	
Coal Production/Preparation							(1,021)	(3,675)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(986)	(3,551)	
Losses							(4,065)	(14,635)	
ELECTRICITY FOR FINAL CONSUMPTION							9,964	35,869	
ELECTRICITY DEMAND	4,736	1,431	2,523	145	123	1,005	9,964	35,870	
INDUSTRIAL SECTOR	2,333.7	1,430.9	198.1	-	-	-	3,963	14,266	
Iron and Steel	438.7	394.9	43.9				877	3,159	
Cement	721.7	0.0	38.0				760	2,735	
Fertilizers	460.8	414.8	46.1				922	3,318	
Other Chemicals	111.2	100.1	11.1				222	801	
Pulp and Paper	27.1	-	1.4				28	103	
Other Metals	123.6	463.4	30.9				618	2,224	
Other Minerals	50.8	-	2.7				53	192	
Textiles	79.7	0.0	4.2				84	302	
Building Materials	11.5	0.0	0.6				12	44	
Non-specified Industry	308.6	57.9	19.3				386	1,388	
TRANSPORT SECTOR	1,005.5	-	26.2	-	-	26.2	1,058	3,808	
Road	11.3						11	41	
Rail	994.2		26.2			26.2	1,047	3,767	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	89.2	-	493.5	26.5	4.5	373.2	987	3,553	
Urban	89.2		446.1	26.3	4.5	326.1	892	3,212	
Rural	-		47.4	0.2	-	47.1	95	341	
AGRICULTURAL SECTOR	287.8	-	6.1	-	-	4.1	298	1,073	
Field Operations	93.8		-			-	94	338	
Processing/Other	194.0		6.1			4.1	204	735	
FISHERIES SECTOR	55.3	-	1.7	-	-	1.2	58	210	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	55.3		1.7			1.2	58	210	
MILITARY SECTOR	726.6	-	1,202.4	-	-	481.8	2,411	8,679	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	5.3		0.3			1.0	7	24	
Buildings and Other	721.3		1,202.1			480.8	2,404	8,655	
PUBLIC/COMMERCIAL SECTORS	237.8		594.6	118.9	118.9	118.9	1,189	4,281	

Table 5-10: Estimated Electricity Supply/Demand Balance for the DPRK, 2018

	END USES								
UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	**MOTORS AND DRIVES**	**PROCESS ELECTRICITY**	**LIGHTING**	**SPACE AND WATER HEATING**	**AIR CONDITIONING**	**OTHER END USES**	**TOTAL ELECTRICITY (GWh)**	**TOTAL ELECTRICITY (TJ)**	**GENERATION FUEL/ ENERGY INPUTS (TJ)**
ENERGY SUPPLY							(168)	(605)	
Imports							111	401	
Exports							279	1,006	
ENERGY TRANSFORMATION	-	-	-	-	-	-	9,841	35,428	122,775
Electricity Generation, of which:							**15,556**	**56,003**	**122,775**
--Coal-fired							4,259	15,332	73,012
--Heavy Fuel Oil-fired							117	421	2,004
--Diesel-fueled							505	1,820	6,740
--Gasoline-fueled							127	456	3,041
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							0	1	6
--Hydroelectric Power							10,485	37,746	37,746
--Solar Power							59.7	214.9	215
--Wind Power							2.9	10.5	11
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(50)	(179)	
Coal Production/Preparation							(956)	(3,443)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(816)	(2,936)	
Losses							(3,893)	(14,017)	
ELECTRICITY FOR FINAL CONSUMPTION							9,673	34,823	
ELECTRICITY DEMAND	4,535	1,247	2,572	174	131	1,012	9,673	34,822	
INDUSTRIAL SECTOR	2,182.4	1,246.7	180.5	-	-	-	3,610	12,995	
Iron and Steel	410.6	369.5	41.1				821	2,956	
Cement	673.4	0.0	35.4				709	2,552	
Fertilizers	257.9	232.1	25.8				516	1,857	
Other Chemicals	111.2	100.1	11.1				222	801	
Pulp and Paper	27.1	-	1.4				28	103	
Other Metals	123.6	463.4	30.9				618	2,224	
Other Minerals	50.8	-	2.7				53	192	
Textiles	79.7	0.0	4.2				84	302	
Building Materials	12.6	-	0.7				13	48	
Non-specified Industry	435.6	81.7	27.2				545	1,960	
TRANSPORT SECTOR	965.6	-	25.0	-	-	25.0	1,016	3,656	
Road	14.0						14	50	
Rail	951.6		25.0			25.0	1,002	3,606	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	96.7	-	532.9	53.5	10.5	372.2	1,066	3,837	
Urban	96.7		483.4	52.2	10.5	324.0	967	3,481	
Rural	-		49.4	1.3	-	48.1	99	356	
AGRICULTURAL SECTOR	271.9	-	5.9	-	-	3.9	282	1,014	
Field Operations	86.6		-			-	87	312	
Processing/Other	185.3		5.9			3.9	195	702	
FISHERIES SECTOR	38.7	-	1.2	-	-	0.8	41	147	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	38.7		1.2			0.8	41	147	
MILITARY SECTOR	738.2	-	1,221.8	-	-	489.6	2,450	8,819	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	5.3		0.3			1.0	7	24	
Buildings and Other	732.9		1,221.5			488.6	2,443	8,795	
PUBLIC/COMMERCIAL SECTORS	242.0		604.9	121.0	121.0	121.0	1,210	4,355	

Table 5-11: Estimated Electricity Supply/Demand Balance for the DPRK, 2019

UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	END USES: MOTORS AND DRIVES	PROCESS ELECTRICITY	LIGHTING	SPACE AND WATER HEATING	AIR CONDITIONING	OTHER END USES	TOTAL ELECTRICITY (GWh)	TOTAL ELECTRICITY (TJ)	GENERATION FUEL/ ENERGY INPUTS (TJ)
ENERGY SUPPLY							(232)	(834)	
Imports							48	172	
Exports							279	1,006	
ENERGY TRANSFORMATION	-	-	-	-	-	-	9,841	35,428	124,123
Electricity Generation, of which:							**15,743**	**56,674**	**124,123**
--Coal-fired							4,260	15,336	73,027
--Heavy Fuel Oil-fired							116	418	1,989
--Diesel-fueled							576	2,074	7,681
--Gasoline-fueled							126	454	3,029
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							0	1	6
--Hydroelectric Power							10,586	38,109	38,109
--Solar Power							75.1	270.2	270
--Wind Power							3.3	11.9	12
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(50)	(179)	
Coal Production/Preparation							(1,115)	(4,014)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(816)	(2,937)	
Losses							(3,921)	(14,117)	
ELECTRICITY FOR FINAL CONSUMPTION							9,609	34,594	
ELECTRICITY DEMAND	4,511	1,247	2,551	173	132	996	9,609	34,593	
INDUSTRIAL SECTOR	2,182.4	1,246.7	180.5	-	-	-	3,610	12,995	
Iron and Steel	410.6	369.5	41.1				821	2,956	
Cement	673.4	0.0	35.4				709	2,552	
Fertilizers	257.9	232.1	25.8				516	1,857	
Other Chemicals	111.2	100.1	11.1				222	801	
Pulp and Paper	27.1	-	1.4				28	103	
Other Metals	123.6	463.4	30.9				618	2,224	
Other Minerals	50.8	-	2.7				53	192	
Textiles	79.7	0.0	4.2				84	302	
Building Materials	12.6	-	0.7				13	48	
Non-specified Industry	435.6	81.7	27.2				545	1,960	
TRANSPORT SECTOR	966.9	-	25.0	-	-	25.0	1,017	3,661	
Road	15.3						15	55	
Rail	951.6		25.0			25.0	1,002	3,606	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	91.9	-	508.1	50.9	10.0	355.4	1,016	3,659	
Urban	91.9		459.4	49.6	10.0	307.9	919	3,308	
Rural	-		48.7	1.3	-	47.4	97	351	
AGRICULTURAL SECTOR	248.9	-	5.1	-	-	3.4	257	927	
Field Operations	86.6		-			-	87	312	
Processing/Other	162.2		5.1			3.4	171	615	
FISHERIES SECTOR	38.7	-	1.2	-	-	0.8	41	147	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	38.7		1.2			0.8	41	147	
MILITARY SECTOR	738.2	-	1,221.8	-	-	489.6	2,450	8,819	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	5.3		0.3			1.0	7	24	
Buildings and Other	732.9		1,221.5			488.6	2,443	8,795	
PUBLIC/COMMERCIAL SECTORS	243.7		609.3	121.9	121.9	121.9	1,219	4,387	

Table 5-12: Estimated Electricity Supply/Demand Balance for the DPRK, 2020

	END USES								
UNITS: GIGAWATT-HOURS (GWh) EXCEPT AS NOTED	**MOTORS AND DRIVES**	**PROCESS ELECTRICITY**	**LIGHTING**	**SPACE AND WATER HEATING**	**AIR CONDITIONING**	**OTHER END USES**	**TOTAL ELECTRICITY (GWh)**	**TOTAL ELECTRICITY (TJ)**	**GENERATION FUEL/ ENERGY INPUTS (TJ)**
ENERGY SUPPLY							(232)	(834)	
Imports							48	172	
Exports							279	1,006	
ENERGY TRANSFORMATION	-	-	-	-	-	-	9,124	32,846	94,384
Electricity Generation, of which:							**14,045**	**50,560**	**94,384**
--Coal-fired							2,505	9,018	42,949
--Heavy Fuel Oil-fired							108	388	1,850
--Diesel-fueled							525	1,891	7,002
--Gasoline-fueled							163	585	3,900
--LPG-fueled							-	-	-
--Natural Gas-fired							-	-	-
--Other Fossil-fuel-fired							0	1	6
--Hydroelectric Power							10,657	38,366	38,366
--Solar Power							82.7	297.9	298
--Wind Power							3.5	12.5	13
--Tidal Power							0.2	0.7	1
--Nuclear Power							-	-	-
Petroleum Refining		-					(52)	(188)	
Coal Production/Preparation							(829)	(2,985)	
Charcoal Production									
Coke Production									
District Heat Production									
Other Transformation									
Own Use							(499)	(1,796)	
Losses							(3,540)	(12,745)	
ELECTRICITY FOR FINAL CONSUMPTION							8,892	32,012	
ELECTRICITY DEMAND	3,963	936	2,552	177	105	1,160	8,893	32,013	
INDUSTRIAL SECTOR	1,750.9	935.6	141.4	-	-	-	2,828	10,180	
Iron and Steel	350.2	315.2	35.0				700	2,521	
Cement	534.1	0.0	28.1				562	2,024	
Fertilizers	128.9	116.1	12.9				258	928	
Other Chemicals	80.9	72.8	8.1				162	582	
Pulp and Paper	21.7	-	1.1				23	82	
Other Metals	93.3	349.9	23.3				467	1,679	
Other Minerals	39.5	0.0	2.1				42	150	
Textiles	58.0	0.0	3.1				61	220	
Building Materials	8.8	-	0.5				9	33	
Non-specified Industry	435.6	81.7	27.2				545	1,960	
TRANSPORT SECTOR	967.5	-	25.0	-	-	25.0	1,018	3,663	
Road	15.9						16	57	
Rail	951.6		25.0			25.0	1,002	3,606	
Water							-	-	
Air							-	-	
Non-Specified							-	-	
RESIDENTIAL SECTOR	161.0	-	889.7	89.2	17.5	622.1	1,779	6,406	
Urban	161.0		805.0	86.9	17.5	539.6	1,610	5,796	
Rural	-		84.8	2.2	-	82.5	170	610	
AGRICULTURAL SECTOR	240.5	-	4.9	-	-	3.2	249	895	
Field Operations	86.6		-			-	87	312	
Processing/Other	153.9		4.9			3.2	162	583	
FISHERIES SECTOR	34.9	-	1.1	-	-	0.7	37	132	
Large Ships	-		-			-	-	-	
Collectives/Processing/Other	34.9		1.1			0.7	37	132	
MILITARY SECTOR	632.9	-	1,050.7	-	-	420.7	2,104	7,575	
Trucks and other Transport							-	-	
Armaments							-		
Air Force							-		
Naval Forces							-		
Military Manufacturing	2.6		0.2			0.5	3	12	
Buildings and Other	630.3		1,050.5			420.2	2,101	7,564	
PUBLIC/COMMERCIAL SECTORS	175.6		439.0	87.8	87.8	87.8	878	3,161	

5.3.2. Residential and Commercial/Institutional Sectors

The residential and commercial/institutional (or public/commercial) sectors in the DPRK consume a smaller fraction of national energy use than in most nations. Use of electricity, and, in fact, all non-biomass energy by the residential and commercial/institutional sectors has fallen substantially since 1990, as the availability of electricity and non-biomass fuels (and, eventually, biomass fuels as well) have declined. By our estimates, however, electricity use in these sectors has grown somewhat in many recent years, relative to the 2000s, with the exception of COVID-afflicted 2020. Below we outline the major assumptions underlying in our estimates of electricity use in the two sectors, present our 2020 and earlier results, describe key energy sector technologies in the sectors, outline what we see as the key energy sector needs, and describe the results of the analysis of a (non-comprehensive) set of electrical energy efficiency technologies for the two sectors.

5.3.2.1.Residential Sector Data and Assumptions

Our estimate of energy use in the residential sector begins with the assumption that 60 percent of the approximately 22 million people in the DPRK as of 1990 (excluding the 1.2 million persons then in active units of the military) lived in urban areas,[597] and that the average number of persons per household in both urban and rural households was 4.65 in 1990.[598] We assumed population growth averaging a small 0.08 percent annually through 2000[599]. From the year 2000 through 2020, with some reservations, we assumed, based on DPRK Census and other data, that the DPRK population increased at an average rate of 1.02 percent annually from 2000 through 2008, 0.536 percent per year from 2008 through 2010,[600] 0.500 percent per year after 2010 through 2014,[601] and 0.39 percent per year from 2014 through 2020, and that a small net rural-to-urban migration continued, with the national fraction of urban households rising to 61.3 percent

[597]Document in authors' files [HT1].

[598] This figure is an extrapolation from a single area (the Ongjin area) in southern DPRK (Document in authors' files [FC1]). Although it may not be an accurate weighted average figure for the country as a whole, it is probably fairly close, based on the authors' own observations in the Western DPRK village of Unhari in 1998.

[599] The US Central Intelligence Agency ("Korea, North", *CIA Factbook, 2001* (World Wide Web Version), USCIA, Washington, D.C., USA, 2001, http://www.odci.gov/cia/publications/factbook/geos/kn.html) lists a 2001 estimated growth rate of 1.22 %/yr and a total population of just under 22 million. The USDOE Energy Information Administration listed a year 2000 population of 21.7 million in its North Korea Country Analysis Brief (www.eia.doe.gov/emeu/cabs/nkorea.html, visited 5/2002). A file of "DPRK Energy Data" provided to Nautilus by the Korea Energy Economics Institute (KEEI, 2002) suggests a year-2000 population of 22.175 million and a growth rate of 0.4 percent annually (with the growth rate decreasing substantially between 1990 and 2000) but uses a year-1990 base population of 20.221 million for the DPRK. While recognizing the extreme difficulty in estimating DPRK population, we continue to assume that year 1990 population was 22 million (as official estimates suggest) and adopt the figure provided by KEEI as the year 2000 population. This implies a very modest net total increase in population over the decade, which is certainly consistent with food shortages and anecdotal but fairly widespread evidence of lack of proper food rations, as well as medical care, for the DPRK populace, offsetting the impacts of a national government program to increase the population.

[600] The 2008 Census document lists total births in the 12 months prior to the census as 345,630 (Table 16), and total deaths in the same period as 216,616. These figures imply a rate of population increase as of 2008 of 0.536% annually.

[601] A compilation of DPRK statistics by the International Fund for Agricultural Development (IFAD), formerly available as http://www.ruralpovertyportal.org/country/statistics/tags/dprkorea, estimates population growth at a slightly lower 0.50% annually as of 2014. We use this value as the estimated growth rate for population between 2010 and 2014, and adopt a slightly lower growth rate through 2020 based on the growth rate implied by population data from the United Nations for 2014 through 2020 (downloaded 1/28/2020 from https://population.un.org/wpp/Download/Standard/Population/), which is also consistent with trends in population in the region in general.

of the total by 2020.[602] By 2020, our estimate is that total DPRK population was 25.4 million, with about 4.4 million urban households and 2.8 million rural households.

That said, our reservations about using these population projections are as follows. The growth rate shown is calibrated to yield the 2008 total population reported in the landmark 2008 DPRK Census (*D P R Korea 2008 Population Census National Report*[603]) prepared under United Nations supervision. This document was welcomed as the first systematic census to be carried out on the DPRK in many years and is generally accepted by demographers as a useful picture of life in the DPRK, especially as no demonstrably superior estimate is available. Several researchers, however, have expressed doubts, privately and in some cases publicly, as to whether the 2008 population of the DPRK was likely, in fact, to be as high as the 24.05 million reported in the Census document. Inconsistencies have been noted between the size and age composition of the population reported in the 2008 Census and what had been known or imputed about population trends since 1990 in the DPRK. As of yet, however, neither we nor any other public documents we have seen have offered a definitive alternative estimate of 2008 population, so we adopt it for the estimated described here. We remain wary, however, of the fact that the 2008 population estimate that we are using could be overstated, perhaps by as much as 20 percent.

For the urban subsector, we assumed, based on the observations of recent visitors to the DPRK (including the authors), that the average urban household lives in a multi-story building in an apartment of approximately 50 square meters.[604] We further assumed an average electricity use of about 770 kWh per household (HH)-year in 1990. This is about 2.4 times the average household use of electricity in South Korea in 1975,[605] but is roughly consistent with a household using several electric lights, a small refrigerator (if used), a few small appliances, and a household's share of common electricity use (pumps, lighting) in common areas of multi-family buildings.

For urban sector cooking, we assumed that in 1990 petroleum-based cooking fuels (liquefied petroleum gas, or LPG, and kerosene) were used exclusively in Pyongyang, but were not used extensively elsewhere, where coal dominated.[606] For rural households, we estimated that in 1990 50 percent of rural households used coal for heating and cooking, 2 percent used LPG for cooking (a guess on our part), and that the rest used wood or biomass fuels. As of 1990, very little electricity was used for cooking or heating in either residential sector, as cooking was mainly fuels-based, and heating used fuels or district heat provided by a central plant or was accomplished using boilers housed in the utility rooms of apartment buildings or complexes.

[602] Though some observers of the DPRK report a significant urban to rural migration, others suggest that the migration is largely seasonal with urban dwellers going to rural areas during the agricultural season and returning to cities at other times of the year. Depending on how "urban" is defined in allocating the DPRK's population, the fraction of the population living in urban areas may be close to 65 percent, though observers suggest that in recent years there has been a "ruralization" of urban life, with many nominally urban dwellers making their living (or much of it) from farming or raising livestock. The recent reported surge in urban dwellers going to ports to help to process an exceptional squid and cuttlefish harvest can be thought of as one manifestation of this "ruralization"—essentially, DPRK residents taking advantage of opportunities to make a living as they are presented.
[603] *D P R Korea 2008 Population Census National Report*, Central Bureau of Statistics, Pyongyang, DPR Korea, 2009, available as https://unstats.un.org/unsd/demographic/sources/census/wphc/North_Korea/Final%20national%20census%20report.pdf,
[604] This size dwelling would be roughly consistent with conditions in parts of China (Liu, F. (1993), *Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects*. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA.LBL-33867 UC-350.
[605]Kim, E.-W., H. Kim, H.-K. Lim, C. Nahm, M.-C. Shin, and Y. Kim (1983), *The Electric Future of Korea*. Resource Systems Institute, Honolulu, Hawaii, USA. Research Materials RM-83-8.
[606] Document from authors' files.

1990 Electricity use in rural households was assumed to be less, on average, than in urban households, namely 512 kWh per HH-year.

Between 1990 and 2020, through a combination of austerity and fuel unavailability, our assumption, based on our own discussions with DPRK residents, our observations while in the DPRK, and on the experiences of other visitors to the DPRK that we have spoken with, as well as our analytical results, is that that residential end-uses of electricity, as well as (though to a somewhat lesser extent) coal, and oil products, declined substantially, particularly before 1996, while the number of households using wood or biomass fuels (though typically in substitution for coal for heating and cooking) rose, though the use per household did not rise much (due to restricted supplies). The fraction of urban households using district heat is assumed to have decreased slightly over time since 2000, essentially because the number of households has grown but we assume that the deployment of district heating systems has not. The use of district heat per connected household is assumed to parallel the use of electricity, since the two are either co-produced or depend on the same sorts of central power plant/central heating plant fuels and infrastructure, and thus would be subject to the same sorts of constraints, on average.

Lacking the data to make well-informed estimates, we have assumed that the fractions of electricity used in the residential subsectors by end use have not changed radically over time. Some shifts are likely—for example, the hours of residential electronics use may be up (when power supplies are available), though increased usage is probably offset by the use of newer, more energy efficient electronics imported from China. Similarly, there has likely been an improvement in lighting efficiency with the (mainly) import of compact fluorescent bulbs which were, when we visited the DPRK in 2009, beginning to overtake the use of inefficient incandescent bulbs, and the deployment of imported LED bulbs since, particularly in combination with the use of small household solar PV panels.

5.3.2.2.Residential Sector Results

Overall DPRK Residential electricity use fell dramatically, by our estimates, between 1990 and 2000 (Figure 5-25), due to a lack of electricity availability caused by a combination of limited fuel supplies for thermal generation and difficulties with hydroelectric output caused by the impacts of floods. In the late 2000s, electricity generation, and residential electricity use, rebounded somewhat, but urban and, especially, rural electricity use fell again between 2010 and 2014 due to the impacts of drought conditions on hydro output, before rising slightly through 2018, and then rising significantly in 2020 due to assumed A) to increased home-based activities due to restrictions on movement to comply with COVID-19 quarantine policies, and B) increased availability of electricity because other large users of power—industries and big institutions, for example—were substantially shut down for a period.

Figure 5-25: Residential Electricity Use by Subsector

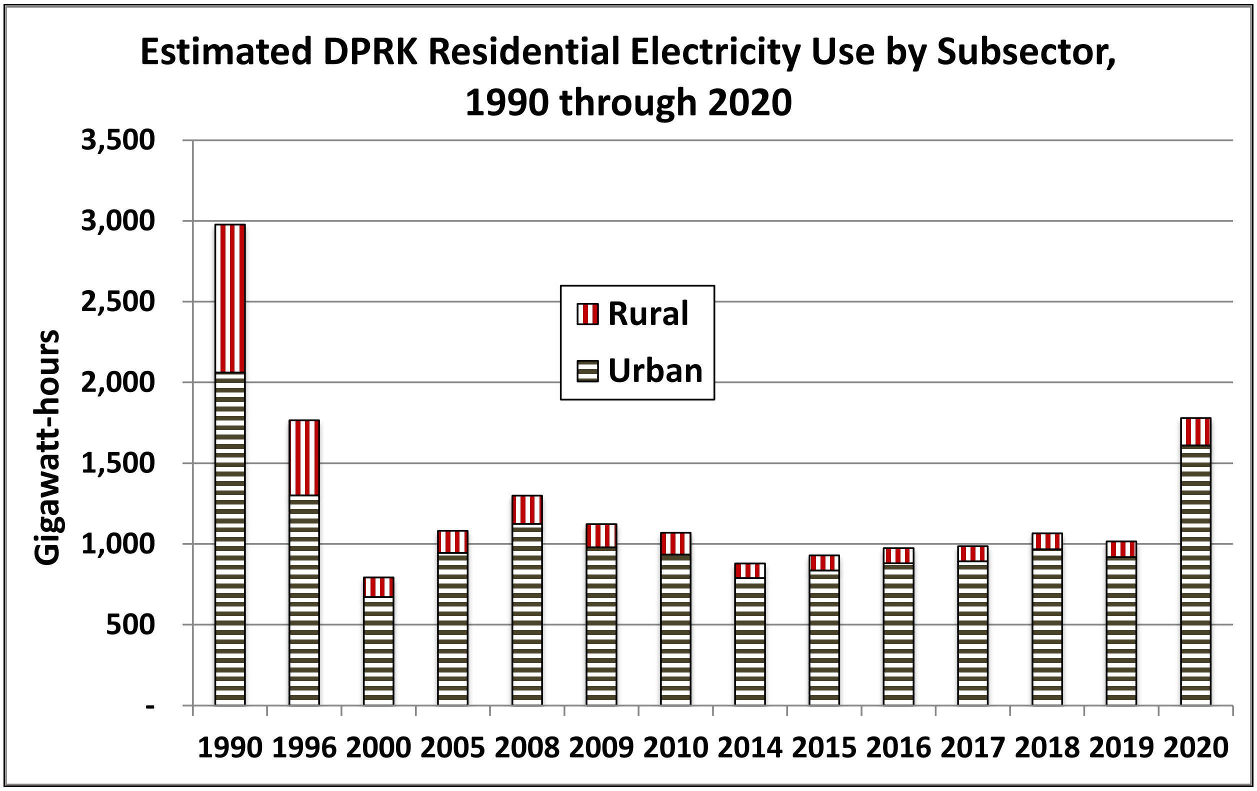
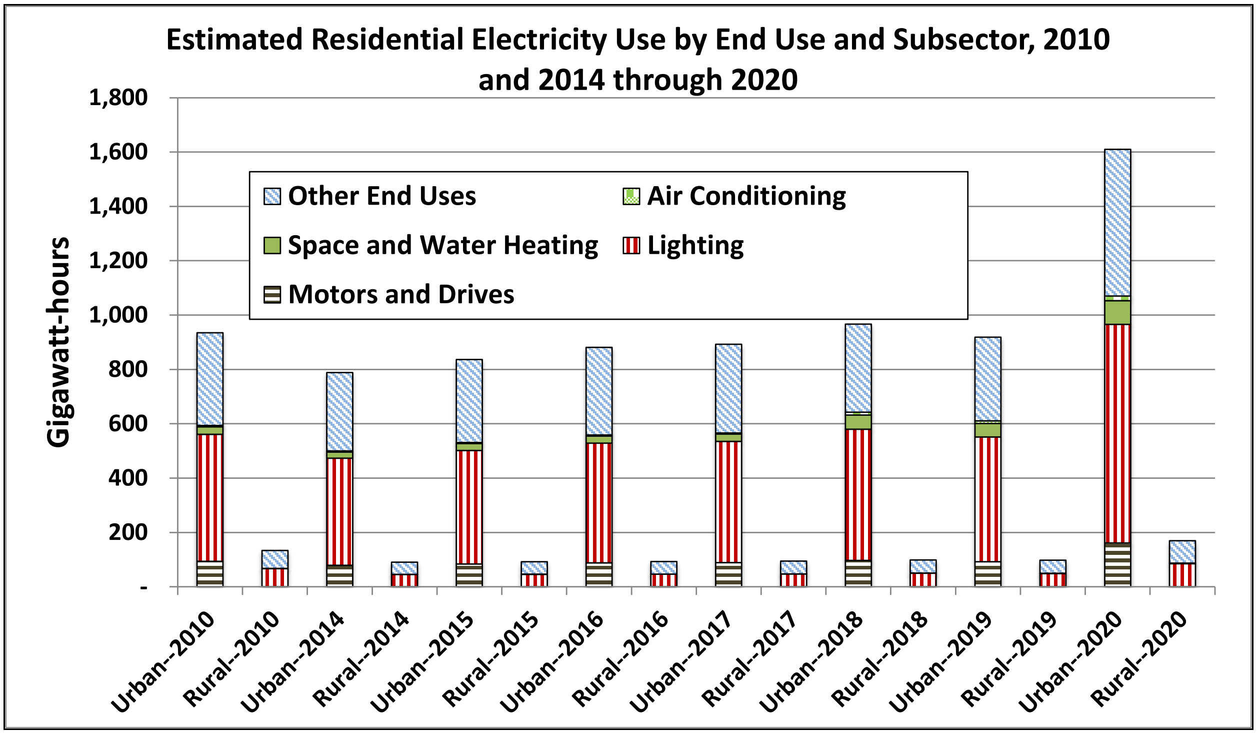


Figure 5-26 shows 2010 and 2014 through 2020 residential electricity use by subsector (urban and rural) and by estimated end use. Clear from a comparison of the two figures is the decline in electricity use—a function of the decline in availability of electricity—in both subsectors from 2010 to 2014, but particularly in the rural subsector, followed by modest growth in most years thereafter, due in part to more access to electricity from solar PV panels and electric generators. The year 2020, as noted above, is estimated to be an outlier due to the extraordinary conditions COVID-19 has visited on the DPRK (and the rest of the world as well). Our estimate is that average 2010 electricity use per household in 2010 was about 252 kWh for urban households, and 56 kWh for rural households, and corresponding figures for 2014 were 199 kWh per annually per urban household, and 36 kWh per year in rural households, the latter the equivalent of just one 40-Watt incandescent bulb (which still, as of 2009, were common, although not the dominant sources of light, even in Pyongyang) burning for 2 to three hours per day. By 2018, our estimate of electricity use per urban household rises to 238 kWh annually, although rural use remains at about 37 kWh. Use of electricity in 2020 per household is projected to be notably higher, for the reasons mentioned above at 368 and 61 kWh for urban and rural dwellings, respectively. We should emphasize, however, that actual consumption will vary widely from household to household and, particularly, from place to place, as some places (most notably, Pyongyang, and places near operating power plants and critical facilities) have and have had far more frequently-available electricity supplies than others (such as rural or otherwise remote locations, such as the DPRK's Northeast). Many locations, particularly in rural areas, probably get no electricity at all in some years, even if their grid connection remains intact. In Figure

5-26, "motors and drives" pertains to electricity that is used mainly in motor and drive systems in urban residential buildings, which in the urban sector would likely be pumps, fans, and in a few cases, elevators. "Other end uses" include consumer electronics such as radios, televisions and DVD players, and chargers for tablets or cell phones (for example). In general, urban electricity use dominates rural use, and electricity use in both sectors was estimated to be lower, due to reduced availability, in 2014 than in 2010, and in 2019 relative to 2018.

Figure 5-26: Residential Electricity Use by End Use and Subsector



5.3.2.3.Commercial/Institutional Sector Data, Assumptions, and Results

We have essentially no direct data on the use of electricity (or other fuels) in public and commercial buildings (which we define to include institutional buildings such as nurseries, schools, and hospitals) in the DPRK. To provide an approximate estimate of these quantities, we started with our estimate of urban residential floor space, and applied the ratio of residential urban floor space to public and commercial floor space (approximately 0.3) that prevailed in the "heating zone" of China as of 1989.[607] To estimate electricity use, we assumed an annual electricity use intensity of 33 kWh/m^2, derived from Chinese data (but about 10 percent higher to account for cooler average temperatures), and applied it to our public/commercial floor space estimate. In order to bring the sum of electricity demand for 1990 in the agricultural, public/commercial, and military sectors up toward (but not quite to) the approximately 25

[607] Liu, F. (1993), *Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects*. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA.LBL-33867 UC-350.

percent share of total electricity demand that these sectors reportedly accounted for, we included an additional placeholder value of 7 million GJ/year for other uses of electricity in the public/commercial sector. We assumed that 15 percent of public/commercial floorspace in 1990 was heated using district heating systems, and that public and commercial sector buildings used wood and biomass fuels in 1990 in an amount equal to 5 percent of their use of coal (on an energy-content basis). We assumed that oil use in the public/commercial sector was modest in 1990, at 0.3 percent of coal use, with 90 percent of oil use in the sector in 1990 being kerosene, and the rest LPG.

Over the period between 1990 and 2020, we assumed that total floor space per unit residential floor space declined somewhat from 1990 levels, as construction of public and commercial buildings received a lower priority for scarce resources, and that electricity (and coal and heat) consumption per unit floor space decreased significantly, particularly between 1990 and 1996, and 1996 and 2000.[608] We assumed a fraction of electricity use relative to 1990 in the year 2000—about 29 percent—that is a function of the same assumed average urban electricity outage rate used for the residential sector, namely that power outages in cities outside the Pyongyang area as of 2000 were by far the rule rather than the exception.

Figure 5-27 and Figure 5-28 chart the trends in electricity use, including by end use (for 2010 and 2014 through 2020), in the commercial and institutional sector in the DPRK. Key trends here, as described above, are the overall reduced use of electricity after 1990, generally tracking energy use in the residential sector as well as electricity availability, and rising slowly from 2014 through 2019 as the economy slowly improved. Electricity use in the sector is projected to have fallen relatively dramatically in 2020 because of COVID-19 restrictions (again, as in most other places in the world), shuttering shops and offices. As in the residential sector, one would expect that the commercial/institutional sector electricity demand in the DPRK will increase substantially if and when sufficient supplies are available, which makes the application of building energy efficiency measures in the sector a huge priority for any assistance activities in the sector. The estimated pattern of electricity use by end use for the public and commercial sector in Figure 5-28 show lighting as the dominant end-use in the commercial/public sector, mainly because most space and water heating (which is reportedly used sparingly in many commercial, public and institutional buildings) is by district heat (fired by coal) or via coal boilers, and air conditioning is relatively rare, though perhaps on the rise in some buildings in Pyongyang. Other end uses, including office machines and other devices, are estimated to use the most electricity in the sector after lighting.

[608] At least one recent account suggests that there has been a significant amount of new construction and new commercial activity in Pyongyang in recent years, though little evidence of such activity in other parts of the DPRK that the visitor (Stephanie T. Kleine-Ahlbrandt of the International Crisis Group) went to. Adam Taylor (2012), "These Pictures Offer A Rare Glimpse Into North Korea's Changing World", Business Insider, dated July 22, 2012, and available as http://www.businessinsider.com/north-korea-photos-provide-a-glimpse-into-a-changing-world-2012-7?op=1.

Figure 5-27: DPRK Public/Commercial Electricity Use

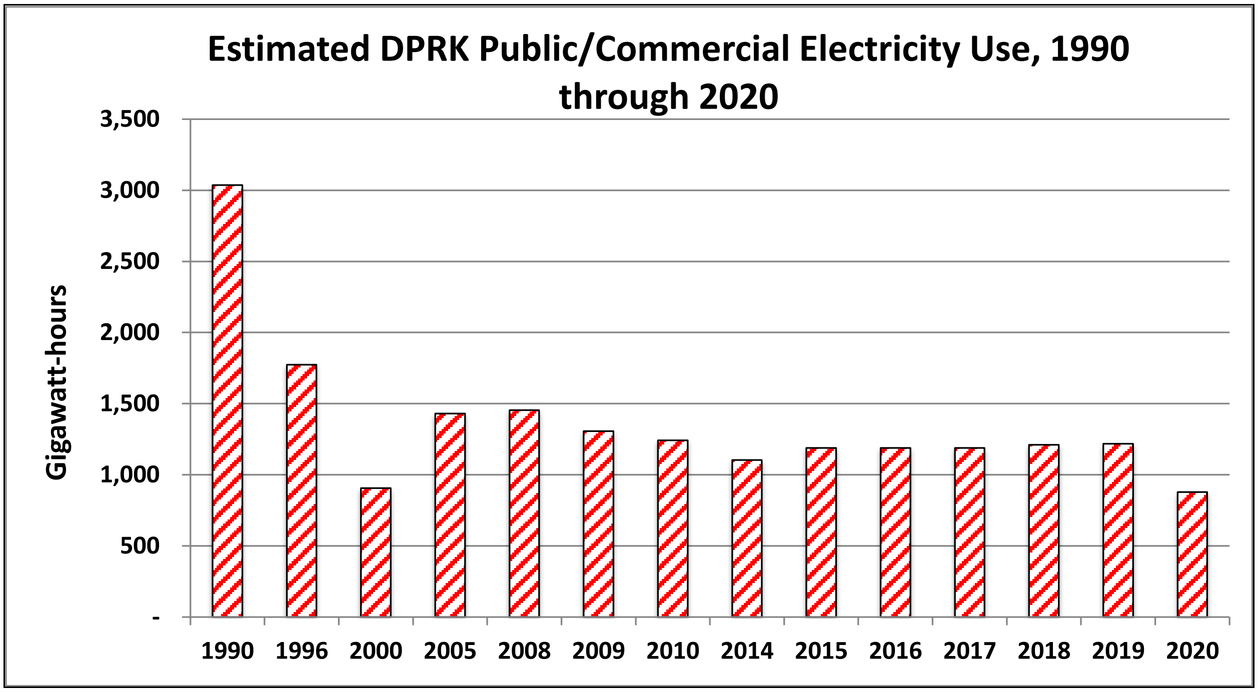
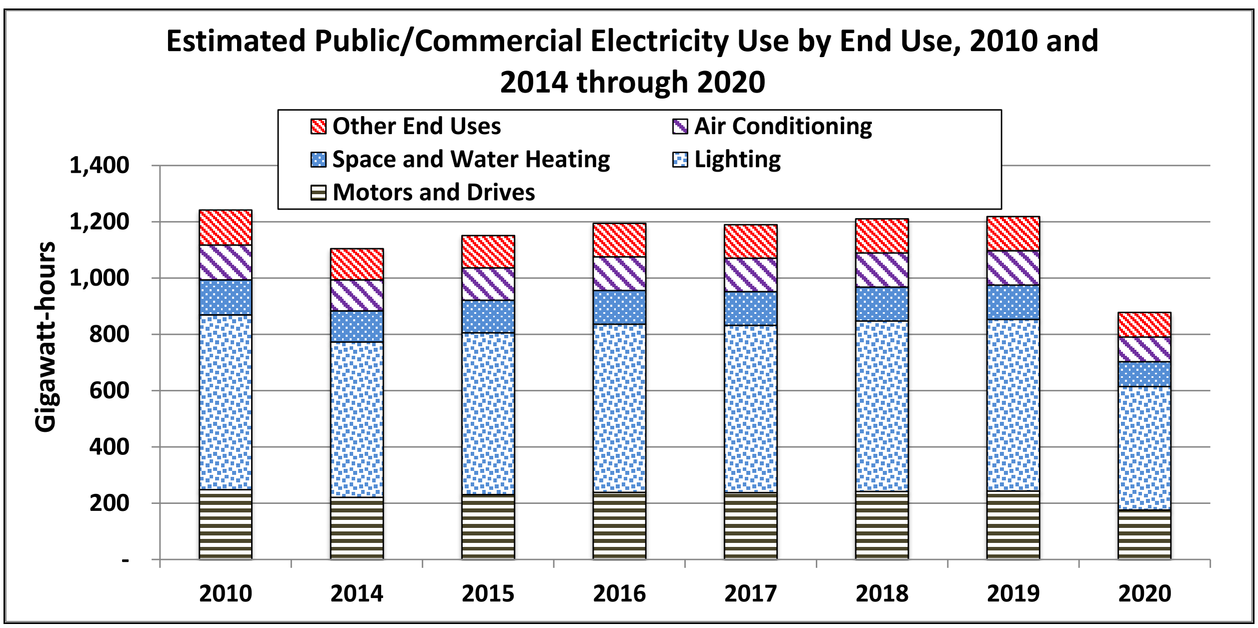


Figure 5-28: Public/Commercial Electricity Use by End Use



5.3.3. <u>Industrial Sector</u>

The industrial sector in the DPRK consisted, as of 1990, of a variety of energy-intensive heavy industries and a number of light industries. Since that time, many of the DPRK's industrial facilities have been idled, or are operating at low capacity factors, due to a lack of fuel, electricity, spare parts, raw materials, markets for output, or (likely, in many cases) a combination of the above. Some new industrial facilities have been commissioned in the DPRK since 1990, sometimes, perhaps mostly, as joint ventures with foreign firms, but the majority of the DPRK industrial sector continues to suffer from low output, particularly in the traditional heavy industries, with the major exceptions being where Chinese firms have invested to produce, for example, mineral products for export to China. Exports of raw materials to China, rather than goods in the DPRK processed, are the norm, with a significant exception being the export of finished clothing to China, an industry that has matured since 2010 and typically involves the import of cut cloth and other imports from China, and the export of clothing sewn by DPRK workers by to China. In some of the years before UNSC sanctions restrictions took hold, trades on the order of a billion dollars of exports and imports in the clothing customs categories were reported between the countries, with the DPRK's net income from the transaction looking much smaller than the gross trade flows—perhaps on the order of $100 million annually, though that sum still represents significant income for the DPRK. Below we outline the major assumptions underlying in our estimates of 2020 and earlier electricity use in the industrial sector, and present our results.

5.3.3.1.Industrial Sector Assumptions and Inputs

To estimate energy use in the industrial sector, our basic approach has been to gather all of the data on the physical output of specific industrial products, as of 1990, that we could for the major industrial subsectors of the DPRK, and multiply those physical output figures by per-unit energy intensities obtained mostly from studies of Chinese industries.[609] In a very few cases, we obtained and used anecdotal figures for energy intensities of key industrial plants in the DPRK, and in a few other cases we were able to use historical energy intensities from the Soviet Union as provided by a colleague in Russia.[610]

It has been estimated that 60 percent of the industrial infrastructure in the DPRK was developed with substantial technical assistance from the former Soviet Union. As such, for many subsectors we realize that it would have been more appropriate to use energy intensity factors from the USSR experience than to use Chinese factors, but we have not had access to sufficient energy intensity data from the USSR to allow us to do so. Happily, our experience thus far has been that industrial energy intensities in the USSR and in China as of 1990 were often not terribly different.

We have made the general assumption that, as of 1990, industries in the DPRK are at least 10 percent more energy intensive than those in China whenever Chinese energy intensities were used, and 15 percent more energy intensive than USSR where Soviet energy intensities were

[609] An alternative approach would have been to obtain output figures expressed in monetary terms and use energy intensities per unit financial output. Unfortunately, the command-and-control nature of the DPRK economy (particularly in the 1990s), coupled with the fixed and essentially arbitrary exchange rates of the DPRK currency with hard currencies such as the dollar, make this approach unusable for most subsectors. Because of the lack of true markets in DPRK (until recently, and even now limited to only selected classes of domestic goods, including some foods, although many manufactured goods imported from China are sold in unofficial markets), the prices of goods have no particular relation to the actual value that the goods would have in a market economy (even a partial market economy like China's), thus cross-national comparisons of per-monetary-unit intensities are highly problematic for use in the DPRK case.

[610] Data for energy intensities in several industrial subsectors was provided to us by Dr. V. Kalashnikov (personal correspondence, September 1997).

used. Although these estimates are rough, we believe that they are appropriate given (among other reasons) A) the testimony of travelers to DPRK about the generally poor condition of North Korean industrial facilities; B) the vintage of most industrial plants in the DPRK (few were built more recently than the 1970s, and some are leftovers from the Japanese occupation of the 1930s and 1940s); C) the low quality of much of the DPRK's coal, which contributes to poor combustion efficiencies; and D) reports of how Soviet industrial designs were "beefed up" (reinforced) to allow equipment to stand up under difficult conditions in the DPRK.

Key estimates of our assumptions as to the evolution of industrial output over time relative to 1990 output are provided in Table 5-13, and described below.

Table 5-13: Estimates of Output in DPRK Industrial Subsectors Relative to 1990

Subsector	1996 Production Relative to 1990	2000 Production Relative to 1990	2005 Production Relative to 1990	2008 Production Relative to 1990	2009 Production Relative to 1990	2010 Production Relative to 1990	2014 Production Relative to 1990
Iron and Steel	35%	18%	15%	15%	21%	21%	20%
Cement	40%	30%	32%	40%	56%	57%	61%
---- fraction of heat from heavy oil	10%	27%	13%	10%	3%	5%	5%
Fertilizers	25%	8%	11%	11%	7%	7%	23%
Other Chemicals	30%	18%	18%	17%	15%	14%	11%
Pulp and Paper	30%	18%	18%	17%	15%	15%	10%
Other Metals	30%	18%	60%	62%	61%	58%	52%
Other Minerals	30%	30%	50%	52%	50%	50%	50%
Textiles	30%	18%	20%	20%	17%	16%	12%
Building Materials	30%	30%	30%	30%	30%	28%	22%
Non-Specified Industry--non-oil fuels	33%	17%	15%	15%	11%	11%	8%
Non-Specified Industry--diesel oil	20%	18%	20%	12%	14%	15%	10%
Non-Specified Industry--heavy oil	30%	36%	28%	28%	25%	29%	28%

	2015 Production Relative to 1990	2016 Production Relative to 1990	2017 Production Relative to 1990	2018 Production Relative to 1990	2019 Production Relative to 1990	2020 Production Relative to 1990
Iron and Steel	18.0%	20.3%	18.2%	17.0%	17.0%	14.5%
Cement	60.9%	64.3%	62.2%	58.0%	58.0%	46.0%
---- fraction of heat from heavy oil	8.0%	8.7%	4.1%	4.9%	4.9%	8.5%
Fertilizers	21.0%	24.0%	16.3%	9.1%	9.1%	4.6%
Other Chemicals	11.0%	11.0%	11.0%	11.0%	11.0%	8.0%
Pulp and Paper	10.0%	10.0%	10.0%	10.0%	10.0%	8.0%
Other Metals	52.0%	52.0%	49.0%	49.0%	49.0%	37.0%
Other Minerals	50.0%	50.0%	45.0%	45.0%	45.0%	35.0%
Textiles	12.0%	12.0%	11.0%	11.0%	11.0%	8.0%
Building Materials	22.0%	22.0%	21.0%	23.0%	23.0%	16.0%
Non-Specified Industry--non-oil fuels	8.0%	8.0%	8.5%	12.0%	12.0%	12.0%
Non-Specified Industry--diesel oil	12.5%	14.0%	7.0%	7.0%	7.0%	7.0%
Non-Specified Industry--heavy oil	23.0%	23.0%	14.8%	15.2%	15.2%	18.0%

In the industrial sector, we assumed that year 2000 industrial output was 18 percent of 1990 levels in all subsectors except cement (30 percent), fertilizers (7.5 percent), and non-specified industries (17 percent).[611] The building materials and "other minerals" sectors were assumed to

[611] WWW.koreascope.com (no longer available as of 2021) in "Production of Major Industrial Items and World Ranking" (visited 6/3/02), listed the ROK production of steel in 1999 as 41 million tonnes. In "Economic and Social Comparison between the Two

have the same relative output as the cement sector[612]. We assumed, based on reports (and our own observations) of eroding industrial facilities, plus the probable impact of poor coal, oil, and electricity on industrial machinery, that the average energy intensity of industrial production was 115 percent of 1990 levels, up from our assumed 110 percent of 1990 levels in 1996. For 2005, we assumed that iron and steel production in the DPRK continued to decline (to 0.87 million tonnes, or under 15 percent of its 1990 level), remaining at that level through 2009 before increasing slightly in 2010 to accommodate increased exports of iron and steel to China. For 2014, we assumed that iron and steel production remained close to the levels of the recent past, at about 20 percent of 1990 levels, falling to about 17 percent of 1990 levels by 2019 due to the impacts of UNSC export sanctions, and still further in 2020 due to a reduction in industrial activity due to COVID-19 restrictions.[613] Figure 5-29 shows an image of what appears to be the Songnim-Hwanghae Iron and Steel Complex, along the Taedong River, as of late 2019.[614]

Koreas", on the same WWW site, the ROK's steel production is listed as being 33 times that of the DPRK, implying an annual production of about 1.24 million tonnes. This figure, about 25 percent of 1990 production levels, seems plausible (though possibly high). A figure that is probably from the same ultimate source, the Korea Iron & Steel Association, suggests a value of 1.086 million tonnes in 2000 along with 1.208 million tonnes in 1996, and 1.168 million tonnes in 2005. It is unclear how these figures were derived. Based on consideration of existing estimates, observations of the overall DPRK economy, we adopt the estimate of 1.08 million tonnes in 2000. The www.koreascope.com source, in the "Economic and Social…" page, lists a DPRK cement production of 4.1 million tonnes, or about 41 percent of year 1990 production, in 1999, which seems plausible. Data that are probably from the same ultimate source, the Korean National Statistical Office and the Korea Cement Industrial Association, suggest that year 2000 cement output was 4.6 million tonnes, and output in 1996 was 3.79 million tonnes. It is unclear how these numbers were derived, and though one would expect the cement industry to decline somewhat less than other industries, as it is/was not largely an export industry, the observed lack of recent construction activity in the DPRK would suggest that the level of 1996 to 2000 increase that the latter source shows is not what one would expect. We assume cement output of 3.3 million tonnes in 2000, and www.nis.go.kr/english/democratic/industry07.html, dated 2001, by the ROK National Intelligence Service, suggested (the site is no longer active) that supplies of fertilizer at the time covered only 40 percent of fertilizer needs in the DPRK. *Causes and Lessons of the "North Korean Food Crisis*", by Tony Boys of Ibaraki Christian University Junior College (2000), lists total fertilizer supply in the DPRK in 1999 of 200 ktonnes of "NPK", of which 32% was produced domestically, 10% imported, and the remainder provided in aid. This would imply that about 11% of 1990 levels of fertilizer production were achieved in 1999. As an alternative source, the presentation "Agriculture and Fertilizer Situation in DPR Korea", by R.V. Misra, formerly available as http://www.fertilizer.org/ifa/publicat/PDF/2006_crossroads_misra_slides.pdf (from the International Fertilizer Industry Association), presented as part of the "IFA Crossroads ASIA-PACIFIC 2006 Conference 'Growing markets, nurturing success'", Chiangmai, Thailand, 13-16 November 2006, suggested that1999 production of fertilizer in the DPRK was 63 thousand tonnes (of nitrogen), which is roughly consistent with the level suggested in the article by Tony Boys that is quoted above. Assuming this figure is correct, we adopt Misra's 2000 fertilizer production figure of 37.5 thousand tonnes of nitrogen.

[612] With the exception of "Other Minerals" and "Building Materials", we assume that the level of activity in other industries relative to 1990 in the year 2000 were approximately the same as in the iron and steel sector. The building materials and other minerals subsectors are assumed to have activities relative to 1990 that are similar to the cement industry. The other minerals subsector includes magnesite (or, when processed like lime for cement, magnesia), which is a valuable export product. An industry source indicates that an 8000 tonne shipment of magnesia (although it may have been magnesite) arrived in Europe in early 2001. Japan imported $3.5 million worth of magnesia in the first half of 2000 (Korea Trade-Investment Promotion Agency data from http://www.kotra.or.kr/main/common_bbs, visited 6/3/02, "Trade Tendencies of the Major Countries"), which, if annualized and assuming a sales price of $US 100 to $200 per tonne (within the range suggested in Queensland Department of Minerals and Energy *Mineral Information Leaflet No 5: MAGNESITE*, dated January 1998, suggests exports of 35 to 70 thousand tonnes to Japan alone, which in turn suggests relatively active production of the mineral. On our trip to the DPRK in October of 2000 we saw working brick or tile production facilities; these were some of the very few active industrial facilities we saw during our time in the DPRK.

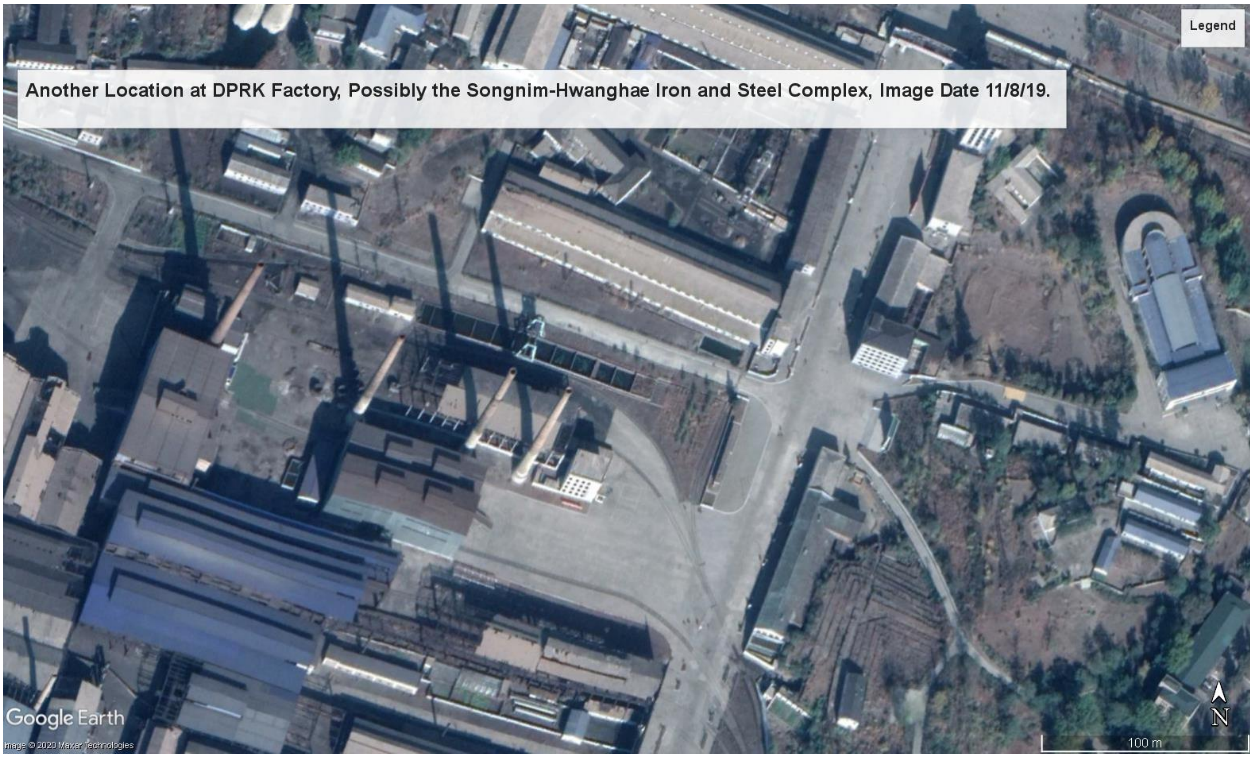
[613] Quoting the Bank of Korea, the Website "Trading Economics" (https://tradingeconomics.com/north-korea/steel-production) offers the following figures for DPRK steel production over the years (thousand tonnes): Web page "North Korea Steel Production". In all probability, these figures are rough estimates, but we use them as figures of merit to scale energy use in the DPRK iron and steel industry. Figures for 2018 and 2019 were not available from this source as of 2/2020.

[614] This Google Earth Pro image of a factory, along the Taedong River between Nampo and Pyongyang, is possibly of the Songnim-Hwanghae Iron and Steel Complex. The image was taken in November 2019. Coordinates are approximately 38.737, 125.634. An active smokestack is visible in the upper part of the image, along with a coal port and coal storage, and storage of what appears to be iron and/or steel products is the lower part of the image, near the river. Other images of this complex, going back several years in time, do not appear to show active smokestacks, suggesting that the plant is often idle.

Figure 5-30 shows a location about 1.5 km up the river (Northwest) from the image in Figure 5-29 that is probably a part of the same complex, on the same day in 2019. The close-up image shows a new building with a brown roof, built between early 2018 and 2019, next to a set of four tall smokestacks that were once a set of six. The site has been otherwise refurbished as well during that time period. Earlier images available on Google Earth Pro show those smokestacks not operating except in 2002, which one of the (then six) is operating. Although of course highly anecdotal, this observation supports that the assumption of a low capacity factor for DPRK iron and steel production over the last two decades is probably justified, but indicates that the DPRK is, in some instances, upgrading industrial sites, although it is difficult to say whether in this case the upgrade is designed for a resumption of iron and steel production or to allow the site to be used for another purpose.

Figure 5-29: DPRK Iron and Steel Complex Near Songnim

Figure 5-30: Close-up of New Buildings at DPRK Iron and Steel Complex Near Songnim[615]



Cement production is assumed to have increased slightly (with the overall increase in economic activity) to 32 percent of 1990 levels by 2005, rising to about 56 percent (6.1 million tonnes) in 2009, 57 percent in 2010, and 61 percent in 2014, and 64 percent in 2015, before falling to 58 percent in 2018 and 2019, and to an assumed 46 percent in 2020, due to production restrictions and reduced demand (due to reduced construction activity) related to COVID-19. For 2009-on, we use cement production figures provided on the website "Trading Economics", which quotes the Bank of Korea.[616] In all probability, these figures are rough estimates, but we use them as figures of merit to scale energy use in the DPRK cement industry. Fractions of heat from heavy oil are estimates used to balance overall heavy fuel oil supply and demand. These production figures seem somewhat high to us, and are somewhat at odds with reports of cement shortages for, for example, hydroelectric plant construction. In addition, the DPRK has generally been a net importer of cement, based on UN Comtrade statistics, since 2015, with reported imports from China dominating and ranging from 77 to 310 thousand tonnes annually between 2010 and 2019 (with considerable annual variation), though the decision to use imported or domestic cement

[615] Source, Google Earth Pro, location 38.742355°, 125.617459°.
[616] Trading Economics (2020), web page "North Korea Cement Production", https://tradingeconomics.com/north-korea/cement-production. As of February 2020, this source did not yet include an estimate for cement output in 2018, thus we assume output in 2018 was somewhat lower than in 2017 due to the general economic slowdown induced by UNSC sanctions. Although the inputs to the DPRK cement industry, with the possible exception of spare parts, are likely of domestic origin (coal, limestone, silica), it seems probable that overall cement use would have declined in 2018 due to a reduction in construction as sanctions affected other industries and the economy in general.

may be a function of either location (construction sites near the Chinese border may find it easier to source cement from China) or of required cement grade or quality.

The Sangwon Cement Plant, located South and East of Pyongyang, is shown in the Google Maps image below (Figure 5-31; rough coordinates, 38.876890, 126.036658).   What we assume to be limestone is supplied to this plant from a set of mines a few kilometers away, as shown in the second Google Maps image below (Figure 5-33; coordinates 38.867119, 126.091016). It is unclear why this mine is labeled "Steel Mine" in the image.

Figure 5-31: Sangwon Cement Plant Near Pyongyang

Figure 5-32: Limestone Mine Feeding Sangwon Cement Plant

Fertilizer output increased slightly from 2000 (to 11 percent of 1990 levels)[617] in 2005, decreasing to about 7 percent of 1990 levels in 2009 and 2010. By 2014, by our estimate, fertilizer output had risen to 23 percent of 1990 levels, and remained at close to that level through 2016, before dropping in 2017 and 2018, to about 16 and 9 percent, respectively. For 2008 through 2010, estimates of fertilizer production were obtained from the UN Food and Agriculture Organization and World Food Program (2010), *Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea*.[618] The most recent update to the above report what we could find is dated 2013, and includes a table that suggests increasing domestic output of nitrogenous fertilizer through 2013.[619] Although we could not find, as of this writing, direct information on fertilizer production in the DPRK in 2014, the trends in the table above suggest increasing domestic output, which is consistent with DPRK announcements and the results of a *38 North* analysis ("North Korea's Namhung Youth Chemical Complex that notes increases in fertilizer production in recent years.[620] Coupled with this, imports of nitrogenous fertilizer from China declined in the early 2010s, based on information from the UN Comtrade database. (The DPRK does imports fertilizer from other countries, but the quantities imported are very small compared with imports from China.) We were unable to find direct estimates of DPRK fertilizer output prepared by others for years after 2012, but a pair of United Nations Food and Agriculture Organization (FAO) studies offer estimates of overall supplies of DPRK nitrogen (and phosphate) fertilizer through 2017,[621] and we used UN Comtrade statistics on fertilizer imports by the DPRK to prepare the estimates for domestic production shown in Figure 5-33. For 2020, we assumed fertilizer production equal to half of 1990 levels, due to restrictions on trade and industrial activity related to the COVID-19 pandemic.

[617] Based on data in 2006 presentation by R.V. Misra, "Agriculture and Fertilizer Situation in DPR Korea", available as http://www.fertilizer.org/ifa/publicat/PDF/2006_crossroads_misra_slides.pdf (from the International Fertilizer Industry Association), presented as part of the "IFA Crossroads ASIA-PACIFIC 2006 Conference 'Growing markets, nurturing success'", Chiangmai, Thailand, 13-16 November 2006..

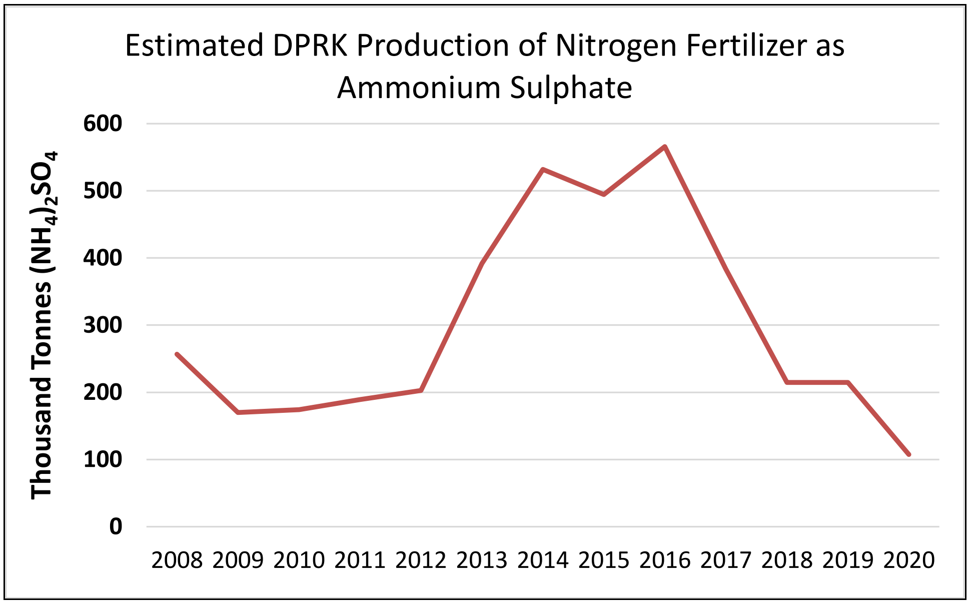
[618] Dated 16 November 2010, and available as http://www.fao.org/docrep/013/al968e/al968e00.pdf. Estimates are derived from data in Table 2 of that document.

[619] UN Food and Agriculture Organization and World Food Program (2013), *Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Democratic People's Republic of Korea*, dated 28 November 2013, and available as http://www.fao.org/docrep/019/aq118e/aq118e.pdf. Table 2 of that report includes fertilizer consumption and production data for the DPRK.

[620] Joseph S. Bermudez Jr (2014), "Seven Years of Construction Pays Off", *38 North*, dated 10 April 2014, and available as http://38north.org/2014/04/jbermudez041014/).

[621] UN FAO (2018), *GIEWS Update: The Democratic People's Republic of Korea, Food Supply and Demand Outlook in 2017/18 (November/October)*, dated 9 July 2018, and available as http://www.fao.org/3/ca0363en/CA0363EN.pdf, and for earlier years, *UN FAO (2016) GIEWS Update: The Democratic People's Republic of Korea, Food Supply and Demand Outlook in 2015/16 (November/October)*, dated 27 April 2016, and available as http://www.fao.org/3/a-i5572e.pdf,

Figure 5-33: Estimated Domestic DPRK Fertilizer Production, 2008-2020



Activity in 2005 in the building materials, pulp and paper, and other chemicals subsectors were assumed to be unchanged from 2000, but to have fallen slightly through 2010, with textiles output up slightly in 2005, but falling slowly thereafter. Output is assumed to have increased substantially in the other metals and other minerals sectors[622] between 2000 and 2005, due in part to output destined for export to China, and to remain at approximately those higher levels through 2010. Output in all of these industries is estimated to have been lower in 2014 than in 2010 as a result of continued displacement of domestic goods by imported (mostly Chinese) goods, the degradation of factory infrastructure due to lack of parts and replacement equipment, and the lack of reliable power supply. Even prior to 2010, anecdotal and fragmented reports of activity, or lack of activity, in industrial installations included:

- "The Wonsan shipyard has not built a new ship since 1985, and struggles in even repair work due to deteriorated equipment, with only 1/6th of the original workforce even reporting."
- "The 6.4 Wonsan Vehicle Factory has ceased manufacturing trains due to a shortage of raw materials and electricity, and now occasionally repairs trains, but also makes doors for buildings; its reporting workforce is about 1/6th of 1990 levels".[623]
- "Production Rate below Thirty Percent at Lanam Mine Machinery Factory in Chungjin" despite the pressure of a "150-day battle campaign" (national productivity push).[624]
- Low output (due to lack of electricity and food) at the Duksa Coal Mine (producing "low

[622] Estimates for these sectors based in part on data provided by Dr. Chung Woo-jin, in his presentation entitled "Mineral Resources in DPRK", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.
[623] *North Korea Today*, No. 298, 10/2009.
[624] *North Korea Today* No. 291, 8/2009.

> heat anthracite coal") of Soodong District, and "[i]dled clothing, shoe, and "market" factories in Hamheung, which used to receive 1000 te/month from the mine."[625]

We assume that there was relatively little change in industrial output in these sectors from 2015 through 2019, but production is projected to fall in 2020 as a result of COVID-19.

As a result of closing of some inefficient plants, improved capacity factors in some industries, and some investment in industrial infrastructure, particularly by Chinese firms,[626] the overall average energy efficiency of those DPRK industrial plants that remained in operation is assumed to have increased slightly between 2000 and 2010, with energy intensities averaging 112 percent of 1990 levels in 2005 and declining to 110 percent of 1990 levels in 2008 through 2010 (and less in some subsectors), in part as a result of simply closing the oldest plants. We assume that these efficiencies were mostly unchanged through 2020, ranging from 108 to 110 percent of 1990 levels, with the exception of iron and steel production, at 99 to 100 percent of 1990 levels, and cement production, at 101 to 102 percent.

To estimate the amount of electricity imported to the DPRK from the ROK, as reported in section 5.2.7, above, we estimated the amount of electricity used in the (mostly) textile firms operating in the Kaesong Industrial Zone. An article quoting the KEPCO manager of the power line running into Kaesong, however, indicates that while the capacity of the substation feeding Kaeosong is 100 MW, the power delivered to Kaesong averaged 30 to 50 MW, presumably in early 2013 when the complex was operating at a "normal" level.[627] The total value of goods from the Kaesong complex was 251.4 million USD in 2008 and 256.5 million USD in 2009, up from 14.9 million USD in 2005.[628] In 2010, the value of goods from the Kaesong complex was 323.3 million USD.[629] More than half of this output value was from textile/apparel firms. In the ROK in 2007, the approximate electricity intensity of the textile industry was 1.379 kcal per ROK Won, or about 1.67 kWh per USD. This would imply electricity consumption at Kaesong of about 419 GWh in 2008, 428 GWh in 2009, and 540 GWh in 2010. These figures are rough estimates, but close enough to the capacity of the line to be plausible. The ROK textile industry, however, is probably more energy-intensive on average than the textile industry in Kaesong, since the latter is mostly smaller businesses involved in assembling garments, not, for example, in making cloth or fiber. We therefore assume that, based on news reports above, the average capacity factor for the 100 MW substation providing power to the complex was 33% in 2010, and estimate electricity use based on the reported value of output (although this is not ideal, as output value is an indirect measure of required energy input at best) and estimate electricity delivery from the ROK to Kaesong accordingly. In 2007, we assume that total electricity provision over the 15 and then 100 MW lines were mid-way between the totals estimated to be provided in 2006 and 2008, or 193 GWh. In 2008, based on the output above, we estimate the

[625] *North Korea Today*, No. 268, March 2009.

[626] See, for example, Professor Li Dunqiu's presentation entitled "DPRK's Reform & Sino-DPRK Economic Cooperation", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.

[627] See, for example, Kang Tae-ho and Ha Eo-young, "Electricity use at Kaesong hums along at bare minimum", *The Hankyoreh*, dated, May 7, 2013, and available as http://english.hani.co.kr/arti/english_edition/e_northkorea/586276.html.

[628] Dick K. Nanto and Mark E. Manyin, U.S. Congressional Research Service (2010), *The Kaesong North-South Korean Industrial Complex*, dated June 1, 2010, and available as www.opencrs.com/document/RL34093/2010-06-01/download/1013/.

[629] Dick K. Nanto and Mark E. Manyin (2011), (US) Congressional Research Service, *The Kaesong North-South Korean Industrial Complex*, dated April 18, 2011, and available as http://www.fas.org/sgp/crs/row/RL34093.pdf.

electricity provision to Kaesong at 225 GWh, with electricity use estimated at 229 GWh in 2009, and 289 GWh in 2010, 350 GWh in 2014, 438 GWh in 2015, and 54 GWh in 2015, with no supplies provided thereafter through 2020.[630]

In 2014, the value of the output of the Kaesong industrial complex was reported as $470 million. Adjusting this value downward somewhat to account for the difference in exchange rates between the ROK Won and USD in 2014 versus 2010 (roughly 10 percent, based on Xe.com data), and USD inflation between 2010 and 2014 about nine percent, yields an equivalent output in 2014 of $392 million, which suggests that ROK electricity provision to Kaesong in 2014 might have been in the range of 350 GWh, Of course, the direct data on consumption of electricity at Kaesong is known to KEPCO and probably others in the ROK, but data on Kaesong electricity consumption were not immediately available to the authors, if indeed they are available publicly.

Our estimate of industrial electricity use by sector and end-use, though generally consistent with international experience, including in 1990s China, should be considered only a starting point to be built upon and refined with further analysis and, ideally, energy use surveys in the DPRK. We assumed that the fraction of electricity used in electric motors and motor drive systems in each industrial subsector and in transportation, agricultural processing, and military manufacturing were and are as indicated in Table 5-14, with lighting accounting for another five percent of overall electricity use in each industrial subsector, and the remaining electricity used in the general "process energy" category. Process energy would, for example, include electrolytic or electric arc processing of metals,

Table 5-14: Fraction of Electricity Assumed Used in Motors and Drives (with Estimated Consumption in 1990)

Subsector	Total TJ/yr	Fraction in Motors & Drives	Total TJ/yr Motors & Drives
		Note 10	
Iron and Steel	2,869	50%	1,435
Cement	1,461	95%	1,388
Fertilizers	1,535	50%	768
Other Chemicals	1,092	50%	546
Pulp and Paper	149	95%	141
Other Metals	2,633	20%	527
Other Minerals	222	95%	211
Textiles	448	95%	425
Building Materials	58	95%	55
Non-specified Industry	2,838	80%	2,270
Transportation	4,185	95%	3,976
Agricultural Processing	1,023	95%	819
Military Manufacturing	21	80%	20

[630] Kim Myong-song (2015), "Output at Kaesong Soars Despite Friction" *Choson ilbo*, dated July 10, 2015, and available as http://english.chosun.com/site/data/html_dir/2015/07/10/2015071000808.html.

5.3.4. Industrial Sector Results

Figure 5-34 shows our estimate of industrial electricity use by subsector from 1990 through 2020. As indicated, industrial electricity use in the DPRK has dropped by about 80 percent since 1990, as a result of the combination of lack of markets for DPRK industrial goods, lack of spare parts for factories built with assistance from the former Soviet Union, international economic sanctions, and, of course, a lack of electricity supplies. As shown in Figure 5-35, the fraction of estimated industrial sector electricity demand accounted for by each subsector has varied over the years, with the cement and other minerals (the latter are mostly for export) sectors accounting for a greater share of total electricity consumption in 2014 than in 1990.

Figure 5-34: Industrial Energy Use by Subsector

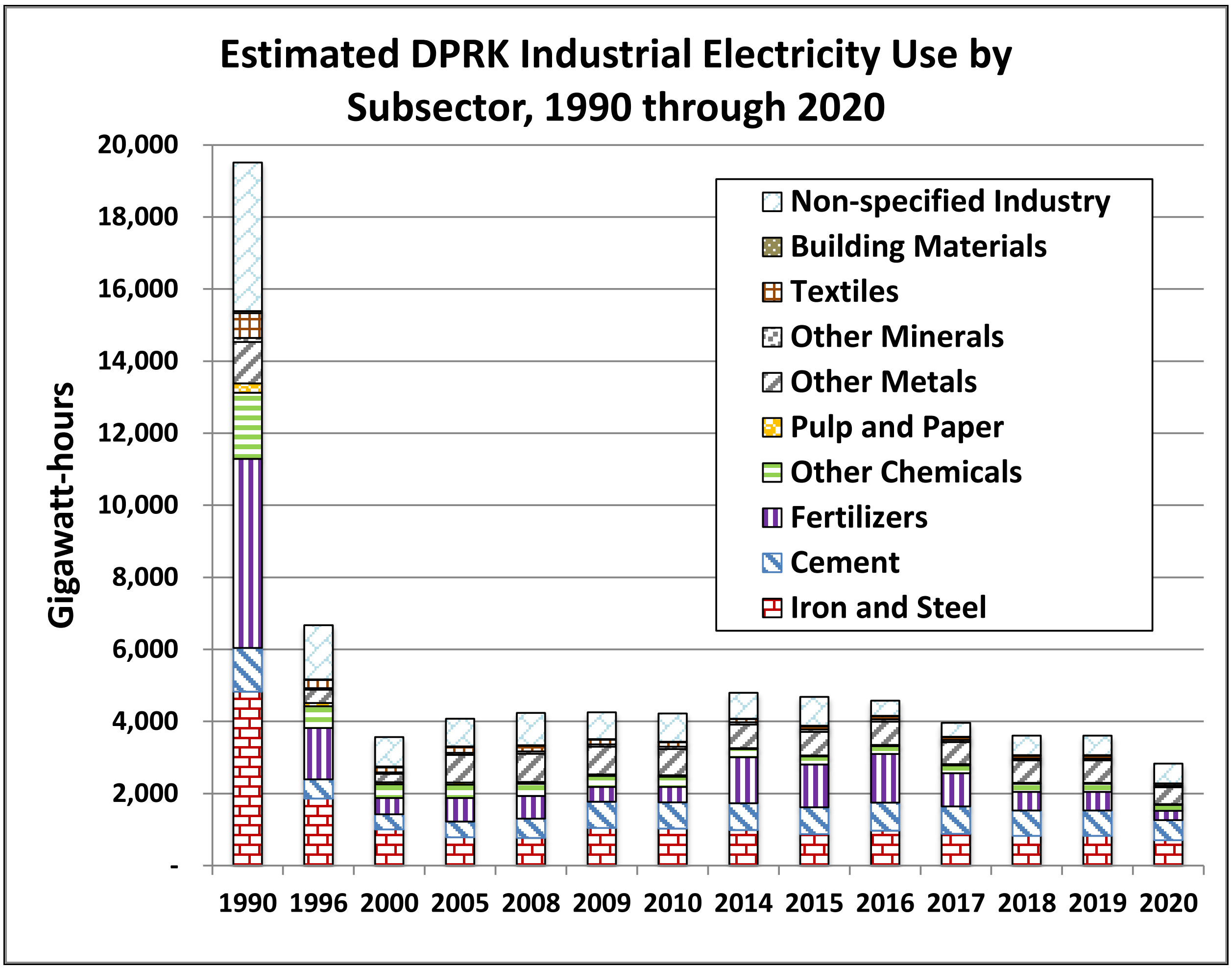
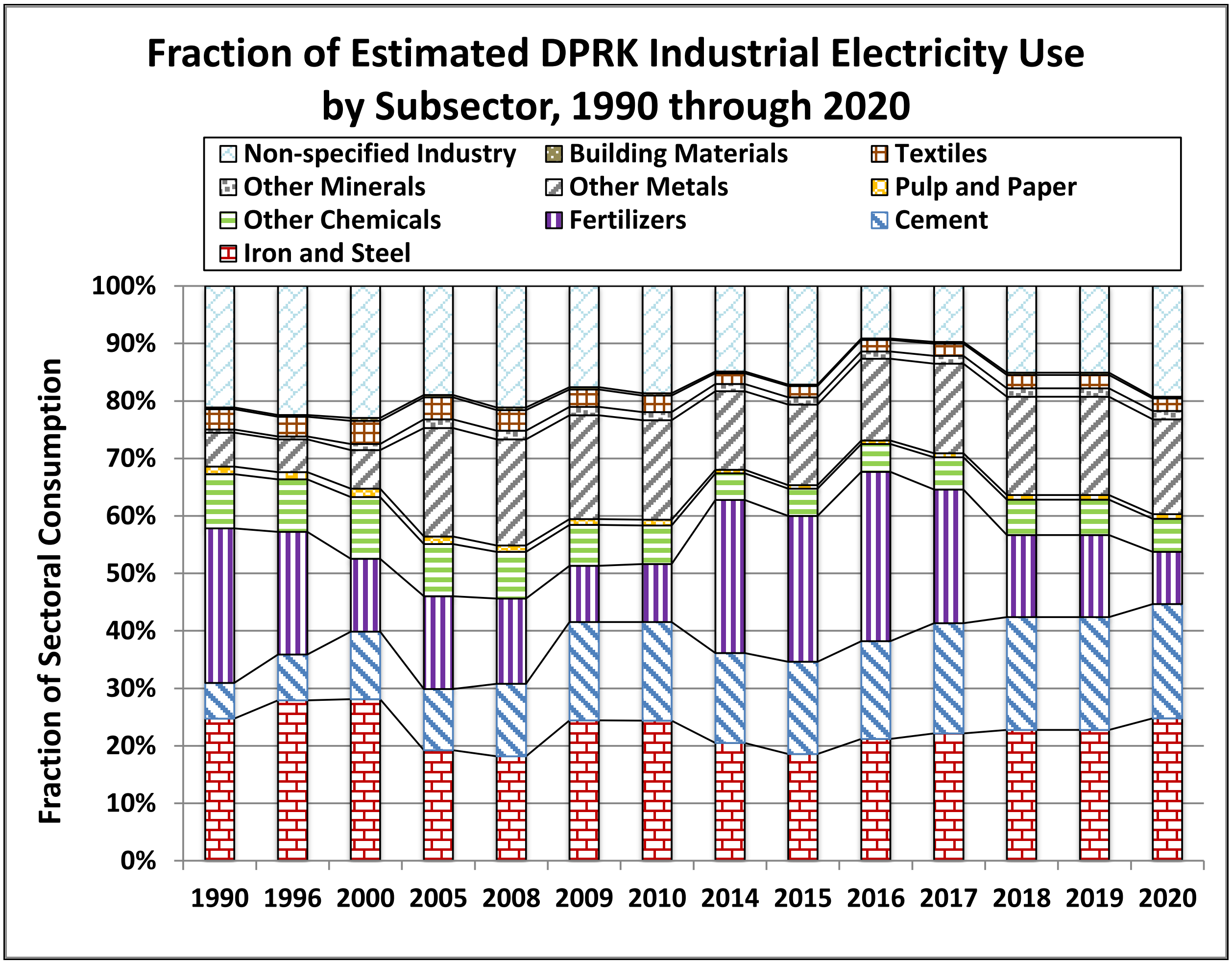


Figure 5-35: Fraction of Sectoral Industrial Electricity Use by Subsector



Our estimate of electricity use by end-use does not at present use different end-use factors in the different subsectors for different years, that is, we used the same assumed end-use breakdown in all industrial subsectors for 2010 through 2020. The results are shown in Figure 5-36 through Figure 5-38. Electricity used in motors and drives generally dominates industrial electricity use, with the exceptions being subsectors, such as metals and fertilizers, where process energy is dominant. Overall, by our estimate, about 57 percent of electricity use in DPRK industry in 2014 (for example) was used in motors and drives—and this estimate may be low. Given the typically antiquated designs of the electric motors we saw in service (and not in service) in the DPRK during our visits, upgrading electric motors and motor drive systems seems likely to be an important and cost-effective way of stretching supplies of electricity, as well as increasing productivity.

Figure 5-36: Industrial Electricity Use by End Use, 2010 and 2014

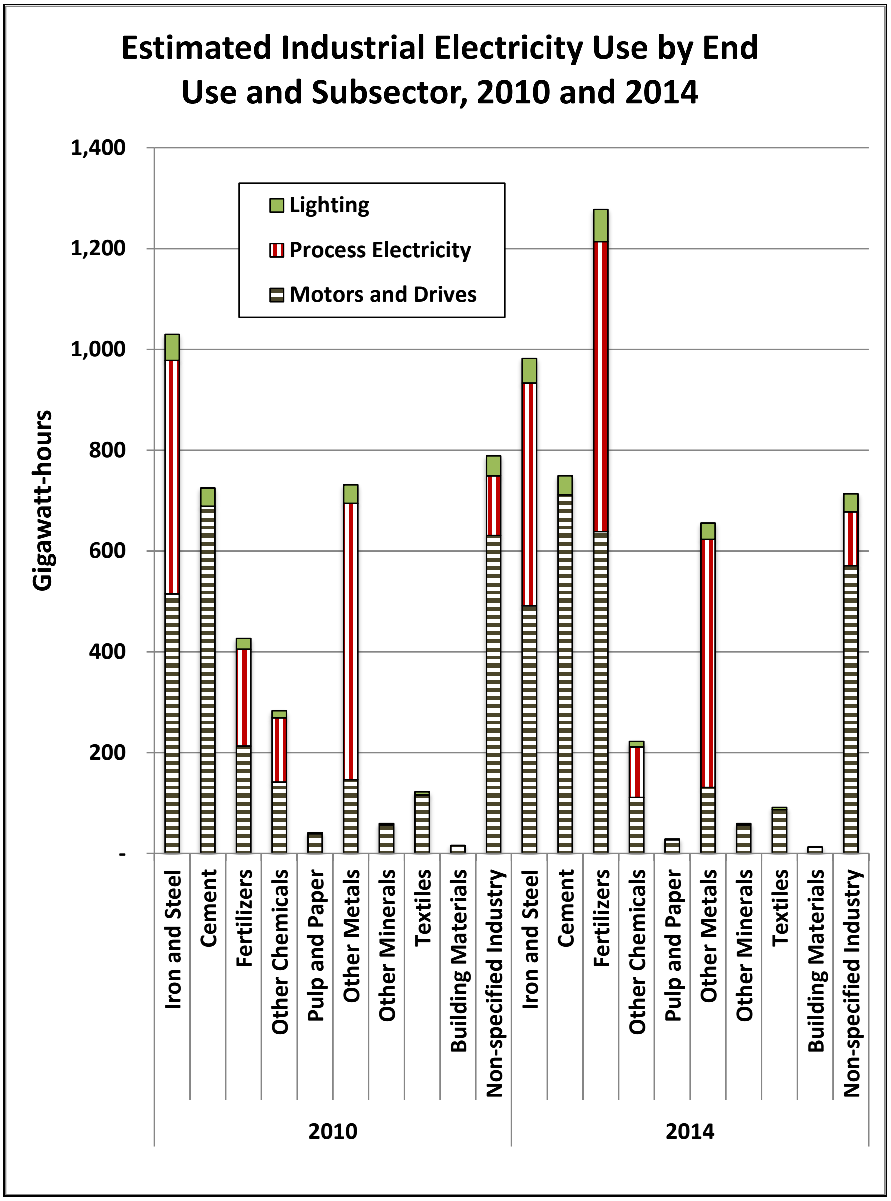


Figure 5-37: Industrial Electricity Use by End Use, 2015 through 2018

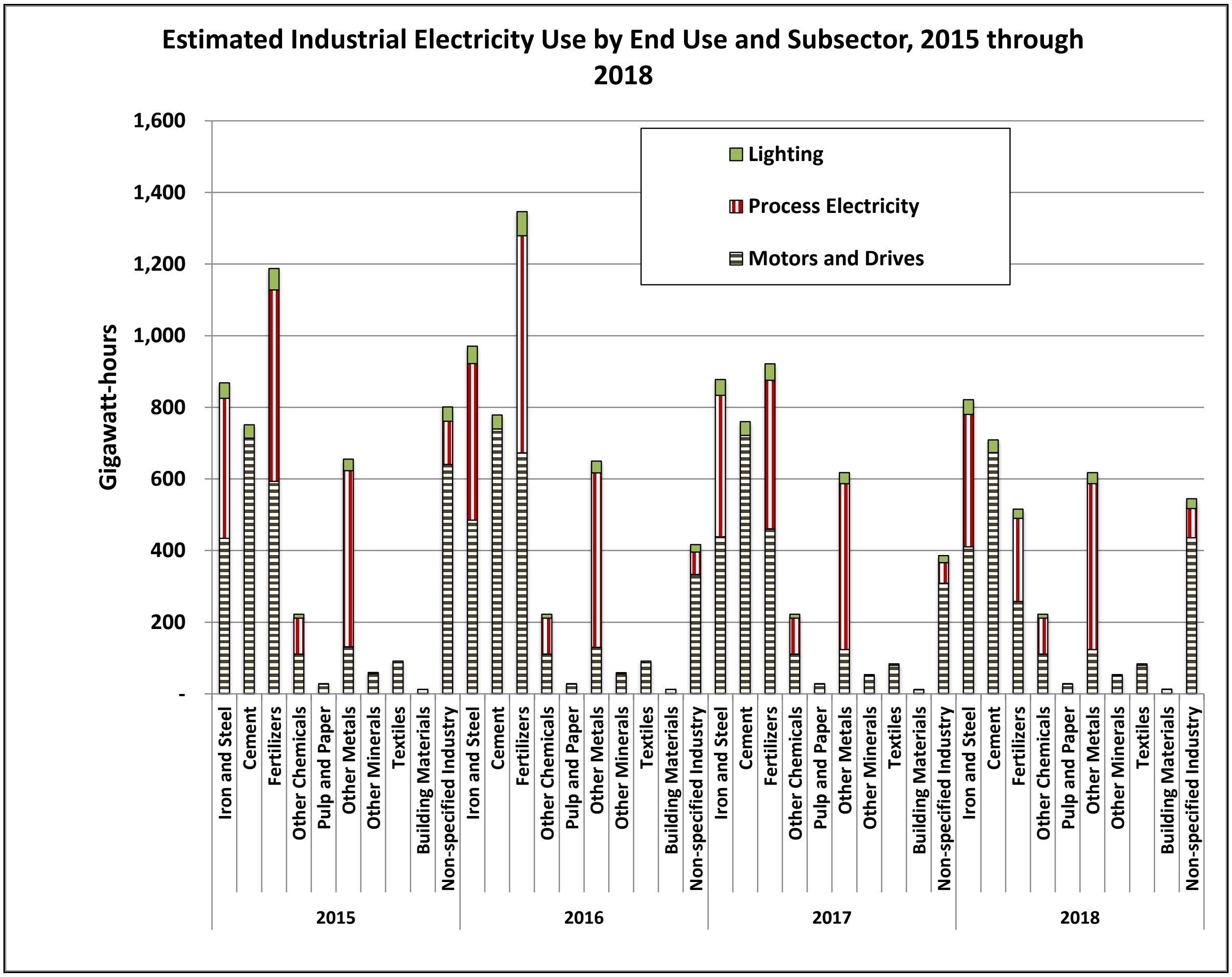
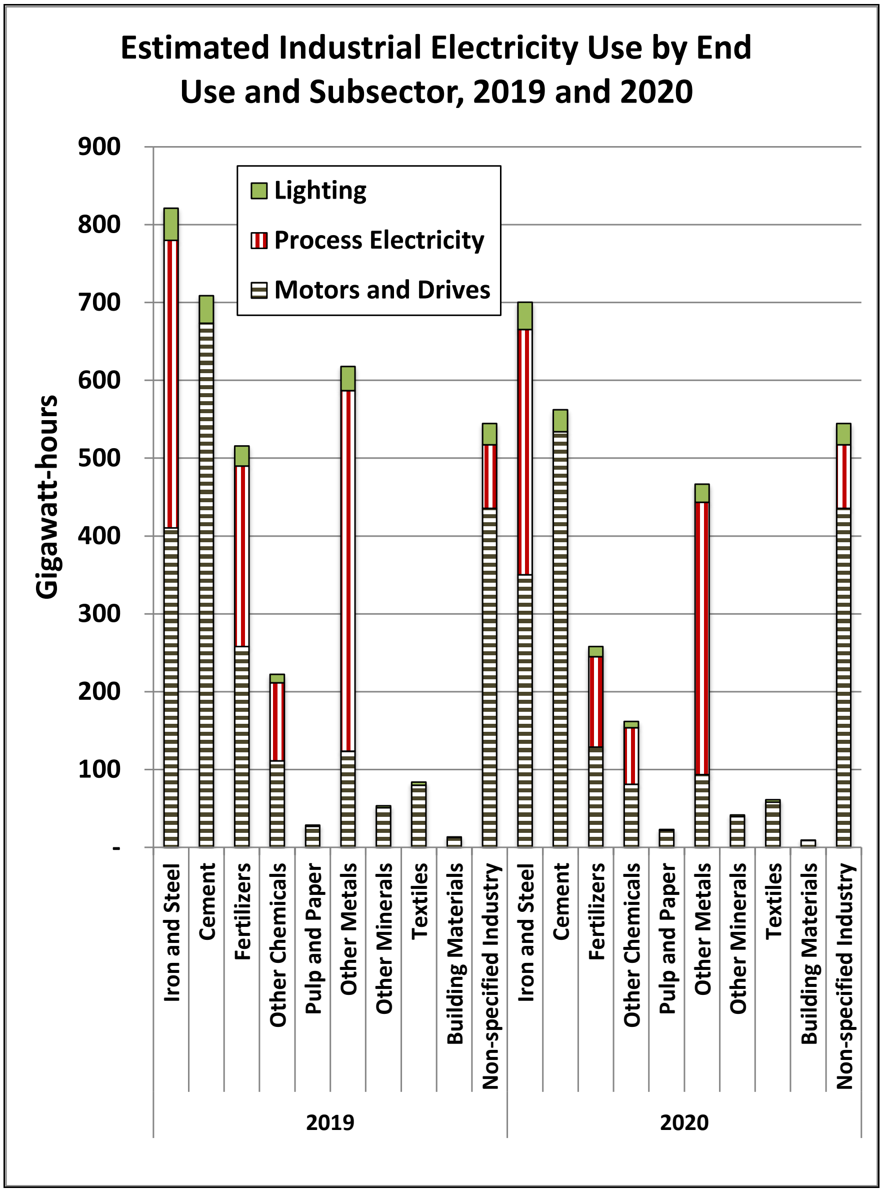


Figure 5-38: Industrial Electricity Use by End Use, 2019 and 2020



5.3.5. Transport Sector

The transport sector in the DPRK, as of 1990, was concentrated on the movement of freight, principally by rail. Visitors to the DPRK have noted that there was relatively little vehicle traffic on city streets and roads—though some visitors report that traffic has been increasing, in Pyongyang at least, in recent years—and that the main form of personal transport appears to be walking. This is aided by the fact that the apartments in which most urban dwellers live are typically located close to their places of work.

5.3.5.1.Transport Sector Assumptions and Inputs

Based on these observations of limited transport use in the DPRK as of 1990, we have assumed 1,200 average passenger kilometers traveled per year in 1990 in motorized transport by the roughly two-thirds of the population that is "economically active". This translates to about 800 kilometers of travel in cars, trains, and buses per person (all residents) per year, which is greater than the 1990 level of passenger transport in China, but less than that in India (and far less than that in industrialized countries).[631]

Significant use of electricity use in the transport sector of the DPRK is currently limited almost entirely to the electric freight and passenger rail, including urban rail such as electric streetcars and buses, and the Pyongyang subway system. Figure 5-39 shows electric buses in Pyongyang, and Figure 5-40 shows a photo of the Pyongyang subway, both as of September, 2009.[632] A growing, but likely not significant in terms of electricity use, additional transport use of electricity is the use of electric and electric-assist scooters, motorcycles and bicycles, which have been appearing in UN Comtrade statistics as imports to the DPRK from China in increasing numbers in recent years. As shown in Figure 5-41, these include an estimated 128,000 units, with an average value on the order of $300 and an average weight of 15 kilograms, likely meaning that most are small scooters or bicycles, in the year 2017.[633] We are guessing it is highly likely that these popular vehicles continued to be imported in significant numbers after 2017, but that fewer trades were Customs statistics suggest that a very few electric cars, perhaps on the order of 75, have been imported to the DPRK from China—based on the UN Comtrade statistics available to us, which lump electric and other non-internal-combustion vehicles into a single "other" category,[634]—but in any case this fleet cannot consume much electricity as yet. A recent *NK News* article shows photos of a fleet of electric tourist vehicles destined for the Wonsan-Kalma resort (see Figure 5-42).[635] A 2015 news article, citing North Korean State TV, shows a "solar powered" bus covered with PV panels, operating in the city of Nampo.[636] The claim that this bus operates entirely on electricity produced by its own panels and stored in its batteries is considered dubious ("One expert in solar technology tells the US-based site that the claim of 140 people riding a fully solar-powered bus has 'no credibility'"), and in fact calculations suggest that it would be physically impossible for such as bus to generate enough electricity in a day from its own solar panels to travel more than a few kilometers even on the

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[631] Sinton, J., editor (1996), China Energy Databook 1996 Edition, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA.LBL-32822.Rev.3. UC-900.

[632] Photos by D. von Hippel, September 2009.

[633] A 2016 article from Reuters, "Power to the people: electric bikes take off in North Korea", by James Pearson, dated May 7, 2016, and available as https://www.reuters.com/article/us-northkorea-congress-bicycles/power-to-the-people-electric-bikes-take-off-in-north-korea-idUSKCN0XY06I, provides additional anecdotal evidence of the rise of the use of personal electric vehicles in the DPRK. This article includes a reference to "A bike made by a Chinese company called Anqi was for sale this week in Pyongyang's Kwangbok Department Store for 2.62 million won - around $330 at the unofficial exchange rate of 8,000 won to the dollar." This price is roughly consistent with the cost per unit for exports from China to the DPRK as seen in Comtrade data for (probably) electric "motorcycles" in 2016.

[634] By way of comparison, according to UN Comtrade data, the DPRK imported on the order of 2000 passenger cars from China in 2014, somewhat fewer than in other recent years, as 2009 to 2013 imports increased steadily from about 2800 to nearly 3900 units.

[635] Colin Zwirko (2020), "Pyongyang to send tourist electric carts to delayed Wonsan-Kalma Resort", *NK News*, dated May 13, 2020, and available as https://www.nknews.org/2020/05/pyongyang-to-send-tourist-electric-carts-to-delayed-wonsan-kalma-resort/. Some of the carts shown in the images in the article are made in China, but others are reportedly made in the DPRK.

[636] BBC News (2015), *BBC News* (2015), "North Korea: State TV promotes solar-powered bus", available as http://www.bbc.com/news/blogs-news-from-elsewhere-34702544.

sunniest of days, but the presence of the bus, the electric tourist vehicles, and the massive private purchases of electric scooters and bicycles, do demonstrate the DPRK's interest in electric transport technologies, and in the use of renewable energy in general.[637]

Figure 5-39: Electric Buses in Pyongyang, 2009

[637] The BBC News article cited in the previous footnote quotes slogans on DPRK billboards as "The development reflects one of hundreds of new slogans unveiled by the communist state in February, one of which urged citizens to: 'Develop and make effective use of wind, tidal, geothermal and solar energy!'".

Figure 5-40: Pyongyang Subway System, 2009

Figure 5-41: Reported Electric Scooters/Motorcycles/Bicycles Imports through 2018

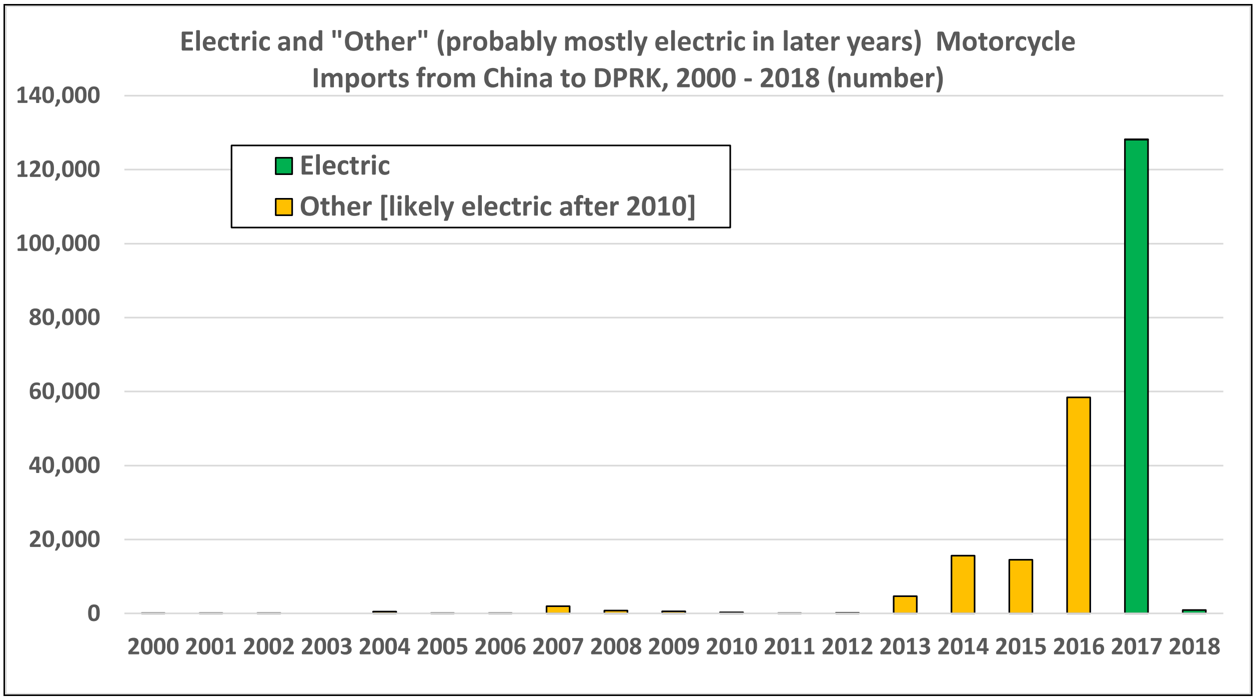


Figure 5-42: Electric Tourists Carts to be Used at Wonsan-Kalma Resort Area

We have relatively little direct quantitative information on the DPRK transport sector and its energy requirements as a whole, or for transport electricity use in particular, but have in previous publications derived estimates for energy use by fuel in the road, rail, air, and water transport subsectors. Of these, only the rail subsector uses a significant amount of electricity. As noted above, Pyongyang, as well as some other cities, do have some electrified buses, but we include the likely small electricity consumption of these systems with our estimates for total electricity consumed in rail passenger transport.

For passenger transport, we assumed for 1990 that 30 percent of motorized public passenger transport (in passenger-km) was by road, with the rest by rail. Rail transport in North Korea is fueled by diesel oil and by electricity. We assumed that practically no passenger transport is by diesel rail, as railways between most cities were, as of 1990, reportedly electrified (though electricity supplies to railroads, as to other parts of the economy, have become less reliable since 1990). The residual 70 percent of motorized public passenger transport not provided in road vehicles was assumed to take place in trains (or trams), at an efficiency of 13.2 kg coal equivalent per thousand passenger kilometers, for an assumed passenger rail energy intensity of 0.39 MJ per passenger-km as of 1990. This value is an average 1989 efficiency for US commute-time train transit. While trains in the DPPK are probably less efficient than US trains, which would result in higher intensities, their load factors are probably significantly higher, resulting in lower intensities. The intensity value used is also similar to that quoted for public municipal electric (presumably, subways, buses, and urban rail) in “developing countries” by Belyaev et al (2002),[638] but is higher than the same source provides for the intensity of passenger rail transport in general.

An ongoing program of electrifying the DPRK rail system had, as of 1990, increased the fraction of freight hauled by electric engines. We assumed this fraction to be 87.5 percent in 1990. For

[638] Lev S. Belyaev et al (2002), *World Energy and Transitions to Sustainable Development*, Kluwer Academic Publishers.

freight transport, we began with an estimate of 169 million tons of freight carried by rail in 1990, and then estimated the average distance (300 km for electric rail, 250 km for diesel rail) of freight transport. We used older Russian energy intensities for both diesel and electrically-powered freight locomotives, with those intensities increased by 20 percent due to presumed difficulties with maintenance and higher operational inefficiency in the DPRK rail sector—the latter due, for example, to much shorter distances between stops than in Russia, requiring more energy for acceleration. We assume that the amount of potential passenger rail transport increases with increasing population, but that due to the availability of electricity supplies for rail travel economic difficulties affecting motorized passenger transport in general, the use electric rail transport falls to 44 percent of 1990 levels by 1996, varying from about 27 percent to 38 percent of 1990 levels through 2010. Electric rail freight varies from 33 to 40 percent of 1990 levels in the years from 1996 through 2010, increasing and decreasing slightly based on the availability of electricity and assumptions about overall economic activity. The intensity of electric passenger and freight rail transport is assumed to be the same as 1990 levels for all years except 1996 (when it is five percent higher), with trends such as improvements in locomotives (some imports of locomotives from China appear in Customs statistics) and/or higher train loadings assumed to be offset by inefficiencies associated with intermittent electricity supplies and/or other technical problems with rail transport.

In recent years, chronic electricity shortages have reportedly caused the DPRK to rely more on diesel-powered trains, including bringing old locomotives reserved for emergency use back into service.[639] We assume that this caused a significant decrease in the fraction of passenger and freight traffic transported by electric rail, with the usage of electric rail for passenger and freight transport falling to 24 percent of 1990 levels by 2014, and rail electric freight to 40 percent of 1990 levels. We assume that passenger electric rail activity rose again in 2015 and remained in the range of 38 to 40 percent of 1990 levels through 2020, but that rail electric freight fell to 30 percent of 1990 levels in 2017, then remained slightly below that level (28 percent) through 2020, as freight was reduced in part because of the impact of UNSC sanctions on the rail movement of goods imports and exports.

5.3.5.2.Transport Sector Results

Estimated electricity use in rail transport in the DPRK from 1990 through 2020 is shown in Figure 5-43. Estimated 2014 transport electricity use was about 8 percent of total electricity use in the DPRK in 2014, with transport electricity use split approximately evenly between passenger and freight rail. Transportation electricity use is estimated to be dominated by motors and drives (electric motors for locomotives, subways, and buses), as one would expect, with a much smaller amount of electricity for lighting and other end uses, as shown in Figure 5-44.

[639] See, for example, Joon Ho Kim, Yunju Kim, and Roseanne Gerin (2015), "North Korea Resorts to Diesel Locomotives to Deal with Rail Power Shortage", *Radio Free Asia*, dated 2015-04-08, and available as http://www.rfa.org/english/news/korea/authorities-use-diesel-locomotives-04082015165102.html.

Figure 5-43: Estimated Rail Transport Electricity Use

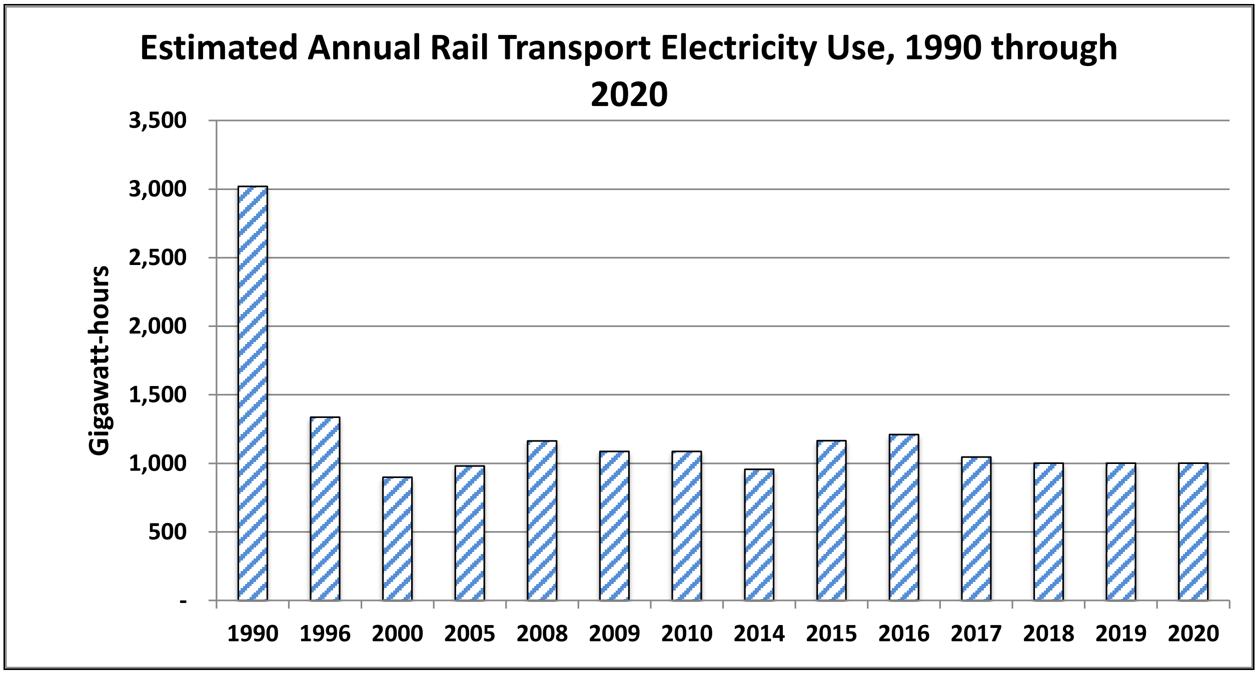
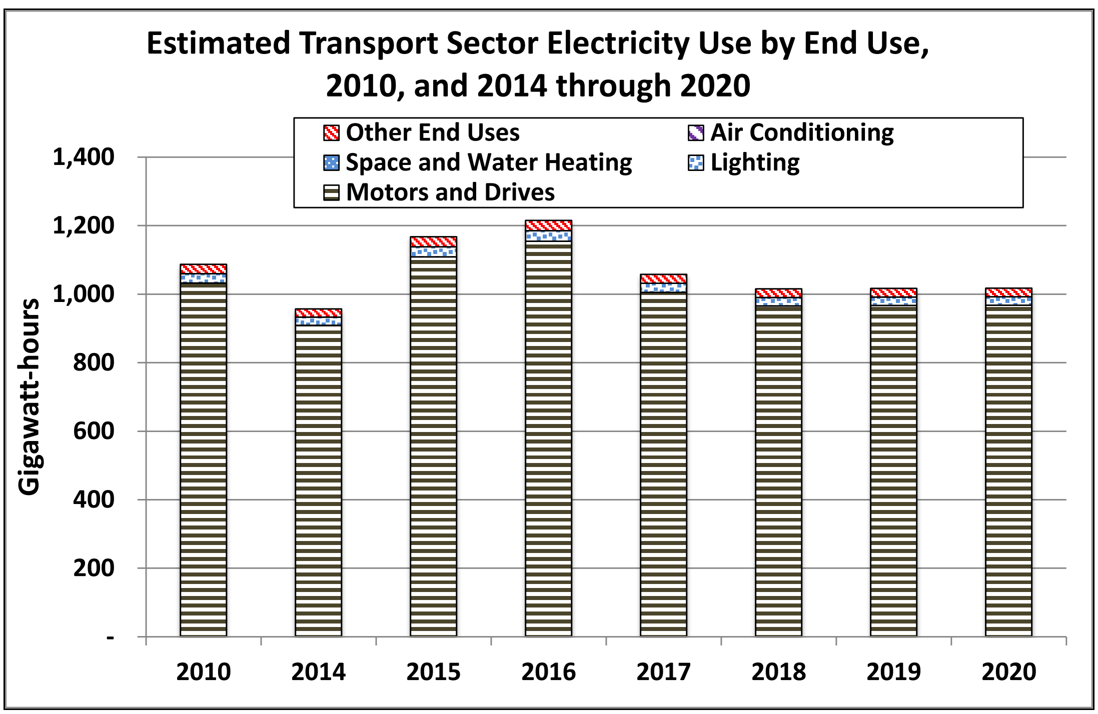


Figure 5-44: Transport Sector Electricity Use by End Use



5.3.6. Agriculture and Fisheries Sectors

The DPRK agricultural and fisheries sectors have the difficult task of providing most of the food for the DPRK's population with limited inputs of land, fuel, fertilizer, and equipment. Below we describe what we understand about these sectors, including our estimates of electricity use and electricity use by end use in each sector.

5.3.6.1.Agriculture Sector Assumptions and Inputs

To estimate electricity and fuel use in the agricultural sector, we started with the area of field crops grown in the DPRK in 1990, approximately 1.7 million hectares. We have divided energy use in the agricultural sector into two components, accounting separately for the energy used in Field Machinery, and that used for Processing of crops and other applications.

Electricity use in field machinery was estimated using a Chinese value of 126 kWh/ha-year in 1990. Most electricity use would probably be for water pumping. We assumed that electricity use in fields declined to 90 percent of 1990 levels in 1996 and 75 percent of 1990 levels in 2000, due to a combination of a lack of electricity and, possibly, problems with keeping pumps operating due to lack of parts. An article in KCNA in English (Pyongyang), dated 14 March, 2005, and entitled "Kaechon-Lake Thaesong Waterway Pays Off", suggested that the waterway, created to provide irrigation water to fields on the west coast of the DPRK (see Figure 5-45), carried 100 million cubic meters of water over two years, and displaced more than 500 water pumps that "had to consume more than 60,000 kW of electricity a year to supply needed water to [the areas served]." Assuming that this note referred to the power input to the displaced pumps as 60 MW, and assuming an annual average capacity factor for those pumps of about 20 percent, this implies a displacement of about 105 GWh, about 42 percent of our estimated field use of electricity in 1990. On this basis we decrease estimated use of electricity in agricultural fields in 2005, but by somewhat less than this estimate (to 65 percent of 1990 levels by 2005), assuming that there may still be additional pumping from the new aqueduct into the fields, and assuming that the KCNA article may present a somewhat optimistic account of the impacts of the waterway. In subsequent years, we assume that electricity use in fields falls still further, to 52.5 percent of 1990 values in 2008, and from 50 percent to 53 percent in 2014 and the years between 2014 and 2020, due to a combination of lack of availability of power for pumping and some additional displacement of pumping electricity use via gravity-fed irrigation.

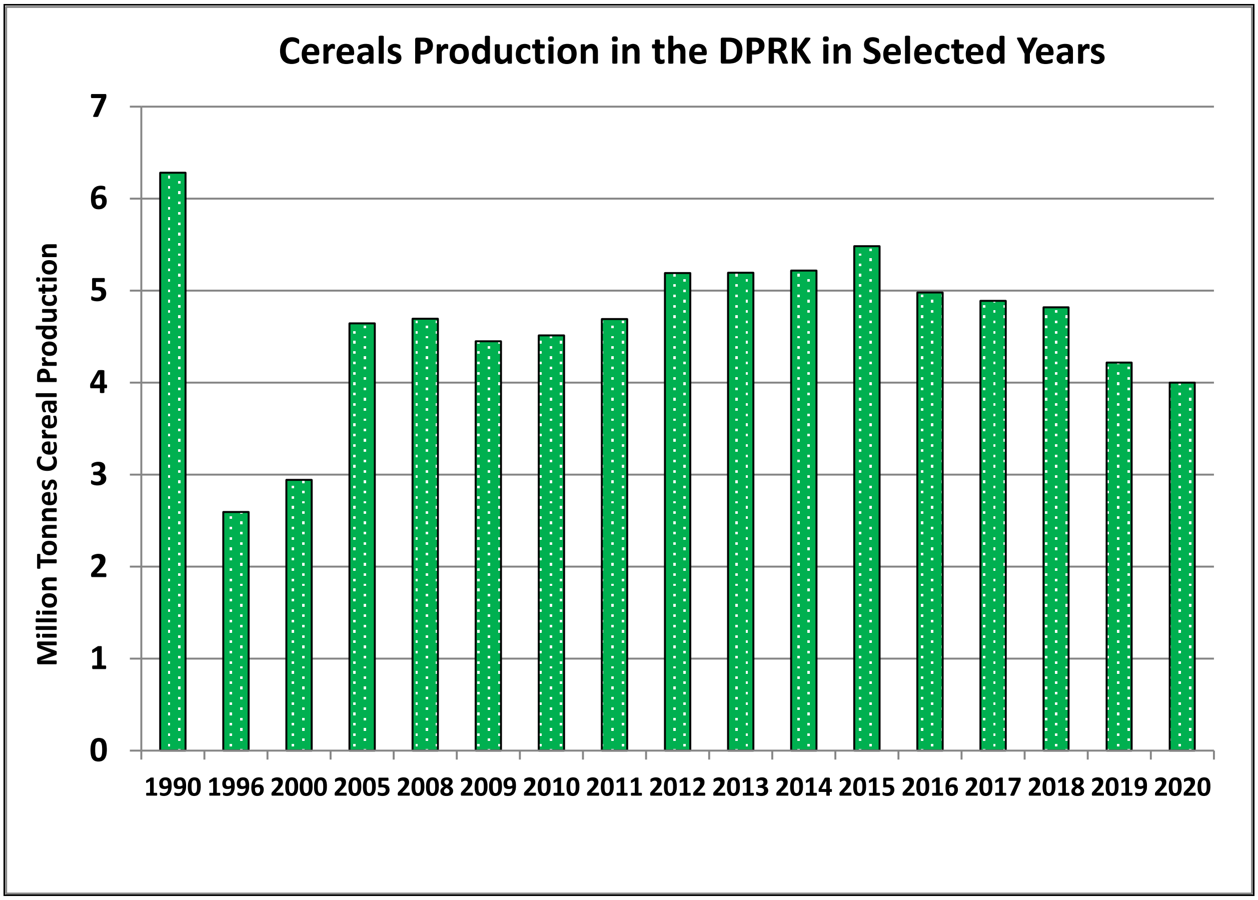
Figure 5-45: Natural-flow Irrigation Waterway in the DPRK Completed Circa 2004-2005[640]

Electricity is also used in crop processing, for example, in the hulling and milling of rice. To estimate crop processing electricity use, we start with an intensity of 444 kilograms of coal equivalent (kgce) per hectare of rice harvested derived from 1987 Chinese data for all (not just rice) agricultural processing electricity use. This figure is applied to the rice harvest in the DPRK (processing electricity is assumed to be mostly for rice) to yield an estimate of overall agricultural processing electricity use in 1990. For the use of electricity (and other fuels) in crop processing after 1990, we assumed that these would increase and decrease in rough proportion with the amount of crops harvested, with annual cereal crop harvest estimates as the metric to calculate a ratio of output versus 1990. Figure 5-46 show the variation in cereals production in the DPRK since 1990 as reported by the UN Food and Agriculture Organization (UNFAO),[641] with our rough estimate for 2020 assuming output slightly lower than 2019.

[640] From John Lewis, "North Korean Energy: 2005-2006 New Technologies and Construction" as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available from https://nautilus.org/projects/by-name/dprk-energy/2006-meeting/papers-and-presentations/.

[641] Based on summary data on DPRK cereals production from UN FAOStat, http://www.fao.org/faostat/en/#data/QC, accessed 8/30/2012, 8/9/2018, the UN FAO document *GIEWS Update: The Democratic People's Republic of Korea, Food Supply and Demand Outlook in 2017/18 (November/October)*, dated 9 July 2018, and available as http://www.fao.org/3/ca0363en/CA0363EN.pdf, and the *DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA (DPRK) FAO/WFP JOINT RAPID FOOD SECURITY ASSESSMENT*, dated May 2019, and available as http://www.fao.org/3/ca4447EN/ca4447en.pdf.

Figure 5-46: DPRK Cereals Production over Time



5.3.6.2.Fisheries Sector Assumptions and Inputs

Very little data are available to describe energy use in the fisheries sector of the DPRK in general, or electricity use in particular. Electricity is used in the fisheries industry in the processing of fisheries products, including, for example, for conveyor belts and lighting in fish processing plants, and in providing refrigeration for fisheries products. For electricity use in processing operations, we have prepared estimates based on an estimate of electricity use in fish processing in Alaska (admittedly a rough comparison at best) of about 110 kWh of electricity per tonne of catch processed, and DPRK fisheries production in 1990 of 2.2 million tonnes, based on UNFAO statistics. After 1990, we assume a decline in both fisheries effort and catch, based on reports from several sources, which, combined with a lack of access to electricity for processing operations, result in electricity use in fisheries processing declining to 45 percent of 1990 levels by 1996, and further to 25 to 40 percent in later years, varying from year to year based on electricity availability and available information on fish catch. Trade statistics show that since at least the years from 2010 the DPRK has been exporting large quantities of fisheries products. China imports the vast bulk of these products—well over 90 percent. Most of China's imports from the DPRK are in the category "Molluscs", a category dominated by imports, specifically, of cuttlefish and squid—exports of products in this category were valued at over $100 million annually for all but one of the years from 2012 through 2017. The increased harvest of squid is due, in part, to an abundance of squid as a result of the same climatic conditions that have led to drought in the DPRK.[642] It has been reported that a substantial portion of the DPRK fisheries industry is under the control of the DPRK military. Figure 5-47 shows an image from late 2019 of Chairman Kim Jong Un visiting a military fish processing factory.[643] The robotic equipment shown is reportedly an ABB (a Swiss equipment maker) design, made in China, and possible exported second-hand to the DPRK.

Figure 5-47: Visit by Chairman Kim Jong Un to a Fish Processing Factory in the DPRK

5.3.6.3.Agriculture and Fisheries Sector Results

Estimates of electricity use in the DPRK in selected years for agricultural field use (water pumping, mostly), agricultural processing, and fisheries processing are provided in Figure 5-48. Our estimates for these subsectors have totaled in the range of 300 to 400 GWh annually in most years since 1996, with agricultural processing the largest of the three subsectors.

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[642] As described, for example, in "North Koreans turn to squid to compensate for drought", prepared by Choi Song Min for *Daily NK*, dated July 15, 2015, and available as http://www.theguardian.com/world/2015/jul/15/north-korea-drought-squid-harvest. See also "North Korea's military orders surge in squid poaching", *Daily Telegraph*, by Mike Firn, dated 28 Nov 2014, available as http://www.telegraph.co.uk/news/worldnews/asia/northkorea/11259846/North-Koreas-military-orders-surge-in-squid-poaching.html. Similarly, "North Korean fishing industry increases output", *NK News*, February 10th, 2015, available as http://www.nknews.org/2015/02/north-korean-fishing-industry-increases-output/,also reports increased output after about 2011.

[643] The UNSC "Panel of Experts" in UNSC (2020), *Note by the President of the Security Council, number S/2020/151, dated 2 March 2020*, and including "Annex: Letter dated 26 February 2020 from the Panel of Experts established pursuant to resolution 1874 (2009) addressed to the President of the Security Council", available as https://undocs.org/S/2020/151. Photo from page 49 of UNSC document, dated November 19, 2019, and originally from the Korea Central News Agency (KCNA).

Figure 5-48: Total Agricultural and Fisheries Electricity Use

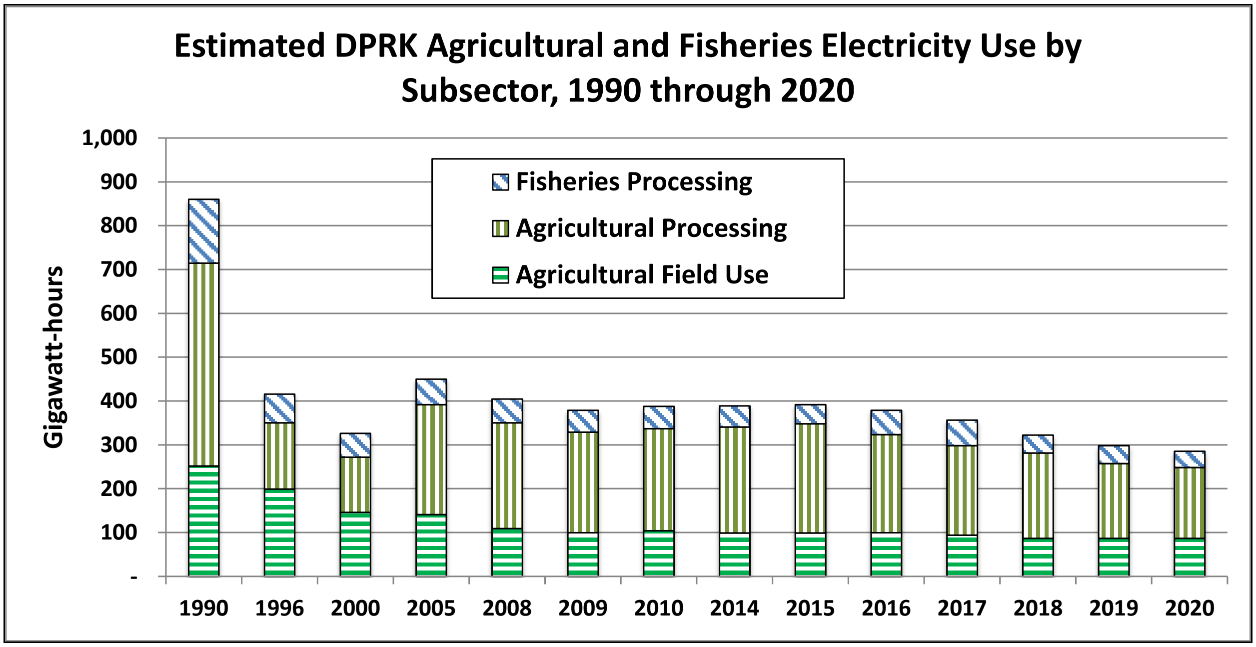


Figure 5-49 through Figure 5-51 show estimated 2010 and 2014 through 2020 use of electricity in the agriculture and fisheries sectors by subsector and end use. The use of electric motors and electric motor drives dominate, with motors use in agricultural processing the single largest end-use.

Figure 5-49: Agricultural and Fisheries Electricity Use by End Use, 2010 and 2014

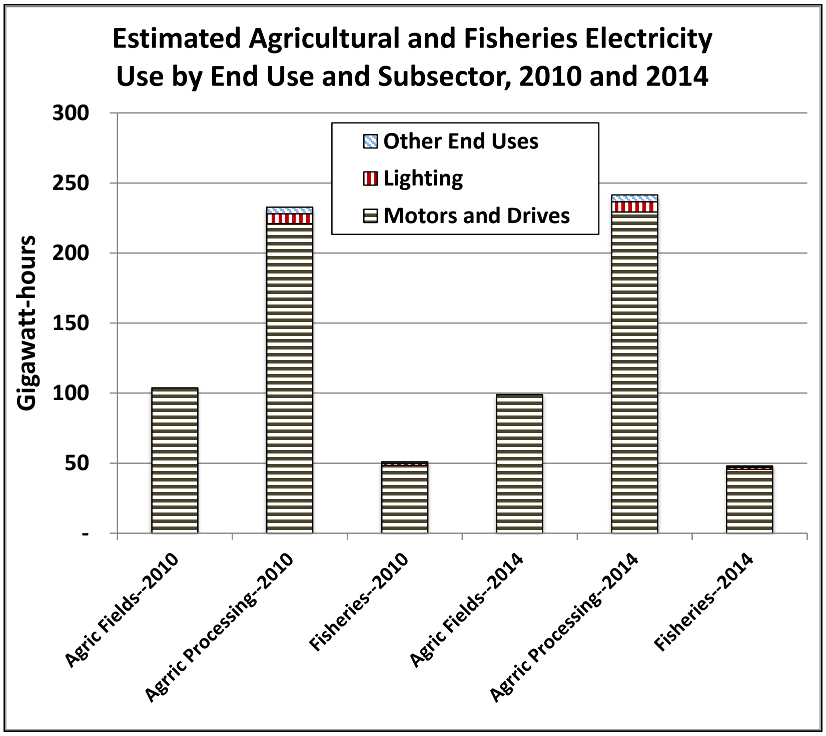


Figure 5-50: Agricultural and Fisheries Electricity Use by End Use, 2015 through 2018

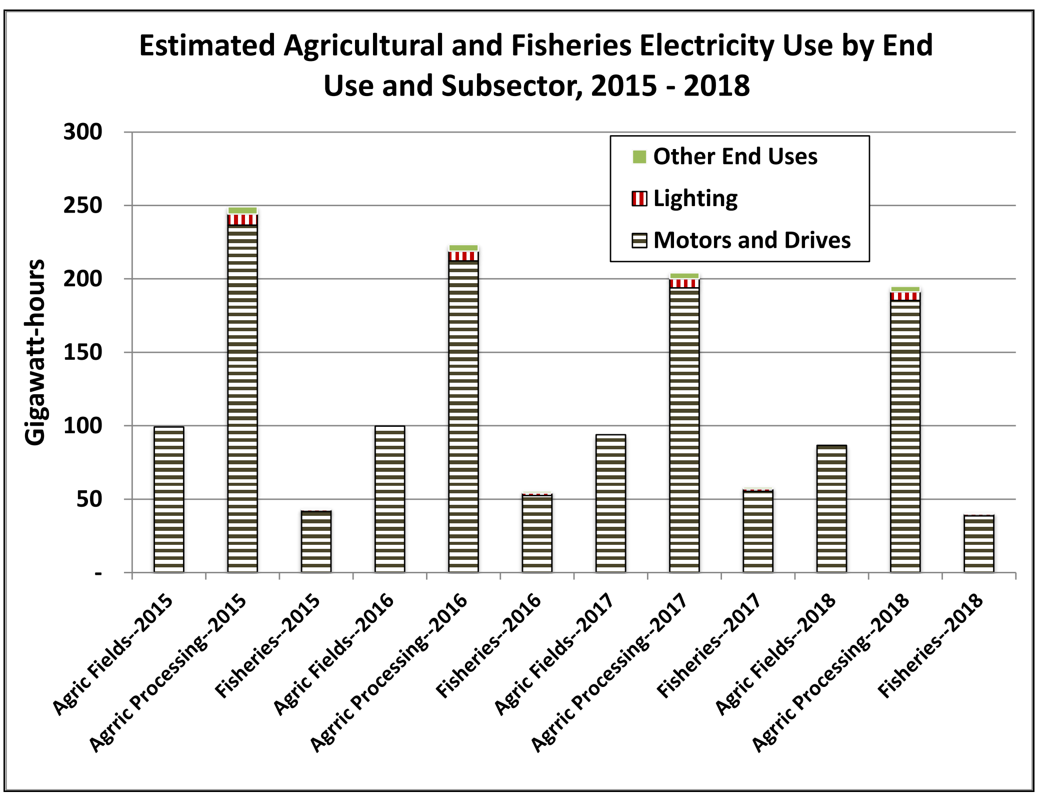
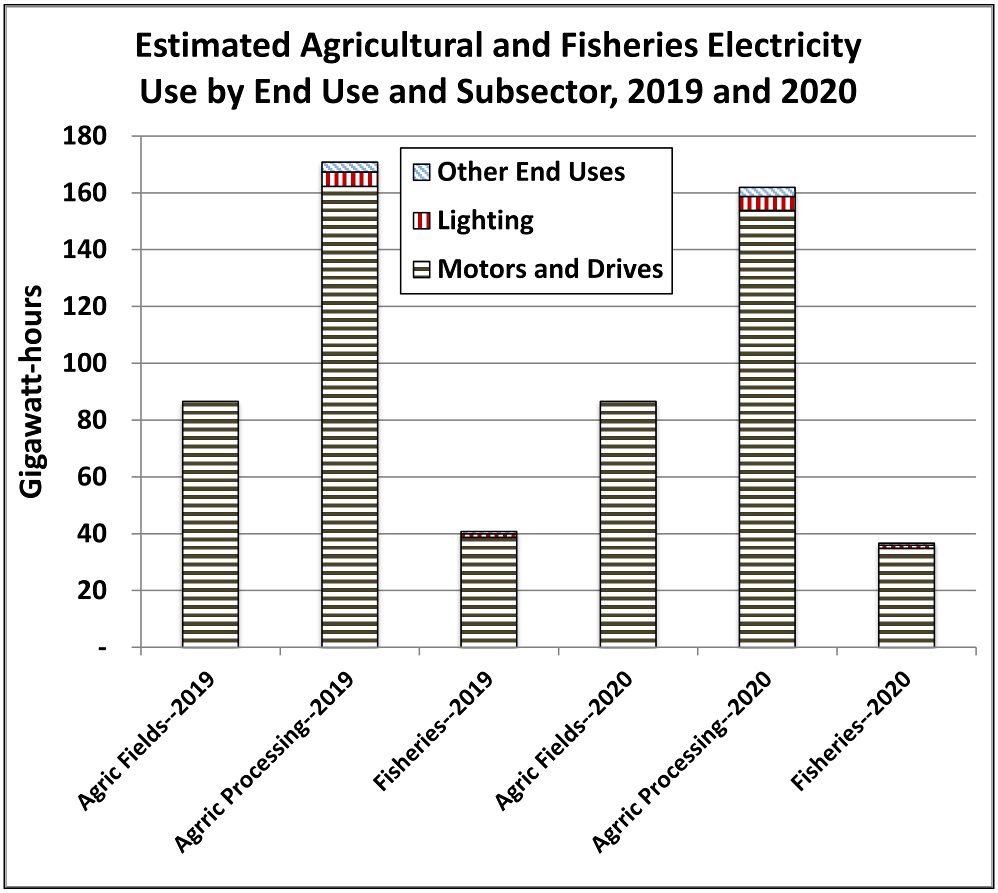


Figure 5-51: Agricultural and Fisheries Electricity Use by End Use, 2019 and 2020



5.3.7. Military Sector

There are few other countries in the world, possibly none, where military and civilian lives are so fully entwined as in the DPRK. In addition to having a far larger standing military per capita than any other nation—the world's fourth largest, behind only nations with populations 13 to about 55 times greater[644]—approximately 5 million DPRK citizens are said to serve in the military reserves, representing a significant fraction of the economically active population. Military units are used as labor forces in numerous projects, some mostly civilian in nature (such as bringing in the agricultural harvest, and, most notably for the electricity sector, building dams and canals), and the DPRK military is said to essentially have its own economy, including a supply network for food, fuel, and other goods, and its own industrial facilities, some of which make munitions and armaments, but others of which reportedly make civilian goods, but are controlled by the military.[645] As a result, in addition to the energy used for strictly military activities—exercises

[644] See, for example, Jessica Dillinger (2020), "29 Largest Armies In The World", *World Atlas, dated* January 7 2020, and available as https://www.worldatlas.com/articles/29-largest-armies-in-the-world.html.

[645] Although it is not clear to us how representative this example is military-owned factories in the DPRK—and it probably is an example selected particularly for its public relations value, the online video "N. Korean Disabled Soldiers′ Plastic Goods Factory", dated January 9, 2012, and previously available as http://www.youtube.com/watch?v=uckV5rygOxE, shows a plastic goods and plastic packaging factory run by the DPRK military.

with tanks, artillery, gunboats, and military aircraft, for example, some military energy use provides energy services—for example, for goods and human transport—for civilians as well. Although it is unlikely that significant electricity is used in the operation of military armaments and vehicles at present (though, as in other nations, that will likely change in the future), simply housing and feeding the one-million-plus-person armed forces of the DPRK requires significant fuel and electricity.

One anecdote we have heard that may relate both to strictly military activities and to military ventures that produce civilian goods is that in addition to (and perhaps as part of) having what is effectively a separate economy for the DPRK military, many DPRK military facilities have separate or, at least, back-up power supplies to render them largely independent of the unreliable DPRK grid. For example, although most of the DPRK's transmission and distribution transformers are in poor condition, some military installations have their own, new or newer, largely imported transformers that are in good operating condition, as well as alternative sources of power (such as some of the imported diesel generators described above). To the extent that these newer electricity supply infrastructure items have been implemented for military-owned factories producing civilian goods, those factories might serve as examples for DPRK economic redevelopment, although, of course, issues related to their ownership and control will be non-trivial to unravel if and when the DPRK opens economically.

Below we provide a summary of our assumptions and data sources relied upon in estimating year 1990 through 2020 electricity use in the DPRK military, along with a summary of those estimates.

5.3.7.1.Military Sector Assumptions and Inputs

Although, as with some other sectors, we have been able to obtain essentially no direct data on energy use in the military sector in the DPRK, the DPRK military is monitored closely by the military and intelligence community in the United States and elsewhere. For the purposes of our analysis, this attention has meant that there are reasonably good data on the stocks of energy-using equipment—at least vehicles, armaments, aircraft, and naval vessels—in the DPRK military. These data on stocks have been used in other Nautilus publications (and elsewhere in this Report) as the bases for estimates of petroleum fuels consumption for the DPRK ground forces, naval fleet, and air force. Although these machines do not use electricity directly, the manufacturing of these and other military hardware requires electricity, as do the headquarters buildings, barracks, and other military buildings and installations used by the DPRK armed forces. To estimate the amount of fuel and electricity used in manufacturing military equipment, we estimated the total weight of iron and steel in the Army and Navy equipment inventories (aircraft were assumed to be all imported), applying estimates of the average of lifetimes of each equipment type (assumed to be 20 years for large Ground Force equipment, 10 years for small armaments, and 30 years for ships and boats), and using these figures to derive an average amount of iron and steel needed per year in military manufacturing to replace equipment reaching the end of its nominal lifetime. A Chinese figure of 250 kg coal equivalent per ton of steel,[646] multiplied by an efficiency inflator of 1.1, was assumed to be required for each of the approximately two meltings required to fabricate military equipment.[647] It was further assumed that the fuel (assumed to be coal) used in melting iron and steel for military goods represents roughly 60 percent of the total coal needed for military manufacturing. An estimate of the electricity requirements by this sector was prepared by applying the ratio of electricity to coal consumption estimated for the civilian iron and steel industrial subsector to the coal use estimate for military manufacturing.

Armed forces of on the order of 1.2 million people do not exist without a substantial stock of military buildings. As in other sectors, however, we currently have no direct information on energy use in these structures. To compile estimates of fuel use in military buildings, we have assumed that there were 20 million square meters of floor space in such buildings as of 1990 (about 17 square meters per active member of the armed forces), and that electricity consumption per square meter in these buildings as of 1990 was twice that in civilian public and commercial building (55 kWh/m^2-yr).

We included a placeholder value for 1990 of an additional 10 million GJ annually to account for other uses of electricity in the military. End-uses covered by this assumed allotment as of 1990 could include the operation of fixed radar sites and the DPRK's nuclear research program (nominally a civilian operation), which we estimate may have had an electricity demand in 1990 of approximately 5 MW, as there is no electricity production by the DPRK's 25 MW thermal (though referred to as "5 MW electric") research reactor at Yongbyon.[648]

Military manufacturing was assumed to decrease to 70 percent of 1990 levels by 1996, and to 45 percent of 1990 levels in subsequent years through 2010, then rose to 50 percent by 2019 as the economy improved somewhat. For 2020, we assume that military manufacturing activity will average 25 percent of 1990 levels due to the restrictions on military and other activity related to the response to the COVID-19 pandemic.

We assume that from 1990 to 2000 the use of electricity in DPRK military buildings fell to 53 percent of 1990 levels due to a combination of supply constraints and reduced military activity. We assume that electricity use rose again somewhat in 2005 and 2008 as a result of somewhat better electricity supplies (for which the military probably had priority), to 62.5 and 65 percent of 1990 levels, falling again gradually thereafter due to supply constraints and, possibly, due to the small decreases in activity levels we have assumed for in all branches of the military relative to 2000 levels, which in turn is the result of energy-consuming training activities being limited by

[646] Ross, M. and L. Feng (1990), "The Energy Efficiency of the Steel Industry of China". *Energy*, V. 16, No. 5, pp. 833-848, 1991.

[647] P. Zimmerman, personal communication, 1995.

[648] The nominally 5 MWe nuclear reactor at Yongbyon was shut down under the terms of the 1995 Agreed Framework between the DPRK and the United States, restarted in 2003 after the breakdown in negotiations over the provision of light water reactors to the DPRK and other issues, shut down again in 2007 as a part of the proceedings of the Six Party Talks on the DPRK's nuclear weapons program (and related issues). See, for example, Global Security.org (undated, but probably 2015), "Yongbyon (Nyongbyon)", available as http://www.globalsecurity.org/wmd/world/dprk/yongbyon-5.htm. The Yongbyon reactor was likely restarted once more in 2013 after engagement talks failed again and appears to have been operating at least intermittently and/or at partial power since. See, for example, David Albright and Serena Kelleher-Vergantini (2016), *Update on North Korean's Reactors, Enrichment Plant, and Possible Isotope Separation Facility,* dated February 1, 2016, and available as http://isis-online.org/uploads/isis-reports/documents/Yongbyon_January_2016_Update_Final.pdf. Although this reactor is typically referred to as "5 MWe", and various authors suggest that it produced or produces power, other researchers suggest that it is not clear that it actually has or does generate electricity, although it has, at least in the past, been used to provide heat for the Yongbyon research complex.

fuel supplies, lack of spare parts, and also, possibly, increased time spent by military personnel in economic pursuits.[649] Another possible reason for reduced military activities in some years could be the reportedly lower physical capabilities of soldiers working on shorter rations. As of 2014, we assume that electricity use in buildings and other non-manufacturing applications the military was about 58 percent of 1990 levels, rising slowly thereafter to 63 percent of 1990 levels by 2018 and 2019, perhaps due to better access to generators and/or heightened activity due to international tensions, before declining markedly in 2020 due to COVID-19 response measures.

5.3.7.2.Military Sector Results

Our estimates suggest that the DPRK military sector uses a substantial fraction of the DPRK's overall electricity supplies, perhaps on the order of 20 to 25 percent of total DPRK final electricity use. Almost all of this use is estimated to be in buildings and other end-uses, rather than in military manufacturing, as shown in Figure 5-52. The underpinnings of this high fraction of overall national energy use are the large number of people in the DPRK military, the probably preferential access to electricity by military installations, and the reportedly frequent overlap between military and what would in other nations typically be civilian economic activities. Our estimate of military manufacturing electricity use may be artificially low due to its focus on the steel content of military hardware. As indicated above, however, dividing electricity use between the military and civilian manufacturing economies of the DPRK may be nearly impossible, at least without detailed survey data that is highly unlikely to ever be collected, at least before the DPRK transitions to an open economy—at which point, the current manufacturing economy of the DPRK will likely have ceased to exist. Figure 5-53 shows estimated electricity end-uses for 2010 and 2014 through 2020. Dominated by electricity use in military buildings, the electricity end-use division for the sector is similar to that in the Public/Commercial sector, with lighting a major portion of electricity use, followed by motors and drives and other end uses (such as electronics).

[649] Reviews of the literature describing DPRK military equipment stocks in the different branches of the armed forces are available on http://www.globalsecurity.org, for example, on http://www.globalsecurity.org/military/world/NP/air-force-equipment.htm for air force equipment, http://www.globalsecurity.org/military/world/NP/kpa-equipment.htm for ground forces equipment, and http://www.globalsecurity.org/military/world/NP/navy.htm for the navy. These reviews find relatively little change in the DPRK's stock of energy-using military equipment in recent years, but note that it is not entirely clear whether these results stem from a lack of recent insights, on the part of analysts, as to any changes in the DPRK military, or to a lack of changes in the actual equipment inventory in the DPRK.

Figure 5-52: Military Energy Use by Subsector

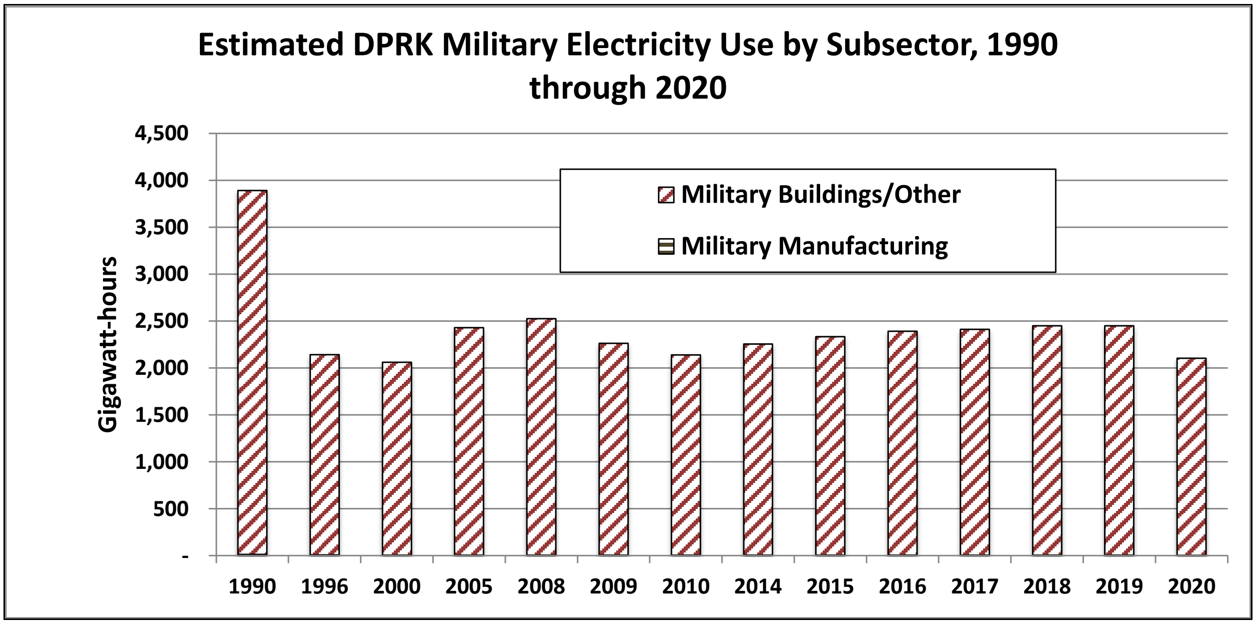
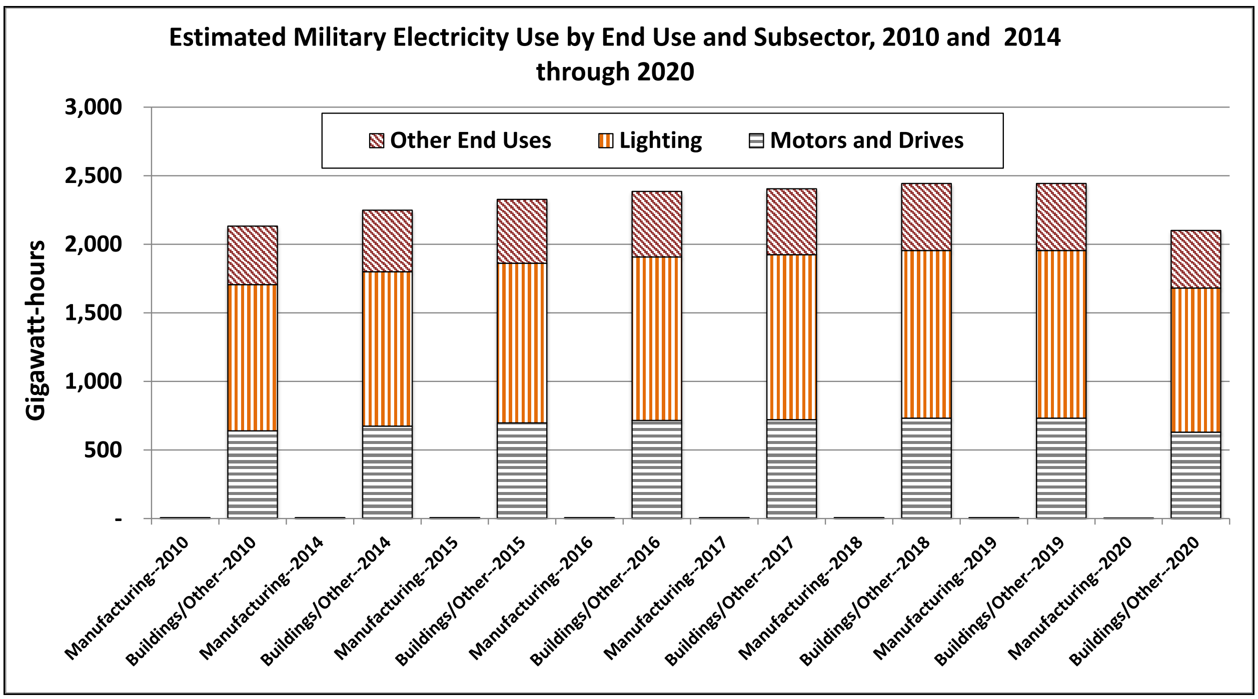


Figure 5-53: Military Electricity Use by Subsector and End Use



5.3.8. Overall Electricity Demand Results and Commentary

As shown in Figure 5-54, estimated overall electricity use in the DPRK has declined by a factor of three since 1990 due to a combination of the lack of availability of power caused by supply-side constraints, but also because of economic difficulties, most notably in the industrial sector. Industry is still the largest sectoral consumer of electricity in the DPRK, but its share of overall electricity use has fallen somewhat over time. Once again, it is important to understand the difference between electricity **use** and electricity **demand** in the DPRK context. It is difficult, probably impossible, to know how much electricity would be demanded by the various sectors if supplies of electricity were not so tightly constrained. Although this difference is not necessarily crucial in understanding the DPRK's energy system today, it is crucial to the estimation of what electricity demand might be in a future DPRK where supplies of electricity are not constrained, and thus must be factored in as a consideration in projects that might seek to redevelop all or part of the DPRK electricity supply and demand system (see Chapter 8 of this Report). .

Figure 5-54: DPRK Overall Electricity Use by Sector and Year

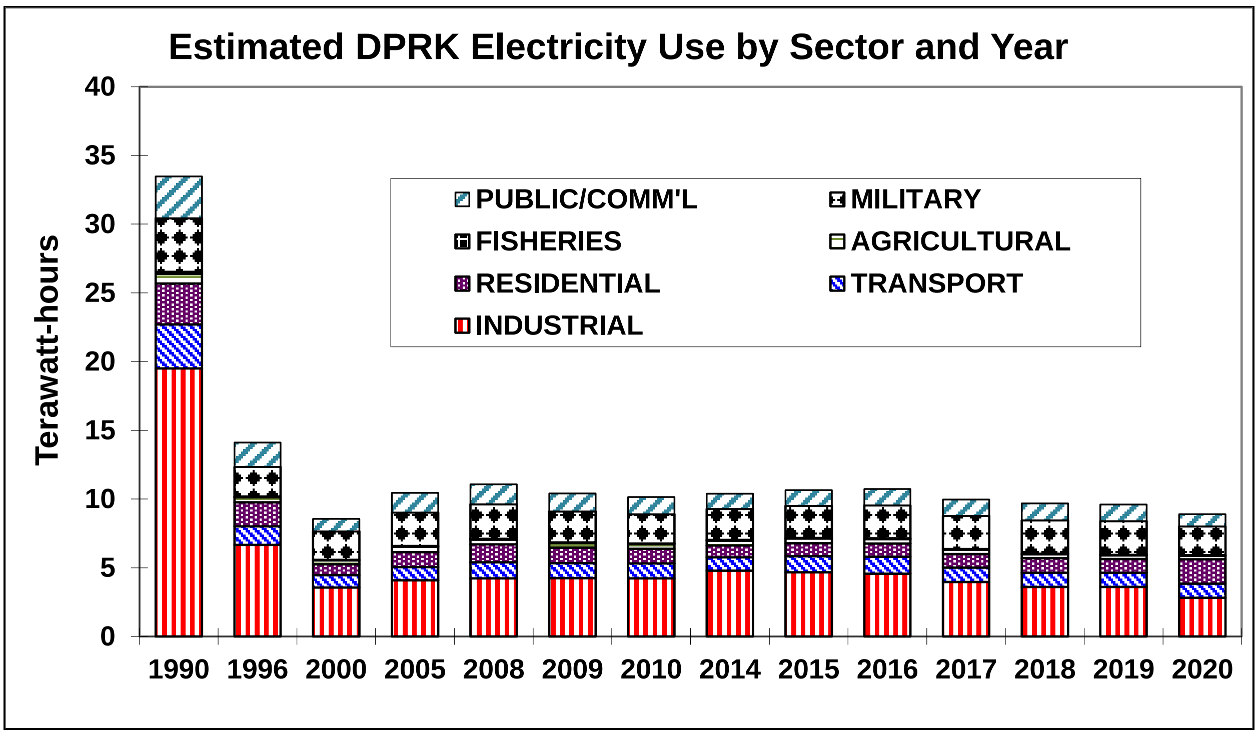


Figure 5-55 presents our rough estimate of overall DPRK electricity use by end use. As indicated in Table 5-15 as well, electricity used in motors accounts for over half of estimated electricity use, with lighting nearly 30 percent, other end-uses about 12 percent, and air conditioning and space and water heating less than two percent each. The latter two categories comprise a relatively small share of current DPRK electricity demand because A) air conditioning is not widely used in the DPRK, especially in residences, and B) space and water heating are mostly supplied using non-electric energy sources. Both of these situations could change, and change rapidly, if electricity supply constraints are lifted for DPRK consumers, thus it is important to keep these end-uses in mind when considering the DPRK's electricity future.

Figure 5-55: Overall DPRK Electricity Use by End Use

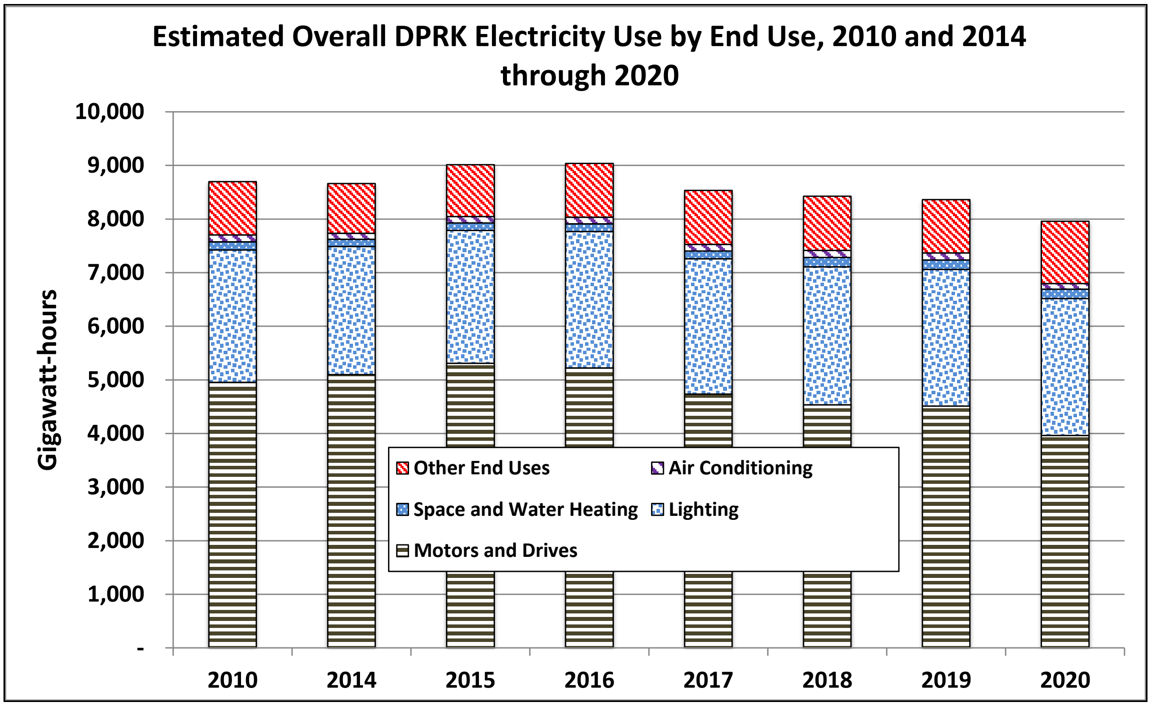


Table 5-15: Overall DPRK Electricity Use by End Use

Estimated Overall DPRK Electricity Use by End Use, 2010 and 2014 through 2020

Electricity Use (GWh)	Motors and Drives	Lighting	Space and Water Heating	Air Conditioning	Other End Uses
2010	4,955.13	2,468.82	152.03	128.91	992.85
2014	5,099.74	2,388.74	133.87	114.42	924.18
2015	5,311.13	2,475.31	139.98	119.36	967.91
2016	5,221.56	2,544.54	145.63	123.93	1,001.65
2017	4,735.99	2,522.66	145.44	123.46	1,005.35
2018	4,535.48	2,572.19	174.49	131.48	1,012.49
2019	4,510.74	2,551.13	172.75	131.84	996.11
2020	3,963.28	2,551.83	176.97	105.29	1,159.62
Fraction of Total by End Use					
2010	57.0%	28.4%	1.7%	1.5%	11.4%
2014	58.9%	27.6%	1.5%	1.3%	10.7%
2015	58.9%	27.5%	1.6%	1.3%	10.7%
2016	57.8%	28.2%	1.6%	1.4%	11.1%
2017	55.5%	29.6%	1.7%	1.4%	11.8%
2018	53.8%	30.5%	2.1%	1.6%	12.0%
2019	53.9%	30.5%	2.1%	1.6%	11.9%
2020	49.8%	32.1%	2.2%	1.3%	14.6%

5.4. Electricity Supply and Demand Conclusions

Throughout this Chapter we have characterized our information on the DPRK electricity sector as estimates, which they very much are. There are few other countries in the world where reliable data on energy supply and demand—and probably many other aspects of life—are so unavailable, at last to outsiders, and probably to all but a very few—if any—residents as well. The few other countries that come to mind that have comparable data constraints are, for example, African nations such as Somalia, or South Sudan, or nearby war-torn Yemen on the Arabian Peninsula, that are frequently in crisis and/or lack functioning governments. It is probable that even North Korean officials, perhaps even those at the top of the DPRK administration, do not have a reliable statistical overview of electricity supply and demand.[650] As a result, we have been forced to use what information is available, often including anecdotal and/or indirect information, to assemble an internally-consistent, but still approximate, picture of electricity supply and demand in the DPRK. We view our work as a tool for understanding the DPRK energy and electricity sector, to be updated whenever possible, and as a consequence welcome inputs from others that can help to refine the estimates presented here.

In this concluding section of this Chapter, we provide a summary of the results of this updated estimate of DPRK electricity supply and demand, offer some thoughts on the implications of the results for engagement with the DPRK on electricity sector issues, and identify a few "next steps" toward a better understanding of electricity supply and demand in the DPRK and towards development of engagement projects.

5.4.1. Summary of Results—DPRK Electricity Supply and Demand

The DPRK's energy sector as of 2020, as well as in most of the preceding three decades, was characterized by a combination of lack of key fuels, particularly oil products and electricity, and mostly antiquated demand- and supply-side equipment and infrastructure, often with difficulties in operation caused by lack of materials for maintenance, particularly in the electricity sectors. As described above, electricity use since 1990 has decreased considerably in all sectors, though not necessarily, by our estimates by the same amount in each sector. Most of this decline occurred during the 1990s—electricity supplies and use appear to have changed relatively little since 2000, as the DPRK continues to operate on the modest supplies that can be provided by aging power plants and a few new small and medium-sized hydroelectric plants, though the latter may have technical issues of their own. Hydroelectric power is currently the major source of electricity, which makes the DPRK vulnerable to even more constrained power supplies in times of drought, such as in the past few years. One trend of note in recent year has been for households and businesses in the DPRK to take power supply into their own hands via the purchase of imported diesel and gasoline-fueled generators and, more recently solar photovoltaic panels and battery systems, for use in providing key energy services (lighting and entertainment, for example) when grid power is not available. Almost all of these imported power systems have come from China. Although this trend toward distributed electricity provision has some positive

[650] On the occasions over the years where we have presented our energy sector estimates to DPRK delegations, delegation members, after some internal discussion, have found our estimates to be, to their knowledge, "pretty close".

impacts (see below), the use of relatively low-efficiency gasoline- and diesel-fueled generators constitute an inefficient use of the DPRK's limited petroleum products supplies, in addition to the negatives of the local pollution and noise created by these generation units.

These results suggest at least two conclusions. First, the status of electricity supply and demand technologies, and the constraints on electricity supplies, mean that there is considerable scope for energy efficiency improvements in the DPRK, as better technologies become available. Widespread deployment of such technologies, of course, are only likely if and once international sanctions are eased and as the DPRK's relations with the international community improve, which in turn is largely dependent on agreement being reached—or at least a path forward being agreed upon—on measures related to the DPRK's nuclear weapons program. Second, and countervailing, once restrictions on electricity supplies are eased and the DPRK economy begins to grow, there will be a considerable increase in energy demand in general, and electricity demand in particular. It will thus be crucial for the ROK and other nations seeking to engage the DPRK in energy sector activities strive to assist the rebuilt DPRK to use electricity (and other fuels) as efficiently as possible to reduce the overall costs and difficulty of supplying electricity to the DPRK economy in the long run.

5.4.2. Implications of Results for ROK and International Community Engagement of the DPRK on Electricity Sector Issues

Some of the key implications of the results of this description of the DPRK electricity system are described in the following subsections.

5.4.2.1. Implications of Findings Regarding the DPRK Electricity Supply System

The DPRK electricity supply system, as noted in Section 5.2, is for the most part aging and antiquated, and faces multiple technical and resource challenges in providing reliable electricity service to the people and organizations of the DPRK. Some of the implications of the DPRK electricity supply situation for the international community and the ROK, as they consider engagement options, include:

- Simple provision, by the ROK (or China, or Russia, for that matter) of large amounts of power from one of the neighboring country grids will not be possible in the short-to-medium term, because the status of the DPRK electricity T&D system will not support such imports, even if they could be made available. Provision of relatively small amounts of power (tens to hundreds of MW) to areas largely isolated from the central grid, such as the power that the ROK has supplied in the past to the Kaesong Industrial Park, may be possible in some areas around the DPRK's borders, but significant infusions of power to the central or a major regional grid are unlikely to be feasible for several years, even if grid reconstruction begins soon.
- Although construction apparently continues on a number of generating stations in the DPRK—mostly hydroelectric, possibly at least one thermal plant as well—even if all of these were to be completed in the next few years, power supply deficits nationwide would hardly be eliminated. Although the power situation in Pyongyang and surrounding areas targeted by most of the new plants could improve, evidence, including at one point

the replacement of electric locomotives with diesel units for routes heading north from Pyongyang, suggest that electricity problems, particularly outside of Pyongyang and away from major power plants, continue to be acute. These deficits continue to present an opportunity to the international community to work with the DPRK, as a part of a carefully negotiated package of incentives coupled with actions on the DPRK's part related to the eventual dismantling of the DPRK's nuclear weapons program, on electricity supply and demand technologies.

- The status of the DPRK's thermal power plants, including their age, condition, efficiency, and environmental characteristics, may mean that when the DPRK electricity grid is updated, with assistance from the ROK or others, the plants will need to have most of their components, including boilers, emissions control equipment, generators, and substation equipment, totally replaced within a few years of the start of any upgrading of generators. In many cases, even if these plants can be repaired, it is likely that spare parts for the plants, formerly made in the Soviet Union, would not be available. The condition of these thermal units likely means that the ROK or others contemplating assisting with rebuilding the DPRK's generation capabilities will need to be resigned to replacing most of the existing thermal generation infrastructure.
- Similarly, although hydroelectric power comprises, by our estimates, the majority of generation in the DPRK, most of the hydroelectric plants in operation in the DPRK are older, some dating to Japanese colonial times, and likely in need of refurbishment and repair. Some newer hydro plants, in the megawatt to at most several-hundred-megawatt size range, have come on line in the last two decades, but in some cases they are quite small and prone to hydrologic resource restrictions related to river flows, and in other cases there have been disconcerting reports of poor dam stability, substandard materials use, and other technical difficulties that bring into question the true operability, expected longevity, and safety of the dams both for workers and for downstream populations. What this means for the ROK and the international community is that when the DPRK is open to assistance and engagement on its hydroelectric facilities, the first item of business is likely to be a full expert technical review of the status of existing facilities, which may provide sobering and unwelcome news for both North and South Koreans. Thus, although the DPRK's resources for hydroelectric generation are certainly significant, it is unlikely that the ROK could count on the existing hydroelectric infrastructure to help power a unified Korea without considerable additional investment, including, probably outright replacement (or just removal) of some dams.
- The unfortunate accompaniment to problems with thermal and hydro generating stations is the declining condition of the DPRK's electricity transmission and distribution grid. With few modern automatic dispatch centers, substation equipment that was reported, even as of the early 2000s, to be many decades old and on the verge of failure (those units that had not already failed), reports of theft of power lines and equipment for sale on the scrap metal market (mostly to China, during periods of high commodities prices in the late 2000s), the DPRK T&D system is reported to be no longer a unified grid, but a patchwork of regional grids centered around power plants. The condition of substation equipment at power plants and other locations constrains the amount of power that can be delivered to consumers in many areas, as well as the power that could be put into the grid from new power plants or from imports. Renewing the T&D system—meaning likely

replacing everything except, possibly, some power line towers/utility poles—will be a giant undertaking, with costs likely in the tens of billions of dollars.

- The sum of the status and needs of the DPRK's thermal generation, hydroelectric generation, and electricity T&D systems mean that massive investment and work by perhaps hundreds of thousands of engineers and technicians would be needed to fully modernize the DPRK's electricity supply system using a conventional (central grid) approach. Even in the (highly unlikely, in our view) scenario where the current DPRK government completely but peacefully collapses, and the ROK is left to fill the void of administering the DPRK, the raising of funds for a complete, all-at-once overhaul of the DPRK electricity system would be extremely daunting, and the logistics of carrying out the overhaul while providing a clamoring North Korean population with even basic energy (and other) services would be extremely daunting from many perspectives. As such, the approach that will probably need to be required is to build/rebuild power grids—including electricity generation, perhaps with a focus on renewable generation, T&D ("mini-grids"), and probably even energy demand infrastructure— in local area, possibly as small as villages, towns, or counties, and slowly aggregate those areas into more regional and then a national grid over time. Such an approach would allow the ROK and its international partners to start on DPRK grid modernization even under a limited economic and diplomatic opening by the DPRK, and would allow learning on a practical scale by both DPRK officials and technicians and their international partners that would allow the scope of the overhaul (and/or replacement) to be efficiently and smoothly increased as capabilities for engagement on both sides of the DMZ, as well as in the international community, are enhanced.

5.4.2.2.Implications of Electricity Demand Findings

The findings of our estimates of electricity demand in the DPRK have implications for ROK and international community engagement with the DPRK on electricity issues that include the following:

- The substantial decrease in electricity demand—or rather, electricity **use**—since 1990 is in part due to degradation of end-use equipment (see below on the topic of industrial electricity demand) but is more closely associated with a lack of electricity supplies. This means that particularly in the residential and public/commercial sectors, but in the agriculture/fisheries, transport, and to some extent, industrial sectors as well, when constraints on electricity supplies are relaxed—assuming some degree of economic revitalization—demand for electricity will surge. This means that if and when the ROK makes plans for providing North Koreans with power, requirements will not be in the 7 to 9 TWh range we estimate for electricity use in recent years, but considerably more, perhaps two or three (or more) times that amount within a very few years, depending on the pace and extent to which regions of the country away from Pyongyang have their power supplies restored/redeveloped, and increasing rapidly after that. A DPRK engineer is quoted in a *Radio Free Asia* article as suggesting that the country's current electricity supplies are in fact a fifth of what the DPRK needs for economic development.[651] This estimate may in fact not be far off, assuming a decade or more of a sustained transition to an open economy.

- It also means that it is crucial that those who help the DPRK to overhaul its electricity supply system also pay attention to end-use equipment purchases by households and other consumers as reliable electricity supplies come on line. It will be much less expensive (as well as less-polluting) to supply "negawatts" of power—that is, to save electricity through assuring purchase of high-efficiency equipment—than to build additional generation. For example, refrigerators are not particularly common in DPRK households, especially outside of Pyongyang and especially in rural areas, because unreliable power supplies make them less than useful. If reliable power supplies are provided, and incomes are sufficient, it is probable that many households will quickly purchase refrigerators. The temptation may be for many DPRK households to purchase used older and less-efficient refrigerators from, for example, the ROK, Japan, or China. Refrigerator efficiency, however, has improved markedly in recent years, particularly in Chinese-made units, so the difference between the annual electricity required by a used and a higher-efficiency new refrigerator may be significant, perhaps a factor of two. Multiplied by perhaps several million refrigerators that might be purchased in the first few years after reliable power service is available, the difference between deploying, or regulating the deployment, of less- and more-efficient refrigerators could be on the order of many hundreds of GWh per year, perhaps the approximate equivalent of the output of a 100 MW power plant. A similar case can be made for upgrading the lighting of all DPRK buildings to modern LED (light-emitting diode) bulbs and other high-efficiency lighting systems, many of which use on the order of a tenth of the energy (or less) per unit of light output of the DPRK's rugged-but-very-inefficient standard-issue 40-Watt incandescent bulb, which was until the last 15 years or so the most common lighting device in the DPRK. High-efficiency industrial motors and motor drives is yet another example of where it will much less expensive to invest in demand-side energy efficiency—by either subsidizing consumers to purchase high-efficiency units, by preventing the import of used or low-efficiency new units, and/or by providing information and design services to firms and government organizations that use motors.
- The DPRK's industrial sector as of 1990 was in large part tuned to provide inputs for, and use outputs of, industries in the Soviet Union. In the years since, although not exclusively, DPRK factories have, insofar as can be determined, been operating in pretty much the same way as they did in 1990, albeit at much lower levels of production, overall, due to a combination of lack of markets (or access to markets), lack of inputs, lack of spare parts, lack of fuel and electricity, lack of investment capital, and lack of access to modern industrial equipment (due to international economic sanctions on the DPRK. If the ongoing political impasse on the DPRK's nuclear (and other) weapons programs can be overcome, and an opening of the DPRK economy begins, it is not clear what the DPRK's industrial economy will look like, once change takes hold, but it likely will not, for the most part, look like what it did in 1990. Smaller, lighter manufacturing

[651] Sung Hui Moon (2013, translated by Doeun Han, and written in English by Joshua Lipes), "North Korea Seeking Electricity Supply from China", *Radio Free Asia* Korean Service, dated 2013-10-21, available as http://www.rfa.org/english/news/korea/electricity-10212013160033.html.

may become much more prevalent, for example, although the DPRK's mineral wealth and lower labor costs than in the ROK and other nearby nations may leave the basic metals and minerals sectors, in upgraded form, a key part of the industrial economy. What this means for electricity use remains to be seen, but it seems possible that electricity use per unit of economic output could decline in the DPRK under an economic opening scenario, and the growth in electricity requirements for industry may be lower than the growth in electricity use in other sectors. The implications of a changing industrial sector for the ROK and the international community include both expanded opportunities for new businesses in the DPRK, and opportunities to guide the acquisition of new end-use equipment so as to restrain the growth in DPRK industrial sector electricity consumption, and the requirement of supplies to serve that consumption, without impinging on economic growth.

- If and when the DPRK electricity sector is overhauled and modernized, presumably with the help of ROK and international organizations, it will likely be expected that North Koreans will ultimately be responsible for at least a significant share of the cost of the upgrades. A key problem in the DPRK shouldering those costs, however, is that electricity markets essentially do not exist in the DPRK. With a very few exceptions, electricity in the DPRK has been distributed for a minimal monthly flat fee, not metered by the kilowatt-hour. As a result, markets for electricity, and the organizations and technical infrastructure to operate (and regulate) them, must be created as or before the electricity system is modernized in order for at least a significant portion of the costs of electricity supplies to be recovered from consumers, as well as to send price signals to discourage inefficient use of electricity. Building those markets will be a key undertaking for the ROK and the international community as engagement with the DPRK on electricity sector issues begins.

5.4.2.3.Potential Implications of Surge in Solar PV System Sales in the DPRK

In a way, and perhaps not entirely intentionally, the DPRK seems to be approaching the same renewable energy path that German policies have been emphasizing for some years. A recent article in *Foreign Policy* describes the trend, under a policy called *Energiewende*, in which the orchestrated use of mostly local renewable energy sources has been replacing power from central stations:[652] "[i]n just a dozen years, industrial-powerhouse Germany has replaced around 31 percent of its nuclear and fossil fuel generated electricity with green power, produced overwhelmingly from moderately sized onshore wind, solar PV, hydro, and bio-energy installations—an achievement no one predicted when the Energiewende commenced in 2000." One of the features of the German approach has been an emphasis on increasing the use of renewable energy starting at the local and regional levels, a "citizen-led energy boom" in which local projects increasingly use smart grids to manage local demand and supply and, increasingly, to trade power with other cities and regions. Such an approach, if not necessarily consistent with how the DPRK government has typically managed its energy sector, is certainly consistent with

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[652] Paul Hockenos (2014), Germany's Revolution in Small Batch, Artisanal Energy", *Foreign Policy.com*, dated October 31, 2014, and available as http://www.foreignpolicy.com/articles/2014/10/31/german_green_energy_revolution_backyard_windmills_solar_gas.

both the North Korean philosophy of *juche*, or self-reliance, as well as with DPRK government exhortations, in recent years, to local areas to provide their own energy sources to augment central supplies. Consistent with this direction is the recent announcement of the organization of a "natural energy institute" in Pyongyang "with various rooms for researches into wind energy, geotherm, solar heat and other natural energies, e-library, laboratories, a pilot plant, etc".[653] Setting up such an institute was a topic that Nautilus Institute talked about with DPRK counterparts as early as 2000. The DPRK government's longstanding interest in renewable energy, coupled with the widespread grassroots adoption of solar PV and other renewable technologies, mean that cooperation in renewable energy systems will likely serve as an attractive (to both sides) and helpful approach to engagement between the DPRK and the international community.

The DPRK's growing markets for solar PV systems in the last decade (and presumably continuing, although recent trade data are lacking) suggest two things. First, it suggests that that there is likely a high level of suppressed demand for electricity in the in both rural and urban areas. Second, the evident willingness on the part of DPRK citizens to pay high costs per unit of electricity delivered by use of PV/battery systems reflects the very high "opportunity cost" of foregoing the use of electricity when it is needed.

In South Korea, on the other hand, in contrast with German policies, and also in contrast, for example, to the strong growth in installation of solar power in Japan (driven in part by the post-Fukushima anxiety about reliance on nuclear power, as well as by the high prices of electricity in Japan and Japanese Feed-in Tariff policies), the ROK government's commitment to promoting the domestic use of solar PV power waned in the mid-2010s.[654] Under the Administration of President Moon Jae-in in the ROK, a renewed commitment to renewable power development has been made, but progress remains limited. In the DPRK, the need to rehabilitate virtually the entire power sector may, paradoxically, coupled with the demonstrated interest by individual DPRK citizens in harvesting the benefits of renewable energy (and thereby receiving at least some of the energy services they have been missing), make it easier, not harder, for the DPRK to follow the German model of growth of local and even household renewable energy systems into local, then regional, then national renewables-dominated smart grids. Achieving such a future rapidly will of course require investment, as well as technical and other assistance, from outside the DPRK, assistance that can only come via cooperation and engagement with the international community. It is even possible that a DPRK focused on using renewables for green growth will help to spur the ROK to take more meaningful steps in the same direction, thus moving South Korea more rapidly toward the goals implied by its government's stated, and as far back as 2008, and recently renewed, intent to undertake a green energy path.

[653] Korean Central News Agency (KCNA, 2014), "Natural Energy Institute Established in DPRK", dated November 4, 2014, and previously available as http://www.kcna.co.jp/item/2014/201411/news04/20141104-10ee.html.
[654] BusinessKorea (2014), "Dark Outlook: Domestic Solar Power Demand Expected to Plummet", dated October 15, 2014, and available as http://www.businesskorea.co.kr/news/articleView.html?idxno=6812.

5.4.3. Possible "Next Steps"

"Next steps" related to understanding of the DPRK electricity sector, and, ultimately, to engagement of DPRK counterpart organizations in collaborative projects on electricity sector topics might include the following.

5.4.3.1.Potential Research Projects

Research organizations, whether governmental, non-governmental, private, or affiliated with regional multinational organizations, could help to develop additional background information to assist DPRK engagement projects in several different ways, including:

- **Continuing to update, at every opportunity, the publicly available knowledge about the electricity sector (and broader energy sector and economy) in the DPRK**. Related research efforts could include working with visitors to the DPRK, including, for example, Chinese and Russian commercial interests who have worked on electricity projects there, to obtain a more complete view of the DPRK electricity sector, working with DPRK refugees in the ROK and China to learn about electricity availability in different locations and different sectors in the DPRK, and continuing to otherwise gather and assemble, within an organized structure (including, for example, a Geographic Information System—GIS—database[655]), updated information on the DPRK electricity sector, as has been summarized earlier in this Report.
- **Continue to investigate and refine future electricity scenarios for the DPRK**, so as to learn more about the potential for different approaches to electricity sector redevelopment, including the relative cost and performance of different approaches. This work could include assembly of updated information on electric energy efficiency and renewable energy measures that might be applied in the DPRK. Future electricity scenarios should be evaluated in the context of overall energy scenarios for the DPRK, in order to assure consistency across the entire energy economy, and should also, ideally, be integrated with analysis of energy futures in neighboring countries that might share electricity generation and other resources with the DPRK, particularly that of the ROK.
- **Undertake an examination of the costs and requirements to bring the DPRK's electricity generation and T&D system up to 21st century standards.** This would involve doing a careful estimation of the electricity supply system needs under different DPRK electricity demand scenarios and would likely involve both the exploration of different types of supply systems (for example, distributed versus centralized grids) as well as the requirements and options for merging the DPRK grid system with that of the ROK and/or exploring regional grid interconnections with, for example, the Russian Far East.
- **Assemble a roster of experts on DPRK electricity issues, including those from the ROK and elsewhere**, and call together a meeting of a group of experts similar to the Energy Experts Working Group Meetings that Nautilus convened in 2006, 2008, and 2010, to allow experts to share experiences and learn from each other, and also to inform selected others,

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[655] An example of a GIS database for the DPRK is that compiled by 38 North in their *DPRK Digital Atlas*, available as http://38northdigitalatlas.org/.

potentially including ROK government representatives and key members the international community (including bilateral and multilateral aid agencies and donors, for example).

- **Work to develop electricity products and related goods for application in the DPRK and elsewhere**. Research organizations could also undertake R&D into what types of electricity supply and demand approaches—for example, solar photovoltaic/battery and efficient end-use equipment systems for different types of humanitarian and other needs in the DPRK—might be most applicable and cost-effective in a DPRK context, so as to be ready to deploy those technologies in the context of engagement projects (and ultimately, commercial sales in the DPRK) when the opportunity arises.

The ultimate goals of all of these types of research are to increase the readiness of the international community, and particularly the ROK, and to provide useful, well-informed, and well-designed assistance to the DPRK electricity sector when the opportunity arises to do so.

5.4.3.2.Potential Engagement Projects—Training

In all likelihood, the first set of engagement projects undertaken between any ROK or other foreign institution and their DPRK counterpart will be related to training/capacity-building, whether in the electricity sector or in other areas. Here the typical sequence of training on any topic would likely be:

1. Start with trainings in a third (not ROK) country, such as China or possibly Mongolia, for a few (4-10) DPRK counterparts. The training can be provided by experts from the ROK, US, or other nations, and should probably involve a brief local study tour. Such a training could, and in some cases would optimally, involve trainees from other nations, particularly those friendly to the DPRK and to others (such as Mongolia or other developing Asian nations), for whom the training is also applicable.
2. Offer DPRK counterparts the opportunity to undertake short courses of study at academic institutions in a third country, and/or organize study tours for DPRK counterparts in Europe, North America, Australia or elsewhere on the desired topic.
3. Send a delegation of experts to the DPRK to provide a course of perhaps one to three weeks in a desired topic for perhaps several dozen DPRK trainees. A follow-up course may also be necessary. One of the goals of such a training would be to “train the trainers”, that is, train DPRK counterparts sufficiently that they can pass on what they have learned to others, or at least be “up to speed” sufficiently to be active participants in pilot and demonstration projects (such as those described below). A part of this visit will be for the foreign experts to assess the skills and needs of DPRK trainees, and see what “works” in the DPRK, so as to be able to improve the design of course offerings in the future.
4. Work to integrate trainings into more formal and regular course offerings at DPRK institutes of higher learning and/or research institutes.
5. Provide opportunities for DPRK researchers to undertake graduate courses of study abroad in various energy-related fields.

This generic sequence would be applicable to any of dozens of different training topics in the energy and related fields. For the electricity sector, these topics could include (but are most certainly not limited to) the following, which are presented in no particular order of importance, though all would be extremely useful in the DPRK:

- Organization and operation of electricity markets, including methods of electricity pricing, billing, and collections.
- Development of stable financing arrangements and markets for independent power producers, including developers of local mini-grids.
- Renewable electricity generation resources assessment.
- Electricity supply planning and electricity demand survey design and implementation.
- Building energy efficiency, including efficient use of electricity in lighting, heating/cooling, and other end-uses.
- Renewable electricity system design and implementation, including solar, wind, and small/mini/micro hydro power.
- Energy economics, including techniques for economic assessment of electricity projects and alternatives.
- Application of energy planning tools, both for broad energy sector use and specifically for modeling in the electricity sector such as electricity transmission and distribution and production cost modeling.
- Environmental impacts of electricity generation systems, including environmental monitoring and estimation of emissions from power plants.
- Development of Clean Development Mechanism projects in the electricity sector.
- Electricity transmission and distribution system equipment, control, planning, and monitoring.

5.4.3.3.Potential Engagement Projects—Energy Assessments and Energy Planning for the Electricity Sector

The first step to addressing electricity sector needs in the DPRK is to better understand the existing problems and current conditions, as well as to explore options for addressing those problems with DPRK counterparts. These could include:

- Carrying out joint **surveys of electricity use** in various sectors, as well as surveys of the use of other fuels that might be used as substitutes for electricity (due to the lack of electricity availability). Examples here include rural and agricultural electricity use, household electricity use, and electricity use in specific industrial facilities, including, for example, a survey of the types, sizes, and uses of electric motors in industry. The results of these surveys, which should be carried out jointly with DPRK counterparts and used as both data gathering and capacity-building opportunities, would then help to inform, for example, the development of pilot and demonstration projects as suggested below, and ultimately, to sector-wide implementation of electric energy use improvements. Working hard to maintain transparency at all levels of energy surveys will be a key to their success in the DPRK. That means involving DPRK counterparts in all phases of the survey process, from survey design to implementation, data processing, and interpretation of results.

- **Electricity demand/supply assessment**s. Researching and compiling (with local authorities and engineers/technicians/researchers) a thorough quantitative assessment of the electricity demand of a particular subject facility or area, which could be a hospital, school, industrial facility, or a village or town, together with an assessment of the existing electricity supply resources (thermal, hydro, wind, and portable generators, for example) and infrastructure (power supplies, fuel storage, mines, electricity T&D, and others) available to provide electricity One tool in carrying out such assessments is energy surveys like those above, but other types of tools will be needed as well. The assessments themselves should, by involving a team of DPRK counterparts, help to complete the necessary surveys and measurements, provide "teachable moments" to start to build the capability to carry out such assessments wherever they are needed in the DPRK, which is essentially everywhere. As such, it will offer a first step in what will need to be a similar process nationwide, as the DPRK figures out (with whatever outside assistance can be practically provided) how to modernize its electricity system to support a sustainable economy.
- **Engagement built around energy planning topics and tools**. Ideally in conjunction with some of the activities described above, it will be useful to engage DPRK researchers in carrying out the building and testing of different electricity scenarios for the DPRK. A software tool such as LEAP (Low Emissions Analysis Platform, formerly Long-range Energy Alternatives Planning[656])—which we have used to prepare and evaluate quantitative scenarios for the DPRK energy sector, as reported in Chapter 8 of this Report and in previous Nautilus publications, and in which we have trained a number of DPRK delegations in the use of—could be used as an organizing mechanism for teaching and assembling data, as well as for learning about what data are missing. Other types of energy planning that could be explored, some of which could use LEAP, include greenhouse gas emissions mitigation/Clean Development Mechanisms application associated with the electricity sector, utility integrated resources planning, climate change adaptation related to the electricity sector, electric energy efficiency measure implementation, and transmission system planning. In each case, the subject for these energy planning exercises could be the DPRK as a whole or, if that is initially politically difficult within the DPRK, could start with a smaller jurisdiction, such as a single county or province, moving on to a country-wide assessment (and, perhaps eventually, a two-Koreas effort), as DPRK authorities become more comfortable with the concept.

5.4.3.4.Help to Build/Reinforce Centers of Expertise

The DPRK has a tradition of developing centers of expertise on various topics, including, for example, electricity supply and renewable electricity generation, which are used both as R&D facilities and as means for dissemination of technologies and practices to places and organizations where they are needed. Potential options for engagement in building new, or enhancing existing, Centers of Expertise related to electricity supply and demand include:

[656] The LEAP software tool has been developed and is offered by the Stockholm Environment Institute—United States (SEI-US). See https://leap.sei.org/default.asp?action=home.

- **Renewable Energy and Energy Efficiency Training Center**. This concept, discussed at some length and with great enthusiasm with several DPRK delegations we have hosted, would involve combining provision of information materials (a process already begun by Nautilus and other), assembling assessment tools (such as measurement devices for wind and solar energy, and more basic measurement tools for temperature, pressure, heat flow, electricity, and other parameters), and, above all, providing training by experts in renewable energy and energy efficiency for DPRK actors who would then serve to further disseminate the information. This concept was, in fact, the topic of a partial proposal written jointly by Nautilus and a DPRK delegation in 2001, and still very much in favor in the DPRK, though political conditions since late 2002 have not allowed the joint proposal effort to move forward.
- **Center of Expertise for Building Energy Efficiency**. An important special case of an energy efficiency center, one worthy of standing on its own, is developing a Center of Expertise for building energy efficiency, including efficient building design, training of building energy auditors, provision of computer tools and analytical hardware related to building energy design and efficiency, and R&D on materials for energy-efficient buildings. The Center would also include a component related to the development and analysis of building energy codes (including a library of codes from other countries). Many US and Korean organizations, both governmental and non-governmental, exist that could be engaged in helping to provide training and materiel for such a center, and we are certain that DPRK counterparts are interested in this idea.
- **Center of Expertise on Environmental Management**. This concept would involve equipping a DPRK center to do research on the environmental conditions in the DPRK, including, for example, monitoring of toxins in the environment, air and water pollutants, ecological health, and other parameters. Engagement options could include providing training on a variety of environmental issues, including those associated with electricity supply facilities, for DPRK scientists and technicians, and carrying out pilot remediation projects, initially small, to address environmental concerns in local areas. This concept was originally suggested by Nautilus and others in the context of possible "repurposing" of the Yongbyon nuclear facility for peaceful purposes,[657] but could be applied to existing research or academic centers in the DPRK, could involve creating a new center on a new site, or could be used to find new purposes for other types of industrial or military research units.

5.4.3.5.Pilot and Demonstration Projects

Demonstration projects have great value in the DPRK, where they serve as a key tool for dissemination of technologies, experience, and know-how in the country. A few of the many opportunities for such projects in the electricity sector include:

- **Solar photovoltaic system deployment**: Solar PV systems imported from China have already proven extremely popular in the DPRK, as noted above. A project could implement solar photovoltaic/battery systems for humanitarian (at one or more schools, hospitals, and/or

[657] See D. von Hippel (2010), Possible Energy, Economic, and Other Engagement/Assistance Activities to Combine with Yongbyon Decommissioning/Conversion, dated January 2010, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Yongbyon-Decommissioning-and-Conversion.pdf.

nurseries, for example) and/or for economic (tourist facilities) use. The project would start with imported solar panels but could include a component for design and fabrication of support structures in the DPRK, as well as providing training on the maintenance and monitoring of solar PV systems, and/or to the ultimate integration of larger PV systems with local electrical grids, either existing or new.

- **Mini or micro-hydro system pilot project**: There are apparently many mini- and micro-hydro projects in the DPRK, but their level of performance is unknown, and thought to be suboptimal. Choosing a mini- or micro-hydro site, whether new and existing, and applying cost-effective construction methods to develop both the dam and generator and the systems to use power from the generator (probably including some local economic development and/or humanitarian project using the power) would provide a pilot facility that could, if well-designed, be replicated in many parts of the DPRK.

- **Wind power pilot projects:** Alternatively, a pilot project could be launched to assess the wind resource in one or more candidate areas where the wind power potential is expected to be good, followed by deployment, working closely with DPRK engineers and researchers, of (probably imported) wind machines, and follow-up monitoring of same. Here it should be noted that if the wind power project is to be stand-alone, it should probably be integrated with another renewable energy project, such as micro-hydro or mini-hydro, and an energy storage system, such as battery electricity storage or pumped-storage hydro, as well as a new distribution grid and related equipment for the area served. If the project is to be grid-integrated, a prior assessment of the local grid will be needed to see if it is adequate to support the wind machines. In the likely event that it is not, it may be necessary to build a new grid in the local area, supplied with power from hydro and/or diesel generation. In any case, a key part of such projects would be training on installation and maintenance protocols, in wind power technology and economics, and in monitoring and assessing wind resources. Wind power can also be interpreted more broadly to include water pumping windmills, which have many applications in the DPRK, and can be made locally.[658]

- **Development of new "green buildings" for use as clinics, schools, or for other purposes**: An activity that could involve and help to retrain DPRK workers in the building sector might be to work closely with international counterparts in the ROK, US, Europe, and elsewhere to design and build one or several highly energy-efficient "green buildings" incorporating, for example, solar passive or active heating, along with many electric and other energy efficiency measures. The idea is that the building would be a laboratory and showcase for electric and other building energy efficiency measures for the DPRK, and available for monitoring and study as a part of the work of the **Center of Expertise for Building Energy Efficiency** and/or the **Renewable Energy and Energy Efficiency Training Center** described above.

- **Energy efficiency in existing residential and institutional buildings**: More generally, existing residential and institutional buildings on a chosen site, which could possibly be the sites of an existing institutes that might be project partners, as well as nearby support buildings (child care centers, schools, cafeterias, and similar facilities) could be fitted with

[658] In our trip to the DPRK in 2000, we provided our counterparts with an example of a relatively easily fabricated water-pumping windmill. Our understanding is that this design has in fact been replicated and deployed in some areas.

energy-efficient lighting systems and with building control and monitoring systems (heat, electricity, and temperature sensors, meters, and recorders) to allow the buildings to also be energy efficiency "laboratories" to help to advance energy efficiency practices in the country as a whole. This type of demonstration project could also be an undertaking of staff of the **Center of Expertise for Building Energy Efficiency** and/or the **Renewable Energy and Energy Efficiency Training Center** described above. The buildings might well (almost certainly will) need to be largely rewired to take advantage of electrical system efficiency upgrades, which would provide an opportunity to wire the host institute campus for telecommunications (especially computer networks) as well. The energy efficiency upgrade process would be preceded by assessments of energy-efficiency needs for the targeted buildings, which would again provide an opportunity for initial training of DPRK expert trainers-to-be who, in turn, might help to staff one of the Centers of Excellence described above.

- **Development of local power options and T&D systems**: This option would begin with an assessment of one or more local electricity grid and power supply systems, and, depending on the findings of the assessment, could include partial or wholesale rebuilding of the electricity distribution grid in local areas, replacement of existing substations or transformers, and possibly the addition of new power generation, either in the form of combined heat and power systems (as above) and/or with independent power systems, probably, judging from the terrain and the presence of a river nearby (if applicable), a mini- or micro-hydro system (as noted above), but possibly integrated with a small ridge-mounted wind-power system (and/or pumped-storage hydro system) as well (in part for demonstration/training purposes). Once again, energy supply assessment process, and the development of local power systems and T&D networks, can be expected to contribute to local and national expertise in these areas, and the new energy infrastructure set up as a result of this effort could/should be configured with sensors and other attributes so as to be used as pilot and demonstration systems for further training and study for researchers and technicians from throughout the DPRK.

- **Providing agricultural assistance for local areas**: Providing a combination of technical assistance, and improved electric equipment (crop processing equipment, irrigation equipment, and food storage equipment, for example) for one or more villages could help to boost local food production, providing both a humanitarian benefit and a demonstration of sustainable modern agricultural practices, as well as a way for foreign experts to learn about which practices are likely to applicable in the DPRK, and which are now. Monitoring of agricultural soils and products for soil composition and, if the area has a history of, for example, industrial pollution, for toxins, with remediation as needed, could also be a part of this type of assistance. Making sure that those in the project area have as much control as possible over their food security—by providing them with enhanced wherewithal to produce their own food to the extent possible, would also be a goal (perhaps unstated) of this option.

- **"Energy Independent Village" Demonstration Project**: An "Energy-Independent/Green Energy Village" (GEV) project could integrate many of the pilot project concepts described above. Such a project would combine elements of renewable energy supply, rebuilt or replaced electricity infrastructure, energy needs assessment/energy planning, deployment of building energy efficiency and other energy efficiency technologies, and local economic development opportunities, among others. A GEV project would meet the needs of a DPRK village or town by, for example, providing energy supplies and livelihoods for village dwellers that reduce their dependency on the state while demonstrating "green" technologies and green energy concepts that could be applied throughout the DPRK. A GEV project could also be a laboratory for applications of energy-efficiency and renewable energy (EE and RE) concepts developed in the ROK, as well as an opportunity to market ROK EE and RE technologies to other nations. A GEV project would also provide a demonstration of low-carbon development, thus it could be a useful illustration of approaches to global environmental problems, as well as an application of Clean Development Mechanisms (CDM) under the United Nations Framework Convention on Climate Change. The humanitarian benefits that an GEV project would be expected to provide will help to meet the political needs of groups in the ROK and elsewhere who would be called upon to support the project, and the economic development elements that must be incorporated in the project will be important in securing both the DPRK and ROK approval for the project.[659]

6. Estimates of Refined Product Supply and Demand in the DPRK, 2010 – 2020

6.1. Overview

The supply of refined oil products in the Democratic People's Republic of Korea (DPRK) has been constrained to varying degrees since the breakup of the Soviet Union after 1990. The economic dislocation in the DPRK—due to severed access to concessional oil supplies, to markets for goods formerly made in the DPRK for use in Soviet republics and satellite nations, and to spare parts for factories largely provisioned by the USSR, among other factors—meant that crude oil and oil products imports in the quantities consumed in 1990 and earlier became unaffordable for the DPRK. What imports were available after the early 1990s were at levels that constrained demand, meaning, for example, that vehicles were used less (and human and animal labor more) in transport and in farming, and that substitute fuels for various end uses became more important. In more recent years, the availability of oil products in the DPRK, at least judging from anecdotal evidence and based on statistics on imports of oil-consuming vehicles and equipment, appears to have been improved.[660] This trend has been interrupted to some extent starting in 2017 by United Nations Security Council (UNSC) sanctions targeting DPRK oil imports in response to the DPRK's nuclear weapons and missile programs, but sanctions do not have appeared to have had the dramatic impact on the DPRK economy that the

[659] Nautilus prepared a detailed report on the "GEV" project concept in 2013 for an organization in the ROK. The report has not yet been released.

[660] See David von Hippel and Peter Hayes (2018), *DPRK Motor Vehicle Imports from China, 2000-2017: Implications For DPRK Energy Economy*, NAPSNet Special Reports, August 23, 2018, available as https://nautilus.org/napsnet/napsnet-special-reports/dprk-motor-vehicle-imports-from-china-2000-2017-implications-for-dprk-energy-economy/, and David von Hippel and Peter Hayes, *DPRK Imports of Generators in Recent Years: An Indication of Growing Consumer Choice and Influence on Energy Supply Decisions?*, NAPSNet Special Reports, November 02, 2018, available as https://nautilus.org/napsnet/napsnet-special-reports/dprk-imports-of-generators-in-recent-years-an-indication-of-growing-consumer-choice-and-influence-on-energy-supply-decisions/. Note that DPRK imports of vehicles and generators as reported in United Nations Comtrade trade statistics (https://comtrade.un.org/data/), most of which are from China, have dropped off steeply between 2017 and 2018. It is certainly possible that some of this decline is due to UNSC sanctions enforcement, but the decline is such that it is difficult to believe that trade channels and relationships between vendors and buyers would have shriveled so quickly, so we suspect that some off-books trades in vehicles and generators continued through 2018.

United States and others had hoped for, likely meaning that oil products are finding their way into the country by routes not reported in, for example, customs statistics.

This Chapter[661] presents Nautilus' estimates of refined oil product supply and demand in the DPRK for the years 2010 and 2014 through 2020, along with the methods and assumptions used to prepare these estimates, key conclusions, and a related comparison of a potential DPRK engagement strategy for humanitarian relief of some impacts of UN Security Council sanctions versus the volume of petroleum products use in the DPRK. Although as of this writing the year 2020 is not yet complete, we include estimates and projections for oil and oil product supply and demand for 2020 here in part to illustrate the likely effects of the coronavirus SARS-CoV2 (COVID-19) pandemic, and national measures put in place to control it, on the DPRK. An additional factor that has led us to update the report at this time has been the finding that the DPRK's main active refinery added a piece of equipment, called a catalytic cracking unit, in approximately 2016, and that the use of that unit has likely changed the mix of products that the DPRK can produce from the crude oil it imports from China. This finding caused us to reexamine our refined product balance for the year 2017, as well as changing our assumptions for subsequent years, and suggests that supplies of (and demand for) diesel fuel and (especially) gasoline were in fact higher in that year than we originally estimated.

Key elements of these results presented in the sections that follow include:

- Estimated refined product balances, showing the origin of refined product supplies (that is, imported or produced in domestic refineries), the use of refined product in energy transformation (such as electricity generation), and estimated demand for refined products by fuel and by sector through 2020.
- Figures showing the estimated volumes of oil product imports and oil products refined in-country by type of refined product for selected years between 2000 and 2020.
- Tables and graphs showing fuel demand by end-use sector (and for electricity generation) for diesel oil, gasoline (petrol) and kerosene/jet fuel.
- A brief description of the potential impacts of a program of rapid-deployment building energy efficiency and solar photovoltaic power measures, were it to be offered by the international community, that would address some of the humanitarian issues associated with UNSC sanctions on the DPRK related to coal exports and oil product imports without removing those sanctions.

Our analysis of DPRK oil products supply and demand shows fairly robust growth in the use of petroleum products in most sectors from 2010 through 2016. This growth included very rapid growth in the use of diesel fuel and gasoline to fuel imported internal combustion electricity generators that were imported in large quantities, particularly in 2014 through 2016, and mostly from China. As UNSC sanctions came into full force, our analysis shows declines in oil products use in most sectors, as well as in electricity generation by households and organizations, between 2016 and 2019, due to the oil supply restrictions brought on by sanctions. Even with

[661] The contents of this chapter was published earlier as David von Hippel and Peter Hayes (2020), *UPDATED ESTIMATES OF REFINED PRODUCT SUPPLY AND DEMAND IN THE DPRK, 2010 – 2020*, NAPSNet Special Reports, dated September 02, 2020, and available as https://nautilus.org/napsnet/napsnet-special-reports/updated-estimates-of-refined-product-supply-and-demand-in-the-dprk-2010-2020/.

reduced demand, we found that a balancing was required between assumptions as to reductions in domestic demand for oil products from 2016 to 2019—given reports of only modest fuel shortages and limited evident reduction in economic activity in the DPRK as reported by visitors—together with what we assume, based in part on reports by others, must be the availability of additional "off-books" oil supplies procured by various means. The combination of the impacts of quarantines to protect the DPRK population from COVID-19, together with the impacts of those quarantines on fuel supplies (both "on-books" and "off-books"), has meant that our projections for fuel demand and supply in 2020 will ultimately be significantly lower than in 2019, although these demand reductions vary significantly by sector.

6.2. Analytical Methods

Although energy supply and, particularly, demand statistics are less complete than analysts might prefer in many countries, the DPRK is an outliner in terms of information provision, as it publishes essentially no direct information on its energy supply and demand. At the same time, its "energy insecurity"—that is, its lack of access to fuels, particularly petroleum fuels, and the energy services that those fuels provide, has been (and continues to be), in our view, a key driver of its decision to pursue nuclear weapons and related missile technology development over the past three decades. As such, understanding the DPRK's fuels supply and demand situation is critical to understanding potential solutions to the current political stalemate that international community actors might pursue.

Given the need to understand the DPRK energy sector, and the lack of direct data available, Nautilus Institute has built and periodically updated its analysis of North Korean energy supply and demand by collecting as much available public sector data relating to energy use and the DPRK economy as possible, including anecdotal information from visitors, customs statistics from the DPRK's trading partners, estimates on sectoral output by international and other organizations, and analyses of the DPRK economy by other researchers. This information was and is used to compile a "bottom-up" (demand-driven) analysis of changes to the DPRK economy, starting in 1990 (the last "normal" year for DPRK energy supply and demand), using as much sector detail as can be included. To ensure that these estimates are internally consistent, we use an "energy balance" approach widely used to report national energy supply and demand worldwide, for example, by the International Energy Agency (IEA).[662]

Our DPRK energy analysis works includes the preparation of energy balances—in which supplies (imports, exports, domestic production) of fuels are balanced by their use and conversion to other forms via energy transformation processes such as oil refining and electricity generation, and, ultimately, by end-use demand—for all of the fuel categories used in the DPRK economy.[663] In addition, we prepare estimated detailed supply-demand balances for oil products

[662] See, for example, the IEA compendium available for sale at http://data.iea.org/payment/products/117-world-energy-balances-2019-edition-.aspx, or the energy balances published by the Korea Energy Economics Institute for the Republic of Korea (ROK) as a part of (for example) *Energy Info Korea 2017*, available as http://www.keei.re.kr/keei/download/EnergyInfo2017.pdf.

[663] Previous versions of our DPRK energy analysis work for all fuels are David von Hippel and Peter Hayes (2012), *Foundations of Energy Security for the DPRK: 1990 – 2009 Energy Balances, Engagement Options, and Future Paths for Energy and Economic Development*, dated September 13, 2012, and available as http://nautilus.org/wp-content/uploads/2012/12/1990-2009-DPRK-ENERGY-BALANCES-ENGAGEMENT-OPTIONS-UPDATED-2012_changes_accepted_dvh_typos_fixed.pdf; and David von Hippel and Peter Hayes (2014), *An Updated Summary of Energy Supply and Demand in the Democratic People's Republic of Korea (DPRK)*, NAPSNet Special Reports, April 15,

in particular, meaning for crude oil and for the refined petroleum products made from crude oil, whether those products are domestically refined or imported. Our most recent estimated refined product balances for the DPRK are provided in the section of this report that follows.

Refined Products Balances, 2010 and 2014-2020

through Table 6-8 present refined product balance tables for the years 2010 and 2014 through 2020, respectively. By our estimates, overall supplies of refined products increased by on the order of 25 percent between 2010 and 2016, with some of that increase being used to expand activity in the transport and other end-use sectors, but much of it going to fuel gasoline- and, particularly, diesel-engine generators, which had been imported in increasing number in previous years, largely from China. Increased use of generators is an indicator of DPRK citizens and organizations taking more of the initiative in providing for their needs for energy services—in this case electricity—in response to limited supplies of electricity available from national and regional grids.

The supplies and thus use of oil products decreased between 2016 and 2017, by our estimates, as the impacts of UNSC sanctions on oil products imports, although it is our estimate that "off-books" imports of oil products must have continued at a significant level in 2017. Supplies decreased only somewhat from 2017 to 2018, despite ongoing UNSC sanctions, again, we estimate, because off-books imports were significant, and also because we assume that crude oil supplies increased somewhat in 2018 (see below).

Another key set of difference between the refined product balances estimated for 2017 and subsequent years versus those of 2016 and previous years is the implication of the impacts of the installation of a catalytic cracking unit at the DPRK's refinery in its far Northwest at Sinuiju, the Ponghwa Chemical Factory. The estimated impacts of the addition of this unit are presented in more detail below, and include a reduction in the amount of heavy fuel oil available to and used by the DPRK (as heavy fuel oil is a key input to the cracking unit) and a nearly corresponding increase in gasoline and diesel oil, with an emphasis on gasoline and similar light oil products.

Although there have been no official-reported cases of COVID-19 in the DPRK, the DPRK government has responded to the pandemic with measures designed to protect North Koreans from the virus. It is clear that the DPRK's response to the pandemic has changed the way that the country operated its economy, including its energy sector, through at least the first half of 2020, and many of these changes seem likely to persist, at least partially, through the end of 2020 at least. Worldwide, national and local "lock-downs" and "stay-at-home" orders have resulted in vast reductions in energy demand, particularly for transportation, in part causing, among other impacts, a vast drop in oil prices, and rapidly filling oil and gas storage depots. The DPRK's energy supply situation is unlike that of other countries, particularly for oil products, due to UNSC sanctions and resulting restrictions on its oil imports. These restrictions require the DPRK to use "unofficial" means to obtain oil supplies and export coal, strategies that are likely more difficult to carry out during the pandemic, due to the need for cooperation by outside trading partners as well as domestic regulations on contacts with foreigners.

The coronavirus pandemic has thus undoubtedly affected DPRK oil product supply and demand. Probably the effect has been significant, as it has in other nations, but since the DPRK provides

2014, available as http://nautilus.org/napsnet/napsnet-special-reports/an-updated-summary-of-energy-supply-and-demand-in-the-democratic-peoples-republic-of-korea-dprk/

no energy statistics, and what international energy statistics there are for trade with the DPRK are unlikely to be available for 2020 for some months (and will likely show little trade anyway, due to UNSC sanctions), determining the net impact of the pandemic is a matter for analysis and estimation. We have assumed that the national COVID-19 "lockdown" has and will continue to restrict fuel products demand in many sectors through 2020, although there may be some reduction in restrictions toward the end of the year, and will also results in restrictions on fuel imports, both on- and off-books, by limiting and slowing cross-border commercial traffic by land and sea. The results of our analyses of energy supply and demand for oil products are provided below.

Table 6-1: Estimated DPRK Refined Product Balance for 2010

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	25,309	3,649	9,523	(426)	1,741	302	-	40,099
Domestic Production	251							251
Imports	25,058	3,649	9,955	684	1,741	430		41,517
Exports			432	1,110		128		1,670
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(25,309)	5,199	1,585	5,728	1,218	2,466	480	(8,634)
Electricity Generation		(135)	(3,428)	(3,546)		(10)		(7,118)
Petroleum Refining	(25,309)	5,333	5,013	9,310	1,218	3,956	480	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(35)				(35)
Other Transformation								-
Own Use						(1,480)		(1,480)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	8,848	11,107	5,302	2,959	2,768	480	31,465
ENERGY DEMAND	-	8,849	11,107	5,302	2,958	2,769	480	31,465
INDUSTRIAL SECTOR	-	-	503	4,915	-	270	-	5,688
Iron and Steel								-
Cement				2,278				2,278
Fertilizers				68		270		338
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				2,381				2,381
Textiles								-
Building Materials								
Non-specified Industry			503	188				691
TRANSPORT SECTOR	-	5,074	4,360	188	717	-	146	10,485
Road		5,074	3,645					8,720
Rail			526					526
Water			188	188				376
Air					717		146	863
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	793	1,278	-	2,071
Urban					699	1,195		1,894
Rural					94	83		177
AGRICULTURAL SECTOR	-	-	1,031	-	-	-	-	1,031
Field Operations			539					539
Processing/Other			491					491
FISHERIES SECTOR	-	-	766	122	-	-	-	889
Large Ships			688	36				724
Collectives/Processing/Other			79	86				165
MILITARY SECTOR	-	3,775	4,447	77	1,386	-	334	10,018
Trucks and other Transport		3,133	53					3,186
Armaments		18	85					103
Air Force		381			1,386		334	2,100
Naval Forces		243	4,233	77				4,553
Military Manufacturing								-
Buildings and Other			76					76
PUBLIC/COMMERCIAL SECTORS					63	355		417
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						866		866

Table 6-2: Estimated DPRK Refined Product Balance for 2014

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	24,870	4,916	12,844	349	1,593	880	-	45,453
Domestic Production	251							251
Imports	24,619	4,916	13,695	349	1,593	1,155		46,327
Exports			851	-		275		1,126
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(24,870)	4,218	(2,225)	5,264	1,019	2,367	485	(13,742)
Electricity Generation		(957)	(7,279)	(3,949)		(69)		(12,254)
Petroleum Refining	(24,870)	5,175	5,053	9,247	1,019	3,891	485	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(33)				(33)
Other Transformation								-
Own Use						(1,455)		(1,455)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	9,134	10,618	5,614	2,612	3,247	485	31,711
ENERGY DEMAND	-	9,135	10,617	5,614	2,613	3,246	485	31,710
INDUSTRIAL SECTOR	-	-	336	5,238	-	825	-	6,398
Iron and Steel								-
Cement				2,530				2,530
Fertilizers				206		825		1,031
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				2,320				2,320
Textiles								-
Building Materials								
Non-specified Industry			336	181				516
TRANSPORT SECTOR	-	4,942	4,362	169	703	-	143	10,320
Road		4,942	3,668					8,610
Rail			525					525
Water			169	169				338
Air					703		143	846
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	780	1,406	-	2,186
Urban					683	1,321		2,004
Rural					97	86		183
AGRICULTURAL SECTOR	-	-	983	-	-	-	-	983
Field Operations			515					515
Processing/Other			469					469
FISHERIES SECTOR	-	-	1,084	138	-	-	-	1,222
Large Ships			996	52				1,048
Collectives/Processing/Other			88	86				174
MILITARY SECTOR	-	4,192	3,852	69	1,066	-	342	9,522
Trucks and other Transport		3,480	47					3,527
Armaments		13	83					96
Air Force		490			1,066		342	1,899
Naval Forces		210	3,644	69				3,923
Military Manufacturing								-
Buildings and Other			78					78
PUBLIC/COMMERCIAL SECTORS					64	427		491
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						589		589

Table 6-3: Estimated DPRK Refined Product Balance for 2015

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	27,734	6,670	14,943	464	2,118	1,097	-	53,026
Domestic Production	251							251
Imports	27,482	6,670	14,943	464	2,118	1,287		52,965
Exports			-	-		190		190
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(27,734)	2,926	(4,426)	6,509	1,135	2,721	541	(18,327)
Electricity Generation		(2,844)	(10,060)	(3,762)		(8)		(16,673)
Petroleum Refining	(27,734)	5,769	5,634	10,307	1,135	4,347	541	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(36)				(36)
Other Transformation								-
Own Use						(1,618)		(1,618)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	9,596	10,517	6,974	3,253	3,819	541	34,699
ENERGY DEMAND	-	9,596	10,518	6,974	3,252	3,819	541	34,700
INDUSTRIAL SECTOR	-	-	419	6,626	-	766	-	7,812
Iron and Steel								-
Cement				3,761				3,761
Fertilizers				192		766		958
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				2,524				2,524
Textiles								-
Building Materials								
Non-specified Industry			419	149				568
TRANSPORT SECTOR	-	5,041	4,424	175	789	-	143	10,573
Road		5,041	3,714					8,755
Rail			535					535
Water			175	175				351
Air					789		143	932
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	974	1,779	-	2,753
Urban					855	1,674		2,528
Rural					119	106		224
AGRICULTURAL SECTOR	-	-	1,042	-	-	-	-	1,042
Field Operations			546					546
Processing/Other			497					497
FISHERIES SECTOR	-	-	748	104	-	-	-	851
Large Ships			681	36				717
Collectives/Processing/Other			66	68				134
MILITARY SECTOR	-	4,555	3,884	69	1,404	-	398	10,310
Trucks and other Transport		3,822	52					3,874
Armaments		14	88					102
Air Force		508			1,404		398	2,310
Naval Forces		211	3,665	69				3,944
Military Manufacturing								-
Buildings and Other			79					79
PUBLIC/COMMERCIAL SECTORS					85	625		710
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						648		648

Table 6-4: Estimated DPRK Refined Product Balance for 2016

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	28,282	6,434	19,004	527	2,452	1,198	-	57,896
Domestic Production	251							251
Imports	28,031	6,434	19,004	537	2,452	1,207		57,665
Exports			-	10		9		20
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(28,282)	3,357	(7,363)	6,982	1,180	2,816	537	(20,772)
Electricity Generation		(2,667)	(13,221)	(3,699)		(27)		(19,615)
Petroleum Refining	(28,282)	6,025	5,859	10,717	1,180	4,523	537	558
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(35)				(35)
Other Transformation								-
Own Use						(1,681)		(1,681)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	9,791	11,641	7,509	3,632	4,014	537	37,124
ENERGY DEMAND	-	9,792	11,640	7,510	3,631	4,013	537	37,123
INDUSTRIAL SECTOR	-	-	470	7,107	-	877	-	8,454
Iron and Steel								-
Cement				4,228				4,228
Fertilizers				219		877		1,096
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				2,511				2,511
Textiles								-
Building Materials								
Non-specified Industry			470	149				619
TRANSPORT SECTOR	-	5,090	4,761	182	843	-	144	11,020
Road		5,090	4,025					9,115
Rail			554					554
Water			182	182				363
Air					843		144	988
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	1,058	1,936	-	2,993
Urban					908	1,819		2,728
Rural					149	116		266
AGRICULTURAL SECTOR	-	-	1,106	-	-	-	-	1,106
Field Operations			579					579
Processing/Other			527					527
FISHERIES SECTOR	-	-	1,313	150	-	-	-	1,463
Large Ships			1,218	64				1,282
Collectives/Processing/Other			95	86				181
MILITARY SECTOR	-	4,702	3,991	71	1,648	-	393	10,805
Trucks and other Transport		3,945	54					3,999
Armaments		15	96					111
Air Force		526			1,648		393	2,567
Naval Forces		216	3,762	71				4,049
Military Manufacturing								-
Buildings and Other			80					80
PUBLIC/COMMERCIAL SECTORS					82	664		746
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						537		537

Table 6-5: Estimated DPRK Refined Product Balance for 2017

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	27,731	4,077	9,778	157	1,363	1,169	-	44,274
Domestic Production	251							251
Imports	27,480	4,077	9,778	157	1,363	1,169		44,023
Exports			-	-		0		0
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(27,731)	5,629	(300)	3,605	1,302	3,863	499	(13,134)
Electricity Generation		(2,982)	(6,768)	(1,735)		(14)		(11,499)
Petroleum Refining	(27,731)	8,610	6,468	5,364	1,302	5,495	499	7
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(24)				(24)
Other Transformation								-
Own Use						(1,618)		(1,618)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	9,706	9,478	3,761	2,664	5,032	499	31,140
ENERGY DEMAND	-	9,707	9,478	3,762	2,664	5,031	499	31,140
INDUSTRIAL SECTOR	-	-	235	3,399	-	595	-	4,229
Iron and Steel								-
Cement				1,930				1,930
Fertilizers				149		595		744
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				1,225				1,225
Textiles								-
Building Materials								
Non-specified Industry			235	96				331
TRANSPORT SECTOR	-	4,973	4,028	169	746	-	128	10,044
Road		4,973	3,343					8,317
Rail			516					516
Water			169	169				338
Air					746		128	873
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	679	2,344	-	3,023
Urban					582	2,165		2,748
Rural					96	179		275
AGRICULTURAL SECTOR	-	-	887	-	-	-	-	887
Field Operations			464					464
Processing/Other			423					423
FISHERIES SECTOR	-	-	1,261	143	-	-	-	1,404
Large Ships			1,171	62				1,232
Collectives/Processing/Other			91	82				172
MILITARY SECTOR	-	4,733	3,066	50	1,170	-	371	9,391
Trucks and other Transport		3,980	55					4,035
Armaments		12	74					85
Air Force		578			1,170		371	2,119
Naval Forces		164	2,858	50				3,072
Military Manufacturing								-
Buildings and Other			80					80
PUBLIC/COMMERCIAL SECTORS					70	802		872
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						1,290		1,290

Table 6-6: Estimated DPRK Refined Product Balance for 2018

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	30,705	2,879	8,263	30	785	1,064	-	43,725
Domestic Production	251							251
Imports	30,454	2,879	8,263	30	785	1,071		43,481
Exports			-	-		7		7
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(30,705)	6,571	423	3,872	1,441	4,302	482	(13,614)
Electricity Generation		(3,041)	(6,740)	(2,004)		(6)		(11,790)
Petroleum Refining	(30,705)	9,612	7,163	5,913	1,441	6,095	482	(0)
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(37)				(37)
Other Transformation								-
Own Use						(1,786)		(1,786)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	9,450	8,686	3,902	2,225	5,366	482	30,112
ENERGY DEMAND	-	9,449	8,687	3,902	2,225	5,366	482	30,112
INDUSTRIAL SECTOR	-	-	235	3,593	-	333	-	4,161
Iron and Steel								-
Cement				2,186				2,186
Fertilizers				83		333		416
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				1,225				1,225
Textiles								-
Building Materials								
Non-specified Industry			235	98				333
TRANSPORT SECTOR	-	4,741	3,894	160	746	-	128	9,668
Road		4,741	3,244					7,984
Rail			491					491
Water			160	160				320
Air					746		128	873
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	325	3,046	-	3,371
Urban					269	2,791		3,060
Rural					56	255		311
AGRICULTURAL SECTOR	-	-	757	-	-	-	-	757
Field Operations			396					396
Processing/Other			361					361
FISHERIES SECTOR	-	-	930	103	-	-	-	1,032
Large Ships			865	45				910
Collectives/Processing/Other			65	57				122
MILITARY SECTOR	-	4,709	2,872	47	1,097	-	354	9,078
Trucks and other Transport		3,980	55					4,035
Armaments		12	74					85
Air Force		564			1,097		354	2,015
Naval Forces		153	2,667	47				2,867
Military Manufacturing								-
Buildings and Other			76					76
PUBLIC/COMMERCIAL SECTORS					58	907		965
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						1,080		1,080

Table 6-7: Estimated DPRK Refined Product Balance for 2019

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	30,705	2,679	9,432	2	864	1,071	-	44,753
Domestic Production	251							251
Imports	30,454	2,679	9,432	80	864	1,071		44,581
Exports			-	79		0		79
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(30,705)	6,557	(518)	3,887	1,441	4,302	508	(14,528)
Electricity Generation		(3,029)	(7,681)	(1,989)		(6)		(12,705)
Petroleum Refining	(30,705)	9,586	7,163	5,913	1,441	6,095	508	(0)
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(36)				(36)
Other Transformation								-
Own Use						(1,786)		(1,786)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	9,237	8,914	3,889	2,305	5,373	508	30,226
ENERGY DEMAND	-	9,237	8,914	3,889	2,305	5,373	508	30,226
INDUSTRIAL SECTOR	-	-	235	3,580	-	333	-	4,147
Iron and Steel								-
Cement				2,173				2,173
Fertilizers				83		333		416
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				1,225				1,225
Textiles								-
Building Materials								
Non-specified Industry			235	98				333
TRANSPORT SECTOR	-	4,515	4,129	160	739	-	119	9,662
Road		4,515	3,473					7,988
Rail			496					496
Water			160	160				320
Air					739		119	858
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	264	3,036	-	3,300
Urban					210	2,788		2,998
Rural					54	247		301
AGRICULTURAL SECTOR	-	-	749	-	-	-	-	749
Field Operations			396					396
Processing/Other			353					353
FISHERIES SECTOR	-	-	930	103	-	-	-	1,032
Large Ships			865	45				910
Collectives/Processing/Other			65	57				122
MILITARY SECTOR	-	4,722	2,872	47	1,243	-	389	9,272
Trucks and other Transport		3,980	55					4,035
Armaments		12	74					85
Air Force		578			1,243		389	2,209
Naval Forces		153	2,667	47				2,867
Military Manufacturing								-
Buildings and Other			76					76
PUBLIC/COMMERCIAL SECTORS					59	922		981
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						1,083		1,083

Table 6-8: Estimated DPRK Refined Product Balance for 2020

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	TOTAL
ENERGY SUPPLY	32,196	381	5,797	30	43	379	-	38,825
Domestic Production	251							251
Imports	31,945	381	5,797	30	43	379		38,574
Exports			-	-		-		-
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(32,196)	6,327	509	4,284	1,511	4,519	361	(14,685)
Electricity Generation		(3,900)	(7,002)	(1,850)		(6)		(12,758)
Petroleum Refining	(32,196)	10,228	7,512	6,189	1,511	6,396	361	(0)
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
District Heat Production				(55)				(55)
Other Transformation								-
Own Use						(1,871)		(1,871)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	6,708	6,306	4,314	1,554	4,898	361	24,141
ENERGY DEMAND	-	6,709	6,305	4,315	1,554	4,897	361	24,141
INDUSTRIAL SECTOR	-	-	235	4,097	-	166	-	4,498
Iron and Steel								-
Cement				2,986				2,986
Fertilizers				42		166		208
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				953				953
Textiles								-
Building Materials								
Non-specified Industry			235	117				351
TRANSPORT SECTOR	-	3,679	2,907	100	471	-	76	7,233
Road		3,679	2,432					6,111
Rail			374					374
Water			100	100				200
Air					471		76	547
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	243	3,193	-	3,437
Urban					188	2,939		3,127
Rural					56	254		310
AGRICULTURAL SECTOR	-	-	741	-	-	-	-	741
Field Operations			396					396
Processing/Other			344					344
FISHERIES SECTOR	-	-	837	92	-	-	-	929
Large Ships			778	41				819
Collectives/Processing/Other			58	51				110
MILITARY SECTOR	-	3,030	1,587	25	804	-	285	5,731
Trucks and other Transport		2,376	33					2,409
Armaments		6	41					47
Air Force		564			804		285	1,653
Naval Forces		83	1,448	25				1,556
Military Manufacturing								-
Buildings and Other			65					65
PUBLIC/COMMERCIAL SECTORS					35	672		707
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						866		866

6.3. Refined Products Use by Sector and Fuel

Overall estimated DPRK petroleum products demand by end-use sector (that is, not including electricity generation) is shown in Figure 6-1. The three major oil products end-use sectors in 2019 (the years 2010 through 2018 show similar patterns) were military, transport, and industry. Most industrial use was of heavy fuel oil, while the military and transport sectors used mostly diesel fuel and gasoline. Agriculture, fisheries (both mostly diesel), residential, and public/commercial (both using liquefied petroleum gas and kerosene) demand were each a small fraction of overall petroleum products use, as was non-energy petroleum use (consisting of feedstocks for industrial processes, asphalt, and other products).

The pattern of overall petroleum products use by sector is estimated to be somewhat different in 2020 (see Figure 6-2), with reductions in the fraction of oil products used by the transport sector and particularly the military, due to the national lockdown, while the fraction of industrial oil use rises (mostly as a result of using surplus heavy oil in the cement subsector), as does oil use in the residential sector (due to more availability because other sectors have been shut down, as well as more time spent at home by DPRK citizens, mirroring the experience elsewhere in the world).

Figure 6-1: 2019 DPRK Petroleum Products Demand by Sector

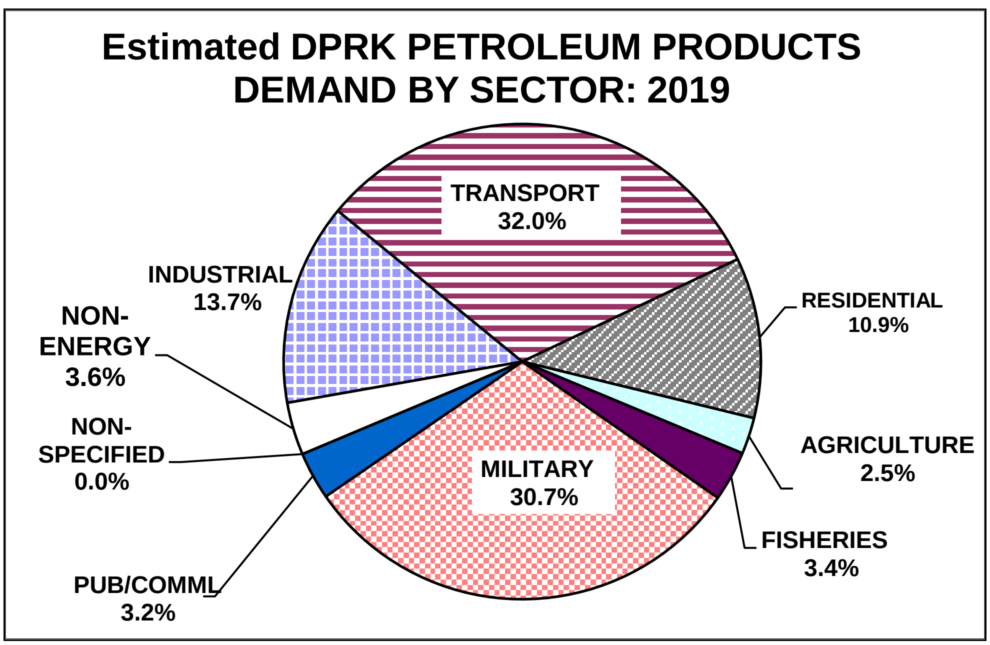
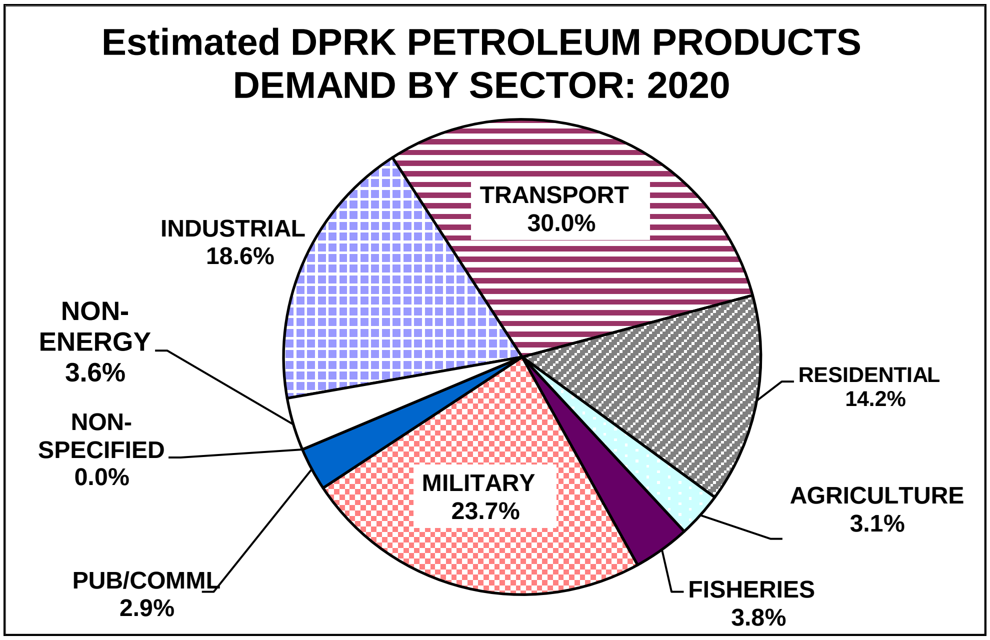


Figure 6-2: 2020 DPRK Petroleum Products Demand by Sector



Use of most refined products (heavy fuel oil being the exception) increased from 2010 through 2016 due to enhanced availability and a more vibrant DPRK economy. Figure 6-3 shows estimated diesel fuel use over time. Diesel fuel use in the transport sector and agricultural sectors increased generally between 2010 and 2016, with increases in transport activity in diesel trucks offset somewhat by decreases in energy intensity (increases in energy efficiency), as newer trucks imported (largely) from China were incorporated into the DPRK fleet. Diesel use in the military changed relatively little, based on our estimates, as there was not a marked change in military activity during the 2010-2016 period, or at least little change that would affect fuel use. The largest change in diesel use during 2010 through 2016 was in the use of diesel for electricity generation, as the combination of broader availability of diesel, increased imports of generators, and continued unreliable electricity supplies allowed consumers to generate more of their own power. We estimate this trend to have changed markedly in 2017 through 2019, when reduced fuel availability caused reductions of diesel use in virtually all sectors, but particularly for electricity generation.

Diesel use in 2020 is estimated to be lower in virtually all sectors than in previous years, particularly for the transport and military sectors, due to restrictions on activity and movement due to the DPRK's response to the COVID-19 pandemic.

Figure 6-3: Estimated Diesel Fuel Use in the DPRK through 2020

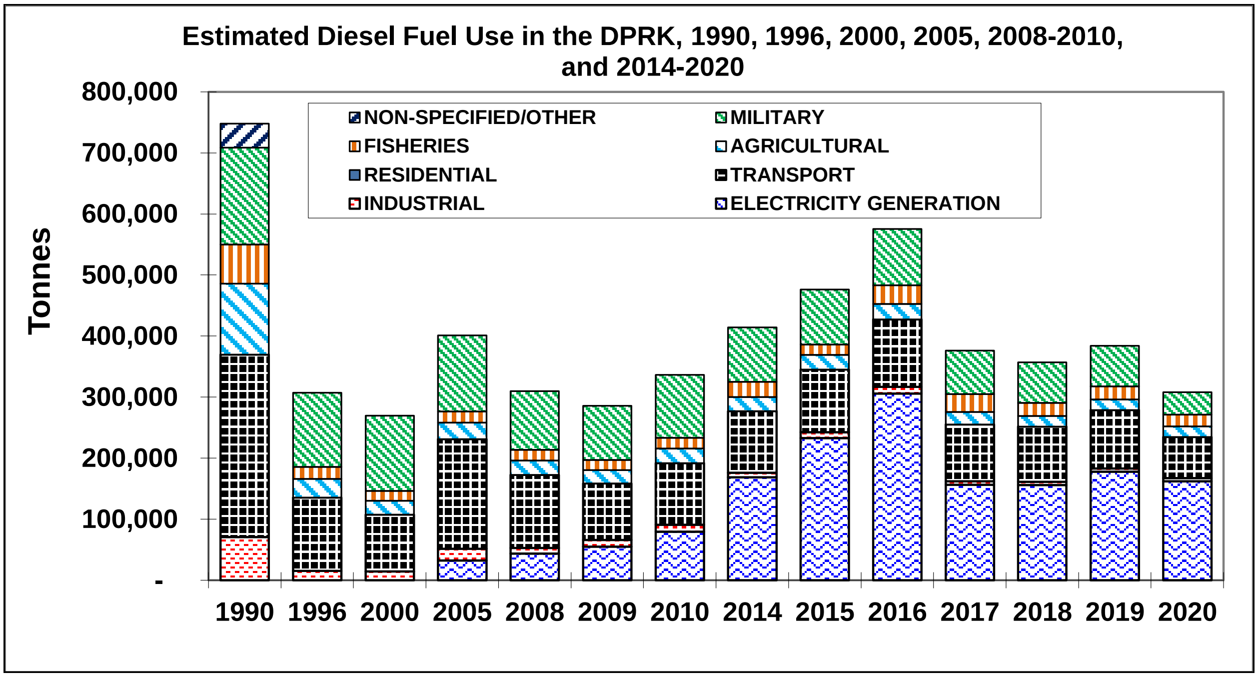


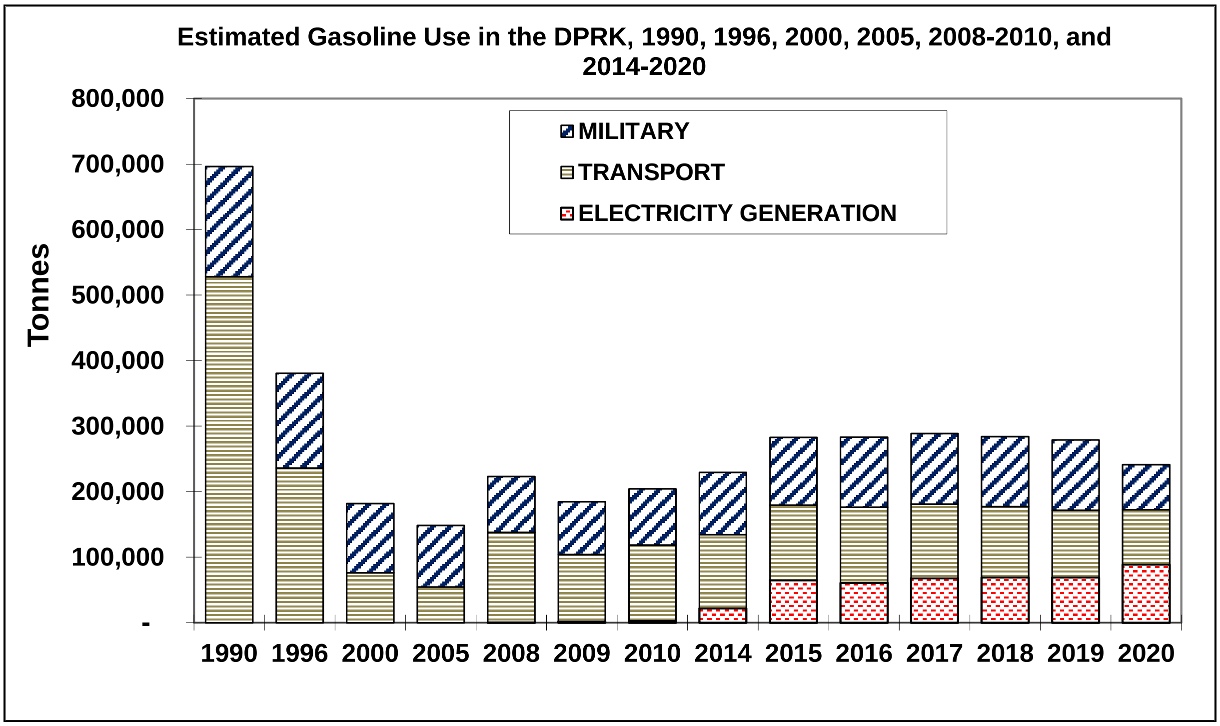
Figure 6-4 shows estimated trends in gasoline use by year. Here the marked increase from 2010 through 2015 stalls in 2016 as estimated supplies did not continue to expand in that year, and declines in 2017 and slightly further in 2018 due to reductions in gasoline availability due to USNC sanctions. The declines in availability of gasoline imports in 2017 through 2019, however, are estimated to have been substantially offset by additional gasoline available from the catalytic cracking unit installed at the Ponghwa Chemical Factory during 2016. To some extent, and mostly in rural areas, reduced motor fuel (in 2017 through 2019, mostly diesel) availability may have been compensated for by a rise in the use of trucks adapted to use "gasifiers" fueled with wood, crop waste, charcoal, and/or coal as a substitute for gasoline. Use of such trucks has been reported regularly during the last three decades in the DPRK, but may have risen in the last few years.[664] As with diesel fuel, the years since 2010 have seen a marked rise in the use of small imported personal/household generators (perhaps 500 to 2000 watts) fueled with gasoline, although we estimate that the rapid increase in use of such generators leveled off in 2016 and

[664] A Radio Free Asia article entitled "Charcoal-powered Vehicles Stage a Comeback in North Korea", dated 2016-12-09, reported by Jieun Kim, translated by Soo Min Jo, written in English by Roseanne Gerin, and available as https://www.rfa.org/english/news/korea/charcoal-powered-vehicles-make-a-comeback-in-north-korea-12092016160533.html, describes the resurgent use of "charcoal" fueled trucks in particularly rural parts of the DPRK, and in the Northeast city of Chongjin, for transport services of all kinds, including transport for hire. The article notes the use of these gasifier trucks (which we assume are actually using charcoal, wood, crop waste, coal, and/or waste oil fuels, as available locally, in on-truck gasifiers), has increased in recent years in some locales due to fuel restrictions, possibly due to sanctions. 1, 2.5, and 15, and 20-tonne truck models have been seen using the technology, but it appears that the 2.5-tonne, DPRK-made Seung-ri 58 (Victory 58) model is most frequently seen fueled by gasifiers. The article also notes that around 70 percent of gasifier-driven trucks (presumably in the specific area described) are from rural military units.

2017 when fuel availability fell and DPRK market prices for fuel, at least in some areas, rose.[665] [666]

For 2020, the national lockdown is estimated to have substantially reduced military and transport (as well as overall) gasoline use, but part of the reduction of gasoline use in those sectors is estimated to have been offset by increased use of gasoline in the small personal generators that would be used in homes (and possibly informal markets) to provide power when grid power was not available.

Figure 6-4: Estimated Gasoline Use in the DPRK through 2020



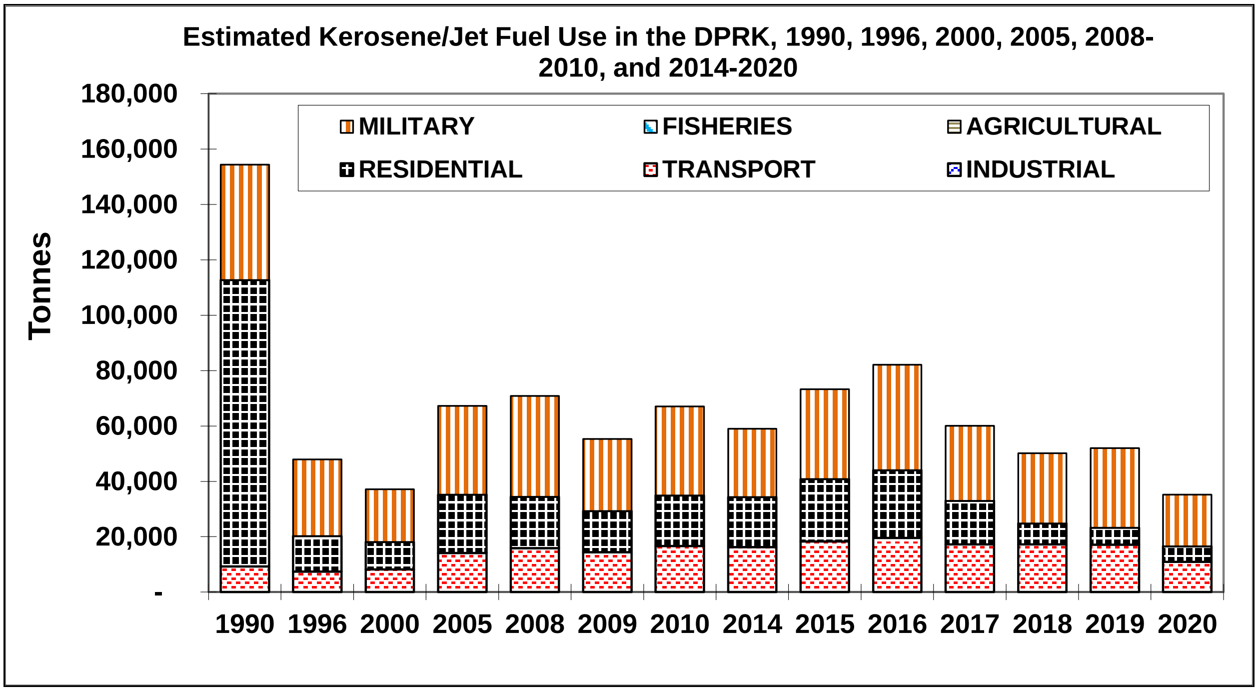
[665] As an example of fluctuating DPRK fuel prices, albeit from 2018, a July 24, 2018 *Reuters* article entitled "Exclusive: North Korean fuel prices drop, suggesting U.N. sanctions being undermined", by Hyonhee Shin, and available as https://www.reuters.com/article/us-northkorea-economy-exclusive/north-korean-fuel-prices-drop-suggesting-u-n-sanctions-being-undermined-idUSKBN1KE15F,
includes the following passage: "China said on Tuesday it strictly abided by U.N. sanctions, but indicated it may have resumed some fuel shipments to North Korea in the second quarter of this year. Gasoline was sold by private dealers in the North Korean capital Pyongyang at about $1.24 per kg as of Tuesday, down 33 percent from $1.86 per kg on June 5 and 44 percent from this year's peak of $2.22 per kg on March 27, according to Reuters analysis of data compiled by the Daily NK website. Diesel prices are at $0.85 per kg, down about 17 percent from March. The website [that collects price data] is run by North Korean defectors who collect prices via phone calls with multiple traders in the North after cross-checks to corroborate their information, offering a rare glimpse into the livelihoods of ordinary North Koreans."

[666] In addition, the rapid growth in imports of generators to the DPRK through 2015, or at least imports as reported in customs statistics available through the UN Comtrade system, ceased in 2016, with reported 2016 imports of generators to the DPRK from China markedly lower than in 2015, 2017 imports lower still, and 2018 imports only a few percent, if that, of 2015 imports. Some of this decline was doubtless due to the impact of UNSC sanctions on DPRK fuel supplies and availability of DPRK funds to pay for equipment, but it is possible that the decline in actual trade was not as steep as is shown in official statistics, because there was some off-books trade in generators. We have no direct evidence of off-books trade in generators, but it would be unusual to see such active trades in a set of products fall quite so rapidly. See Chapter 5 for additional analysis of generator use in the DPRK in the context of electricity supplies.

Figure 6-5: shows estimated kerosene and jet fuel use in the DPRK over the years, divided mostly between use in the transport sector (for jet transport), the military (for military aircraft) and in the residential sector (as a lighting and cooking fuel). We assume that all of these end-uses declined significantly between 2016 and 2017, with reduced use continuing through 2019 (and 2020). Unlike diesel and gasoline, we have heard little suggesting that off-books trade in kerosene and jet fuel has been significant in recent years, though such trades are of course possible. The reduction in transportation use of jet fuel between 2016 and 2017 (and 2018/2019) probably meant fewer domestic flights on jet-engine aircraft, as we assume that international flights (most relatively short, by the national carrier Air Koryo) probably fueled up mostly in their destination countries.[667] The decline in kerosene use in the residential sector could have been partially compensated for by the use of other cooking fuels (LPG, biomass and coal, for example), and/or the use of alternative lighting fuels, such as electricity from photovoltaic panels. In 2018, in particular, we assume that kerosene use declined in large part through substitution by LPG, which is a cleaner and more convenient fuel for many end-uses and seemed to be in more abundant supply in 2018 and 2019. The reduction in military jet fuel use between 2016 and 2017/2018 probably stemmed from a reduction in training flights in fighter and other jets; such flights were already at what would be considered a low level for most other militaries. In 2020, we estimate significant reductions in kerosene/jet fuel use for military and civilian aircraft, but that the use of kerosene in the residential sector changed relatively little.

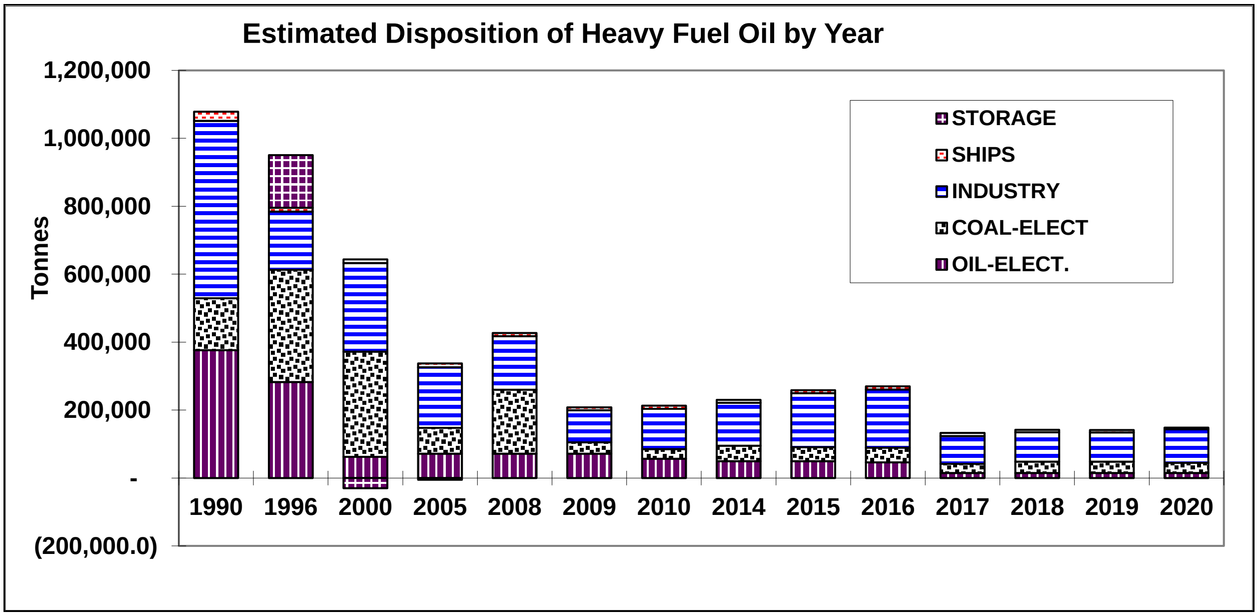
[667] A number of reports have indicated that on a number of instances, at least in 2019, and contrary to expectation, Air China jet aircraft have been seen apparently fueling at the international airport in Pyongyang from an Air Koryo fuel truck. This has raised speculation that Air China is actually *de*fueling in the DPRK and thus providing jet fuel in violation of sanctions, although doing so may be technically difficult. Other explanations for this observed activity. including simply that China was able to get a good price for DPRK-refined jet fuel, are possible, or has brought in its own fuel by truck but is using Air Koryo fueling infrastructure. See, for example, Oliver Hotham (2019), "NK Pro investigation sheds light on Air China's N. Korea fueling arrangements", *NK News*, dated December 16, 2019, and available as https://www.nknews.org/2019/12/nk-pro-investigation-sheds-light-on-air-chinas-n-korea-fueling-arrangements/.

Figure 6-5: Estimated Kerosene and Jet Fuel Use in the DPRK through 2020



Heavy fuel oil (HFO, also sometimes called residual fuel oil) has limited uses in the DPRK. It is used in a very few freighters and ships of the DPRK navy, for some industrial processes (as a fuel, albeit not a major fuel, for cement making and for minerals processing), and as a fuel for electricity generation in two or three power plants designed to use heavy oil, plus as a starter fuel (typically only a percent or two of total fuel use) for coal-fired power stations and district heating boilers. The trend in disposition (use/storage) of heavy fuel oil by year is shown in Figure 6-6. We estimate that heavy fuel oil use rose somewhat between 2010 and 2016, with most of the increase being in the industrial sector, and declined substantially between 2016 and 2017/2018/2019 because of lower availability, as roughly half of the heavy fuel oil formerly produced by the DPRK's one operating large refinery was converted to lighter products using the catalytic cracking unit installed in 2016. This decline in heavy oil use, however, was mainly in sectors and in end uses where coal is a ready substitute for heavy fuel oil. In 2020, we estimate that heavy oil use actually increased somewhat relative to 2019, with most of that increase in the industrial sector, and largely related to increased use (per unit of total fuel use) of HFO for making cement, although the overall volumes of cement manufactured (and used) are estimated to have fallen due to the impact of COVID-19 restrictions on the construction sector. HFO supplies are estimated to have increased in 2020 relative to 2020 because of greater assumed refinery input in 2020 (see below).

Figure 6-6: Estimated Heavy Fuel Oil Use in the DPRK through 2020



6.4. DPRK Domestic Oil Products Production

The DPRK has two major larger oil refineries, located near the border with China at Sinuiju and near the border with Russia at Sonbong. The refinery at Sinuiju, the Ponghwa Chemical Factory (see Figure 6-7) is supplied via a crude oil pipeline from China and appears to have operated more or less continuously for three or more decades. A refinery of somewhat larger capacity, the Seungri Chemical Complex refinery, in the DPRK's northeast near Sonbong, was fueled with Russian, and then Middle Eastern, crude oil in the 1980s and early 1990s, but has reportedly operated only sporadically since, and perhaps hardly at all in the last decade (see Figure 6-8). A third refinery, of relatively small capacity and using fairly basic technology, was reportedly in use in the Nampo area, possibly operated by the DPRK military.

Figure 6-7: Refinery at Sinujiu, Northwest DPRK[668]

[668] From Google Maps, accessed May 23, 2019, https://www.google.com/maps/place/Sinuiju,+North+Pyongan,+North+Korea/@40.0735202,124.5453298,964m/data=!3m1!1e3!4m5!3m4!1s0x5e2afe38ccd630eb:0xd9765aa741246bf5!8m2!3d40.0823213!4d124.4489192.

Figure 6-8: Refinery at Sonbong, Northeast DPRK[669]

There have been reports of crude oil production in the DPRK dating to the 1990s and possibly earlier, including an onshore well and possibly some offshore production. These reports have been difficult to corroborate, and though experts contacted by the authors believe there is probably (or at least has been) some domestic DPRK oil production, the quantity produced appears to be (or have been) small. We assume production of just under 6 thousand tonnes annually, about 1 percent of what the DPRK imports from China, but that must be seen as a rough estimate.[670]

[669] From Google Maps, accessed May 23, 2019, https://www.google.com/maps/search/sonbong+refinery/@42.3113238,130.348157,2387m/data=!3m1!1e3.

[670] See also section 4.2.2 in this Report.

Although crude oil imports, likely mostly by sea, to its refinery in Sonbong have dwindled over the years, the DPRK continues to import oil by pipeline to its Sinuiju refinery. The pipeline from Dandong, on the Chinese side of the Yalu River, to the Ponghwa Chemical Factory outside Sinuiju is fed with oil transported from the Daqing oil fields by train to Dandong, where it is loaded into the pipeline (see Figure 6-9).

Figure 6-9: Possible Yalu River Crossing Point for Dandong-Sinuiju Crude Oil Pipeline[671]

These crude oil flows were reported in China's customs statistics through 2013, when reporting stopped, although the flows of oil apparently have not. A recent article confirmed that China continues to send crude oil across the border to the DPRK, in part because the waxy nature of the oil means that if flows are allowed to stop, particularly during cold weather, it would be very difficult to return the pipeline to operation. We have assumed that 2014 crude oil exports from China to the DPRK via pipeline were 578,000 tonnes, the same as was reported in customs statistics in 2013, were 645,000 tonnes from 2015 through 2017, and increased, possibly temporarily, to 715,000 tonnes in 2018.[672] We assume that inputs of crude oil by pipeline

[671] We are not entirely sure where the pipeline crosses the Yalu River from China to the DPRK, but the *Google Earth Pro* image below, located at approximately coordinates 40.154, 124.44, shows what could be the pipeline crossing the Yalu diagonally from upper left to lower right. Image date 2.19-2020.

[672] A 2018 article in *NK Economy Watch*, "Chinese oil exports to N Korea increased after KJU's third visit to China", dated July 19th, 2018, by Benjamin Katzeff Silberstein includes the following passage: "China also dramatically increased oil shipments to the North. A source in Beijing said it nearly doubled crude oil supplies to the North through pipelines from Dandong since Kim's recent visits. 'Some 30,000 to 40,000 tons of oil is enough in the summer to maintain the lowest possible flow of oil in the pipelines to ensure that they don't clog, and about 80,000 tons in winter," the source added. "Though it's summer now China has recently increased flow to the winter level." (Units are assumed to be metric tonnes.) Original source, "China Doubles Oil

from China were the same in 2019 as assumed for 2018. For 2020 we assume—and this is largely conjecture on our part—that in China's desire to help the DPRK manage the coronavirus pandemic,[673] it provides somewhat more oil by pipeline to the DPRK. The opportunity cost of China in doing so would be quite low, considering reduced demand for oil in China and low international oil prices during the pandemic. We thus assume that the flow through the pipeline in 2020 will total 750,000 tonnes. Figure 6-10 summarizes crude oil and refined oil product exports to the DPRK from China since 1999, as reported in Chinese customs statistics. China reported just under 7000 tonnes of non-crude oil products exports to the DPRK in 2018, far less than in previous years. Although some oil export statistics have been published for 2019 in the UN Comtrade database, no information on oil exports from China have been published there for 2019 or 2020 as of this wrting. China did, however, report to the "Panel of Experts" of the UNSC oil product exports to the DPRK during the first 10 months of 2019 totalling just under 23,000 tonnes, with the Russian Federation reporting about 31,000 tonnes of exports to the DPRK over the same period.[674]

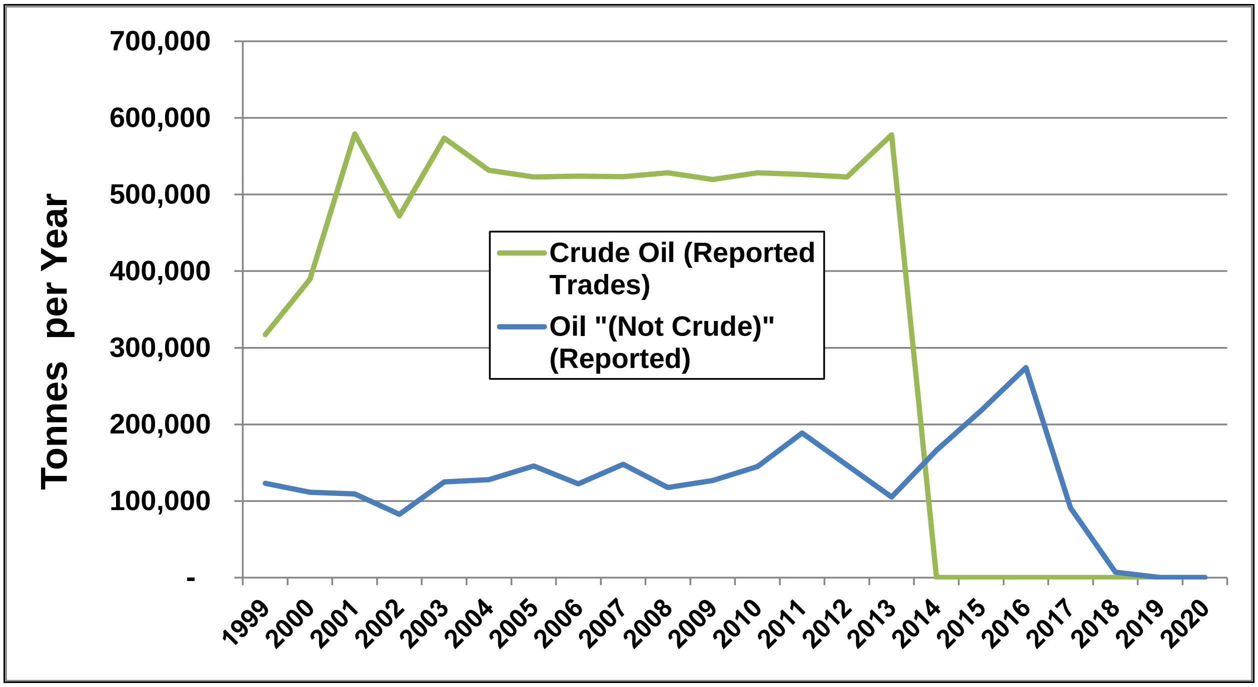
Shipments to N. Korea After Kim's Visit", Lee Kil-seong and Kim Myong-song, *Chosun Ilbo*, 2018-07-19. Assuming that this physical reason for China to maintain minimum flows through the pipeline is correct (and we have heard this explanation elsewhere), one can estimate a minimum flow through the pipeline in a "normal" year by assuming 35,000 metric tonnes per month over a 7-month (April-October) "summer" season of warmer months, with a corresponding average of 80,000 tonnes per month over the remainder of the year, which would yield an average of 645,000 tonnes of crude oil annually. We assume crude imports via pipeline at this rate from 2015 through 2017, with 2018 imports likely, based on the above, to have been at least somewhat higher. Note that the report of the UN Panel of Experts (March 5, 2019 *Report of the Panel of Experts established pursuant to resolution 1874 (2009)*, available as available at https://www.undocs.org/S/2019/171) includes (on page 153) a note on China's exports of crude oil to the DPRK:

"....and China reported that the amount of the supply of crude oil by China to the Democratic People's Republic of Korea was 150,500 tons from December 2017 to February 2018; 147,900 tons from March to May 2018; 108,500 tons from June to August 2018; and 118,100 tons from September to November 2018." These figures total 525,000 tonnes, which is the maximum allowed under the UNSC sanctions regime. Although these periods in total do not quite match up to the 2018 calendar year, we assume that they are approximately the same as a calendar year total. We feel that the higher estimate of crude oil provision based on the physical limitations of the China-DPRK pipeline operation as described above may be a better figure than the reported total here, thus we use the higher total crude oil imports for 2018 and 2019 estimated as described.

[673] See, for example, BBC News (2020), "Coronavirus: China offers to help North Korea fight pandemic", dated 9 May 2020, and available as https://www.bbc.com/news/world-asia-52597749.

[674] The UNSC "Panel of Experts" in UNSC (2020), *Note by the President of the Security Council, number S/2020/151*, dated 2 March 2020, and including "Annex: Letter dated 26 February 2020 from the Panel of Experts established pursuant to resolution 1874 (2009) addressed to the President of the Security Council", available as https://undocs.org/S/2020/151, includes information on both recorded petroleum product exports by member states (China and the Russian Federation) to the DPRK that are allowed under sanctions, and a range of estimates of suspected volumes of ship-to-ship transfers of oil products ultimately delivered to the DPRK that would have been in evasion of sanctions.

Figure 6-10: Reported Crude Oil and Oil Products Exports to the DPRK from China, 1999 - 2020[675]



As noted above, a key change—and one of the few reported in recent years—in the DPRK's oil refining capacity has been the addition of a catalytic cracking unit at the Sinuiju refinery (the Ponghwa Chemical Factory). Although the details of this addition, estimated from satellite images to have been installed in approximately 2016, are not available, basic oil refining equipment tends to be similar the world over.

In late July 2019, we were made aware[676] that the DPRK's refinery at Sinuiju had installed a new unit in 2016, most likely a fluid catalytic cracker unit (Figure 6-11).[677] Based on expert advice,[678] it is likely that this unit is being used to convert some of the heavy fuel oil produced by the refinery into lighter products.

It is most likely that this cracking unit was supplied by a Chinese vendor, and that this size of unit would be available from Chinese manufacturers. Our review of trade statistics suggests that the DPRK did import significant quantities of catalyst materials (over $1 million worth) from China in each of the years 2015 – 2017[679] but there is no way to know if these catalysts were used for this cracking unit. We have thus far been unable to identify with any certainty a customs statistics category in which the import of this unit by the DPRK is identified, as there

[675] Data from United Nations Comtrade Statistics, https://comtrade.un.org/. No data for oil trades from China to the DPRK for 2019 had been entered in Comtrade as of mid-2020, and no 2020 data were yet available.
[676] Leo Byrne, then of *NK News*, personal communication, 7/29/2019.
[677] Figure from Google Maps, 2019. Location of cracking unit (latitude and longitude) is approximately 40.071680, 124.551321.
[678] The remainder of this paragraph and the next paragraph drew on input from Dr. David Fridley, formerly of Caltex, for which we are grateful (personal communications, July 30, 2019). The authors remain solely responsible for any errors of fact or interpretation therein.
[679] From review of annual trade statistics at: https://comtrade.un.org/data. Catalyst trades from HS category 3815.

are several possible categories under which the trade could have been listed, if the trade was in fact recorded.

Such units, however, are typically provided in a small number of discrete sizes. We therefore assume that the unit is sized to use approximately 50 percent of the HFO produced by the refinery into lighter products. This would imply a capacity of about 250,000 tonnes per year for the cracker unit--a common size for such units--albeit at the smaller end of the size range of cracking units typically sold internationally.

The product slate for the throughput of the cracker is estimated to be as shown in Table 6-9. Applying the cracking unit to half of the refinery's output of heavy fuel oil results in the outputs, expressed as a fraction of crude oil input, shown in Table 6-10.

Table 6-9: Estimated Output of Cracking Unit, by Product

<table>
<tr><th>Product</th><th>Fraction of Output of Cracking Unit</th></tr>
<tr><td>Heavy Fuel Oil</td><td>0%</td></tr>
<tr><td>Gasoline</td><td>55%</td></tr>
<tr><td>Diesel Oil (light cycle oil)</td><td rowspan="2">20%</td></tr>
<tr><td>Kerosene/Jet Fuel (light cycle oil)</td></tr>
<tr><td>LPG/other gases/Refinery Gas</td><td>18%</td></tr>
<tr><td>Bottoms and Coke (non-energy)</td><td>7%</td></tr>
</table>

Table 6-10: Estimated Refinery Output after Addition of Cracking Unit, by Product

Fuel/Fuel Category	**Output as weight fraction of input**
Heavy Fuel Oil	19.0%
Gasoline	32.1%
Diesel Oil (light cycle oil)	23.1%
Kerosene/Jet Fuel (light cycle oil)	4.6%
LPG/other gases/Refinery Gas	12.0%
Bottoms and Coke (non-energy)	4.7%
Implied overall Refinery efficiency with Fluid Catalytic Cracker Unit	**95.4%**

Figure 6-11: Likely Catalytic Cracking Unit Installed at Ponghwa Chemical Factory

Figure 6-12 shows the site at the Ponghwa Chemical factory where the cracking unit is currently located as of May 2015, before the unit was installed. The red circle in this image, as well as in Figure 6-11 and Figure 6-13, indicate the location of the unit. Little work on the site is in which the catalytic cracking unit was later installed is evident in this image, but the installation appears complete as of an image from February 16. 2017 (Figure 6-13), suggesting to us that the unit was not operational during 2015 and probably most of 2016, but was operational for most or all of 2017 and thereafter. This timing, of course could be made more definitive by review of additional images taken between the time points shown in the figures, but additional images were not immediately available to the authors.

Figure 6-12: Site of Future Catalytic Cracking Unit as of May 26, 2015[680]

[680] Image from Google Earth.

Figure 6-13: Probable Catalytic Cracking Unit at Ponghwa Chemical Factory as of February 16, 2017[681]

Figure 6-14 presents our estimates of refined products outputs by the DPRK's refineries through the years. Most evident here is the drop-off in output between 1990 and 1996 and later years. As 1990 was arguably the last "normal" year for the DPRK economy—the impacts on the DPRK of the collapse of the Soviet Union were just starting to be felt then—the difference between 1990 and subsequent refined products output is an indicator of the DPRK's "energy insecurity", that is, the restrictions in the availability of fuel that has been in significant part driving DPRK policies. By our estimates, refined product output, constrained largely by the availability of crude oil imports, mostly from China, changed relatively little between 2010 and 2020, with the exception of the reduction in heavy fuel oil output, and increase in (mostly) gasoline output, starting in 2017, with the installation of the catalytic cracking unit described above. We also estimate about a 10% increase in output in 2018 relative to 2017, and another small increase in output in 2020, based on our estimates of somewhat higher crude oil supplies to the Ponghwa Chemical Factory refinery via pipeline from China, as described above.

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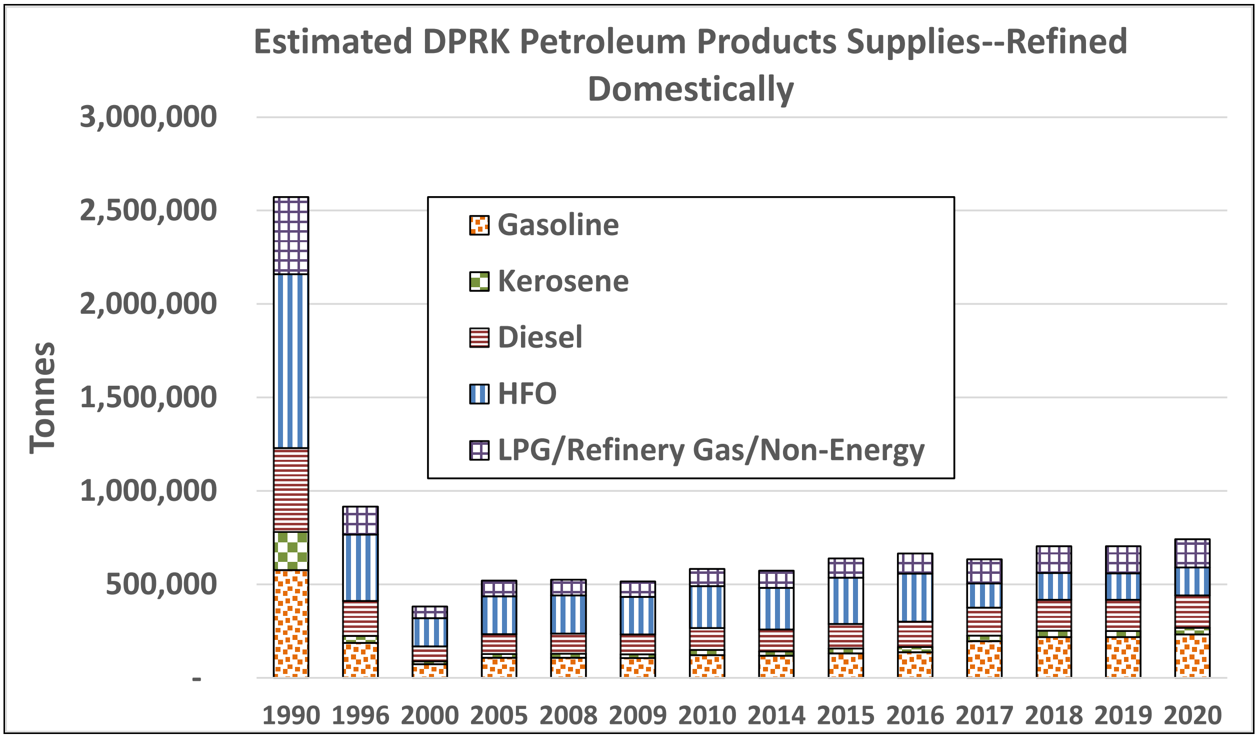
681 Source: Google Earth.

Figure 6-14: Estimated DPRK Petroleum Supplies Refined Domestically



Our estimates of the fractional outputs of refined products by fuel type in the DPRK in 2019 are presented in Figure 6-15. Results for other years from 2017 to 2020 are similar. In general, the ability of a given refinery to change the fractions of the different products it produces is limited by the refinery's infrastructure and by the type of crude oil it uses. As a consequence, for example, although the DPRK's needs for gasoline and diesel are greater than its needs for heavy fuel oil (HFO), it was constrained by the type of reactors available at its refinery and the composition of the crude oil that it (mostly) gets from China to produce more HFO than either of the more valuable motor fuels. This situation changed with the installation of the new cracking unit in approximately 2016, which allowed the DPRK to produce more of the products needed by the economy. Further changes in the aggregate product "slate" of the DPRK's refineries could come through use of different types of crude oil,[682] if and when such imports (or, likely further into the future, significant crude oil supplies from domestic resources) are available, as well as through expansion or reactivation of existing refineries.[683]

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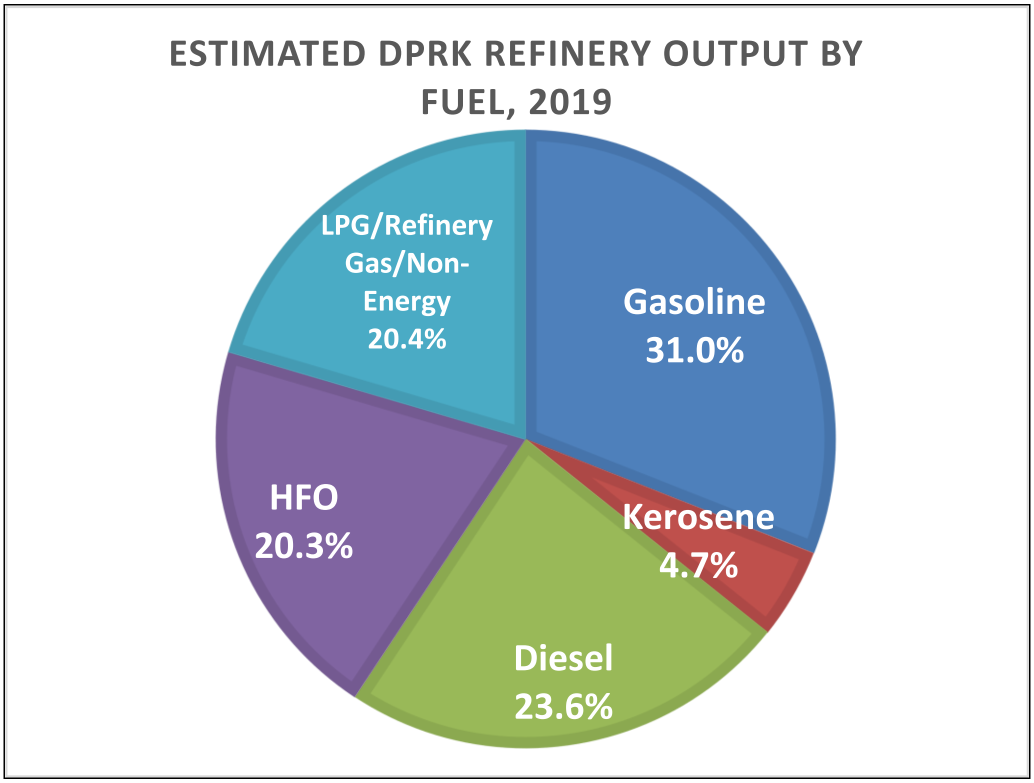
[682] Comtrade statistics for 2017 show exports of a very small amount of crude oil, 165 tonnes, from the Russian Federation to the DPRK. This quantity of oil would not have materially changed the DPRK's overall product slate.
[683] Thinking further into the future, however, the advance of non-fossil energy technologies may ultimately mean that in a time when the DPRK has resolved its differences with the international community it may choose to base production of fuels and chemicals on, for example, processes that use hydrogen produced with renewable electricity together with carbon dioxide from the atmosphere or other sources, rather than simply upgrading its existing venerable refineries. See, for example, Stephen Leahy (2018), "This Gasoline Is Made of Carbon Sucked From the Air", *National Geographic*, published June 7, 2018, and available as https://www.nationalgeographic.com/news/2018/06/carbon-engineering-liquid-fuel-carbon-capture-neutral-science/.

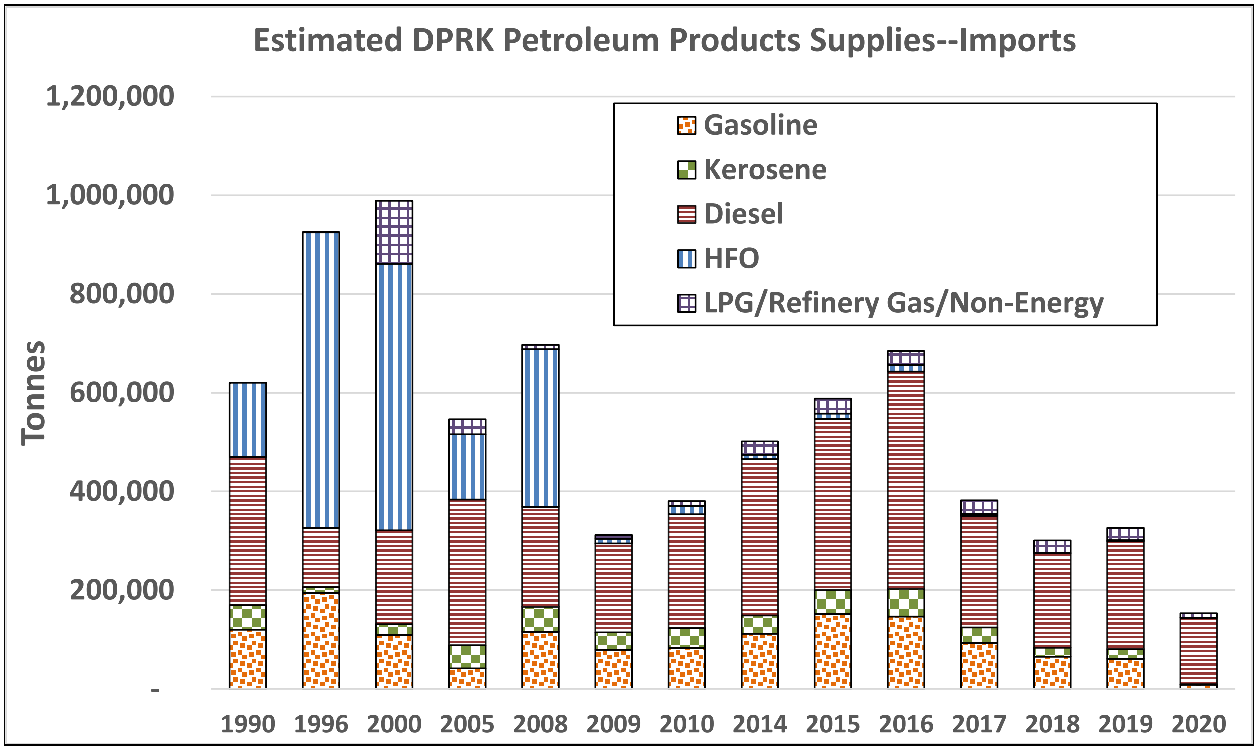
Figure 6-15: Estimated 2019 DPRK Refinery Output by Fuel



6.5. Imports of Refined Products

DPRK petroleum products imports, by our estimates, increased sharply between 2010 and 2016, providing fuel for the economic growth in the DPRK witnessed by many visitors (see Figure 6-16). We estimate that refined product imports declined in 2017 through 2019 due to the enforcement of UNSC sanctions by the international community, but that a significant volume of refined products still must have reached the DPRK through “off-books” channels, with those trades assumed to continue through 2020. In 2020, however, oil product trades are assumed to be reduced by transport/import restrictions, including reductions in truck, rail, and ship traffic, and slowdowns at border facilities, caused by the DPRK’s quarantine procedures related to the COVID-19 pandemic.

Figure 6-16: Estimated DPRK Petroleum Products Supplies--Imports



Oil products imports have reached and reach the DPRK in a variety of ways:

- Official (that is, reported in customs statistics) oil product exports from China. Up until about 2010-2015, this was the largest source of oil products imports to the DPRK in most years and included many different categories of fuels and non-fuel oil products. In recent years, official oil product trade from China to the DPRK have fallen dramatically due to UNSC sanctions. We assume that this oil has entered the DPRK mostly by sea-borne tanker, but some doubtless also arrives across the DPRK's northern border in rail tanker cars and trucks.
- Official (on-books) trade of oil products—largely, it appears, diesel fuel—from Russia to the DPRK. This reported trade has tended to vary significantly from year to year, with some years showing trades of hundreds of thousands of tonnes (2005 to 2007, for example), and others showing trades of only a few thousand tonnes (2009, 2012, 2016, and 2017, for example), with a total of about 25,000 tonnes of exports from Russia to the DPRK in 2018. These shipments are also by ship, rail, and truck.
- Official (reported in customs statistics) shipments from other countries to the DPRK, including spot market purchases from oil trading centers such as Singapore. In most recent years, these imports have been in the thousands to tens of thousands of tonnes, and come from a variety of countries around the world. In some cases, however, we have assumed that trades must have been reported in error. For example, we find it unlikely that India sold 800,000 tonnes of gasoline to the DPRK in 2008 for three-quarters of a billion dollars. It seems more likely that this trade was mis-reported, and

actually involved the Republic of Korea (that is, was mistakenly recorded as exports to North Korea rather than South Korea) or another country.

- Unofficial (not reported in customs statistics) trades involving Chinese companies, including, for example at-sea ship to ship transfers of oil.[684]
- Unofficial or semi-official (not reported in customs statistics, but in some case acknowledged by Russian authorities) shipments of oil from Russia to the DPRK.[685] [686]
- Smuggling of oil from unknown sources.[687]

The first three of these import modalities are (to the extent that customs statistics are accurate) straightforward to quantify. The last three are quite difficult to quantify, and probably, absent the most advanced and assiduously applied intelligence tools (which are certainly not available to the authors of this paper), impossible to quantify accurately.

In order to estimate "off-books" imports of oil products to the DPRK in recent year, we have adopted and adapted estimates from several sources (including those above), then estimated what a reasonable reduction in DPRK oil products use might be to meet the level of estimated supply, taking into account the apparently modest economic impacts of oil supply reductions on the DPRK economy that have been observed by visitors in recent years.

In the report *The Rise of Phantom Traders: Russian Oil Exports to North Korea*, dated July 2018, The Asan Institute for Policy Studies estimates, based on tracking customs transactions between the Russian firm Independent Petroleum Company (IPC) and three North Korean business entities, that refined oil product sales to the DPRK in the years 2015 through 2017 were as follows:[688]

Metric Tonnes of Oil	2015	2016	2017	Total
Land	42,026	88,066	18,610	148,702
Sea	150,800	258,743	64,634	474,177
Total	192,825	346,810	83,244	622,878

[684] See, for example, Yosuke Onuchi (2019), "North Korea's oil smuggling blows past import cap: UN report: Ship-to-ship transfers become increasingly sophisticated", *Nikkei Asian Review*, dated February 26, 2019, and available as https://asia.nikkei.com/Politics/Trump-Kim-Summit/North-Korea-s-oil-smuggling-blows-past-import-cap-UN-report.

[685] For example, a *Reuters* article in 2017 ("Russia says its oil supplies to North Korea are negligible", by Denis Pinchuk, dated September 5, 2017, and available as https://www.reuters.com/article/us-russia-northkorea/russia-says-its-oil-supplies-to-north-korea-are-negligible-idUSKCN1BG13N), quotes Russian President Vladimir Putin as saying "We have supplies of 40,000 tonnes of oil and oil products to North Korea a quarter", which would imply about 160,000 tonnes per year. This is close to the lower end of the range of oil exports from Russia to the DPRK, as estimated by other analysts.

[686] A North Korean émigré has been quoted in various publications as estimating that Russia exported 200,000 to 300,000 tonnes of oil products annually in recent years to the DPRK via dealers based in Singapore ("…Ri Jong Ho, a former official in North Korea's Office 39, supplied in a recent interview with Kyodo News."). See, for example, Benjamin Katzeff Silberstein (2017), "North Korea's ICBM-test, Byungjin and the economic logic", dated, July 4th, 2017, and available as http://www.nkeconwatch.com/category/energy/oil/.

[687] Courtney Kube and Dan De Luce (2018), "Top secret report: North Korea keeps busting sanctions, evading U.S.-led sea patrols", NBC News, dated December 14, 2018, and available as https://www.nbcnews.com/news/north-korea/top-secret-report-north-korea-keeps-busting-sanctions-evading-u-n947926.

[688] The Asan Institute report is available as document http://en.asaninst.org/wp-content/themes/twentythirteen/action/dl.php?id=45032; data shown from table on page 27 of that report.

These figures are reasonably consistent with the estimates offered in both the references cited above (Reuters article quoting President Putin, and quote from DPRK émigré) We therefore assume that the Asan Institute estimates apply as the total amount of oil exported "off books" from Russia to the DPRK in 2015 through 2017, and further estimate that 90 percent of the oil products in these shipments were diesel fuel, with the other 10 percent being gasoline, based roughly on the pattern of on-books trades in the two products from 2005 through 2017 (based on customs statistics). We further assume that this pattern of trade was established prior to 2014, but that in 2014 imports from Russia by this mode were a bit lower, at 180,000 total tonnes, with diesel and gasoline (or similar products) sold in approximately the same proportions as assumed for 2015 through 2017.

A more recent range of potential ship-to-ship transfers of oil products during part of the year 2018 is included the March 5, 2019 *Report of the Panel of Experts established pursuant to resolution 1874 (2009)*, which includes an analysis of potential ship-to-ship oil transfers allegedly used by the DPRK to circumvent UNSC sanctions restricting imports of refined products. The Panel of Experts analysis remotely tracked the berthing of relatively small-capacity (approximately 900 to 5000 deadweight tonnes) tankers at DPRK ports, most notably Nampo, but also including Chongjin, Najin, Wonsan, and others. The Panel of Experts analysis calculated the volume of oil that would have been delivered by those vessels over the period from January 1 through August 18 of 2018 under assumptions that the vessels were 33 percent, 50 percent, and 90 percent full when they docked (and delivered that quantity of fuel). Under these three assumptions, the total fuel delivered would have been about 108,000, 164,000, and 295,000 tonnes of oil products, respectively.[689] Official reviewers of this analysis from the Russian Federation did not find the analysis acceptable, for reasons not fully specified. It seems possible to us that in counting all of the vessels docking at these ports, the analysis may have included some transfers of oil products purchased under the allowed UNSC 500,000-barrel (bbl) limit, and/or some transfers of refined product from DPRK refineries (most notably the refinery at Sinuiju, the Ponghwa Chemical Factory) to one or more of these ports. And/or some of these shipments might have represented transfers from port to port, and thus have been effectively double-counting oil shipments. Still, we take the Panel of Expert's point is that even if these vessels were a third full, they would represent oil transfers greater than the 500,000 bbl limit, and thus is it improbable that all of the transfers viewed by these ships were of oil obtained through transactions that allowed under sanctions. Further, the volumes calculated by the Panel of Experts did not cover all of 2018. Starting with the Panel of Experts estimate of the amount of oil that would have been delivered by the observed tankers if they were on average half full, and assuming that the deliveries continued at about the same pace through the rest of 2018, the tankers would have delivered about 260,000 tonnes of oil products. We consider this as an upper limit on off-books oil product imports to the DPRK for 2018.

For 2019, in addition to the officially-reported volumes of exports from China and Russia to the DPRK described above, the March 2020 “Panel of Experts” UNSC document previously cited[690] includes descriptions, provided by a Member State (the US), of 64 deliveries of oil products (or, at least, visits to oil terminals) by foreign-flagged tankers to the DPRK (paragraph 10, page 9), and another "at least" 157 suspected deliveries (paragraph 33, page 20) from DPRK-flagged

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[689] Figures above from Panel of Experts report (2019), Table 1 of Annex 2, starting on page 74 of the referenced document, available at https://www.undocs.org/S/2019/171.

[690] UNSC Panel of Experts (2020), ibid.

tankers. Some or many of the oil products that made up these deliveries were apparently obtained through ship-to-ship transfers at sea, either from foreign-flagged to DPRK-flagged vessels, or from foreign-flagged to other foreign-flagged vessels. The US report to the UNSC Panel of Experts estimated the total deliveries of petroleum products over the first 10 months of 2019 under three scenarios, as follows: with tankers providing deliveries averaging of 1/3rd full 1,436,412 bbl, if averaging 50% full, 2,164,113 bbl, and if averaging 90% laden 3,894,426 bbl. The tankers used in these shipments appear to vary in capacity from about 8000 to 44,000 tonnes of oil products.[691] It is not clear whether these recorded deliveries include those "on-books" transfers recorded in the (roughly) 409,000 bbl from Russia and China, and it seems possible to us that some of these port visits could have been intra-DPRK transfers from its Sinuiju refinery (via transfer from train cars or tanker trucks, or from an oil product pipeline connected to the Ponghwa Chemical factory, if such a pipeline exists). Assuming the deliveries described above continued through 2019 and were at the 50 percent level on average, and an average of 8.0 bbl of oil products per tonne, the total deliveries reported by the US in the UNSC report would be 324,617 tonnes. If the "on-books" deliveries are included in this total (we cannot tell whether they are or are not), the total additional "off-books" imports, at least via ship (which is highly likely to be most, perhaps nearly all, of total off-books imports) would be 260,266 tonnes in 2019. The figure before subtracting on-books trade (if it is included) is somewhat higher than the corresponding figure for 2018 (see above). To what extent that reflects a real increase in off-books imports by the DPRK or is simply the result of better methods of/more complete detection of deliveries is not possible for us to determine.

For 2020, we estimate and project that oil product imports to the DPRK, both on-books and off-books, will be significantly reduced due to restrictions in cross-border transport and quarantine arrangements related to the DPRK's response to the COVID-19 pandemic. As a result, we assume that 2020 on-books exports of diesel and gasoline to the DPRK from China and Russia will total 35 percent of 2019 levels, and that off-books exports from Russia sum to 30 percent of the 2017 values estimated as above.[692]

Comparing the total petroleum product supplies based on the on-books and off-books estimates above, together with our estimates of supplies from domestic DPRK oil refining, with our estimates of trends in demand, for 2014 through 2020 we assume that ion each year there were at least some oil product imports to the DPRK that are not captured in any of the statistics or estimates of "off-books" trade above for those years. These imports may come from Russia, China, or other international vendors, and may be coming in by land or sea. They may be barter trades or products imported via the black market. Our assumptions as to imports by product, from 2014 on, are as follows:

[691] From the first Table in Annex 1 of UNSC 2020 report, totals on page 86.
[692] This value is reasonably close to the actual year-on-year 2020 versus 2019 January through June reported shipments of oil products from China and Russia to the DPRK. Quoting a UNSC document of 7/22/20 that was not immediately available to us, Yonghap News Agency, in "Chinese, Russian oil shipments to N. Korea plunge amid coronavirus pandemic", dated 7/22/20 and available as https://en.yna.co.kr/view/AEN20200722008000325, lists total deliveries from China and Russia to the DPRK of 14,302 tonnes of refined products, compared with an approximate reported 29,602 tonnes in the first half of 2019 (a rough estimate, as we do not have at hand monthly figures for Russian exports during 2019), which would be about 48% of 2019 deliveries. This represents, however, only the "on books" trades reported in the first half of 2020, and the impact of COVID-19 on total on- plus off-books trades is likely to have been different.

Product	2014	2015	2016	2017	2018	2019	2020
Gasoline	15,000	-	15,000	-	35,000	35,000	-
Diesel	85,000	60,000	20,000	120,000	110,000	110,000	100,000
Kerosene/ Jet Kerosene	-	-	-	15,000	15,000	20,000	1,000

For 2017, when UN Security Council restrictions on oil imports were in full force, our assumption is that even after the addition of the catalytic cracker unit to the Sinuiju refinery, without a significant amount of fuel--likely diesel and some kerosene/jet fuel, beyond the imports described in customs statistics and off-books imports from Russia above, signs of fuel shortages, particularly for diesel fuel would have been more evident in the DPRK than visitors describe. We therefore assume that there were reductions in fuel use across the board, but also the amounts of fuels shown above made their way into the country. For example, the 120,000 additional tonnes of diesel fuel that we assume were imported "off-books" is more or less consistent with the (sanctions-evading) shipments recorded as received or planned through a Taiwanese company, as reported by the UNSC "Panel of Experts".[693]

The installation and start of operations of the catalytic cracking unit at Ponghwa, depending on how and when its operations were phased in, may have resulted in a change in the market for gasoline in the DPRK. Manifestations of this change in the short term, until the market adjusted to increased supply through, for example, more use of gasoline vehicles relative to diesel vehicles, could have included reductions in off-books imports of gasoline, some additional storage of gasoline (augmenting stocks temporarily or for the longer term), and/or reduced gasoline prices at DPRK filling stations.

For 2018, we assume that the total off-books trade in oil products with the DPRK was on the order of 160,000 tonnes, which would be at the low end of the set of sensitivity values provided in the Panel of Experts analysis, if those figures were extrapolated to 12 months of deliveries. Our estimate for 2019 is much the same but includes slightly more imports of kerosene/jet fuel. For 2020, we estimate that in addition to our (projected) on-books and off-books estimates of imports above, another 100,000 tonnes of diesel (plus 1000 tonnes of kerosene/jet fuel) would be needed to meet fuel demand at the levels we estimate, even factoring in a substantial demand reduction due to COVID-19. This would represent about one-third of the medium scenario (tankers averaging half-full) 2019 estimate of deliveries of oil products to the DPRK provided in the March 2020 Panel of Experts Report. We feel that this level of imports is consistent with the general reported reductions in DPRK/China cross-border traffic and trade into and out of the DPRK in general in 2020 as described by many observers.

6.6. Considerations in Analysis of Recent DPRK Oil Product Supply and Demand

Key caveats to the analysis presented above include:

- Although we have done our best to estimate energy demand by sector, based on what is known about physical sectoral outputs, and what can be guessed at based on reports by

[693] From paragraphs 71 and 72 of UNSC (2018), *Note by the President of the Security Council, number S/2018/171*, Annex: Letter dated 1 March 2018 from the Panel of Experts established pursuant to resolution 1874 (2009) addressed to the President of the Security Council, available as http://www.un.org/ga/search/view_doc.asp?symbol=S/2018/171&referer=/english/&Lang=E.

visitors and other analysts, there is little solid information about energy demand in the DPRK. As such, although we provide trends that seem consistent with availble information, true figures, if indeed they are ever ascertained, may be different.

- For the years 2014 through 2020 we have estimated volumes of oil products imported "off-books", that is, not captured in customs statistics, that exceed, at least for 2017 (though not necessarily for 2018 and 2019) the volumes of such imports estimated by others, because we feel that it A) likely that some off-books imports have inevitably gone undetected, and B) assuming that our energy demand results for earlier years are reasonable, it seems improbable that DPRK oil products demand could decrease enough to account for the decrease in reported (on- and off-books) fuels imports without severe and visible economic dislocation, which visitors have not reported.
- We have also estimated that China shipped to the DPRK by pipeline in 2018 and 2019 was somewhat more oil than it reported to the Panel of Experts—though crude oil exports from China to the DPRK have not appeared in customs statistics for several years. This estimate is based on an estimate, which we find persuasive, of crude oil flows that factor in the technical characteristics of the pipeline into the Ponghwa Chemical Factory refinery, and results in higher 2018 and 2019 domestic production of refined products in the DPRK than would otherwise be the case. For 2020, we assume that these exports, which cost China relatively little, will ultimately be about 5 percent higher than in 2019 and 2018. It is, however, very difficult for an outsider to know how much oil China is shipping to the DPRK in a given year, and it is probable that even the most careful remote analysis of how much crude oil goes into the Dandong/Sinuiju pipeline will have margine of errors of greater than 5 or 10 percent.[694]
- It is possible that off-books imports were either greater than we have estimated, in which case served demand for oil products would be higher (particularly in 2017 through 2019) than we show in the tables and figures above, and/or that some of the oil product demand in 2017 through 2019 was served by drawing down stocks of oil products. If we had to guess, we would probably say that off-books imports were greater than we have estimated, rather than less.

6.7. Potential Energy Impact of Humanitarian Engagement Strategies Relative to DPRK Oil Imports

In a Nautilus Institute Special Report published in 2018, David von Hippel and Peter Hayes described a rapid-deployment (6 months) $100 million "Program" of humanitarian energy assistance and engagement that the international community might provide for the DPRK (see https://nautilus.org/napsnet/napsnet-policy-forum/rapid-relief-of-humanitarian-stress-from-energy-sanctions-building-energy-efficiency-and-solar-pv-measures-for-rapid-installation-in-pyongyang/). The Program centers on the use of A) building energy efficiency measures in

[694] Such an analysis would be possible using high-resolution and regular satellite images to count the number of oil cars/trains discharging cargo at the oil storage and pumping terminal at Dandong. We do not have access to a complete annual set of such images, as our work is limited to the use of publicly available images such as those in Google Earth or images that other authors have published. Even with a very complete set of images, it would be difficult to know for certain that one has accounted for all of the trains discharging their cargo, due to unloading missed due to the timing of satellite images or prevailing cloud cover. And even with a complete count of every train car that has been unloaded at Dandong, one would still not know with certainty how full the train cars were, on average.

apartments in the DPRK, likely in Pyongyang, to provide heating services to residents, and B) installation of solar photovoltaic mini-grids in schools and clinics to provide to reliable power for those facilities. Both sets of measures provide opportunities for on-the-ground and highly visible engagement between the international community and the DPRK.

The 50,000-apartment building energy retrofit (insulation, improved windows and doors, weatherstripping, heating controls, and other measures) we propose would reduce coal use (assumed to be central heating) by about 900 TJ (terajoules, a unit of energy equivalent to about 24 tonnes of oil products) annually, or 22,000 TJ over the lifetime of the measures. An alternative to providing heat with coal-fired central heating (or boilers) in the DPRK might be to use diesel-fueled generators (which have been imported in large numbers in recent years, see https://nautilus.org/napsnet/napsnet-special-reports/dprk-imports-of-generators-in-recent-years-an-indication-of-growing-consumer-choice-and-influence-on-energy-supply-decisions/) to produce electricity, then for apartments to use electrical resistance heat. If heating is provided via diesel generating sets, the savings in fuel from the building energy efficiency measures is about 2400 TJ/year, or about 60,000 TJ over the lifetime of the measures.

The photovoltaic (PV) installations (about 14 MW total) for schools and/or clinic would save 300 TJ per year in displaced coal for electricity generation or about 7,000 TJ over the life of the systems.

By way of comparison with refined products volumes, the 1200 (900 + 300) TJ of displaced coal per year would be about 3% of the approximately 35,800 TJ of diesel, gasoline, kerosene/jet fuel, and LPG that we estimate was used in the DPRK (including for electricity generation) in 2017, and a slightly higher percentage of the about 34,900 we estimate was used in 2018. The 35,800 used TJ in 2017 excludes heavy fuel oil, but includes all sources of refined products, both reported and “off-books”. Using the “genset-and-resistance-heating” comparison, the total rises to 2700 TJ/year, or about 8 percent of refined products use (again excluding heavy oil). The analog to the 35,800 TJ figure for 2017 in 2016 is about 44,000 TJ, meaning that our estimate is that use of these fuels (including for electricity generation) fell by about 8.5 PJ (petajoules, or thousand TJ) between 2016 and 2017 as a result of accommodations to the lower availability of oil product supplies in the DPRK (including reduced fuel use and, in some sectors, fuel substitution) due to UNSC sanctions.

If our six-month program is ramped up to approximately four times its size in a 2-year engagement strategy, the expanded program would save coal use on the order of 13 percent of DPRK 2017 petroleum products supplies, which would be more than half (in TJ) of what we are estimating the DPRK reduction in oil use between 2016 and 2017 might have been. If one assumes that some or all of the program savings are displacing electricity generation by diesels generator sets to generate heat for apartments, the relative savings is greater.

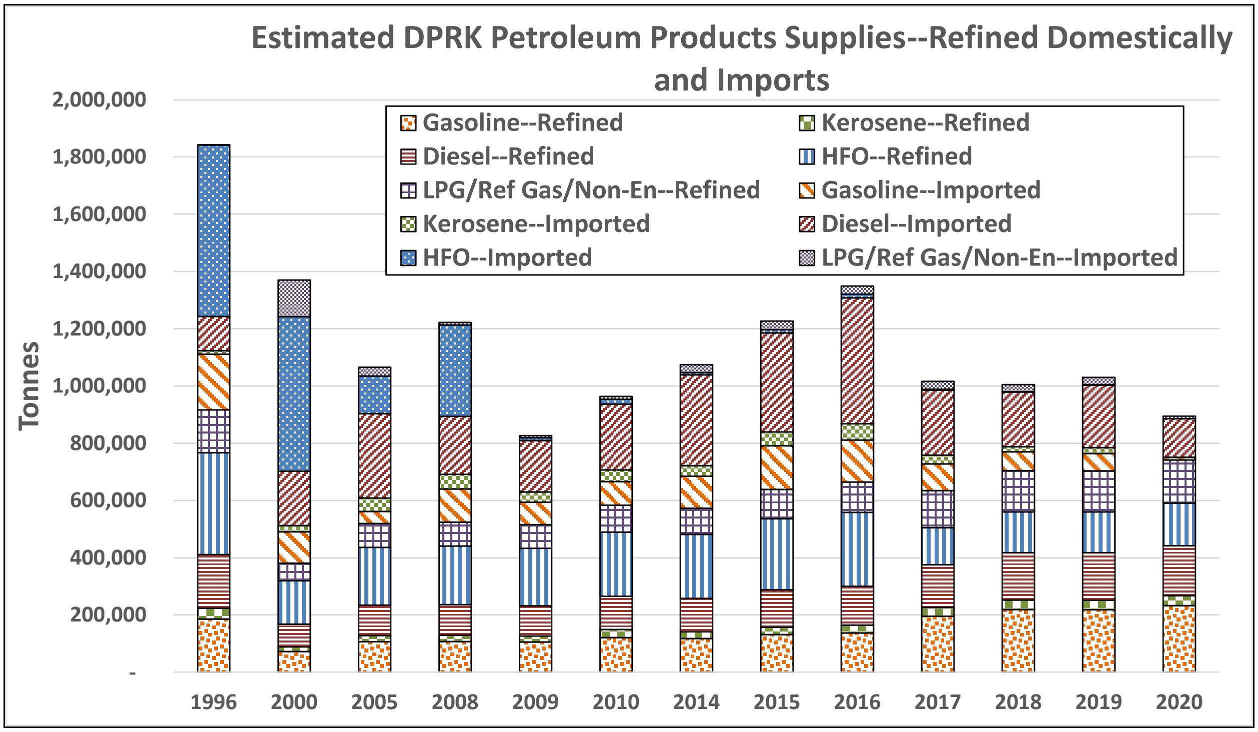
This type of engagement serves to relieve some of the humanitarian impacts of sanctions, with a particular focus on addressing impacts on ordinary DPRK citizens but leaves the sanctions regime largely intact pending progress in talks to address the DPRK’s nuclear weapons program. It thus represents an important option for engagement and confidence-building while talks continue, with few “downsides” in terms of potential diversion of significant benefits to the DPRK military or to elites.

6.8. Conclusions

We estimate the overall supplies of oil products in the DPRK as shown in Figure 6-17. Refined products produced (almost entirely) from crude oil imported by pipeline from China serve as a consistent, if minimal, source of fuel supply for the DPRK economy, but it has been imports, which increased markedly from 2010 to 2015, that have allowed the DPRK economy to grow. Some of these imports were from on-books (customs-reported) trades, but many most likely were not, particularly after the advent of UNSC sanctions. We estimate that 2017 through 2019 oil supply (and thus use) was less than in 2016, based on at least transient price spikes for diesel and gasoline as reported by visitors to the DPRK, but do not see the type of reductions in oil product availability that the authors of the UNSC sanctions on oil product imports probably hoped to see. For gasoline, in particular, supplies in the DPRK were likely improved in 2017 by the addition, in 2016, of a catalytic cracker unit at the DPRK's Ponghwa Chemical Factory, its oil refinery near the Northwestern city of Sinuiju. This unit allowed some of the heavy fuel oil formerly produced by the refinery to be converted into lighter products, most notably gasoline. 2018 and 2019 supplies from domestic refining may have been slightly higher than in 2017, if our assumptions about crude oil flows to the Sinuiju refinery being higher than reported are correct. It is also possible that 2017 through 2019 oil supplies to the DPRK were in fact greater than we have estimated, but we do not think it is likely that supplies would have been much less. For 2020, we estimate that the result of the DPRK government's measures to prevent the COVID-19 pandemic from severely affecting the DPRK have and will have resulted in reduced oil product use in 2020, particularly in the transportation and military sectors, and likely also limited imported refined oil product imports.

As time goes on, it is likely that the DPRK will get more adept, rather than less, in obtaining off-books the oil (oil products in particular) imports that it needs, and the enthusiasm of some countries for preventing such imports may wane. We therefore suggest that an even stronger emphasis on engagement with the DPRK by the international community is called for on issues vital to the DPRK's energy security (and addressing its energy insecurity), such as the building energy efficiency/renewable energy engagement strategy described above.

Figure 6-17: Estimated Overall DPRK Petroleum Products Supplies



7. The DPRK's Mineral Resource Base

7.1. Introduction

Minerals, including metal ores and non-metallic minerals, constitute a major economic resource for the DPRK. The DPRK has the world's largest known resource of the refractory mineral magnesite, estimated at up to 50 percent of the world's resources. The DPRK has seven minerals, including tungsten, molybdenum, barite, and fluorite, for which the DPRK's resources rank among those of the top ten countries in the world.[695] Minerals and metals represent an important current source of income for the DPRK, and will be an important short-to-medium-term area of investment to spur the redevelopment of the DPRK economy. The DPRK website "DPRKorea-Trade" listed graphite, gold, silver, platinum, palladium tellurium, bismuth, selenium, zinc, talc and granite among the metals and minerals that the DPRK currently seeks to export.[696] A 2016 article quoting a DPRK minerals researcher described (and lauded) the DPRK's mineral wealth, including "…the copious amounts of over 500 types of quality mineral reserves in North Korea..", and quoted the researcher as noting that the DPRK's mineral endowment was a result of "…the long history and diversity of crustal movement over time. . . .

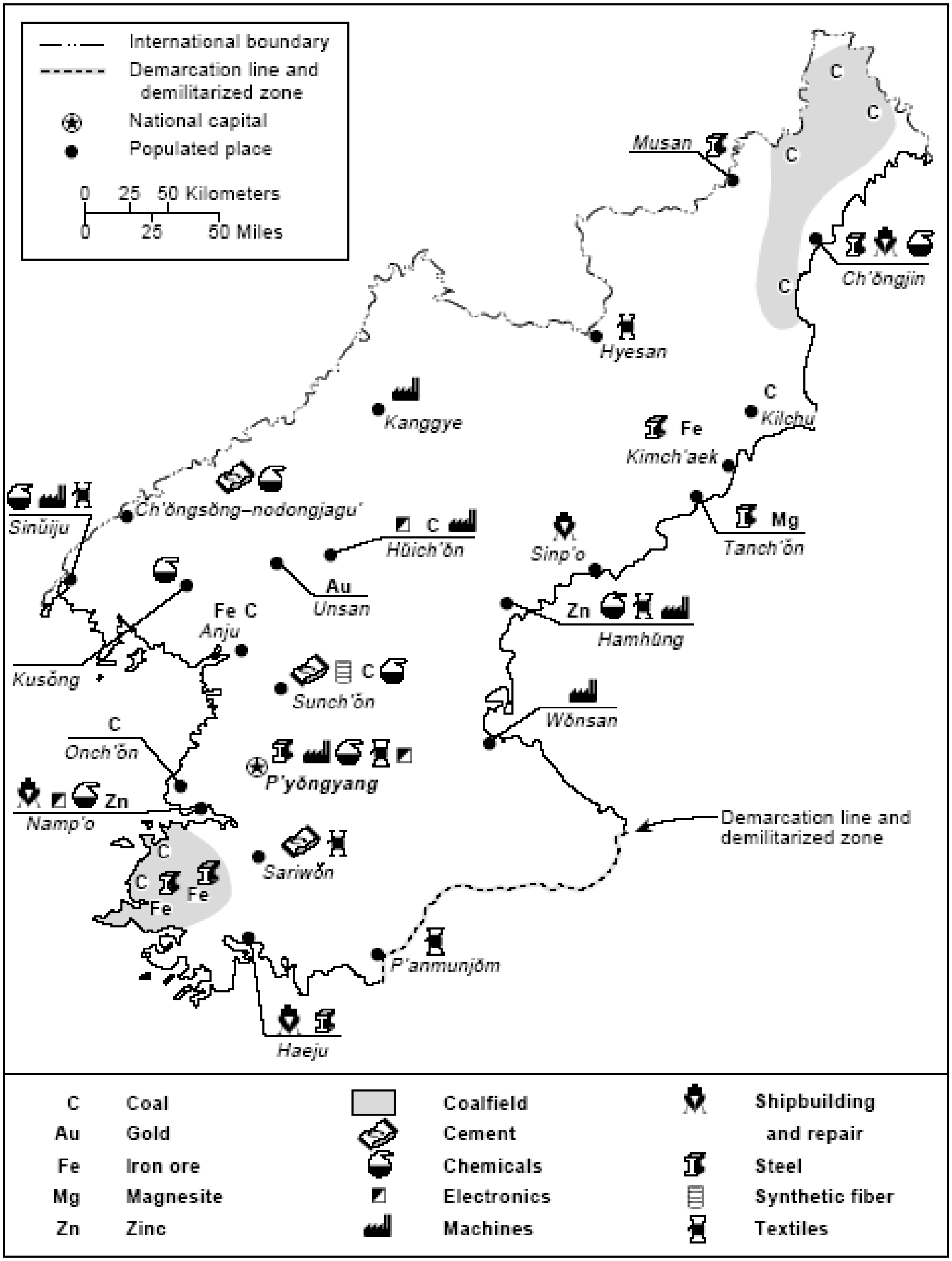
[695] *Changchun Killim Sinmun* (Internet Version-WWW) in Korean 31 Aug 06 - 08 Sep 06, "Guide to DPRK Mineral Resources".
[696] Formerly available as http://www.dprkorea-trade.com/metals/metals01.htm, "DPRKorea-Trade, Metals, Minerals and Stones Export Items" visited 4/2/07.

the earth of our country has a long history of more than 3.6 billion years."[697] Figure 7-1 and Figure 7-2 show selected minerals deposits and industries in the DPRK, with Figure 7-2 focusing on the locations of key reserves. Table 7-1 shows ROK estimates of reserves of a group of metals and minerals in the DPRK and in the ROK, with the estimated value of those reserves. The subsections that follow provide additional information on DPRK resources for iron, other base metals and precious metals, uranium and other heavy metals, and key non-metallic minerals. Also provided are descriptions of the existing minerals-related infrastructure in the DPRK, and key minerals-related government authorities and training organizations in the DPRK. The text, tables, and figures in this Chapter largely draw upon three studies prepared for Nautilus in 2008, 2010/2011, and 2019. These studies are:

- A presentation by Choi Kyung Soo of the ROK-based North Korea Resources Institute, titled "The Mineral Resources of North Korea", prepared for the 2010 DPRK Energy and Minerals Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/05.-Choi.pptx
- A presentation by Chung Woo-jin of the Korea Energy Economics Institute (KEEI), dated March 2008, titled "North Korea's Mineral Resources and Inter-Korean Cooperation", and prepared for the 2008 DPRK Energy Experts Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/Chung1.ppt.
- A report prepared by Edward Yoon entitled *Status and Future of the North Korean Minerals Sector*, dated January 2011, and available as http://nautilus.org/wp-content/uploads/2011/12/DPRK-Minerals-Sector-YOON.pdf. Slightly edited versions of sections in Mr. Yoon's report are the primary source for the text in sections 5-3 through 5-5 of this Chapter, as well as in other sections, as indicated.
- An update to the report above by Edward Yoon entitled *Recent Activities in The DPRK Minerals Sector* prepared for Nautilus in 2019 as a part of the Regional Energy Security Project.[698]

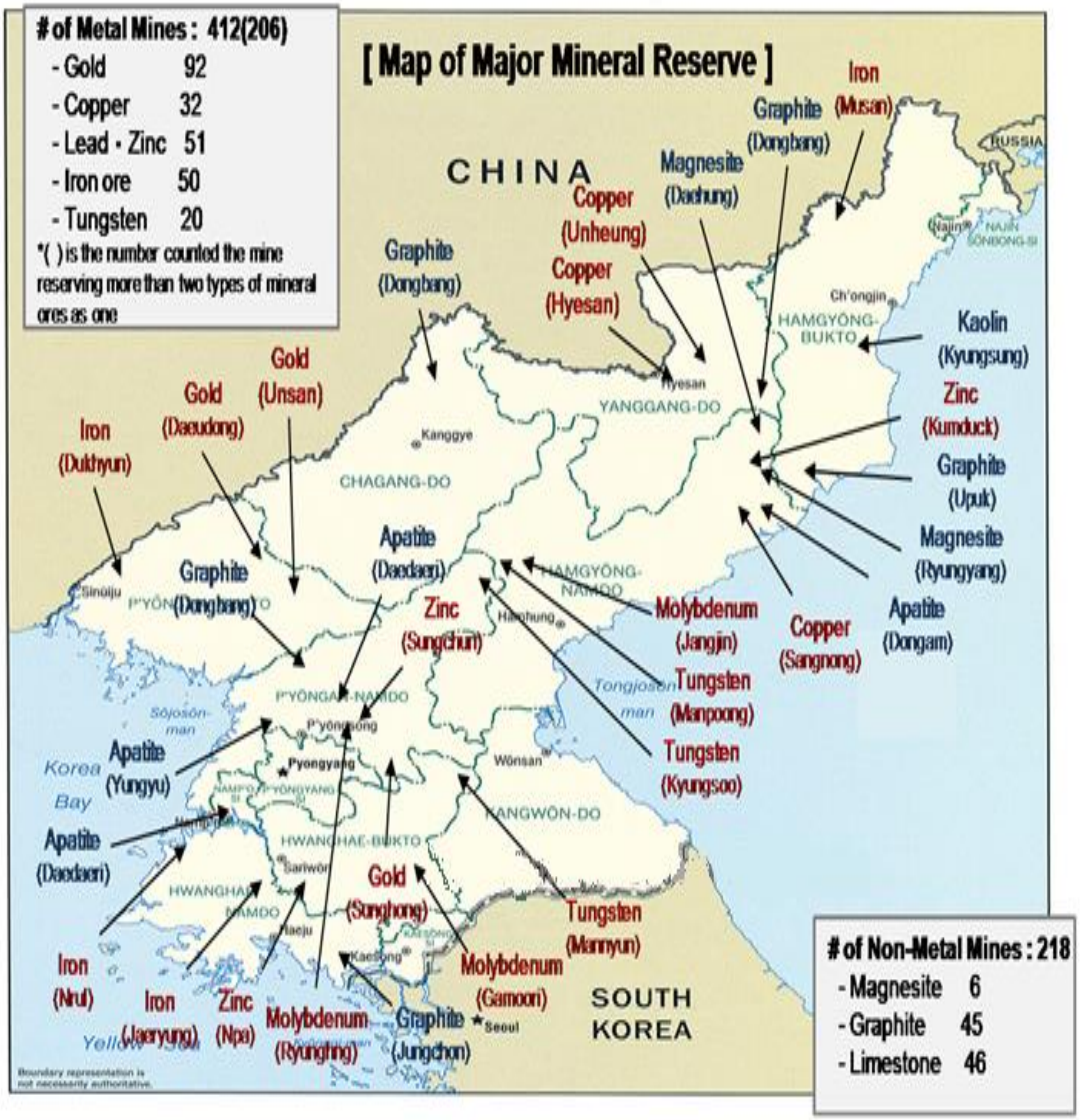
[697] North Korean Economy Watch (2016), "Over 500 types of high-quality mineral reserves in North Korea", dated March 3, 2016, and available as https://www.nkeconwatch.com/category/mining/rare-earths/.
[698] Edward Yoon (2019), *Recent Activities in the DPRK Minerals Sector*, NAPSNet Special Reports, dated April 03, 2019, available as https://nautilus.org/napsnet/napsnet-special-reports/recent-activities-in-the-dprk-minerals-sector/.

Figure 7-1: Location of Selected Minerals Deposits in the DPRK[699]



[699] Map from Federation of American Scientists web page on "Other Industry" in North Korea, http://www.fas.org/nuke/guide/dprk/target/industry.htm.

Figure 7-2: Location of Selected Minerals Deposits in the DPRK[700]



[700] Map from Choi Kyung Soo's 2010 presentation prepared for Nautilus, as referenced above.

Table 7-1: Estimates of Metals and Minerals Reserves in the ROK and DPRK[701]

Mineral Type	Reserves (1,000 ton except as noted)		Potential Value ($ million)	
	South Korea	North Korea	South Korea	North Korea
Gold (Au100)	0.030	1-2	469	23,450
Silver (Ag100)	1.175	3-5	296	1,007.7
Copper (Cu100)	41	2,155	55.1	2,896.1
Lead (Pb100)	305	6,000	117.4	2,309.5
Zinc (Zn100)	440	10-20 (million)	264.8	9,027.3
Iron (Fe50)	19,700	2-4 (billion)	484.9	73,842.6
Tungsten	100	200-300	86.9	217.3
Molybdenum	10	1-3	208.6	41.7
Manganese	123	100-300	20.8	6.5
Nickel	-	10-20	-	3.6
Graphite	1,837	6,000	1,183.4	3,865.2
Limestone	6,547,800	100 (billion)	65,248.6	996,496.5
Kaolin	74,357	2,000	1,143.8	30.8
Talc	5,451	600	545.1	60
Asbestos	511	13	55.2	1.4
Fluorite	345	500	53	76.8
Barite	712	2,100	75.5	222.7
Magnesite	-	3-4 (billion)	-	126,000

[701] Table 7-1 is from a presentation by Dr. Chung Woo-jin, entitled "Mineral Resources in DPRK", as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA), and available as http://nautilus.org/wp-content/uploads/2012/01/Chung.ppt. The table shown has some minor edits and format differences from the table in Dr. Chung's presentation. A similar table, with generally similar estimates of resources, is available (as Table 2) in the 2011 report by Edward Yoon referenced above.

Table 7-2: Estimates of Metals and Minerals Resources in the DPRK[702]

Type of Minerals		Unit	DPRK Publication #1	DPRK Publication #2		
			Total deposits	Confirmed & remaining	Forecasted	Total deposits
Coal	Anthracite	billion tons	20.5	2.6	20.1	22.7
Precious Metals	Gold	tons	2,000	317	655	972
	Silver	tons	5,000	974	6676	7,650
Metals	Copper	1,000 ton	2,900	1,438	3,523	4,961
	Pb	1,000 tons	10,600	2,577	7,391	9,968
	Zinc	1,000 tons	21,100	9,477	18,706	28,183
	Iron	billion tons	5.0	1.7	3.0	4.7
	Tungsten	1,000 tons	246	36	119	155
	Molybdenum	1,000 tons	54	18	29	47
	Nickel	1,000 tons	36	25	35	60
Non-metals	Graphite	1,000 tons	2,000	18,729	-	18,729
	Limestone	billion tons	100	1.3	5.0	6.3
	Magnesite	billion tons	6.0	1.3	6.3	7.6
	Apatite	tons	1.5	0.8	1.7	2.5
	Barite	tons	2,100	2,399	2,426	4,825

Table 7-3 summarizes ROK estimates as of 2008 of mineral resources output from major mines in the DPRK. In this table, production data for North Korean minerals in 1990 have likely been understated, with production somewhat overstated after 1990. A reason for these inaccurate estimates by ROK organizations is that North Korean natural resource production capacity actually reached its highest level in 1990 but declined dramatically through 1999. This decrease in DPRK mining capacity was not well known to ROK analysts. As a result, the numbers in Table 5-2 are inaccurate reflections of true DPRK minerals production. Based on the testimony of former North Korean miners, mining production in the DPRK declined dramatically from the early 1990s (from about 1993-1994) through 1999.[703]

[702] Table 7-2 is from Edward Yoon (2019) as referenced earlier in this Chapter, derived from a report by Dr. Chung Woo-jin, "A Study on the Actual Condition of Energy Trade in North Korea", Korea Energy Economics Institute, 2015. The table shown has some minor edits and format differences from the table in Yoon's report.

[703] Information on reduced DPRK minerals production described here are based on personal observations and interviews conducted by E. Yoon, as described in the 2011 document referenced earlier in this Chapter.

Table 7-3: ROK Estimates of Output of Major Metallic Ores in the DPRK [704]

	Gold (tonnes)	Silver (tonnes)	Copper (1,000 tonnes)	Tungsten (ton)	Pb (1,000 tonnes)	Zinc (1,000 tonnes)	Iron ore (1,000 tonnes)
1990	5	50	15	1000	80	230	8430
1992	5	50	16	1000	75	200	5747
1994	5	50	16	900	80	210	4586
1996	4,5	50	16	900	80	210	3440
1998	4.5	50	14	500	70	100	2890
2000	2	40	13	500	60	100	3793
2001	2	40	13	500	60	100	4208
2002	2	40	12	600	60	100	4078
2003	2	20	12	600	60	100	4579
2004	2	20	12	600	12	100	4580
2005	2	20	12	600	13	100	5000
2006	2	20	12	600	13	100	5000

An estimate of DPRK minerals production in more recent years by the United States Geological Survey (USGS) is provided in Table 7-4.[705] Like the ROK estimates above, these must be considered rough at best, and many do not change from year to year, indicating that the authors had received little new information to inform changes in the estimates. Compared with the ROK estimates for earlier years, the USGS estimated about the same production of gold and iron ore, higher production of silver, somewhat higher production of copper, significantly higher production of tungsten, lower production of lead and zinc. It should be emphasized, however, that these changes do not necessarily indicate changes in DPRK production between 2006 and 2012, as the methods used by the two groups to estimate production were likely different.

An additional estimate of DPRK production of coal and six other minerals was provided by Yoon (2019) and is shown in Table 7-5.[706]

[704] Korea Mineral Improvement Corporation Report, *Deposits of Mineral resource in DPRK and trading between South and North Koreas*, 2008.
[705] Jaewon Chung (2010), "The Mineral Industry of North Korea", In United States Geological Survey (USGS) National Minerals Information Center, *USGS Minerals Yearbook 2016, volume III, Area Reports—International*, Excel workbook with embedded Word file downloaded from https://www.usgs.gov/centers/nmic/asia-and-pacific#kn. First posted October 1, 2019.
[706] Yoon (2019), ibid, based on data from North Korea Natural Resource Institute, (www.nokori.or.kr) visited Dec.22 2018.

Table 7-4: USGS Estimates of DPRK Metals and Minerals Production, 2012-2016 (values in Metric Tonnes unless otherwise specified)

Commodity[2, 3]		2012		2013		2014		2015		2016
METALS										
Cadmium metal, smelter		200		200		200		200		200
Copper:										
Mine production, Cu content		16,000		17,000		19,300		20,000		20,000
Refinery production:										
Primary		10,000	r	10,000	r	10,000	r	10,000	r	10,000
Secondary		5,000	r	5,000	r	5,000	r	5,000	r	5,000
Smelter production, undifferentiated		15,000	r	15,000	r	15,000	r	15,000	r	15,000
Gold, mine output, Au content	kilograms	2,000		2,000		2,000		2,000		2,000
Iron and steel:										
Pig iron	thousand metric tons	250		250		250		250		250
Steel, raw	do.	1,220		1,210		1,220		1,080		1,220
Iron ore:										
Gross weight	do.	5,200		5,500		5,500		5,000	r	5,300
Fe content	do.	3,220	r	3,400	r	3,400	r	3,000	r	3,300
Lead:										
Mine production, Pb content		38,400	r	58,800	r	36,000	r	32,400	r	54,100
Refinery production, primary		7,000	r	7,000	r	7,000	r	7,000	r	2,400
Silver, mine production, Ag content	kilograms	50,000		50,000		50,000		50,300	r	50,400
Tungsten, mine production, concentrate, W content		100		65		70		70		50
Zinc:										
Mine production, Zn content		35,000		36,000		32,000		26,000		30,000
Smelter production, primary and secondary		35,000		35,000		30,000		20,000		20,000
INDUSTRIAL MINERALS										
Cement, hydraulic	thousand metric tons	6,400		6,600		6,700		6,700		7,100
Graphite		30,000	r	30,000	r	30,000	r	30,000	r	30,000
Magnesite		500,000		700,000		700,000		700,000		700,000
Nitrogen, ammonia, N content	thousand metric tons	70	r	70	r	70	r	70	r	70
Phosphate rock:										
Gross weight		300,000		300,000		300,000		300,000		300,000
P_2O_5 content		90,000	r	95,000		95,000		95,000		95,000
Salt		500,000		500,000		500,000		500,000		500,000
MINERAL FUELS AND RELATED MATERIALS										
Coal:										
Anthracite	thousand metric tons	11,700		12,000		12,200		12,400		14,000
Bituminous	do.	10,900		11,200		11,400		11,600		13,100
Lignite	do.	3,290		3,390		3,450		3,500		3,960
Coke, metallurgical	do.	2,000		2,000		2,000		2,000		2,000

[r]Revised. do. Ditto.

[1]Table includes data available through April 9, 2018. All data are reported unless otherwise noted. Estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]In addition to the commodities listed, sand and gravel, sulfur, stone, and refined petroleum products may have been produced in North Korea, but available information was inadequate to make reliable estimates of output.

[3]Because of the lack of official reported data, mineral commodity production numbers have been estimated.

Table 7-5: Output of Major Mineral Products in the DPRK (2013-2017)

Item	Unit	2013	2014	2015	2016	2017
Coal	1,000 tons	27,861	27,081	31,115	35,741	21,738
Iron ore	1,000 tons	5,716	5,487	4,020	4,280	4,473
Magnesite	Tons	143,848	179,450	149,599	160,935	172,488
Copper	Tons	33,429	38,563	42,826	62,768	8,749
Zinc	Tons	144,556	149,044	181,329	265,877	142,685
Pb	Tons	95,458	96,529	93,187	94,458	95,944

Presentations of what is known about key mines, output trends, and infrastructure for each of several different important types of minerals are provided below in section 7.2, below, followed by a section providing a description of major mining, metals refining, minerals transport, and related infrastructure (section 7.3), a review of the policies, organizations and human resources involved in the DPRK minerals sector (section 7.4), and a presentation of conclusions regarding the DPRK minerals sectors offering potential strategies for overseas investors who might wish to become involved in development of the sector (section 7.5).

7.2. Mining and Other Infrastructure, Output Trends, and Related Information for Key Types of Minerals

7.2.1. Iron

The DPRK's iron ore reserves are substantial. In addition to the ROK estimates of DPRK reserves, at 2 to 4 billion tonnes, other sources note reserves of 3 billion tonnes.[707] The Korea Mining Corporation (ROK) estimated the overall size of deposits of iron ore in the DPRK at 3.5 – 4.0 billion tonnes (including ores of quality in the 22-50% Fe range) as of 2008. The Musan (or Moo-san) mine, in the DPRK's northeast, is described by one source as "the largest open air [presumably meaning open pit] mine in Asia", and has been a recent target of investment by Chinese mining companies.[708] Major iron ore regions are the Moo-san, Lee-won, Buk-Chong, Hur-chon areas (Ham-Kyung province), and Eun-Ryul, Shin-Won, and Jae-Ryong (in Hwang-Hea province). Details of key mines and factories using iron ore are provided below

Table 7-6 summarizes the major iron ore mines in the DPRK, including their location, the reported size of their deposits, and the reported grade of their ore bodies, as well as estimates of

[707] MSN Encarta, previously available as http://encarta.msn.com/encyclopedia_761555092_2/North_Korea.html.
[708] *North Korea Brief No 06-4-8-1*, "Digging for Answers in the DPRK Mining Sector: Seeking Solutions for the North Korean Economy", lists reserves for the Musan mine at "7 trillion tons", which we assume is a mistranslation, a mistake in units, or both—probably the proper value is 700 million tons or 7 billion tons.

their output as of 2011. There have reportedly been no major new iron ore mines opened in the DPRK in the last five years.   Iron ore production in the DPRK peaked in 1985 (at 9.8 million tonnes, based on ore with Fe content of 65%) but sharply declined to 2.89 million tonnes as of 1998.[709]

[709] Source: "DPRK's Industry", Korea Industrial Bank (ROK), 2011.

Table 7-6: Major Iron Ore Mines in the DPRK[710]

Area	Mine name	Location	Deposit	Grade	Others
East	Moo-san	Moo-san, Ham-kyung province	1.5 billion tonnes	25-35 %	8 million tonnes. (30%), 3 million tonnes (60%)
	Lee-Won	Lee-won Ham-Nam, prov.	20 years operation	49%	
	Poong-San	Poong-San Ran-gang prov.	120 million tonnes	45%	
	Hur-Chon	Hur-chon Ham-nam	150 million tonnes	48%	
	Dan-chon	Dan-chon Hamnam	100 million tonnes	45%	
	Jang-Gang	Ja-Gang province	unknown	50%	
West	Eun-Ryul	Hwang-nam province	100 million tonnes	48%	Open mine 1.6 million tonnes
	Jae-Ryung	Hwang-nam province	100 million tonnes	50%	Open mine 500,000 ton
	Chon-Dong	Gae-chon Pyong-Nam province	50 million tonnes	50%	1 million tonnes
	Suh-hae-ri	Eun-Ryul Hwang-Nam province	unknown	55%	Under development
	Hah-Sung	Shin-Won Ham-Nam province	15 million tonnes	45%	Open mine 500,000 ton
	Duck-Hyun	Eui-Joo Pyong-Buk, province	unknown	50%	Iron & copper 500,000 tonnes
	An-Ark	Hwang-nam province	unknown	50%	Newly developed
	Song-rim	Hwang-buk province	unknown	55%	Newly developed
	Hwang-Joo	Hwang-buk province	unknown	55%	Newly developed
	Yon-San	Hwang-buk province	unknown	55%	Newly developed
	Tae-Tan	Hwang-nam province	unknown	55%	Newly developed
	Gae-chon	Pyong-Nam province	17.5 million tonnes	45-55%	Developed 1976

[710] Source: "DPRK's Industry", Korea Industrial Bank (ROK), 2001.

The Moo-san (Musan) Iron Ore Mine

The reserves of the Moo-san mine are estimated at 1.5-2.0 billion tonnes as Magnetite ($FeOFe_2O_3$) containing Fe at 23-30%. Choi (see reference above) describes development of this mine as beginning in 1935, its reserves as 1.73 billion tonnes at an ore grade of 24% Fe. The mine's reserves are considered low-grade ore (average 25%), but as it is a strip mine (an open pit mine), it offers iron ore production at low cost. There are 3-4 mineral veins in the Moo-san mine. The first vein is 400 meters in width, 3,000 meters in length, and 1,000 meters deep. Another 3 veins are known to be similar in structure to the first, but further details on those veins are not available. Starting from an iron content of 28-30%, ore is refined to an iron content of 60%-65% through a dressing (separation of higher-grade ore products) procedure in the mine area. Ore produced from an open surface mine (open pit mine) is sent to 6 ore separators in 25-ton and 50-ton heavy trucks (which were mostly imported from Sweden) then, the ore is sent to dressing plants for further refining by gravity separation methods at a location near the ore separator.

Using this refining method above, the 60-65% Fe powdered ore is produced, then sent to the Kim-Chaek Iron-manufacturing plant in Chong-Jin city, 97 km from the Moo-san mine. Transport is via freight train and via a steel pipeline that is 2 meters in diameter. Unlike most regional one-way railway systems in the DPRK, the railway from the mine is a double line so that powdered ore can be carried out without any delay via freight train if the mine produces at its maximum capacity. The total capacity to carry out powdered ore via the railway and pipeline from the Moo-San mine to the Chong-Jin iron manufacturer) was 6 millon tonnes per year.[711]

The Moo-San mine's production capacity is 3 million tonnes of 65% powdered ore. The mine produced 9.9 million tonnes of raw ore in 1985, but after that production sharply declined to 2.89 million tonnes, or 30% of production in 1985 production, though iron ore production at the mine has reportedly been slowly increasing between late 2002 and 2009. Choi (see reference above) lists the mine's capacity as 10 million tonnes or ore annually, with ore processing throughput capacity of 7.5 million tonnes/yr using a magnetic separation (wet) processing method. Choi estimates the 2006 output of the mine at 5 million tonnes of ore, and 2 million tonnes of concentrate (Fe 65%), at a recovery rate of 79.5%. The mine is linked to the Seodusu hydroelectric power plant over a 60 kV power line, and draws its water from the Duman (or Tumen) river. It is also linked by railroad to the port at Chengjin, 150 km from the mine site.

The mine has been supplying its production to the Kim-Chaek Iron-Manufacturing Company. This iron-manufacturer's annual production capacity is reportedly 2.17 million tonnes, accounting for about 40% of the DPRK's iron production capacity (5.42 million tonnes).[712] Kim-Chaek employed 20,000 workers when operating at peak output, and its annual capacity is reported to be 2.4 million tonnes of pig iron, 2 million tonnes of steel, and 1.4 million tonnes of steel materials (rolled steel) .[713]

[711] Based on data from Kim, Young Yoon *DPRK's Mineral production systems and future*, Korea Reunification Institute, 2007, and personal communications with industry sources.
[712] Based on Korean (ROK) Central Bank report, 2005.
[713] Source, *Han GyeRe* Newspaper, March 3, 2002. Note that the 2.4 tons of pig iron is probably roughly consistent with the estimate of 2.17 tons of iron output noted above.

Eun-Ryul Mine

This mine extracts iron ore in the form of limonite ($Fe(OH)_n H_2O$) and is located in Eun-Ryul-Gun, Hwang-Hae province. Deposits in this mine are estimated to total 200 million tonnes. Due to their high grade of iron ore (Fe 44%) and the convenience of transporting ore in ships (the Eun-Ryul mine is within 20 kms of Hae-Joo port) the Eun-Ryul mine and the nearby Jae-Ryong mine descibed below are likely possible destinations for overseas investment funds.[714]

Jae-Ryong Mine

This mine is located in Jae-Ryong-Gun, Hwang-Hae province. The mine vein is similar to that in the Eun-Ryul mine. Both mines provide their production to the Hwang-Hae Iron-manufacturer.

Hwang-Hae Iron-Manufacturer

The two mines above provide their production to the Hwang-Hae Iron-manufacturer. This factory's capacity in to produce pig iron is approximately 1.14 million tonnes per year.[715] This iron-manufacturer has more modernized and sophisticated facilities relative to the Kim-Chaek Iron-Manufacturer, but it does not operate continuously due to a shortage of iron ore supplies from the Jae-Ryong and Eun-Ryul mines.

Hur-Chon iron ore mine

This mine is located in Hur-Chon Gun, Hwam-Kyung Nam province. The deposit is composed of reserves of hematite (Fe_2O_3), and the quality of iron ore is 44%.

North Korea has been reluctant to export iron ore, but it has encouraged iron ore manufacturers to export steel or pig iron production to China or South Korea. Table 7-7 provides a summary of DPRK steel and pig iron production capacity in units of thousand tonnes per year**.** Table 7-8 shows the supply chains—sources of ore and electricity—for major iron manufacturers in the DPRK.

[714] Sources of information used to describe this and other mines in this section include Kim, Young Yoon *DPRK's Mineral production systems and future*, Korea Reunification Institute, 2007; Chung, Woo-Jin *Strategic Cooperation Plans and Current Situation in Development of South and North Korea*, Korea Energy Economics Institute, 2007, and personal communications with industry sources.

[715] Korea Mining Improvement Corporation report, *Deposits of Mineral resource in DPRK and trading between South and North Koreas*, 2005, p. 9.

Table 7-7: Production Capacity of Major DPRK Iron Manufacturers (1000 tonnes per year, and fraction of total national capacity)[716]

Name	Iron Making (1000 tonnes)	Steel Making (1000 tonnes)	Rolling (1000 tonnes)
Kim-Chaek Iron Manufacturer	2167 (40%)	2400 (40%)	1470 (36.4%)
Hwang Hae Iron Manufacturer	1142 (21%)	1445 (24.1%)	750 (18.6%)
Sung Jin Iron Manufacturer	480 (8.9%)	726 (12.1%)	415 (10.3%)
Chong Jin steel manufacturer	960 (17.7%)		
4.13 Iron manufacturer	516 (9.5%)		
September (Kuwol) Iron manufacturer	96 (1.8%)	90 (1.5%)	550 (13.6%)
Others	60 (1.1%)		
Total	5421	6002	4037

[716] Source: "DPRK's Industries", Korea (ROK) Industrial Bank, 2002. These data are consistent with data provided by Dr. Chung Woo-jin in the presentation listed in section 7.1, above.

Table 7-8: Supply Chains for Major Iron & Steel Manufacturers in the DPRK

Name	Major Products	Iron Ore	Power Plant	Supplies Products for
Kim-Chaek Iron Manufacturer	Pig iron, steels, rolled steel	Moo-san Iron mine	Chong-Jin Thermal power plant	Sung-Jin, Chunrima steel maker
Hwanog-Hae Iron Manufacturer	Pig iron, steels, secondary metal products	Eun-Ryul, Jaer-yong mine	Pyongyang Thermal power plant	Steel sheet, rails, shaped steel
Chunrima steel Manufacturer	General rolled steel steel rope, secondary steel products	Chon-dong, Gea-chon mines	Pyong-Yang Thermal power plant	Construction, building materials
Chong-jin steel manufacturer	Secondary steel products alloy steel products structural steel		Chong-Jin Thermal power plant	Machinery factories, exports

Exports of Iron Ore to China

The share of iron ore in the DPRK's exports to China as of 2016 was not high compared to those of other mineral resources (particularly coal). In 2016, the value of the DPRK's iron ore exports to China amounted to $7.33 million. This was not a large proportion of total exports compared to other mineral resources exported to China, but this share had sharply increased in 2014, and fell to zero for several months after April 2017, then fell again sharply after September 2017 when UNSC sanctions began. As a whole, the value of the DPRK's iron ore exports to China in 2017 (the "Export" line in Figure 7-3) totaled US $100 million, an increase of 43% over 2016.[717]

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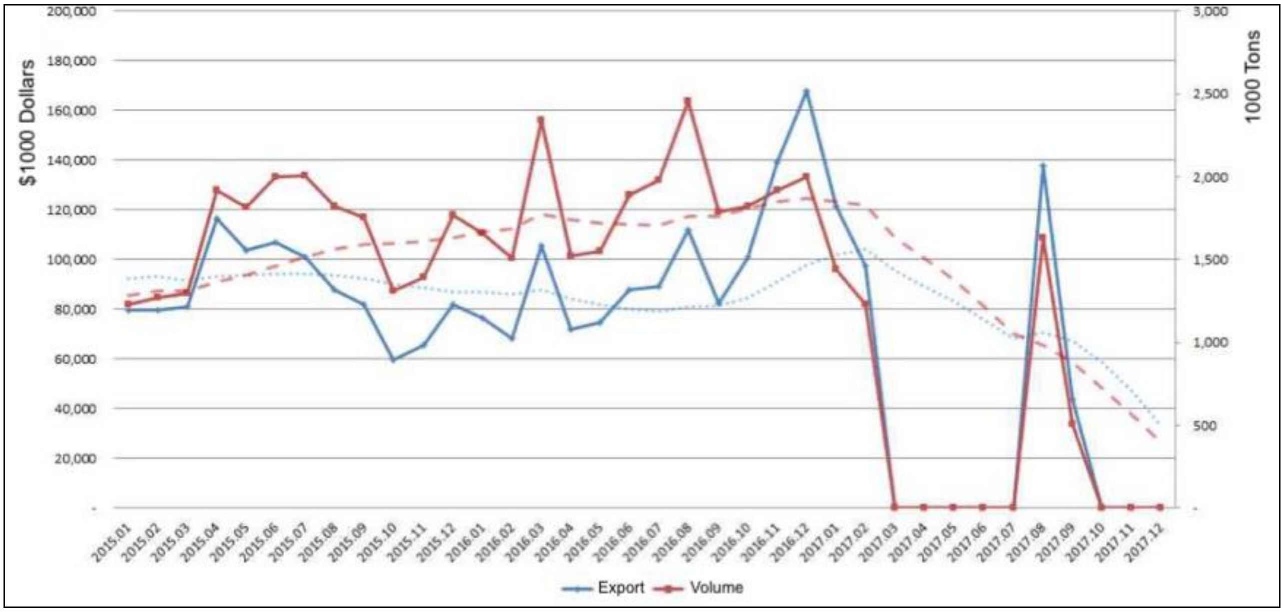
[717] From Yoon, 2019, ibid, original source Information system for Resources of North Korea (2018), (in Korean), available as https://www.irenk.net/.

Figure 7-3 DPRK Exports of Iron Ore to China by Month[718]



7.2.2. Other base metals

Most lead and zinc deposits are found in Ham-Kyung, Pyong-An and Hwang-Hea provinces, and the total and total reserves are approximately 600,000 tonnes (Pb 100%) and 15 - 20 million tonnes (Zn 100%), respectively,[719] ROK estimates, as noted above, place the DPRK's endowments of lead and zinc at 6 and 10-20 million tonnes of metal, respectively. Another source suggests that reserves of these metals are roughly 12 million tonnes each and are concentrated in the Komdok area of the DPRK's Northeast (South Hamgyong province).[720] Surveys for a single mine in Komdok mine show about 2.7 million tonnes of lead, 7.9 million tonnes of zinc, and several other metals, including precious metals, in the mine's estimated 240 million tonnes of ore.[721]

The National total output of lead and zinc around 2010 were reported to be approximately 60,000 tonnes and 100,000 tonnes per year respectively, or somewhat lower than the annual output in 2013-2017 reported in Table 7-5. Most zinc and lead ores are smelted at the Moon-Pyong Refinery (located in Moon-Chon City, Kang-Won province).

Gum-Dock (or Kyumduck) Zinc Mine

This mine is located in Dan-Chon area in Ham-Kyung province[722]. As the largest zinc mine in the DPRK, this mine has rich vein of ore 9 km in extent, and its deposit is estimated at 8 million

[718] Source: Choi, Young Yun, KDI, 2018, www.Kita.net
[719] From E. Yoon 2011 report described above.
[720] MSN Encarta, previously available as http://encarta.msn.com/encyclopedia_761555092_2/North_Korea.html.
[721] From document in the author's files. Other metals described as present in ore from this mine include silver, mercury, and cadmium. The mine's ore-handling capacity is described as about 14 million tonnes/yr.
[722] Choi, in the 2010 presentation listed above, described this mine as the "Kyumduck Zinc mine", located in "Hamkyungnam-do, Dancheon, Kyumgol-dong".

tonnes (Zn 100%), about half of the DPRK's total deposits. Development of this mine began in 1932, and its reserves are estimated at 266 million tonnes of Sphalerite ore at a grade of 4.21% Zn and 0.88% Pb. It is an Underground mine, with a reported production capacity of 10 million tonnes of ore per year, produced with a mining method described by Choi (source as above) as "70% shrinkage, with 30% sub-level stoping",[723] processing the minerals extracted using flotation, with a throughput (capacity) of 10 million tonnes/yr. In 2006, this mine reportedly produced 3.5 million tonnes of ore, yielding 196,000 tonnes of zinc concentrate (Zn 53%), at a recovery rate of 52%, and 31,800 tonnes of lead (Pb 63%) at a recovery rate of 63%. The mine is powered by a link to the 50 MW Hyeuchen hydroelectric power plant, uses water from the Bukdaechen river, and is connected to the Kimcheck port by a 78 km rail line. At the Kimcheck port, the loading capacity for product is about 800,000 tonnes per year. Figure 7-4 provides photos taken from the outside and inside of the Kyumduck Zinc mine.

Figure 7-4: Photos of Kyumduck Zinc Mine[724]

Copper reserves in the DPRK are estimated by ROK experts at about 2.2 million tonnes. The Honchon mine, in Honchon County, South Hamgyong province, is reported to have reserves of about 400,000 tonnes of copper, and the nearby Sangnong mine has reported copper reserves of over 500,000 tonnes.[725] The four major copper refining facilities in the DPRK are listed as Nampo, at 41,400 tonnes/yr, Heungnam, at 4000 tonnes/yr, Wunheung, at 25,000 tonnes/yr, and

[723] According to Wikipedia (http://en.wikipedia.org/wiki/Stoping_%28mining_method%29), The mining technique known as stoping "is the removal of the wanted ore from an underground mine leaving behind an open space known as a stope".

[724] From presentation by Choi Kyung Soo of the ROK-based North Korea Resources Institute, titled "The Mineral Resources of North Korea", prepared for the 2010 DPRK Energy and Minerals Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/05.-Choi.pptx.

[725] From document in the author's files. Gold reserves in these two mines combined are listed at about 400 tonnes.

Pyungbuk, at 20, 000 tonnes/yr. These facilities are described as small in scale, by international standards[726].

North Korean authorities have been deliberately reluctant to reveal information about North Korea's copper mines and copper production capacity to outsiders, including China and South Korea, due to the fact that copper has been a significant material for producing military equipment, for including copper cable, bullets, shells and missile-related.[727] It is thus not easy to gather data related to copper mines and copper production in North Korea. There are 3 major copper mines in the Northern part of the DPRK: Hur-Chon Copper Mine, Hye-San copper mine and Yong-Heong Copper Mine. These mines are owned by the People's Army Department (PAD), as they provide strategic war industry supplies, and are controlled and operated by the PAD. The information available on these mines is as follows.

Hye-San Youth Copper Mine

This mine is located in the Hye-San region in Ryang-Gang province. The copper ore deposit for this mine is known to be 20 million tonnes, the mine's annual production capacity is 30,000 tonnes (of 30% copper concentrate) and its employees number about 2,500. Copper ore from the mne is processed in a concentrator unit at the mine, and the concentrated ore is carried by freight train to the Dan-Chon metals refinery. There are two copper mines in this region: Gap-San copper mine and Shin-Pa copper mine in Ran-gang province.

DPRK-China joint venture at the Hyesan Youth Mine

The "Hyejung Mining Co.", which runs the Hyesan Youth Mine in Yanggang Province, an operation that the DPRK and China's Wanxiang Group have jointly established, is reported to be greatly expanding production and has been operating normally in recent years. The Hyejung Mining Co., Ltd., a joint venture between Wanxiang Resources Co., Ltd. and Hyesan Youth Mine in Yanggang Province, DPRK produced 5,000 tons of copper concentrate in about 2018, local sources said. The Hyejung Mining Co., Ltd. was established in 2007 with an ownership arrangement that China Wanxiang Resources Co., Ltd. owned 51% of the shares, and Hyesan Youth Mine of North Korea secured 49% of the shares. Due to a conflict between the DPRK and China over mining operation rights, it was only in September 2011 that the venture was officially launched. Sources have said that the "Hyesan Youth Mine" was almost the only copper production mine in the DPRK. The Hyesan Young Mine was introduced as a successful example of foreign investment in efforts to attract additional investment, and sources contacted have indicated that the mine is operating normally, and that production has been rapidly increasing.[728] Figure 7-5 shows an image of the Hyesan Youth Mine as of 2020 (location approximately 41.366, 128.157), showing what are likely waste ponds related to copper production. Several of the buildings shown in the image appear to have been added or renovated since 2005.[729]

[726] Presentation by Dr. Chung Woo-jin, same source as listed for Table 7-1.
[727] Yoon (2019), ibid, cites "Private source, 2018" as the source for this information.
[728] Yoon (2019), ibid, cites a private source, 2018, and Radio Free Asia, 2014-10-17 for this information.
[729] North Korea Economy Watch (2011), "Chinese joint venture company takes over Hyesan Youth Copper Mine", dated 9-19-2011, and available as https://www.nkeconwatch.com/2011/09/19/chinese-joint-venture-company-takes-over-hyesan-youth-copper-mine/.

Figure 7-5: Google Earth Pro Image of Hyesan Youth Mine as of June 2020

Hur-Chon Copper Mine

This mine (likely the same as the "Honchon" mine described above) is located in the Hur-Chon region of Ham-Kyung province. The known copper ore deposit for the mine as 15 million tonnes, and Gold and other rare minerals are also found in the deposit. The annual production capacity of the mine is 20,000 tonnes (Copper 40%) and it employs 5,500 personnel. Copper ore is processed in a concentrator at the mine and is carried by trucks and freight trains to the Dan-Chon refinery.

Yong-Heong Copper Mine

This mine is located in the Yong-Heong region in Ham-gyung province. The known copper ore deposit is 12 million tonnes, and is associated with Gold and rare minerals. The annual production capacity of the mine is 10,000 tonnes (Copper 40%), it employs 1,500 workers. Copper ore is concentrated in concentrator units at the mine, and is also carried by trucks and freight trains to the Dan-chon refinery.

Rim-gang District Copper Mine Joint Venture Investment Plan

Copper ore reserves in the Rimgang District, Yang-gang Province are reported to be of a 12% grade, with 20 million tons of reserves, and confirmed by geological exploration. Cu reserves in this area generally are estimated to be the equivalent of 24 million tons at 100% copper. The value of the total reserves thus amounts to $183 billion (about 200 trillion won) at current (late 2020) copper prices, which are near historical highs.[730] Production plans by the joint venture estimate that 3 months after the first investment, 3,000 tons per month of copper concentrate (300 tons/month of net tons of copper) can be produced, with the value of the planned monthly output at international prices estimated (at the time) at 300 * $7100 = $ 2.13 million.

Power supply and copper concentrate sales plans are as follows. As the mine is located within 3 km of the Chinese border, supplies of electricity will come from China, but it is possible that the mine will be supplied with electricity using an on-site generator. The copper concentrate produced (using ore dressing yielding a Cu concentration of 30% or more) is exportable to China. It can be transported via the Hyesan-Dancheon railway line and exported from the Dancheon port.[731]

The DPRK has aluminum resources sufficient to support exports of up to 20 thousand tonnes of "unwrought" aluminum annually to China.[732] China imported about 800 tonnes of bauxite (the ore typically used to produce aluminum) from the DPRK in 2005, and nearly 3000 tonnes in 2007, but in most other years its imports were on the order of 100 tonnes. In 2007, for example, China paid about one-third as much per tonne for DPRK bauxite (about $15) as it did for bauxite on the world market on average (about $44), suggesting that either DPRK bauxite has a lower Al

[730] December 2020 copper prices were about $3.2 per pound, or $7.6 per kg, or $7600 per tonne. See, for example, https://www.macrotrends.net/1476/copper-prices-historical-chart-data,

[731] Information from Yoon (2019), ibid, based on conversations with a private source.

[732] The UN Comtrade database shows imports of Al from the DPRK to China of 20 thousand tonnes in 2013, although this figure dropped markedly in subsequent years, to about 5000 tonnes in 2014, 2000 tonnes in 2015, and 300 tonnes in 2016. The DPRK has also been an importer of aluminum scrap from various countries in recent years, although in quantities of just a few hundred to a thousand or so tonnes.

content than the average of China's other sources (mostly Indonesia and India), and/or China was using its market power to strike a favorable deal with the DPRK. We have no further quantitative information at present about DPRK reserves of this metal. A Czech website notes the availability of DPRK-made bauxite mills and describes the DPRK as having bauxite, but this mention does not seem definitive.[733] Another source also mentions bauxite resources in the DPRK and provides a map in which bauxite deposits are identified as being near Danchon in the Northeast of the DPRK, and also near the DMZ about 100 km inland from the East coast.[734]

7.2.3. Precious and specialty metals

The DPRK has gold reserves estimated at 1000-2000 tonnes, and silver reserves estimated at 3000 to 5000 tonnes. In addition, the DPRK has significant reserves of the strategic minerals tungsten and molybdenum, used in specialty metal alloys, and also has, at least in the past, offered for sale the precious metals platinum and palladium (see above). Tungsten output in the years around 2000 was estimated at 500 tonnes/yr.[735] The largest of a reported 51 gold mines in the DPRK is Woonsan, located in the DPRK's Northwest. DPRK gold mines, like many other industrial establishments, lack modern equipment, are relatively small, and in some cases have worked existing seams for some time, resulting in declining productivity.[736]

Gold ore is typically produced with silver ore and also with copper ore in the DPRK.[737] Gold and silver ore reserves total a few million tonnes of raw ore, according to a Korea Mining Corporation source. Major gold mines in the DPRK are the Soo-An Mine (Soo-an-gun, Hwang Buk province), the Hol-dong mine (Yonsan-gun, Hwang Buk province), the Dae-yoo-dong mine(Dongchang –gun, Pyungbuk province), the Woon-san mine (Woonsan-gun, Pyong-Buk province), the Sung-hong mine (Hoi Chang-gun, Pyongnam province), the Sang-nong mine (Huh-chon-gun, Hamnam province), the Ong-Jin Gold mine (Hwang-Hae province) and the Kum-kang mine (Kumkang-gun, Kangwon province). The total production from these 7 major gold mines has not been officially reported, however it is clear that the annual gold production capacity is approximately 5 tonnes in these major mines, and annual silver production is approximately 40 tonnes. In particular, the annual production capacity of the Woon-San gold mine is about 1.5-1.8 tonnes according to private sources (as of 2018), worth about $90 to $105 million at the (near historically high) prices prevailing in late 2020. This mine's capacity is estimated to amount to over 40% of the DPRK's gold production capacity. The Woon-san mine's deposits of gold ore are estimated as 1,500 tonnes alone, which is almost 50% of North Korean gold reserves, and nominally worth on the order of $100 billion.

The DPRK has been experiencing a shortage of technology and infrastructure in precious metals mining. For example, the large mines described above generally have 30–40-year-old (or older) production equipment, including some equipment inherited from the 1940s Japanese colonial period. As a result, these mines' production capacity is likely similar to their 1940s era

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[733] Sky Blue (2020), includes listings for "North Korea Bauxite Ball Mills Fireproof" and "North Korea Bauxite", at https://www.restaurant-lahabana.cz/24267/jiUzt//.
[734] Intelligent Security Solutions Limited (2015), *DPRK Current Situation and Future Intentions Briefing & Analysis*, available as http://issrisk.com/wp-content/uploads/2015/04/DPRK-current-situation-and-analysis.pdf.
[735] Pui-Kwan Tse, "The Mineral Industry of North Korea", p. 14-3 in *U.S. GEOLOGICAL SURVEY MINERALS YEARBOOK—2002*. Available as http://minerals.usgs.gov/minerals/pubs/country/2002/knmyb02.pdf.
[736] Presentation by Dr. Chung Woo-jin, same source as listed for Table 7-1.
[737] Text in the remainder of this subsection is derived from material from the 2011 report by E. Yoon, as referenced earlier, and based on a combination of ROK sources and personal contacts, as referenced in the original report.

production capacity. DPRK authorities have declared that all gold production in the country should belong to the Labor Party's assets (which are controlled by the "39" Department (or "Office No. 39"), which was Kim Jong Il's private assets manager), and as a result no other organization has the authority to deal with and to produce gold in the DPRK. Deeper and deeper strata in the gold mines described above have been worked due to the mines having been operated for more than 50 years, and the increasing depth of pit (tunnel depth) is making it more complicated and difficult to extract gold ore from these mines.

Due to a decline in gold ore production at the time, DPRK authorities contacted, in the years before 2010, Chinese businessmen and Japanese business interests in an attempt to attract funds to invest in those major gold mines. These contacts implied that the Labor Party (39 Department) wished to produce more gold ore to earn more hard currency to support the newly-announced (as of 2010) military leader, Kim Jong Un.

As of 2010, investment proposals made to overseas investors by DPRK authorities were reportedly as follows: (1), investors should invest at least 1 million US dollars in cash to produce gold ore (Hol-dong gold mine, Kum-Kang, and Woon-san gold mine), (2), the North Korean government would be the guarantor to protect the investor's funds, and (3), investors would have the authority to bring out gold ore from the mine they invested in, and export it to overseas locations for refining into gold metal.

Gold mining regions use trucks and freight trains as major carriers of ore from mines to refineries, with heavily-armed guards to protect shipments against potential theft.

The following are examples of proposals and ongoing projects for, respectively, Chinese and domestic investment in DPRK gold mining ventures:[738]

1. **Proposal for a joint venture between Kangsung Trading Company and China to develop a gold mine in Dong-chang-gun, North Pyongan Province**

Despite UNSC sanctions, the DPRK is pursuing underground resource development by attracting Chinese capital. The ROK's Channel A Broadcasting Company in 2019 reported on a proposal from a Chinese company to invest in DPRK gold mining development. A 50-year long-term contract was being discussed in the context of a proposal to invest in the development of mines run by the "Kang Sung Trading Company", which operates under the North Korean People's Army. This proposal was offered by Chinese investors to DPRK officials. This was a joint venture proposal for the development of the gold mines in Dong Chang, North Pyongan Province. Reportedly the DPRK had the right to exploit the mines' resources, but the production and operation facilities were to have been owned 51% by the DPRK and 49% by Chinese partners. At the same time, investors had secured an annual income guarantee of about 23.4 million dollars and about 26.5 billion won. A source in the DPRK met with Channel A and said, "The development period is 50 years and the long-term contract is underway."[739] (Channel A News source.)

[738] From Yoon (2019) ibid.
[739] Channel A News (Korea), dated July 19, 2018.

2. Development of North Daebong Gold Mine

Local sources say that North Korean authorities are concentrating their investment in Daebong Mine located in Rojung-Ri, Yangkang Province. Daebong mine, in which mining began in the mid-1990s, is a mine that produces high-quality gold, tungsten, and quartz, according to sources. Dae Bong Mine belongs to the Daesung Administration, which belongs to Office No. 39 of the Labor Party, which controls the secret funds of Chairman Kim Jong Un. In the mid-1990s, the monthly production of pure gold rose to 40 kg, and the income from this production played an important role in getting the DPRK out of "The March of Suffering" period under the Kim Jong Il regime, the source explained. According to another source in Yanggang Province interviewed recently, "The monthly production of the Daebong Mine, which was sent down from the center this year, is 25 kg of pure gold. And the annual production plan is 300 kg of pure gold. [Producing this volume of gold] is not a difficult task if transportation and electricity is guaranteed." Presently, North Korea's gold production is strictly authorized by the Daesung Administration operating under Office No. 39. The source added that if other foreign currency-earning-institutions wanted to produce gold they needed to have approval from the Daesung Administration, and would be required to provide a certain amount of the gold produced to the Daesung Administration in return.[740] A 2020 Radio Free Asia report describes the diversion of electricity supplies to gold mines run by Office 39, underscoring the importance of these mines to the DPRK regime, particularly during the current period of high gold prices.[741]

A proposed joint venture for silver ore production at the **Gu-jang silver mine** in the DPRK was described as follows:

- The quality of ore reserves of the silver mine in Gujang, North Pyeongan province was reported at 0.06% (about 600g of pure silver per tonne of silver ore), and it was confirmed through geological exploration that the mine has 4 million tons of reserves. It thus is estimated that silver reserves were about 2,400 tons at 100% purity. These reserves are estimated to be valued at close to 1.9 billion dollars (about 2 trillion ROK won) at current silver prices.
- Electricity can be supplied via a power line from China, as the mine is located only 50 kilometers from the border, or electricity can be supplied by an on-site generator.
- The joint venture is reported to include a planned profit distribution in a ratio of 6:4, namely 60 percent to the investor, and 40 percent to the DPRK's Chosun Daebang by exporting 60 percent of the silver ore overseas while 40 percent of the ore is managed by DPRK business partner.
- The joint venture is to be authorized through issuance of a guarantee certificate by the Chosun (DPRK) government and the Second Economic Committee for 100 percent of the investment funds, along with a national institutional certificate for joint development and operation rights for the 60 percent of the operations assigned to the investor.

[740] Radio Free Asia, Jan. 13, 2017.
[741] Hyemin Son, Leejin Jun, and Eugene Whong (2020), "North Korea's Office 39 Diverts Electricity to Gold Production", *Radio Free Asia*, dated 8-12-2020, and available as https://www.rfa.org/english/news/korea/gold-08122020213702.html.

The Man-Nyun Mine produces tungsten and molybdenite. This mine is located in Shin-Pyong – Gun, Hwang-Hae province. Tungsten reserves in this area are approximately 20 million tonnes (WO_3 65%), accounting for half of North Korea's total reserves. There are 10 veins of Tungsten in the deposit, of 3–6-meter width and 1,800 meter length. This mine also produces manganese ore and copper pyrite ore. The mine's ore separator's capacity is 1000 tonnes/day, and the mine produces 500,000 tonnes of ore annually (measured as WO_3 65%). The mine employs 3,500 workers and has 8 work tunnels to support mining activities.

The DPRK is thought to have substantial reserves of rare-earth minerals, global production of which is now dominated (95 percent) by China, although other nations, including the United States, have produced significant quantities of these minerals in the past and hold substantial reserves. News reports as of 2012 suggested that the ROK's Korea Resources Corp. (KORES) was been in discussions with DPRK officials about developing DPRK rare earth resources.[742] As of 2013, a privately-held company called SRE Minerals (see below) announced "the discovery in North Korea of what is believed to be the largest deposit of rare earth elements anywhere in the world."[743] A 2019 *Radio Free Asia* article reported that the DPRK was under discussion to trade rights to DPRK rare earth deposits to China in return for construction of a large solar power plant in the DPRK, although according to at least one source apparently the Chinese response to the proposal was thought unlikely to be positive, in part because the types of rare earth minerals available in the DPRK largely contain the lighter, rather than heavier, rare earth elements, and lighter rare earths are fairly common in China.[744] The apparently vast potential of DPRK rare earth continues to be a topic of international discussion as of 2020.[745] Clearly this resource could be a major earner for the DPRK if and when its issues with the international community are resolved (or on the way to resolution), perhaps even aided by current trade and other tensions between the west and China, as countries look to diversify suppliers of rare earth minerals.

Yoon reports the following about DPRK exports of rare earth minerals to China and investments in DPRK rare earth production ventures:[746]

The DPRK has exported large quantities of rare earth mineral ores, a source of elements (examples are yttrium and neodymium) important for but used in small quantities in the production of high-tech products, to China in recent years. According to trade statistics published by the Korea International Trade Association (KITA) in 2017, North Korea exported about $550,000 of rare earth mineral ore to China in May of 2016, followed by exports of $1,329,000

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[742] See, for example, Wall Street Journal Asia, July 24, 2012, "South, North Korea Discussed Rare Earth Mining", available as http://blogs.wsj.com/korearealtime/2012/07/24/south-north-korea-discussed-rare-earth-mining/.

[743] Frik Els (2019), "FLASHBACK: Largest known rare earth deposit discovered in North Korea", *Mining.com*, dated May 29, 2019, originally published in December, 2013, and available as https://www.mining.com/largest-known-rare-earth-deposit-discovered-in-north-korea-86139/.

[744] See Hyemin Son, Leejin Jun, and Eugene Whong (2019), "North Korea Trades Rare Earth Mine Rights to China for Investment in Solar Plants", *Radio Free Asia*, dated 10-12-2019, available as https://www.rfa.org/english/news/korea/nk-rare-earth-solar-10212019133544.html, and Li Xuanmin and Shen Weiduo (2019), *Global Times*, dated 2019/10/24, and available as https://www.globaltimes.cn/content/1167917.shtml.

[745] See, for example, Patricia Schouker (2020), "The Trillion Dollar Battle Over North Korea's Rare Earth Elements Is Just Beginning", *The National Interest*, dated June 15, 2020, and available as https://nationalinterest.org/blog/reboot/trillion-dollar-battle-over-north-koreas-rare-earth-elements-just-beginning-162834,

[746] Text adapted from Yoon, 2019 (ibid).

in June of that year. The DPRK exported its first rare earth mineral ore (worth $24,700) to China in January of 2015 and after 15 months of no recorded trades, exports resumed.

Apart from rare earth mineral ores, the DPRK has been exporting rare earth-containing carbonate mineral compounds to China since 2011. Up until the first half of 2016, however, the export volume was small, remaining at around $170,000 for three years and for the six months up until the first half of 2016.[747]

It has been reported that North Korea has established a joint venture with international private equity funds in order to develop rare earth mineral resources in the DPRK. The International private equity fund SRE Minerals announced that it has signed a joint venture agreement with North Korea 's Chosun Natural Resources Trading Company to develop rare minerals in Jung-ju, North Pyongan Province. According to a press release made available on April 4 of 2013, Pacific Century, a joint venture located in the British Virgin Islands, has been granted the rights to develop all rare minerals in Jungju over the next 25 years. It was also given the right to extend the contract for 25 years.[748]

SRE Minerals has announced that it has been able to build a rare minerals processing plant in Jungju in accordance with the agreement and has already conducted preliminary surveys in Jungju and planned to conduct further exploration work in March of 2014. SRE Minerals said that it was possible that Jung-ju, North Korea, is the largest rare mineral reserve in the world. The company website estimated that the value of Jungju rare minerals will reach about $65 trillion. Another source places SRE's estimate of rare earth ores at 6 billion tons, with 262 million tonnes of rare earth oxides.[749] Other articles published since, however, have suggested that SRE and related companies have "opaque" ownership structures, and may be making dubious claims.[750]

7.2.4. Uranium

DPRK resources of uranium are discussed in the context of fuels for electricity generation in section 5.2.2.9. Some of that discussion is repeated here for completeness of the content of this chapter, along with additional information about DPRK uranium mining.

Figures on the DPRK's reserves of uranium are difficult to obtain, and their accuracy is unknown. It has been reported that uranium has been mined to supply the DPRK's domestic nuclear industry from mines located in various areas around the country, including Pyongsan, Pakchon, Hongnam, Jusong, Ungki, Sunchon 2, Hamheung, Hekumkang, and Najin.[751] Another source refers to a uranium mine near Hungnam (probably the same as "Hongnam"), where the Japanese built a cyclotron in 1943-44.[752] Two sources suggest that the DPRK's uranium

[747] *Yonhap News*, (ROK), July 28, 2016
[748] *Voice of America*, December 9, 2013
[749] (*Creamer Media's Engineering News* (2013), "Largest Known Rare Earth Mineral Deposit Discovered", dated 4th December 2013, and available as http://www.engineeringnews.co.za/print-version/largest-known-rare-earth-mineral-deposit-discovered-2013-12-04.
[750] See, for example, Mailey, J.R., 2016, "Hiding in Plain Sight: Cowboys, Conmen and North Korea's $6 Trillion Natural Resource Prize", *38 North*, dated April 6, 2016, and available as https://www.38north.org/2016/04/jrmailey040616/.
[751] Document in the authors files, referencing several Korean and international literature sources [ELE-96]
[752] Federation of American Scientists (1998), "Hungnam N39°49 E127°37' Hungnam Chemical Engineering College Hungnam Fertilizer Complex", available as http://www.fas.org/nuke/guide/dprk/facility/hungnam.htm.

deposits “are estimated at 26 million tonnes”.[753] [754] One of the sources describes these deposits as “high grade ore”, so it seems virtually certain that the references are to tonnes of ore, not tonnes of uranium metal (or uranium oxides). Another source states:

> “It has been estimated that, at its peak in the early 1990s, North Korea was able to produce about 300 tonnes of yellow cake [U_3O_8] annually, equal to approximately 30,000 tonnes of uranium ore.”[755]

Other analysts of the subject have reported estimates of 3 and 4 million tonnes of “reasonably assured resources”, based on older OECD and ROK estimates, respectively. Still another source cites a figure of 4.5 million tonnes of uranium ore, and quote “Russian scientists who have visited North Korea” as saying that the DPRK’s “mining and milling capabilities produce 2000 tonnes of natural uranium, per year”[756].

The DPRK is reported to have exported significant amounts of uranium ore over the years, starting in (at least) the 1947-1950 period, with the export of “over 9,000 tonnes of uranium [presumably ore] and an unknown amount of monazite to the USSR”, and continuing with a reported “$6 billion worth of uranium ore” to the USSR in 1985, “1,500 tonnes of monazite[757] annually” in the 1990s to “China, Japan, Spain, and Hong Kong”.[758] More recently, an advertisement by the DPRK's International Chemical Joint Venture Corporation was published in an English-language DPRK trade journal in 2001 and 2002 advertised ammonium diuranate (ADU), a processed form of yellowcake, for sale on the international market.[759] A report in late 2006 that the DPRK and Russia had been negotiating, apparently since 2002, a deal that would give Russia “exclusive rights” to the DPRK’s uranium deposits “in exchange for Moscow's support at six-party talks aimed at denuclearizing Pyongyang“, suggested that Russia would enrich DPRK uranium for re-export to Vietnam and China as nuclear fuel. The report was dismissed as “rumors” by Russian authorities.[760] Exports from the DPRK to China of 90.54 tonnes of "Uranium, Thorium Ore and Concentrate" were listed in China Customs statistics for

[753] Larry A. Niksch, United States Congressional Research Service (CRS), *CRS Issue Brief for Congress: North Korea’s Nuclear Weapons Program*, updated January 17, 2006. The same figure is also quoted in Yo-Taik Song, “IN OUR TIMES SERIES, PART 6, The North Korean Nuclear Program: Technical and Policy Issues”, previously available as http://www.phy.duke.edu/~myhan/ot6-song.html.

[754] The DPRK has been highly reluctant to reveal the extent of its deposits of Uranium ore and its annual production capacity to the outside world. This same estimate of reserves (26 million tonnes of ore), however, was provided in information from private sources in China and DPRK business contacts compiled by E. Yoon for the 2011 report described above.

[755] *North Korea’s Nuclear Weapons Programme*, by the International Institute for Strategic Studies, 2006, available as http://www.iiss.org/publications/strategic-dossiers/north-korean-dossier/north-koreas-weapons-programmes-a-net-asses/north-koreas-nuclear-weapons-programme.

[756] “North Korean Hullabaloo”, by Paul Vos Benkowski, 6 - *Nukewatch Pathfinder*, Winter, 2006-2007, page 6.

[757] Monazite is a name for a group of rare earth phosphate minerals, the most common form of which (Monazite-(Ce)) contains Cerium, Lanthanum, Thorium, Neodymium, and Yttrium. Monazite is radioactive, and it seems likely to have been exported in this instance primarily as a source of Thorium, though that is just the authors’ conjecture. A description of Monazite can be found at Amethyst Galleries “THE MINERAL MONAZITE”, http://www.galleries.com/minerals/phosphat/monazite/monazite.htm.

[758] “North Korea Profile, Nuclear Exports”, prepared for the Nuclear Threat Initiative by the by the Center for Nonproliferation Studies at the Monterey Institute of International Studies, 2003, available as https://www.nti.org/learn/countries/north-korea/nuclear/.

[759] *Foreign Trade of the DPRK*, 1 Jul 2001, and1 Oct 2002.

[760] *NUKEWARS*, “Moscow Dismisses Rumors On Uranium Deal With Pyongyang” by Staff Writers Moscow (AFP—Agence France-Presse), Dec 04, 2006; and “NKorea, Russia in secret deal over nuclear talks: report”, Tokyo (AFP) Dec 03, 2006. Available as http://www.spacewar.com/reports/Moscow_Dismisses_Rumors_On_Uranium_Deal_With_Pyongyang_999.html.

the year 2004. The listed value for these shipments, about $22,000 USD, suggests that the exports were of ore, not refined metal. Uranium exports from the DPRK to China are not listed for other years between 1995 and 2005.[761]

There are two major Uranium ore mines in the DPRK: the Pyong-San mine, and the Woong-Gi mine, as described below, along with brief desciptions of important institutions and infrastucture related to uranium mining.[762]

Pyong-San Uranium Mine

This mine is located in Pyong-San–Gun, Hwang-Hae province and has been operating for 30 years under the control of the People's Army Department. The deposit in this mine area was estimated at 1.5 million tonnes (as Uranium ore), and the mine's annual production capacity is 10,000 tonnes (private source). The mine has own separator for concentration of ore. All products are sent to the Nyung-Byun (Yongbyon) Nuclear power station under armed guards. Recently, a new facility for Uranium extraction has been built in the Pyong-Won area.

Woong-gi Uranium Mine

This mine is located in Woong-gi, Ham-Kyung province and has been operating for 35 years under the control of the People's Army Department. The deposit in this mine area was estimated at 10 million tonnes (as Uranium ore), and its annual production capacity is 19,000 tonnes. The mine has its own separator for concentration of ore. All products are sent to the Nyung-Byun Nuclear power station under armed guards. The mine's operation has been kept secret from outsiders, and even from North Koreans, due to the fact that output from the mine is known to have been used for nuclear weapon development purposes. As a result, the workers and engineers in the mine have been reportedly restricted to the area within the mine facilities even if they suffered from nuclear radiation-related disease.

Educational Institute for Uranium Mines

In the fields of geological exploration and engineering , the Kim-Chaek Engineering University, the Chong Jing Mining and Metal University, and the Sariwon Geology University have been playing major roles in staffing exploration activities to find additional Uranium ore deposits. Nyung-Byun Physics University and Lee-Gwa University have been playing major roles in the areas of mining and ore separator operation within mines, as well as logistics, for security reasons.

Infrastructure and Facilities for the Mines

Unlike other mining industries in the DPRK, Uranium mines have been targets of heavy investment, and its high grade engineers and skilled workers receive preferential treatment in terms of food, salary and social status. Funds invested in the mines have been used for mining equipments and facilities,. In particular, instead of freight railway shipping of ore, sophisticated trucks, imported from Sweden and Japan, are operating to support production activities.

[761] China Customs statistics as compiled by N. Aden for *North Korean Trade with China as Reported in Chinese Customs Statistics: Recent Energy Trends and Implications*, as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Dr. Aden's paper is available as http://nautilus.org/wp-content/uploads/2012/01/0679Aden1.pdf.

[762] From Yoon, 2011 (ibid), citing a private sources.

7.2.5. Non-metallic minerals

A number of key non-metallic minerals are present in the DPRK in significant quantities. Of primary importance is magnesite, for which principal mines are the Namgye mine (Ryanggang province Baegam county), the Danchun mine (South Hamgyung province Danchun city), the Daehung mine (South Hamgyung province Danchun city), the Ryongyang mine (South Hamgyung province Danchun city), and the Saengjang mine (Ryanggang province Unhung county).[763] Estimates of Magnesite reserves range from the 3-4 billion tonnes cited in Table 7-1 to 6 billion tonnes.[764] North Korea's magnesite reserves are the world's largest. The Ryongyang mine is reported to have reserves of 4 billion tonnes of magnesite ore, and the Daehung mine has reserves of 2.3 billion tonnes; the two mines had estimated production capacity, as of the mid-1990s, of 1.0 and 0.8 million tonnes magnesite per year, respectively.[765] The Danchon Magnesia Clinker Factory is reported to have production capacity of about one million tonnes of magnesia clinker per year, if a combination of heavy oil and coal is used as fuel (output is lower with just coal).[766] Crude magnesite output in the DPRK has been estimated by several sources at about one million tonnes annually. Magnesite is used to produce magnesia clinker, which is used in making refractory materials (materials to line high-temperature furnaces for the metals industry, for example).

The deposit in the Baekgumsan area is approximately 3.6 billion tonnes and is 7,660 meters length, 7 to 100 meters in depth, and is the site of a major strip mine. North Korean production of Magnesite as of 2005 was estimated at 1 million tonnes of concentrated ore. The Ryong-Yang (Ryongyang) Mine is located in Don-san dong, Danchun city and is a subsidiary of the Dan-Chon Regional Mining Group. The Magnesite ore grade in the mine is 30% MgO, and an alternative the mine's capacity to produce Magnesium ore is reportedly 8 million tonnes per year, which after concentration of the ore (to 55-60% Mg) yields 3 million tonnes of concentrated product. Note that this estimate, from the E. Yoon 2011 study described earlier in this Chapter, appears somewhat at odds with the capacity described above for this mine. Mining operations use two methods, terraced strip mining and underground mining. Heavy trucks operate from inside the mine to transfer points outside of the mine tunnels, and freight trains are used as the major carrier to move ore from the mine area. Double railways were built early in the 1990s as infrastructure for this mine. Freight railways operating from the seaside (Dun-chon City) to the mining sites are, however, on steep slopes, and alternative freight methods need to be considered to serve the mine.

A major ore separator was built within the mine in 1988, and the reported capacity of the separator is 8 million tonnes of ore per year.

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[763] Personal correspondence with ROK expert, 1999.

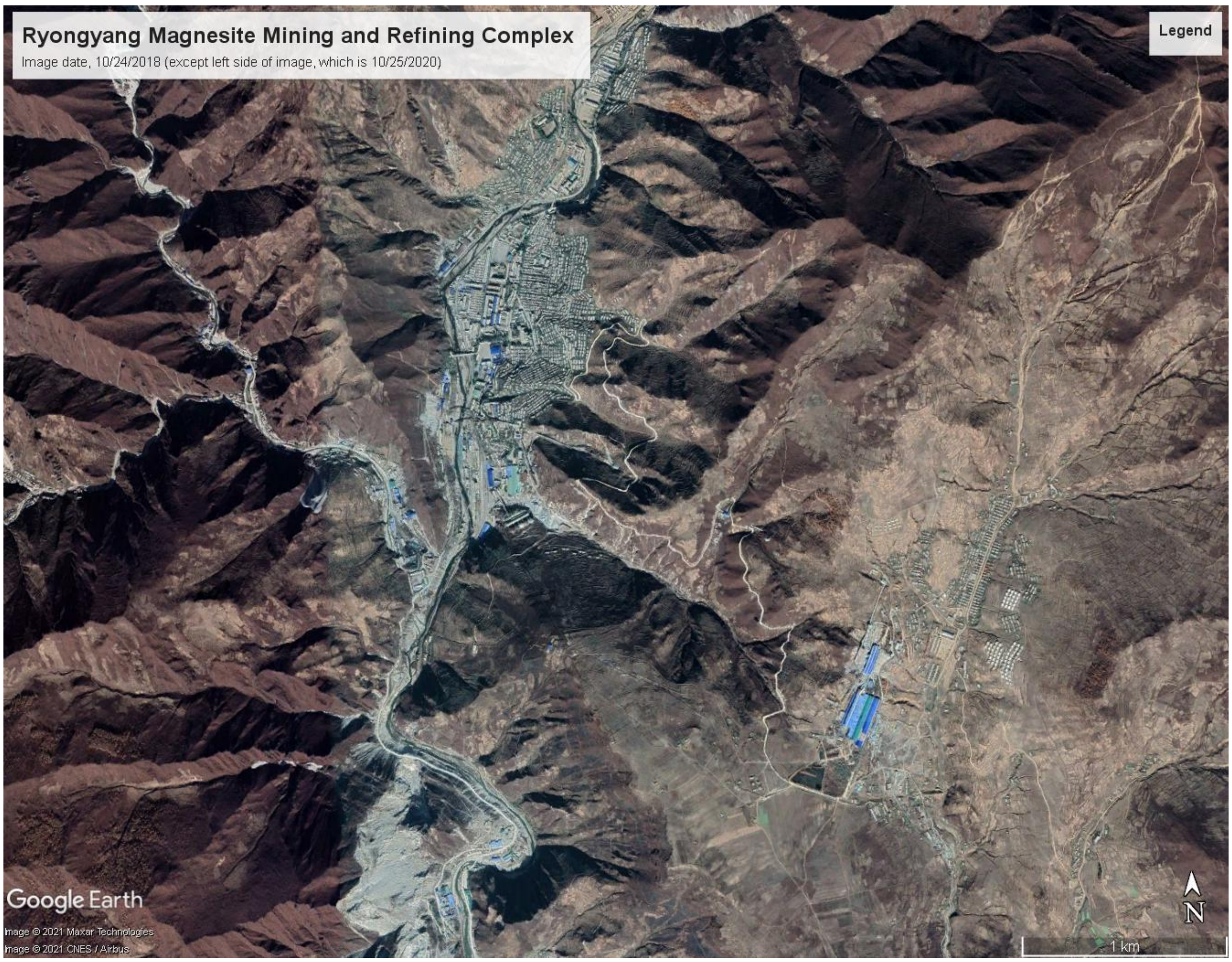
[764] MSN Encarta, previously available as http://encarta.msn.com/encyclopedia_761555092_2/North_Korea.html.

[765] Another source describes three major mines in South Hamgyung Province, one open-pit—with a capacity of 1.3 million tonnes/yr, and two underground, with combined capacity of 1.3 million tonnes/yr ("MAGNESIUM COMPOUNDS", by Deborah A. Kramer, *U.S. GEOLOGICAL SURVEY MINERALS YEARBOOK—2003*, pages 47.1 – 47.5, available as http://minerals.usgs.gov/minerals/pubs/commodity/magnesium/mgcommyb03.pdf). Professor Li Dunqiu describes the DPRK's reserves of magnesite as being 56 percent of the world's total (Nautilus Institute Policy Forum Online 06-70A: August 23rd, 2006, *DPRK's Reform and Sino-DPRK Economic Cooperation*, available as https://nautilus.org/napsnet/napsnet-policy-forum/dprks-reform-and-sino-dprk-economic-cooperation/).

[766] From document in the author's files [MIN-99].

The Ryongyang mine is operating as a subsidiary of the Korea Magnesia Clinker Industry Group (KMCIG), and this parent company has three mines and three clinker manufacturers with 30,000 employees. In addition, the KMCIG operates four kilns for producing CCM (caustic calcined magnesia) and dead burned magnesia, and its capacity of production is 750,000 tonnes per year. The Ryongyang area (see Figure 7-6) is a mining/refining complex that includes several mines and processing facilities, as well as transport infrastructure and lodging and services for workers. Bermudez and Cha (2019) provide considerable additional detail about infrastructure and activities at the Ryongyang complex.[767]

Figure 7-6: Ryongyang Magnesite Mining Complex (Google Earth Pro, location approximately 40.82, 128.813)



Choi[768] provides the following information about the Dae-Hyeung (Daehung) Magnesite mine:

[767] Joseph Bermudez and Victor Cha (2019), "Mining North Korea: Magnesite Production at Ryongyang Mine", CSIS *Beyond Parallel*, dated August 16, 2019, and available as https://beyondparallel.csis.org/mining-north-korea-magnesite-production-at-ryongyang-mine/.

[768] Choi Kyung Soo (2010), ibid.

- Location: Hamkyungnam-do, Dancheon, DaeHyeung-dong
- History: Redevelopment in 1982
- Reserves: 820 million tonnes
- Ore Grade: MgO 46.77%, SiO_2 0.73%, CaO 0.79%, R_2O_3 0.67%
- Mining method: Open pit and underground (in the winter season)
- Mine production(capacity): 600,000 t/yr
- 90% open pit, 10% underground.
- Mineral processing: Crushing and screening throughput (capacity): 600,000 t/a
- Production in 2006: About 360,000 tonnes of concentrate at a grade of MgO 46.77%
- Infrastructure: Power station, 50 MW, link to Hyeucheun hydroelectric power plant; Railroad, 98 km from mine site to Kimcheck port; Kimcheck port, loading capacity about 800,000 tonnes per year.

Figure 7-7 presents photos of the Daehung mine.

Figure 7-7: Photos of Daehung Magnesite Mine[769]

[769] Photos and information above from presentation by Choi Kyung Soo of the ROK-based North Korea Resources Institute, titled "The Mineral Resources of North Korea", prepared for the 2010 DPRK Energy and Minerals Working Group Meeting. This presentation is available as http://nautilus.org/wp-content/uploads/2011/12/05.-Choi.pptx.

The DPRK possesses significant reserves of graphite (6 million tonnes, as estimated by ROK sources), a form of carbon with a number of industrial uses. A 2006 report from KCNA describes the opening of the Jongchon Natural Graphite Mine, apparently as a joint venture with the ROK.[770] Other important minerals in the DRPK are limestone[771] (with reserves on the order of one hundred billion tonnes), kaolin (used in ceramics), barite, and talc.

7.3. Mining Infrastructure

Infrastructure in mine areas can be classified into three categories: 1) transportation facilities including trucks roads and railways, 2) power facilities for mining and related industrial operations, and 3) metal refining industries including refineries and iron manufacturers. Each of these is discussed below.

7.3.1. Transportation Facilities

7.3.1.1.Railway systems

Most mines are linked with freight railways. Railways are single lines in most areas in the DPRK, although double track railways have been built over the 97 km between Moo-San (iron mine area) and the Choing-Jin refining facilities. Open freight cars have been used for carrying iron ore and other ore materials. The DPRK's railway system is experiencing deterioration in its technology and operational system. Most locomotives are electric-powered, for example, and thus rely on consistent supplies of electricity. Most mining operations cease when sufficient supplies of electricity, typically generated by thermal power plants, are unavailable. Railroad tracks are mostly so old (built in the 1940s and partially replaced in the 1970s) that fatal accidents have occurred annually. Quoting a private source, Yoon (2019) suggests that the railway system and its operating conditions must be improved or replaced within the next few years if transportaton of products from mines in large quantities is to be sustained. As a result of the generally poor condition of the road system, freight trains have become the major means of transportation for iron ore and coal. Most open cars of freight trains are of 60 tonnes capacity for heavyweight cargoes, but some 30 tonnes cars are also used as coal carriers.[772]

7.3.1.2.Road Transport Systems

With regard to facilities for truck transport of mine products, the North Korean roads system identifies roads linking provinces as 1st Class roads. Second Class roads link counties within a province, and 3rd Class road link towns within a county. Most roads used to carry mining products (and inputs) fall into the 2nd or 3rd road Classes. Ore products are sent typically via railway facilities, as previously noted, but some products are not sent via freight trains due to safety or security concerns. Gold and other rare metal ores are therefore carried using heavy trucks, made in the DPRK or imported from Russia, Sweden, and more rarely, China. Thus 2nd, 3rd Class roads should be considered as important infrastructure serving mines. In fact, however, although 1st Class roads have been paved with asphalt since the1990s, 2nd Class roads are not paved with asphalt due to a shortage of asphalt, which must typically be imported from China or

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[770] KCNA, Pyongyang, April 27, 2006, "New Graphite Mine Commissioned". Available as https://kcnawatch.org/newstream/1451884512-588937038/new-graphite-mine-commissioned/.
[771] Limestone is the principal raw material for cement and is a building material in its own right.
[772] Text adapted from Yoon, 2019 (ibid).

Russia. Most 3rd Class roads also are not paved with asphalt, so that operation of trucks on those roads entails higher costs for repair, tires and fuel. For instance, trucks operating on unpaved roads have more than 20% higher maintenance, fuel, and tires expenses, according to a DPRK research centre. In recent years, due to a lack of dollars for operation of heavy truck (for tires and oil and truck components/parts), heavy trucks are being operationed with inappropriate maintenance, contributing to more frequent breakdowns and shortening vehicle life. China and Russia, however, are keen to participate in road construction projects in the DPRK For example, Russian authorities indicated a wish to participate in a DPRK railway development and improvement construction business, and were willing to invest 200 million dollars, according to an article in the *Vladivostok News*, 17th July, 2008.

7.3.1.3.Ports

Key to the export of minerals and mineral products from the DPRK are the port facilities available to handle these materials. Brief summaries of the specifications of the major North Korean ports used to handle minerals and mining products are provided below.

1. **Nampo Port**: Located in Nampo City, this port is the largest port and the most important facility for shipping infrastructure in the DPRK. An estimated 78% of trade cargo and containers are coming to DPRK through the Nampo port.[773] The port plays the role of exporting mineral ores and coal produced from the Pyong-an coalfields, as well as shipping metallic materials refined in the Nampo refinery to China and the ROK. Figure 7-8 shows an image of what appears to be the major coal terminal at Nampo, as of late 2019. The larger of the two ships at the bottom of the image appears to be a “Handymax”-class vessel with a length of about 180 m, and thus a capacity of about 50,000 dwt (deadweight tonnes).[774]

[773] Text in this section also adapted from Yoon, 2019 (ibid). The estimate of Nampo port traffic here and details for other ports below provided to Yoon by a private source.
[774] For a guide on sizes of bulk carrier vessels, see, for example, Septrans (2018), “Bulk Carriers”, available as http://septrans.in/dry-cargo-vessels/.

Figure 7-8: Coal Terminal at Nampo Port (Google Earth Pro Image, dated 11-8-2019)

2. **Najin Port**: Najin port is located in the Na-Jin Sun-bong (also known as Rajin-Sonbong) Free Trade area. The port specializes in importing and exporting bulk oil and mineral ores. Approximately 100,000-ton capacity cargo ships can be handled at this port. The port was modernized in 2013 with support from Chinese and Russian enterprises.[775] According to several 2008 news reports, a development district plan has been approved by Jillin province (China) authorities for development of Najin port to expand Jilin province's exports to Japan and the USA. Another report suggested China wa planning to invest more than 10 million dollars to expand a 54 km highway to link Hoon-Choon and Na-Jin city, and would also support construction to expand Na-Jin port to build the

[775] Information on ports adapted from Yoon, 2019, ibid, from private sources (2018).

port's third and fourth docking areas. Two 2010 publications described a ten-year lease of a pier at Najin Port by China as a mainly commercial, not military, investment.[776]

3. **Chong-Jin Eastern & Western Port**: Chong-Jin (Chongjin) Port is one of the three major ports in the DPRK and is located in Chon-Jin, Shin-am district and Po-hang district. The port is important for iron ore and iron-related products exports. Approximately three 100,000-ton cargo ships can be handled by this port at the same time. The port was modernized in 1984 with support by Russian enterprises[777], and underwent a second modernization in 2001.
4. **Heong-Nam (Hungnam) Port**: This port is a major port and is located in Ham-Huong (Hamhung) City. Mineral products produced in the Hur-Chon and Ham-Nam region are exported via this port. The port was fully modernized in 2008. Loading facilities such as dock cranes and warehouses are in good condition and prepared for use.
5. **Dan-chon (Danchon) Port**: This port is located in Dan-Chon city and is used for exporting Magnesite ore and Zinc ore to overseas and domestic locations. Its capacity to load goods is 300,000 tons/month, expressed as the capacity of the ships that this port can handle.[778]
6. **Hae-Joo (Haeju) Port**: This port is located in Hea-joo (Haeju), Hwang-Hae province. The port plays a significant role in exporting iron ore and steel produced at the Hwang-Hea Iron manufacturer and the Eun-Ryul and Jae-Ryong Iron mines. Its loading facilities were modernized in 1999 with imported dock cranes from Russia and Japan.

Additional information from studies by Lee Sung-woo and based on "Chosun Geographical Manual - Transportation Geography" Pyongyang Educational Publishing House, 1988:[779]

The DPRK has 137 ports (55 ports in North Pyongan province, 27 ports in South Pyongan province, 1 port in North Hwanghae province, and 54 ports in South Hwanghae province) on its west coast and 152 ports (65 ports in North Hamkyong province, 53 ports in South Hamkyong province, and 34 ports in Gangwon province) on its south coast. As shown in Figure 7-9, there are 9 ports (Heungnam, Chungjin, Najin, Wonsan, Sunbong, Nampo, Haeju, and Songrim) that are responsible for international shipping (trade port facilities), and 24 ports that primarily deal with coastal cargos. The remaining small ports are more fishing ports rather than commercial port facilities and are used mainly by fishing boats.[780] In the 1970s and 1980s, the first port modernization period, the Nampo, Chungjin, and Haeju ports were modernized rapidly. From 1990 to 2010, however, the DPRK did not make further investments in the ports except for the Najin port, and therefore many ports are slowly deteriorating. The DPRK received Russian

[776] See, for example, Russell Hsiao (2010), Strategic Implications of China's Access to the Rajin Port", The Jamestown Foundation, dated March 18, 2010, and available as https://jamestown.org/program/strategic-implications-of-chinas-access-to-the-rajin-port/; and *Chosun Ilbo* (2010), "China's Jilin Wins Use of N. Korean Sea Port", dated March 09, 2010, and available as http://english.chosun.com/site/data/html_dir/2010/03/09/2010030900360.html.

[777] Original sources for information on DPRK ports include Kwon, Hyuk-Soo, *Current Situation of DPRK's Coal Mining Sector* Korea Resource Institute, 2000, as well as private sources contacted by E. Yoon.

[778] Yoon (2019), ibid, citing private sources.

[779] Original source, Lee, Sung-Woo *Development Direction of North Port for Integration and Expansion of Korean Logistics,* KDI (Korea Development Institute) North Korea Economy Review, February 2018.

[780] Names for the nine major ports in roman character have been added in Figure 7-9 to the original map with Hangul characters as provided by Lee. Note that the romanization of names of these ports varies in the descriptions provided here, due in part to differences in romanization used by Yoon versus that of other sources.

investment in Najin Port after 2010, renovated part of Nampo Port, and modernized the Dancheon Port in 2012 as an international shipping port. Since then, there has been little or no attempts at further modernization of the ports.

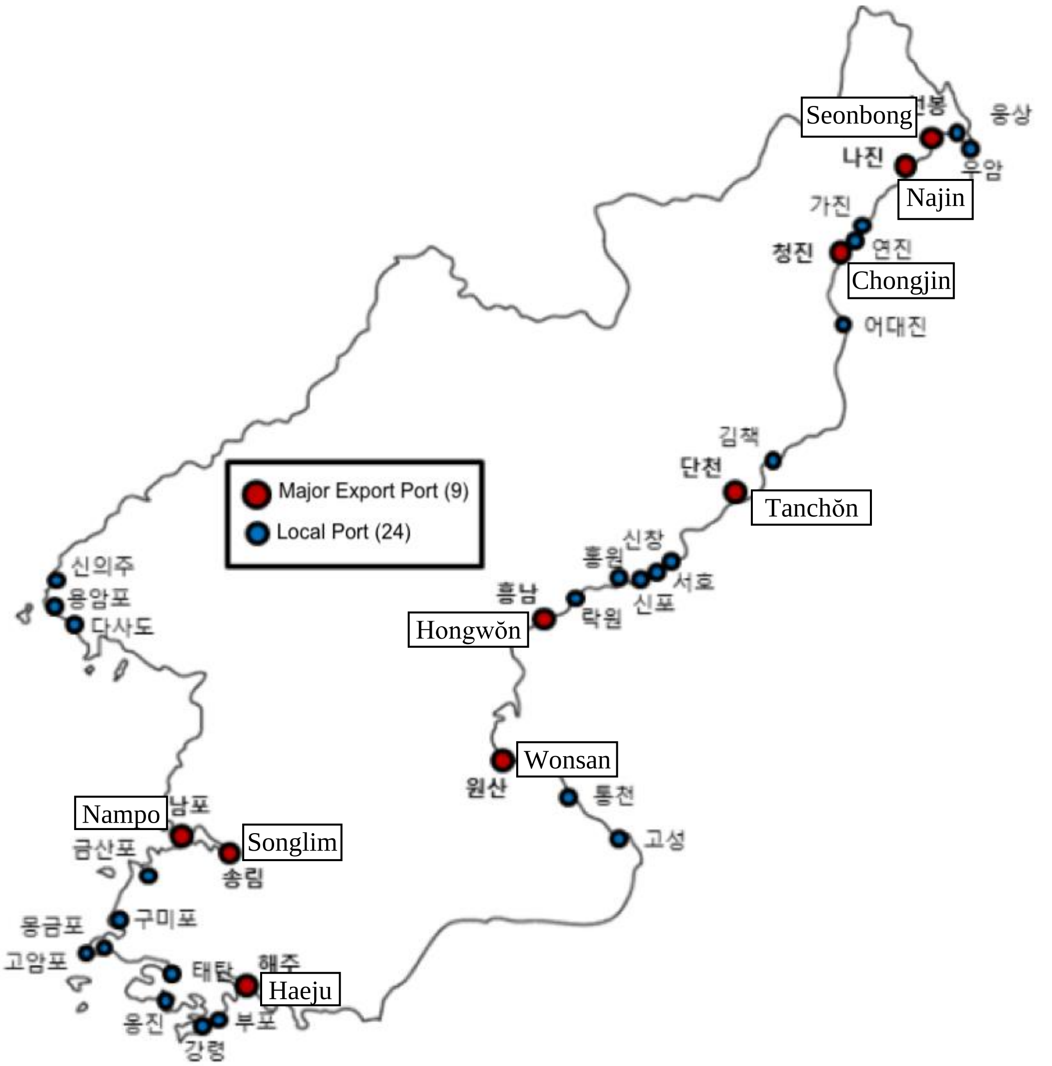
Depending on the literature source consulted, there are discrepancies in the documentations of the current status of North Korean port facilities. The document *Chosun Geography Book* (1988). released by the DPRK and *State of North Korean Port Facilities* (2018), released by the ROK Oceanic and Fisheries Development Institute are believed to include the most accurate data. There are some similarities and differences between the two documents. Since 1988, there have not been many changes in the North Korean ports other than minor changes in the Nampo, Haeju, Danchun, Chungjin and Najin ports described above.

Comparison of the Current Status of the North Korean Port Facilities (Reference 1988/2018)

According to the Marine Traffic statistics, nine trade ports: Nampo, Songrim, Haeju, Sunbong, Najin, Chungjin, Danchun, Heungnam, and Wonsan ports, handle the most cargo in North Korea. 40 ships from Nampo, 31 ships from Wonsan, and 23 ships from Najin were found to have been entering and leaving the port during the two years from January 2015 to January 2017.[781]

[781] Lee (2018), ibid.

Figure 7-9: Location of Major Export and Local Ports in North Korea[782]



7.3.2. Power Facilities

7.3.2.1. Major Thermal Power Plants

The connection between power plants and the minerals and coal mining industries is crucial for mining operations in the DPRK. All industries rely on power plants that were built in major cities or major industrial areas. More than 60 percent of the DPRK's electricity needs for the mining and minerals industries in recent years have been supplied by five major thermal power plants fueled with coal and heavy oil. These are the Chongjin and Danchon thermal power plants (Ham-Kyung province), the Buk (or Book, or Puk)-Chang and Hamhuong thermal power plants, the Pyongyang thermal power plant, the Chongcheon Gang thermal power plant, and the

[782] Source: Lee Sung-woo (2018), *North Korea Economic Review*, KDI, March 2018.

Nampo thermoelectric power plant (Pyong-An province). For example, the Chongjin power plant supplies electricity to the Moo-San (Musan) mine and the Kim-Chaek Iron manufacturer group, and the Buk-Chang power plant supplies electricity to the Pyong-An coalfields and to major Pyong-An metals refineries. The annual electricity production capacities of each power plant are sufficient to supply its client companies, but the power plants often fail to produce enough power due to a shortage of coal and heavy oil. As with other types of entities in the DPRK, power is allocated to mines based on their designated importance, with "express" or "first class" facilities receiving relatively regular supplies, and other facilities sometimes receiving little power from the grid. A confidential source reports that grid power costs for mines averaged about $0.13 per kWh as of 2019.

7.3.2.2.Private Power Supplies and Microgrids

As a result of power deficits resulting, in recent years, in perhaps only 40 percent of mining electricity demand being actually supplied by the central grid,[783] some DPRK mining operations, particularly those involving Chinese or other foreign investors, have been turning to providing their own power supplies. On-site power in mining operations, which may be present in on the order of a fifth of DPRK mines, involves the use of diesel power generators (mostly, like those described in 5.2.3.2 of this report, imported from China) or, more recently, coal-fired gasification generators imported from China (see Figure 7-10).[784] In some locations, where local hydraulic resoruces are avaialble, mini- or micro-hydro systems may provide some or all of the power used on a private mine grid network.

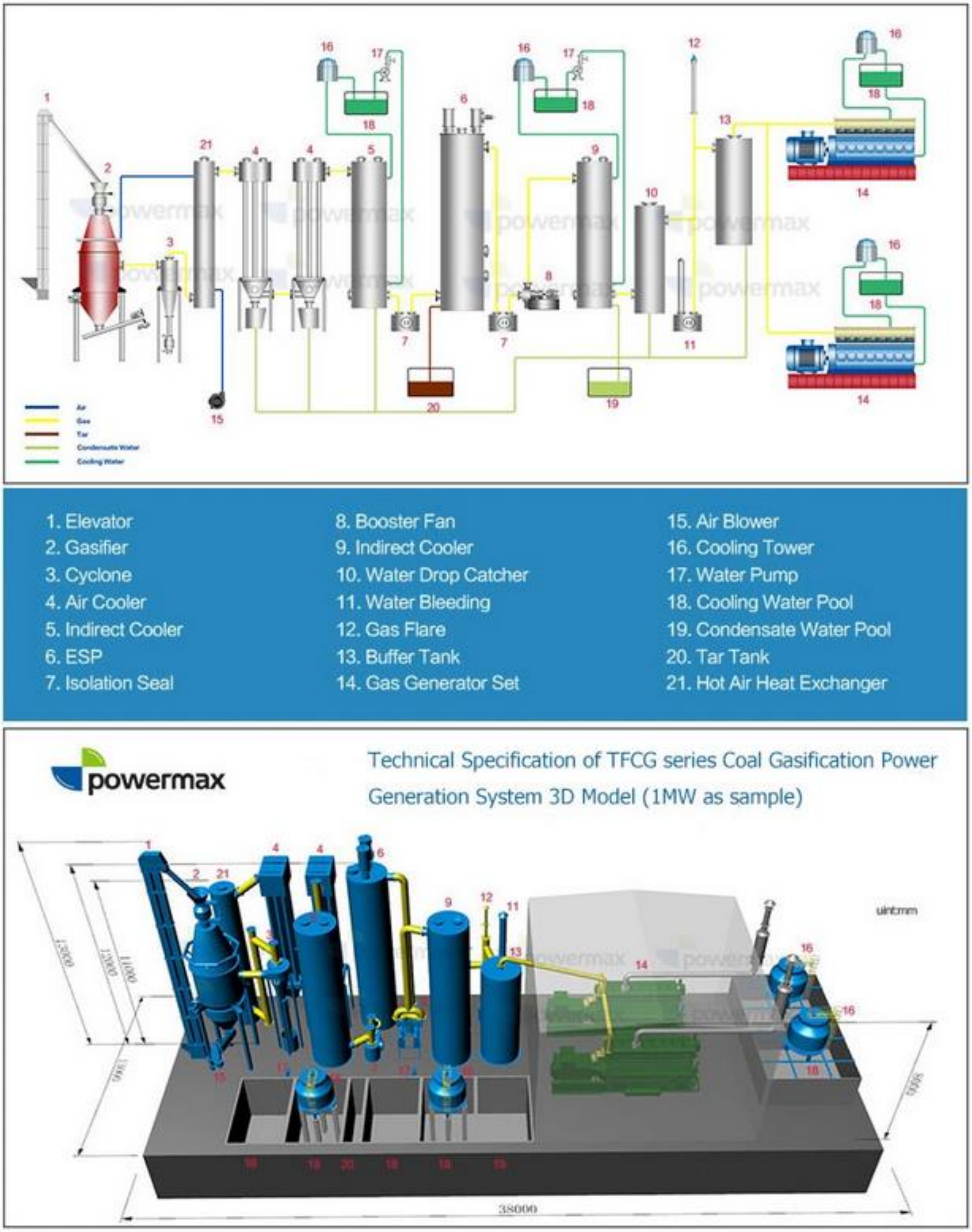
Most of the mines in the DPRK that use on-site power are small-to-medium-sized mines generating hard currency income by selling products such as gold, copper, graphite and molybdenum abroad, and are thus able to afford to purchase power systems. Mines with their own power sources typically have their own microgrid distributing power for mining processs, offices, barracks/living quarters, and sometimes to nearby parts of host communities. In some mines near the Chinese border, DPRK mines run with Chinese investors and managers obtain power via cross-border supplies from China.

As described in Chapter 10 of this report, the provision of microgrids for DPRK mines, and perhaps microgrids powered wholly or in part by renewable energy (solar, wind, and/or hydro), may ultimately be a very attractive (and economically sustainable) engagement option to offer the DPRK in talks to address DPRK nuclear weapons issues.

[783] Confidential source, 2020.

[784] Figure from "Coal Gasification Power Generation Plant", a listing in Alibaba.com at https://www.alibaba.com/product-detail/Coal-Gasification-Power-Generation-Plant_1703514696.html?spm=a2700.galleryofferlist.normal_offer.d_title.6447e3c7k1YVbc. As of this writing (December 2020) this listing offered gasifier generation systems ranging in size from 50 kW to 1.2 MW, with the capital equipment costs for the larger size probably in the vicinity of $700 per kW, and therefore more expensive than diesel-fueled generators, which might cost only a tenth as much to purchase (see, for example, https://www.alibaba.com/product-detail/heavy-duty-generators-1250kva-stand-by_62011572215.html?spm=a2700.galleryofferlist.normal_offer.d_title.41bc3ef21BhzR6), but would be much more expensive to fuel (and for which fuel would be more difficult to get in the DPRK) than the coal-fired systems.

Figure 7-10: Example of Chinese Coal Gasification Electricity Generation System



7.3.3. Metals/Minerals Refining Facilities

Some of the more important metals and minerals refining facilities in the DPRK are listed below.[785]

Moon-Pyong Metals/Minerals Refinery

Most of the DPRK's zinc and lead ore is smelted at Moon-Pyong (or Munpyong) Smelting Factory, which is located in Moon-Chon (Munchon) City, Kang-Won province. The annual production capacity of this smelter is: Pb: 35,000 tonnes, zinc:110,000 tonnes, gold: 600 kg, silver: 40 tonnes, tin: 115 tonnes, antimony: 100 tonnes, cadmium: 450 tonnes, sulfuric acid: 240,000 tonnes, and superphosphate of lime: 200,000 tonnes. This facility is mentioned in two 1950s CIA documents, including one (from 1951) that notes that the smelter was founded in 1936 by a Japanese industrialist, and operated before World War Two (WWII), starting in 1938, producing silver, gold, copper, and lead, refined from ore from nearby mines, but produced lead during the WWII.[786] Figure 7-11 shows a large industrial facility that we believe is probably this smelter, as it include two large stacks, numerous factory buildings, a set of what appear to be administration buildings (lower middle of image) around a courtyard with what appears to be a commemorative obelisk in the center, several impoundments that look like waste settling ponds (lower middle/left of image), piles of coal and spoil (and in images taken at other times, what appear to be piles of ore), rail line access, an electrical substation, and access to shipping facilities. Some buildings with new roofs are evident on the site, which as a whole is centered at approximately coordinates 39.257, 127.256. The 1951 CIA document lists the coordinates (when converted into digital form) as 39.233, 127.367, which would be somewhat to the South of the existing facility. This difference could either be due to a rounding error or the smelter may have been moved, as there does appear to be a smaller industrial facility near the CIA coordinates that looks abandoned. A more recent USGS document lists the Munpyong refinery close to the coordinates we have identified, and as being under the authority of the Korea Zinc Industrial Group.[787]

Based on the 1954 CIA document (see footnote 786), the Munpyong refinery was the only one of the three major metals refineries extant as of that time that was not badly damaged by bombing during the Korean War.

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[785] Text adapted from Yoon (2019), ibid.

[786] U.S. Central Intelligence Agency (CIA, 1951), *Munp'yong Refinery*, dated 28 September 1951, and available (partially redacted) as https://www.cia.gov/readingroom/docs/CIA-RDP82-00457R008300670001-0.pdf; and U.S. Central Intelligence Agency (CIA, 1954), *Intelligence Memorandum: Reconstruction in North Korea* dated 26 July, 1954, and available as https://www.cia.gov/readingroom/docs/CIA-RDP79T00935A000200370001-2.pdf.

[787] United States Geological Survey (2010), "Table1.—Attribute data for the map "Mineral Facilities of Asia and the Pacific," 2007 (Open-File Report 2010-1254).", available as https://pubs.usgs.gov/of/2010/1254/pdf/USGS_ofr2010_1254_table.pdf.

Figure 7-11: Possible Location of Munpyong Smelting Factory as of 4-12-2020 (Google Earth Pro Image)

Nam-Po Metals/Minerals Refinery

The Nam-Po (Nampo) refinery is one of the major gold refineries in the DPRK, but the use of the refinery facilities for gold production has been hidden from the public. The refinery has capacity to produce 2 tonnes of gold and 15 tonnes of silver annually. The refinery at Nampo is also quite old, having been built in the 1940s and modified in the 1970s, thus its infrastructure and production systems are not only inefficient, they are also not environmentally friendly.[788] The area where the facilites are located (Nampo City) is polluted by heavy metal wastes from the refinery, and an unknown number of patients have reported health problems, in particular dental problem and skin diseases.

As one of the largest smelters in the DPRK, the Nampo Refinery Group also produce non-ferrous metal products. The annual production capacity of the refinery is: electrolytic copper: 414,000 tonnes (99.97%), electronic zinc: 45,000 tonnes, tin: 200 tonnes, gold: 500 kg, copper cable: 10,000 tonnes, and superphosphate of lime: 200,000 tonnes.

In order to operate its electric furnaces, the power requierments of this refinery are supplied by the Buk-Chang (Pukchang) and Pyongyang thermal power plants, for which the refinery is a major consumer.

[788] Yoon (2011), ibid, citing Kim, Young Yoon (2007), "DPRK's Mineral production systems and future", Korea Reunification Institute; Chung, Woo-Jin (2007), "Strategic Cooperation Plans and Current situation in Development of South and North Korea", Korea Energy Economics Institute; and private sources, 2010.

Heong-Nam (Hungnam) Refinery:

This refinery is located in near Ham-Heong (Hamhung) City and produces copper, gold, and rare earth materials using mineral ores supplied from the Hye-San and Dan-chon mines.

Hae-Joo Refinery:

This plant is located in Hae-Joo (Haeju). Its main products are gold, copper, tungsten, and rare earth materials using ore mined in Hwang-Hea province. These facilities have the potential to be used to extract gold and copper for export via Hae-Joo port as a part of a foreign investment.in the DPRK mining sector.Figure 7-12 shows a Google Earth Pro image, as of early 2018, of the possible location of the Haeju mineral refinery, showing a number of updated roofs and other changes in recent years (coordinates, approximatly 38.029, 125.666).

One confusing aspect of historical images of this facility, however, is that the most recent (2018 and 2019) images appear to show the blue roofing that was applied to many buildingsand other equipment (such as the roofs of conveyor belts) in approximately 2017 being removed again. This leads us to wonder whether UNSC sanctions caused plans to reopen or increase output at the facility to have been scuttled, prompting the salvaging of roofing materials for use elsewhere. This is pure conjecture on our part, but could be investigated further with access to a series of more frequent historical satellite photos than were available to use through Google Earth Pro.

Figure 7-12: Possible Location of Haeju Minerals Refinery (as of 3-18-2018)

The 7.27 Gold Refinery:

A third major gold ore refinery in North Korea is the 7.27 Refinery (Heong-Nam 2 refinery). The 7.27 Refinery is located in Ham-Heong (Hamhung) City, and was established in 1983 as a subsidiary of the People's Army Department. Its annual production capacities are gold, 1 tonne, and silver 10 tonnes, respectively.

7.3.4. Mining Machinery Manufacturers

Another key category of infrastructure related to the DPRK mining industry is the supply chain for equipment used in mining. Table 7-9 provides information about manufacturers of key mining machinery, and Table 7-10 lists key manufacturers of equipment specific to coal mining and transport.

Table 7-9: Major Mining Machinery Manufacturers in the DPRK

Name	Size	Products	Notes
Nack-Won Machine Manufacturer	Site: 93,000 m^2 employees: 4,500 1st class firm	Oil pressure (hydraulic) excavators	Specialized in Excavator production
Koo-Sung Mining Machinery Manufacturer	Site: 27,000 m^2: employees: 5,000	Drillers, lorries, crushers, pumps	Built in 1957
Dan-chon Mining Machinery manufacturer	Site: 10,000 m^2 employees: 2,000	Lorries, crushers, polishers, pumps	Also called the 4.28 factory
Sariwon Mining Machinery Manufacturer	Site: 43,000 m^2 employees: 2,500	pumps, conveyors, belts, compressors, winches	
Shin-Ui Joo Mining Machinery Manufacturer	Employees: 1,500	High-speed excavators, rock drillers	Also called the 8.9 factory

Table 7-10: Coal Mining Machinery Manufacturers in the DPRK[789]

Province	Name of Manufacturer	Products	Size
Ham-Gyung Buk province	Hei-Ryong Coal mining Machinery Manufacturer	Coal carrier car production, iron supports, compressors, cranes, machinery parts, crushers, comprehensive drillers	29,000 m^2 2,500 employees 1st class company
Ham-Buk Province	Na-Nam Coal mining machinery Manufacturer	Various coal mining drills, carrier cars, cranes, safety equipment production	1st class enterprise (3,000 employees)
Pyong-Yang City	Pyong-Yang coal mining machinery manufacturer	Supports, hydraulic machinery, hydraulic coal mining machines, pumps, conveyors, rock drills	1st class company 64,000 m^2 35,000 employees
Pyong-An province	Duck-Chon Coal mining machinery Manufacturer	Coal lorries, coal drills, pressure horse winches, belts, reduction gears	1st class firm 50,000 m^2 4,000 employees
Hwang-Hea province	Jae-Ryong coal mining machinery manufacturer	coal lorries, coal drills, pressure hoses winches, belts, reduction gears, air chargers, mine buses	2nd class firm, 1,600 employees, 31,000 m^2

7.4. Policies, Organizations and Human Resources Involved in the DPRK Minerals Sector

Brief summaries are provided below for North Korean mining industry policies and mining-related organizations, as well as the organizations in charge of minerals exploitation in the DPRK, development of technology related to geological exploration, and the educational system for mining and minerals-related occupations.

[789] Original Source: *DPRK's Industries*, Korea Industry Bank (ROK), 2002,

7.4.1. North Korean Mining Industry Policy and Related Organizations

Mining Policy

The mining industry has been a top priority industry for the DPRK government since the 1970s, exceeding other industries in importance because of its key role in providing sufficient materials and energy sources for the DPRK. For successful development of the mining industry, the DPRK has established three major policies: first, strengthening geological exploration to promote new coal and minerals mine development; second, promoting technological development in the excavating of underground tunnels and in ore collection procedures; and finally, scientific research in digging equipment and exploration. Another major principle in the DPRK mining industry is the self-supporting and self-sufficiency policy. This policy has been interpreted such that most mineral resources produced domestically are to be used for domestic purposes. As a result, the domestic supply rate for minerals resources in the DPRK is very high compared to the DPRK's historical imports of mineral resources. For example, the DPRK is 100 percent self-sufficient in iron ore, pig iron, partially-finished steel products, copper, cement and graphite.

In spite of this self-sufficiency policy, North Korean authorities have since the 1990s been pursuing opportunities for minerals exports to earn hard currency, according to KORTRA (ROK) data. In fact, resource development in DPRK has also been closely related to the needs of North Korea's munitions industry; for example, copper, uranium and iron mines exploitation have been developed substantially to meet military equipment and weaopns needs.

Natural Resource Law in the DPRK

According to this law (Section, 21 of *DPRK Published Laws*, 2003), the North Korean cabinet is in charge of the exploration, exploitation, and use of minerals, with several organs of consultation involved in the approval of exploration, development and standards for minerals deposit estimation by geologic exploration institutions. Section 40 of the law indicates that an organization or individual company should acquire a permit from a government body when the organization plans to export precious metals or iron ore overseas, and section 51 indicates that in case of any breach in the law, the company or organization should be punished. Section 46 indicates that any skilled labor or engineer, equipment, materials, or funds related to the mineral exploration industry may not be used for other industrial purposes. In particular, section 17 emphasizes that any existing mine or coal mine cannot be closed (abandoned mine issues) without permission from the government consulting body.

Mining Industry-related Organizations

The DPRK mining industry is essentially under the control of the Labor Party and the Cabinet at the same time, but the Party's power dominates the Cabinet's role in the DPRK. As part of the Geological Exploration Institute system, the DPRK established in 1995 the Central Mineral Resource Institute in Pyong-Sung, which is a scientific city and part of the Pyongyang capital city. This Central Institute controls all geological organizations and institutes of the DPRK, including the Hamhung and Pyongyang Exploration Institutes.[790]

DPRK commercial organizations involved in trading and development of mineral resources include the Cho-sun General Mining Trading group, the Chosun Magnesite Clinker trading

[790] Based on reports from *Chosun News*, 26 January 2002, and other sources reviewed by E. Yoon.

group, the Myong-Ji group, the Dae-Sung Trading Company, the Chosun Baek-Gumsan Trading Company, and the Chosun Maebong-san Trading Company, as well as others. These organizations are described briefly below.[791]

- Chosun General Mining Trading Group

The company is located in Joong District, Pyongyang City. Its primary business is to trade nonmetallic minerals. It has 10 subsidiaries in 10 major cities throughout the DRPK, and two branch offices. Zinc, copper-related products, and silver are the major export items handled by the company, in addition to nonmetallic refinery-related equipment and facilities, tin, antimony, aluminum cable and bar, coated wire, and other products.

- Chosun Magnesite Clinker Trading Enterprise

The major trading items of this company are magnesite clinker, magnesite ore, magnesite brick and diatomite for export. The company also imports coking coal, chrome steel, mining equipment and machinery.

- Myong-Ji Corporation

This company was called Samchonri Group, but changed its name. Zinc and heating coils are its major export items.

- Kang-Sung Trading Company

This company operates under the North Korean People's Army

- Chosun DaiJin Trading Company

This company is located in Pyong-Yang and is controlled by the 39 Room (also sometimest translated as "Office" or "Department") of the Labor Party. Its focus is on trading to obtain hard currency, and it specializes in exporting coal and mineral ore overseas and in importing commodities and electric goods from Hong-Kong, Macau and China for Chairman Kim Jong Un's family and others.

- Cho-sun Natural Resources Trading Company

This is a newly established company focusing on international cooperation projects in the natural resources area.

- Other Companies

The Chosun-Daesung Group, the Chosun DongHeong Trading Company, the Chosun Baekgumsan Trading Company, and the Chosun Maebong Company are major and exporters raw mineral resources to overseas buyers, and importers of machinery and equipment from overseas.[792]

[791] As described by Yoon (2019), ibid, citing private sources, 2018.
[792] Original source cited by E. Yoon, Lee, Hea-Jung Development of Mineral Resources of DPRK, Hyun-Dai [Hyundai] Economic Research Institute, 2008.

7.4.2. Sysetm for Authorization of Mineral Resource Exploitation

In cases of independent development of mineral resources, the National Underground Resource Development Committee is in charge of providing permission for mining activities through the Ministry of Gathering Industry and the Ministry of Electricity & Coal Industry. Once permission is granted, an individual mine or company would be able to commence the development process. In this step, foreign investors could be involved in the process by contracting with an individual mine or company. In other words, once overseas investors invest by purchasing facilities and equipment for mining, the investors can bring out of the country a contracted amount of produced ore or refined products, which they can offer for sale.

With regard to mining operations and development, skilled workers and engineers are responsible for management and engineering affairs in mines and minerals-related companies, and military servicemen and skilled workers are responsible for the required labor. The mineral ores produced are then sold by the independent mining company to overseas buyers for dollars (or Euros, Yuan, or other hard currencies), or to domestic clients.

7.4.3. The DPRK's Geological Technology Development

Geological technologies for minerals exploration have been developed in the DPRK since the 1990s. There are two major elements of geological exploration. The first is geological technology, and the second is earth physics exploration technology. According to a technical and geological magazine published in the DPRK, there are 10 major technology development needs facing the DPRK mining industry, namely (1) new explorathon methods to look deep into the earth's crust, (2) computer controlled drilling under GPS (global positioning system) guidance, (3) development of new earth physical exploration methods for depths up on 2,500 meters, such as 3-dimensional elastic wave exploration, (4) satellite-controlled exploration methods development (for coal, gold, geothermal heat, natural gas, and underground water prospecting, for example), (5) far-infrared radiation controlled exploration, (6) bio-earth physics exploration, (7) electrical exploration development, (8) tomography technology for finding coal and colored metals (such as gold or copper), and (9) advanced chemical exploration methods development. These technologies are related to Earth Physics exploration methods.

7.4.4. An Analysis of the Educational System for Mining-related Occupations

The DPRK maintains a three-level higher-educational system for mining-related occupations. The first level is central government-controlled universities, the second level is local government-controlled colleges, and the third level is enterprise- or company group-controlled colleges used as occupational skill schools. The Mining and Metals and Nonmetallic engineering-related educational system in the DPRK has been well established for development of the industries in comparison with the treatment of these discriplines in the ROK and Chinese educational systems—for example, there is only one Earth Physics Exploration course in South Korean Universities.

University Curricula

With regard to the curricula and quality of education in fields related to mining and minerals, the technology and equipment used for training in the Universities are mostly from Russia or China, and more rarely from Japan. In Yoon's view,[793] the quality of education on these topics in the DPRK is competitive with that offered South Korean students**,** but needs additional support to reach USA or European standards. The situation in each of the three levels of education in mining-related topics is described below.

Universities Controlled by the Central Government

There are five major Universities with courses in areas of mining and metals, geological exploration, and Earth physics exploration: Kim Il Sung University, Kim-Chaek Engineering University, Chong-Jin Mine and Metal University, Pyong-Sung Coal Mining Engineering University and Sari-won Geology University.

- **Kim-ll-Sung University** is located in Pyongyang. It has 12,000 students, including 600 students in the geology exploration course. The university has three courses, Geology Exploration, Earth Physics Exploration and Earth Chemical Exploration. In order to graduate from the university, students must attend five years of courses including at least one year spent doing a practicum in their field . Students in these courses learn English and Russian (most students learn English since about 2000). Graduates of this university are dispatched by the University to geology-related exploration companies and research institutes throughout the DPRK. The graduates have no opportunity try to find jobs that they favor as individuals, rather they are obliged to follow the orders of authorities because their university have studieswere supported by the government, which paid for their school fees and dormitory costs, including clothes and food. The graduates are classified into three categories: those destined to work as Labor Party officials, those who will work as government cabinet officials (in Ministries, for example), and those who will work as exploration company experts or in research institutes. The classification of the graduates is done by the Education Department of the Central Labor Party. Graduates are granted Bachelor degrees in their mining or minerals course and become official experts of their industry. For example. If a student graduates from the Geology Engineering course in this university, she/he will be entitled as a Geology Expert with a Bachelor's degree of Geology Exploration.
- **Kim-Chaek University** is aksi located in Pyongyang. It has 10,000 students including 1,800 students of Geology Exploration, Mining Engineering, Metal and Nonmetallic Engineering courses. The university has six related courses, Geology Exploration, Earth Physics Exploration, Earth Chemical Exploration, Metal and Nonmetallic Engineering and Colored Metal Engineering, Refinery Engineering and Iron engineering, and Material Analytics courses. In order to graduate from the university, students must attend a five-year course including one year at least for practicum. Students at Kim-Chaek also learn English and Russian, with English the language of choice since about 2000. Graduates of this university are dispatched to geology related exploration companies and research institutes, mines, Iron manufacturing companies, and refineries throughout the DPRK. The graduates are classified into three categories by Central Labor Party officials as described above. If a student graduates from the mining engineering course in this university, she/he will be entitled as a mining engineer with a Bachelor's degree in Mining Engineering.

[793] Yoon (2011), ibid.

- **The Chong-Jing Mines and Metals University** is located in Chongjin, Ham-gyung Province. This university was established in 1959 to support the Moo-san (Musan) mine, the Kim-Chaek iron manufacturing group, and other coal mines with personnel trained in engineering, management, and exploration work. This university has 6,000 students. There are 20 courses related to mining, iron making and management of refinery companies. A selection of these are as follows. The geological exploration courses are the Underground Water Exploration Course, the Drilling Engineering Course, and the Earth Physics Exploration Course. In Geology Engineering School, mining-related courses are:Mining Engineering, Coal Mining Engineering, the Mine Management Course, and the Mining Analytics Course. The university ofers two mining mechanical equipment courses: Mining Mechanic Engineering, and Coal Mechanic Engineering. In order to graduate from the university students must fulfill the same requirements listed for the universities above, and are similarly dispatched to geology-related exploration companies and research institutes, mines, iron manufacturing companies and metals refineries throughout the DPRK by decisions made by the Education Department of the Central Labor Party.

- **Sariwon Geology University** is located in Sariwon (Hwang Hae province) to support minerals and coal mining in the province. The University has five exploration courses including Earth Chemical Exploration, Earth Physics Exploration, Drilling, Underwater Exploration, and Analytics. Graduates become geology engineers and are sent to exploration companies and to be university teachers for colleges. Other arrangements as to graduation and certification of graduates are similar to those of the universities described above. This university has 3,000 students.

- **Pyong-Sung Coal Mining University** is located in Pyong-Sung city and supports coal mining engineering in Pyongan and Hwang-hae provinces. The University offers 10 major coal mining-related courses, including: Coal Mining Engineering, Coal Exploration, Coal Mining Mechanics and Analytics, as well as management courses. Most graduates are dispatched to coal mining and exploration companies as engineers. Other conditions for graduation from the University are similar to those of Chong-Jin Mines and Metals University. This university has 4,000 students.

Colleges Controlled by Local Governments

Each province has a mining engineering college and a exploration engineering college. College students take 3-year courses in their majors. All financial support for school fees, dormitory costs, food, and clothes are provided by the government. Graduating students are dispatched to local mines, coal mines, and exploration companies as junior engineers. Students must finish a university course of two years or more, following their training at the provincial level, if they wish to be engineers in their industry. The dispatching of graduates to their positions is carried out by the local government department for human resources. Each college has 700-800 students in every province. For example, the Danchon Exploration College has 800 students and has three courses: Geologic Exploration, Drilling, and Underground Water Exploration. After graduation from this college, graduates are granted positions as junior engineers and are dispatched to exploration companies in Ham-gyung province. Their wages are typically 70 to 80 percent of those of engineers graduating from universities.

Colleges Controlled by Enterprise Groups

The college system controlled by enterprise groups is built upon an educational scheme first established during the 1970s. Large enterprise groups such as the Kim-Chaek Iron Manufacturing Group or the Moo-san (Musan) Mining Group operate colleges called “Factory Colleges”. College students study after work from 7 pm to 9 pm twice or three times per week in these colleges to obtain more advanced skills and knowledge. Education in these colleges provides good opportunities for promotion or professional development within the company or organization, but the courses taken in these colleges are not recognized by other companies or organizations. These college’s curicula are different than those of other universities and colleges, but are worthwhile students in that they provide applicable work skills for their jobs. For example, if a worker in mining company studies in a factory college, she/he would be granted an increase in job level from 3 to 4, and the next year, would receive an increase from level 4 to 5, accompanied by a promotion and an increase in wages. It is estimated that there are 100 “factory colleges” throughout the DPRK, with an estimated current enrollment of more than 100,000 students.

7.5. Conclusions and Strategies for Overseas Investors

7.5.1. The Most Fruitful Areas for Foreign Investment in the DPRK Minerals Sectors

The most fruitful areas for foreign investment in the DPRK minerals sector are as described below.

(1) The iron mines in the Moo-San and Eun-Ryul areas have great potential to produce significant benefits for overseas investors due to the fact that the DPRK’s biggest iron manufacturers, the Kim-Chaek and Hwang-Hae corporations, could be used to process iron from those mines, and the steel and pig iron products could be exported to provide return on investment with low costs for transportation.

(2) Gold and copper mines could be beneficial investment projects offering low transportation expenses. In recent years, as described above, DPRK authorities have proposed that overseas funds be provided to invest in gold mines and copper mines. In fact, newly explored and developed mines such as the Sang-Nong, Gap-San and Shin-pa copper mines may be great opportunities for overseas investors.[794]

(3) Another possible mine for investment is the Dan-Chon Magnesite Mine, which could be developed to export product to China and the USA. In this case, it should be possible to cooperate with the authorities for a “win-win” strategic investment. According to private sources,[795] a DPRK company has made a deal with a Chinese trading company for the export of Caustic calcined Magnesia (MgO 90%, CaO 2.5%, SiO_2 2.5%, Fe_2O 1.05 %, LOI 3.5%, Size; 200 mesh 95%). In this deal, the selling price of the material FOB Heong-Nam port was US$ 88.0 per metric tonne.

[794] Hwang, Jung-Nam (1999), *Strategy and Current Situation of Cooperation of Mineral Sector between South- North Koreas*, Korea Energy Economy Institute.
[795] As cited by Yoon, (2011), ibid.

(4) Mining of limestone ore is another possible application of overseas investments, coupled with construction of cement factories in the DPRK and export of cement product to China and the ROK. In addition, with investments in the cement industry, overseas funds could be involved in SOC (State-owned Corporations) in the DPRK, as well as North Korean calcium fertilizer industries, which can provide products key to helping DPRK agriculture to be more productive.

(5) The coal mining industry could be an alternative investment for foreign investors, as the DPRK needs to increase production of coal as a required energy source to drive the country's economic engine. In this industry, exploration and development of new coal mines would bring significant benefits to overseas investors.

(6) Investing in zinc ore mines such as the Gum-dok, Hye-san and Ruck-Yon mines has potential for investors due to the fact that the DPRK has sufficient existing industrial capacity to refine the zinc ore, and thus zinc metal could be exported, providing a good return on investment.

(7) Tungsten mines could be alternative destination for investment due to the high price tungsten fetches in the international market, its low transportation expenses, and huge deposits of tungsten ore exist at the Man-Nyun mine, which is currently being further developed and expanded.

(8) New exploitation of deposits of rare-earth elements such as titanium, indium, and cerium are another area in which the DPRK's natural resources could be developed. Rare–earth element production has in recent years been dominated by Chinese mines, which have 30% of global deposits, but account for 97% of global production.[796] The DPRK is known to have reserves of these materials in the Gyung-Sung and Hur-Chon areas. In particular, the Saen-gi-ryong area in Kyung-sung country is not only abundant in Kaolin, the raw material for ceramics, but also has some indium and cerium elements in abundant wastes rocks from the kaolinite mining process.[797] Due to the DPRK's competitive labor costs relative to costs of Chinese labor, development of DPRK rare-earth resources for export would yield significant benefits.

7.5.2. Obstacles to Effective Minerals Sector Development through Foreign Investment, and Solutions to Overcome Obstacles

Key obstacles to effective minerals development in the DPRK with funds from overseas investors include 1) the shortage or lack of adequate and consistent constant supplies of oil and coal for energy in the DPRK; 2) the fact that the DPRK lags behind other nations in technologies and operational methods for minerals (due to reliance on old methods), as well as in the use of modern equipment in mining and other minerals sector operational activities; and 3) a shortage of funds for education of engineers and for investment in technologies.

Key solutions to the obstacles above are as follows: 1) stabilizing coal mining operations to supply adequate coal for power plants, and/or promote the deployment of local microgrids, including those using renewable-based power sources, for mines ; 2) attract overseas funds for investment in modernization of mining equipment and related technologies; and 3) provide better

[796] Yoon (2011), ibid, citing *Chosun News*, 22 October.2010.
[797] Yoon (2011), ibid, citing private sources, 2018.

balance in mining business management between production and export operations, thereby providing more of an emphasis on sustainable production and making operations less sensitive (and potentially more reponsive) to swings in export markets.

7.5.3. Infrastructure Investments for Stable Operation of Mining Industries

With the above obstacles and solutions in mind, key infrastructure investments to allow stable operation of mining industries in the DPRK will be:

- Thermal power plants should be stabilized in order to provide reliable sources of power for mining and minerals refining facilities, thus investments in the DPRK's coal mining industry should be carried out as soon as possible as a short-term solution.
- Modernizing minerals processing facilities such as metals refineries and iron manufacturers is necessary for the DPRK to be able to export secondary goods derived from mineral resources, steel, or refined metals at higher prices (relative to raw ores) so that the DPRK can increase its foreign exchange earnings.
- In the longer term, a self-supporting accounting system for the management of mining and minerals refinery industries should be applied and implemented (adopted) in the DPRK. Capacity-building will be needed to train DPRK workers and officials in management techniques consistent with operating self-supporting businesses.

7.5.4. Feasible Strategies for Overseas Investors

Cooperating with South Korean firms would be beneficial for overseas investors in order to assist in enhancing the security of investments in the DPRK minerals sector, and to build relationships with future consumers of mineral products. South Korean firms investment in the mining industry in the DPRK, and Chinese firm's experience in the DPRK in investment in mining trading and mineral resource development represent valuable experience that overseas investors can learn from.[798] South Korean firms are also likely to be willing buyers of minerals products from the DPRK.

Building sustainable relationships with DPRK authorities in mining departments, as well as with other officials, is significant for hedging risks in the uncertain business environments that prevail in the DPRK. First, using the Korean-Chinese business network, for instance, by trading between the DPRK and China via Chinese-Korean community channel, would be beneficial. These Chinese live in the DPRK and have been playing major roles to in the trading business between the two countries since the 1980s. According to private sources, approximately 5,000 Chinese live in the DPRK (with Pyongyang home to about 2,000 Chinese expatriots, and with South Hamgyong province, South Pyongan province, and Ryangang province homes to another 3,000). These Chinese have knowledge of outside news and skills for trading between the two countries, and could play major roles to promote international business for overseas investors. Second, contributing towards the DPRK's social and humanitarian needs (for example, by providing free supplies of basic medicines, milk, childrens' clothes, and food) is an alternative strategy to deal with those focused targets. In fact, DPRK authorities wish to build partner relationship in developing the country's mining sectors. As an example, during a visit by Tony Namkung, an advisor to the governor of the US state of New Mexico, to Pyongyang, DPRK

[798] Yoon (2011), ibid, citing private sources, 2010.

officials suggested foreign investment in DPRK mineral resource development be considered by the USA, in particular, in the Dan-Chon Magnesite mine for mine development and exporting of ore.[799]

7.5.5. Alternative Strategies and Issues for Overseas Investors

Alternative strategies and special issues relating to investment by foreign companies in the DPRK's minerals sector are described below, incluidng possible funding approaches for development of the minerals sector, issues to consider when reviewing investment possibilities, approaches to making investments in the sector, and provision of mining rights issues for foreign investors. A case study of an investment possibility in a Molybdenite mine concludes this section.

Establishing Special-purpose Enterprises (SPEs) for Funding Development of the DPRK Mineral Sector

Due to the large amount of funds needed for investment in this sector, one approach for developing mining businesses would be to establish SPEs and then issue company debentures or bonds to attract large amounts of investment funding. In fact, individual and institutional investors would be interested in this business opportunity due to the fact that the DPRK's mineral sector could generate significant benefits (return on investment) if the US or South Korean government could provide assurance for those investments as, for example, the ROK government has been providing assistance and assurance to Korean companies investing in Kaesong and other joint ventures.[800] According to the South Korean government policy for investing in the DPRK, funding for ventures could be subsidized by the South Korean government on the basis of its contrbution to North-South Korea economic cooperation. This means that more than 50 percent of investment funds could be provided in the form of government assistance. The USA and other governments can also provide such assistance for overseas mineral exploration businesses, assuming that UNSC sanctions on the DPRK are lifted.[801]

Factors to Be Considered When Evaluating Potential Investments

There are five major issues that should be considered when overseas investors are making decisions regarding investment in DPRK's mineral sector: (1) the attributes of the deposit of mineral resource with repespect to its possible development; (2) the quality and cost of available labor; (3) the availability and status of infrastructure needed for mining, such as power plants , railways, roads, and ports; (4) the status of environmental regulations; and (5) the political and economic stability of the country. In the case of the DPRK, in its current situation, (5), (1), and (3) should be improved to allow safe investment in the mineral sector. Based on the experience of South Korean companies, DPRK authorities seem to have principally been considering three factors when overseas investors offer investment possibilities: (1) the scale of the investment, (2) whether the investment will result in the transfer of mining technologies to DPRK, and (3) whether the investment will support infrastructure development.

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[799] See, for example, Michael Ha (2008), "NK Seeks Textile Exports to Wal-Mart", *Korea Times*, dated 5/16/2008, and available as http://www.koreatimes.co.kr/www/news/nation/2008/05/116_24317.html.
[800] Yoon (2011), ibid, citing private source, 2010.
[801] Korean Central Bank (2008), *Comparison of South & North Korean Economies*.

Possible Scenarios for Investment

Contracting for equipment supply in exchange for mineral products is an option that avoids the possible failure of large investments in the DPRK. Due to environmental concerns in developed nations that result in mine closures and a surplus of mining infrastructure, second-hand mining equipment and facilities could be assembled at low cost and exchanged for minerals resources in initial deals with the DPRK then, if the deals proceed as expected, small amounts of funds could be invested in DPRK mining operations in a step-by-step fashion.

In addition, investing in mines already operating and drawing on economic deposits of mineral resources reduces risk. Investing in new mine development requiring an initial exploitation step is a significantly more risky business when compared with investing in existing mines. Investing in existing mines would be an appropriate strategy to reduce the possibility of failure of investments in the DPRK. With regard to difficulties in the DPRK energy sector, which might affect the more than 20 mine development projects for overseas investors that have been identified by DPRK authorities (according to private sources and South Korean sources), energy supplies can be provided if investments in mining projects require energy supply upgrades.

The DPRK has been experiencing a lack of technology and equipment in the mining sector. Thus, overseas investors or companies could offer exploration systems and equipment and engineers as an in-kind investment in the DPRK minerals sector, and new minerals finds or production could be shared between the DPRK and the company providing the technology and expertise.

Mining Rights Issues for Foreign Investors

In cases of cooperation between foreign investors or overseas companies in development or exploitation of DPRK minerals resources, it is very rare that mining rights will be transferred to foreigners who invest in mining technology, equipment, and facilities such as dump trucks and drills. Rather, foreign companies would likely gain only the rights to sell the products produced by the mining operation.

There are a number of reasons why the DPRK has been reluctant to transfer its mining development rights to foreign companies and investors thus far. The first reason is political concern that the authority’s power would be reduced in terms of its power/ability to mobilize workers, that is to control its people, therefore resulting in political risk. Second, the authorities believe that mineral resource development could be a significantly beneficial business in the future, and thus are reluctant to offer rights to outsiders. Third, the DPRK expects that it could make enormous profits in this industry if funds, facilities and mining engineering technologies one day become available, despite the current shortage and lack of those resources for mine development. This means that DPRK authorities have likely been overstating the potential profits from their mining development businesses, and are less willing, as a result, to part with mining rights.

Case Study of Investment in a Molybdenite Mine

According to the (DPRK) Pyongyang IP Centre, as relayed in a research paper (obtained from confidential sources) focused on estimating the potential economic benefits from expanding the Yon-San Molybdenite ore production and exporting venture, US$ 397,307 would need to be invested in equipment and an electricity generating plant, materials, labor costs, and freight costs in order to increase the annual production capacity of the mine from 10,000 tonnes to 40,000 tonnes. The authors of the research paper estimated that the investment would have a six-month payback. The analysis, however, incorrectly estimated that the investment could produce 17.2 million dollars as profit within 5 years ($3.94 million per year). In fact, it should be considered that production capability per DPRK worker is unlikey to be higher than a South Korean worker's production capacity, given the South Korean workers will have generally superior tools and conditions to work with, but the per-capita productivity of Molybdenite ore by N. Korean workers was estimated to be higher than that of South Korean workers in the research paper. This appears to be an example of the overstatment of the potential economic benefits from mining businesses by DPRK authorities. This tendency to overstate potential benefits suggests that DPRK authorities would likely suspect, in reviewing estimates prepared using standard procedures and provided by Western companies, that foreign investors or companies are underestimating its mineral resources.

The DPRK lacks experience in attracting foreign investors to participate in its minerals sector development. This example shows that negotiations between foreign investors and DPRK authorities should be implemented carefully, and based on reasonable and transparent estimation procedures and international benchmarks in the industry, with supervision and participation by DPRK experts who have some experiences in the industry.

7.5.6. Establishing Sustainable Mining Practices

Prior to, or at the very least concurrent with, the expansion of foreign investment in the DPRK minerals sector, capacity-building on sustainable mining practices are needed to ensure that a rush to exploit the DPRK's mineral wealth does not results in significant adverse environmental and social impacts. Rather, investment and joint-ventures in the minerals sector should do everything possible to improve conditions for mine workers, and to amerliorate existing environmental problems associated with the DRRK minerals sectors. There is much to be learned by DPRK officials, mining company personnel, technicans, and engineers from both potential regional partners in minerals development and from experts in the broader international minerals arena, and any large-scale minerals sector development in the DPRK, particularly if it involves foreign partners, should include a component of capacity-building on sustainable mining practices, backed up by project organization and investments in equipment and monitoring practices designed to implement sustainable practices. Several presentations on the topic of sustainable mining practices from different nations and different points of view were provided at the 2010 DPRK Energy and Minerals Working Group Meeting organized by Nautilus Institute and convented September 21st and 22nd in Beijing, China.[802] The presentations from this Meeting are avaialble at http://nautilus.org/projects/by-name/dprk-energy/2010-meeting/papers/.

[802] Examples of relevant presentations from the 2010 Meeting include Peter Denura, "The Global Minerals Sector: Production Trends, Markets, and Lessons for the Future", Arabella Imhoff, "Key Issues and Best Practices for Minerals Sector Development: Overarching Themes", Ji-hyun Lee "Key Issues and Best Practices for Minerals Sector Development: ROK Case Study", Allen Clark, "Minerals, Economic Development, and Local Communities: Key Approaches and Case Studies from Asia", Natalia Lomakina, "A Case Study on Mineral Development in the Russian Far East: Best Practices for Sustainable Development", Odonchimeg Lundaa, "The Mongolian Minerals Sector, Future Plans, and Regional Cooperation", Ren Peng, "Development of Environmental Policy for PRC Investment in Mineral Sectors Abroad"', Hu Yuhong, "Key Issues and Best Practices for Sustainable Minerals Sector Development in China", and Chung Woo-jin and Park Jimin, "Experience and Goals of the ROK in Regional Mineral Sector Development Cooperation".

7.5.7. Policy Proposals to Maximize Inter-Korean or Foreign Investment in the Development of DPRK Mineral Mines and Coal Mines

Even if the current political situation between the DPRK and the international community is resolved, South Korean entities (or foreign companies) will still face many problems in investing in the field of mineral resources in the DPRK. Investment in the DPRK's mineral resources sector should be pursued after addressing various infrastructure issues, especially the stability of electric power supply.[803]

A gradual investment approach has been considered reasonable with most mine development investment in the DPRK, starting with small-scale investment and exploring the various risks involved. The results of this study, however, show that for investments in even a small mine in the DPRK, various infrastructure conditions along with electric power problems will make it difficult to conduct business.

To surmount these infrastructure barriers, large-scale investments in infrastructure will generally be needed before investments in individual mines and it is difficult to implement investment in infrastructure unless the DPRK authorities provide measures to guarantee the safety of investment. (A partial work-around to this problem in some cases, particularly for smaller mines that produce high-value products, could be to provide on-site power generation using microgrids, including those powered by renewable energy, as described above and in later chapters in this report.) Guaranteeing infrastructure investments may even require the implementation of new laws or legal systems to replace the current political and institutional practices of the DPRK, and implementation of such laws can be expected to be preceded by a very difficult negotiation process. In particular, to attract investment from the ROK and foreign investment companies in mine development in the DPRK, the DPRK leadership needs to identify and implement new approaches, such as the special regional law implemented in the Kaesong Industrial Complex, to create an investment-friendly environment. Without such changes in the laws governing investment and cooperation, it will be difficult for the DPRK to attract investment from overseas.

1) Exclusion of joint venture type

If the negotiations for mining sector investments between the ROK and the DPRK or between foreign companies and North Korean companies are to proceed, the DPRK will require foreign investors to invest only in the form of joint ventures, in which foreign investors provide capital, technology and facilities but the North Korean companies are responsible for managing the business. This type of North Korean joint venture is not, what is commonly understood as a "joint venture company". Rather, it is close to "compensation trade," in which the capital and facility investments are provided in exchange for a share of the resources produced generated by that investment. Although this type of arrangement is nominally a joint venture, in practice most foreign investors participating in such arrangements are kept in dark about the North Korean company they are working with. In addition, the management of the business is constantly under surveillance by North Korean authorities. This type of business mode should therefore be avoided when investing in North Korean mines.

[803] Yoon (2019), ibid, citing Chung Woo-Jinn (2015), *Investment Potential in North Korea's Mineral Resources Development and Processing*, Korea Energy Economics Institute; and private sources.

2) Separating investment mining companies from existing governance structures

Except for investments in newly developed mines, the mines that South Korean (or overseas) companies would be looking to invest in would be existing mines that have been in operation for quite some time. Under the current management system in the DPRK, it would be very difficult for the two Koreas to jointly manage North Korean mines. Within the framework of the current bureaucratic system (Collective Industry - Unified Business Offices/The Provincial Leadership Department - investment mines) it is virtually impossible to do business independently. The first thing to be addressed by DPRK authorities in order to create a foreign-investment-friendly environment is to allow some independence in the management of mines. The corporate organization of the mines invested in by foreign or South Korean companies should be separated from the existing governance structure in the DPRK and be newly established as independent corporations.[804] On the other hand, it is possible for the DPRK to initiate the separation of the mines invested in by South Korea or overseas companies from the existing governance structure in order to avoid the human and cultural influences of the South. If the mining operation in which South Korean or foreign investment occurs operates in the form of a joint venture, it is expected that operations in the DPRK will remain under the existing management system. If the mine is operated, however, in the form of an equity joint venture and/or South Korea's management participation is high, the DPRK may want to initiate separation.

3) Independent and Joint Management Company (Possibility of the creation of a third-country equity joint venture)

Even if the ROK's (or foreign) investment in a mining company is established as an independent corporation, the issue will be whether the company should be an independent company run by the South or a joint venture run by both the South and the North. Under the current North Korean regime, it is most unlikely that the North will allow independently managed companies, not to mention leaving the resource production company in the hand of an ROK organization to manage. The best type of business the DPRK can accommodate is therefore a joint venture or joint management company, run by organizations from the two Koreas. From the perspective of the ROK, an independent company has advantages in that it can achieve efficiency in management using capital, production technology, and management expertise from the ROK. In particular, for a joint venture or joint management company run by the two Koreas, there would be no concern about the risk of friction or lack of communication with North Korean partners because communications between the partners would be directly between those entities immediately involved in the venture, without the need to communicate through DPRK or ROK government agencies, for example. If problems related to the external environment (such as licensing, purchasing of materials within the DPRK, and dealing with North Korean businesses) arise, the South Korean (or foreign) company will need to figure things out on its own. It will not be easy for the South Korean or foreign company, however, to handle these issues, as they will not be within North Korean administrative procedures and the DPRK legal system. Taking all of this into account, it would be best to conduct investment in DPRK mines in the form of

[804] Yoon (2019), ibid, citing Chung Woo-Jinn (2015), *Investment Potential in North Korea's Mineral Resources Development and Processing*, Korea Energy Economics Institute; and private sources, 2018.

joint companies unless the venture is located is a particularly favorable business environment (for example, located in a Special Economic Zone).

4) Stabilization plan for South-North Korea's joint management

Given the considerations above, the management structure of choice and on which we focus here, one in which a DPRK organization oversees day to day management, while South Korean (or foreign) companies oversee the core management of the company, can be effective. It seems appropriate for South Korean managers to take responsibility for the management of facilities and materials imported from (or brought in from) the ROK, as well as for the management and sale of the products of the company. In addition, the accounting for funds used and generated by the corporation needs to be directly managed by the South Korean (or foreign) management. This provides access to and control over financial information such as the flow of funds, cost treatment, cost structure, size of sales and profits, and the status of assets and liabilities within an investment enterprise. In addition, although the core management field will be somewhat different depending on the characteristics of each company or business, the most important goal is to establish a monitoring function that can have access to all of the information about the internal operation of the company. This ability enables companies to recognize problems in advance and to take pre-emptive actions.[805]

7.5.8. Economic Effects of Inter-Korean Mineral Resources Cooperation

There are significant differences in the current state of mineral resources and in the economic structure of the South and North. These differences, however, can create synergy and bring about various economic results that satisfy the common interests of both countries.

Effect on the ROK

The most direct effect of inter-Korean cooperation related to investing in DPRK mineral resources on the ROK is to contribute to the supply and demand of raw materials for South Korean businesses, and in stabilizing prices for those inputs.

In terms of the South Korean economy, the iron and nonferrous minerals (in which South Korea currently has a self-sufficiency rate of less than 1%) industries are virtually totally dependent on imports and are therefore highly vulnerable to changes in the price and supply-demand situation in the international resource market.[806]

If the ROK invests directly in the DPRK's mineral resource production, and imports products into the South, any increase in international resource prices will be recovered in the profits of domestic companies. Since the distance between the two Koreas is shorter than between the ROK and the other countries that export mineral resources to ROK companies, the South can deal with any market instability faster with materials from the DPRK than with imports from other supplier countries. If the non-metallic mining industry, which is in decline in the ROK, is in effect relocated to the DPRK, it will be able to regain its competitiveness.

[805] Yoon (2019), ibid, citing Chung Woo-Jinn (2015), *Investment Potential in North Korea's Mineral Resources Development and Processing*, Korea Energy Economics Institute; and private sources, 2018.
[806] Yoon (2019), ibid, citing Chung Woo-Jin (2015), *A Study on the Actual Condition of Energy Trade in North Korea*, Korea Energy Economics Institute.

The ROK is losing competitiveness in industries involving the processing of non-metallic minerals, such as the cement, ceramic, pottery, glassware, and tiles industries, due to high wages and environmental constraints. Moreover, if a new production base for the steel and smelting industries is established in the DPRK, it will be possible to create additional value. The ROK has advanced technology and is competitive, but ROK heavy industries are experiencing difficulties in securing sites for expanded production bases within the ROK. In response to these difficulties, the ROK is considering establishing production bases overseas in areas that are rich in raw materials. The DPRK is a good candidate for investment as it is easy, in terms of location, for the ROK to access (assuming the normalizing of political and economic relations) and is relatively rich in raw materials such as iron ore, lead, zinc, and copper ore, as well as being advantageous for its low wages and affordable land costs.[807]

Effect on the DPRK

As overseas investment in the mining sector in the DPRK grows, it will significantly contribute to economic growth in the DPRK. Mining in the DPRK is a key export industry that accounts for an estimated 13.42% of its GDP and for about 70% of its total exports.[808]

Investment in related industries such as steelmaking, smelting and other mineral resource processing industries, along with the development of mines, will generate high value added and contribute to job growth.

If North-South mineral resource cooperation is carried out rationally, it could develop into a strategic, win-win cooperation field that contributes to the DPRK's economic development while the ROK gains profit and reduces raw materials costs for its industries. In so doing, cooperation in the minerals sector could help, under some scenarios of actual or de-facto reunification, to lift the burden of supporting the DPRK financially from the ROK, as profits from minerals products exports from jointly managed companies could help to subsidize infrastructure investments and humanitarian needs in the DPRK.

[807] Yoon (2019), ibid, citing Chung Woo-Jinn (2015), *Investment Potential in North Korea's Mineral Resources Development and Processing*, Korea Energy Economics Institute; and private sources, 2018.

[808] Yoon (2019), ibid, citing Chung Woo-Jinn (2015), *Investment Potential in North Korea's Mineral Resources Development and Processing*, Korea Energy Economics Institute; and private sources, 2018.

8. Potential Future "Pathways" for the DPRK Energy Sector, and Institutional Changes and Support Needed to for Sustainable Redevelopment

8.1. Introduction

Despite a few outward and sometimes intermittent signs (and the key word here is "outward") of economic recovery in recent years—including more activity in the capital and a population that has at least until the last few years looked, in general, better nourished (to at least some visitors)—it is clear that the DPRK energy sector is a long way from good health. What could the near- and medium-term future hold for the DPRK, and what can be done by the international community in general, and the ROK in particular, to make the lives of DPRK citizens somewhat less burdensome? To address this two-part question, the chapter that follows first sketches a set of substantially different storylines (scenarios) for DPRK economic/energy sector redevelopment (and in one case, lack of redevelopment), then translates those scenarios into numbers (energy paths) to yield a more concrete sense of where the economy might go, given different policy emphases both in the DPRK and among the countries and international organizations that might, under certain circumstances, work with the DPRK. This chapter examines these questions and potential energy paths, compares the paths generated with respect to energy security criteria, both qualitative and quantitative, looks for common lessons in the analytical results, and provides some ideas for initiatives that could assist the DPRK in building a sustainable energy sector.[809]

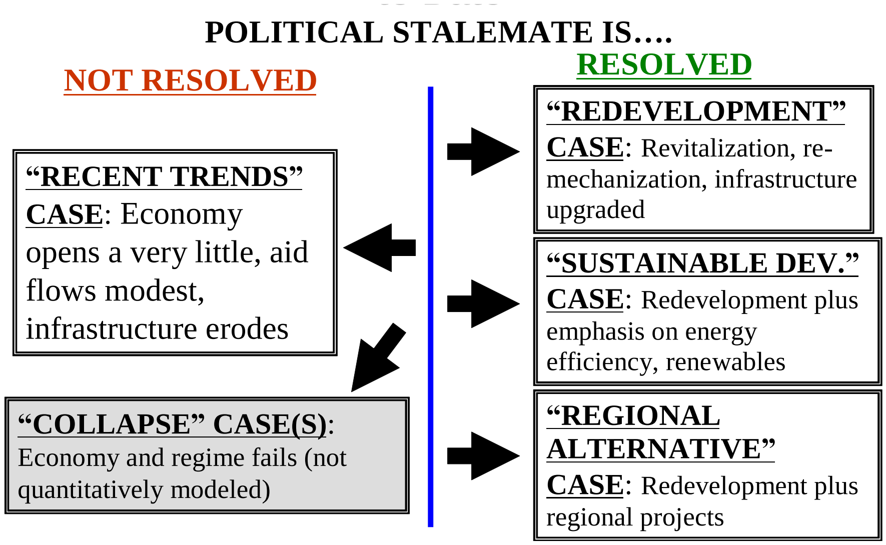
There are essentially three different ways that the DPRK energy sector and economy could evolve from their current states, although many variants to these three paths are certainly possible. First, the economy could open, leading to economic redevelopment. This process, of course, could occur slowly or rapidly, and could take on quite different characteristics, depending on how it is managed (or not managed). Second, the economy could fail to open substantially, leading to a continuation of recent trends of stagnation in the economy and in availability of energy supplies. Third, the Kim regime could collapse in one of many possible ways, leading, in most scenarios, to actual or de-facto economic integration with the ROK. We must emphasize that we do **NOT** think that DPRK regime collapse is likely in the near- or even medium-term. It is instructive, however, to think through the implications of collapse scenarios, and we present an update of our previous work on the topic in Chapter 9, below.[810] The main

[809] Some of the text in this chapter updates material prepared for an earlier paper, David von Hippel and Peter Hayes (2013), "Assessment of Energy Policy Options for the DPRK Using a Comprehensive Energy Security Framework", Paper prepared for the International Studies Association Annual Convention, San Francisco 2013, Panel TA58: "Energy Security: An International Assessment". Also prepared as a Working Paper for the Energy, Governance and Security Center of Hanyang University, Republic of Korea EGS Working Paper 2013-4, and available as https://nautilus.org/napsnet/napsnet-special-reports/assessment-of-energy-policy-options-for-the-dprk-using-a-comprehensive-energy-security-framework/.

[810] See, for example, Peter Hayes and David von Hippel (2011), *DPRK "Collapse" Pathways: Implications for the Energy Sector and for Strategies Redevelopment/Support*, Nautilus Institute Special Report, dated January 18, 2011, and available as http://nautilus.org/napsnet/napsnet-special-reports/dprk-collapse-pathways-implications-for-the-energy-sector-and-for-strategies-redevelopmentsupport/; and Peter Hayes and David von Hippel (2011) "North Korea's 'Collapse' Pathways and the Role of the Energy Sector", Chapter 8 in *The Survival of North Korea: Essays on Strategy, Economics and International Relations*, Edited by Suk Hi Kim, Bernard Selinger, and Terence Roehrig, McFarland & Company, Inc.

variants of the economic redevelopment scenarios fall on the right hand side of Figure 8-1, while "Recent Trends" and "Collapse" scenarios fall on the left side.

Figure 8-1: Main DPRK Energy Paths/Scenarios Considered



In both the Sustainable Development (SDV) and Regional Alternative (RAT) pathways (and variants of same)**,** a greater degree of formal rapprochement with the international community is both required and assumed than in the Redevelopment (RDV) pathway. We would argue that only truly significant and demonstrably continuous progress with addressing the DPRK's nuclear weapons program (and, probably, missile program), coupled with real progress in peace talks with both the US and ROK, can offer the prospect of sufficient international cooperation and economic opening for the DPRK to rebuild its economy in a more coordinated fashion that builds in energy efficiency and other measures geared toward more sustainable economic development.

Four additional paths, themselves variants on the paths above, were also explored. Each assumes that the nuclear reactors initially under construction by KEDO, or, should the existing work on the sites prove unrecoverable (as is increasingly likely as time passes), new reactors on those sites, will be completed, and the bulk of the power from those reactors routed to the ROK until a unified or substantially joined Korean grid (including a rebuilt DPRK grid) can be developed. This "with nuclear" overlay is applied to the Sustainable Development and Regional Alternative paths. A third variant, "Regional Alternative Max Nuclear", builds an additional three reactors in the North by 2045, likely under ROK direction and using ROK designs and components.

One further scenario, the "Recent Trends" path, assumes that the DPRK remains largely a closed economy, but continues to trade with China and others in quantities such that it is able to maintain its economy at close to current levels, with possible modest improvements in some sectors. This assumes that the DPRK's energy infrastructure, in particular its electricity generation and T&D infrastructure receives just enough investment to keep it from failing, but not enough to make significantly enhanced supplies of energy services available to the DPRK's citizens, at least on average. The Recent Trends case serves as a counterpoint to the scenarios above, but is not strictly comparable to them, because it does not produce the same level of economic activity or energy services.

It is critical to emphasize that the small number of future paths for DPRK energy sector development considered below are **illustrative** and are neither intended to be "optimal" or to be construed to in any way exhaust the universe of possible energy futures for the DPRK. Future work can and should explore other possible trajectories for the DPRK economy, preferably in consultation and in collaboration with Koreans from both sides of the DMZ. Such paths could and should explore in more detail opportunities to sustainable redevelopment of the DPRK economy in the context of sustainable development of the nations of the Northeast Asia region as a while, including paths that illustrate ways to get to "net zero" carbon emissions for the DPRK by 2050. Given that much of the energy and economic infrastructure in the DPRK will likely need to be upgraded in the event that the DPRK economy is transformed, there may be an opportunity to make DPRK economic development a model for sustainability, though effectively seizing that opportunity depends significantly on how the internal and international political processes underway in and related to the DPRK play out in the coming years.

8.2. The DPRK Under a Medium-Term "Redevelopment" Pathway and Under Variants of Same

Below we describe, in a very qualitative way, what a medium-term "Redevelopment" path might look like for the DPRK economy and, by extension, for the DPRK energy sector. This qualitative sketch is a first step to the estimation of the quantitative attributes of such a path—what the path might mean in terms of future terajoules of energy used and supplied, such as annual tonnes of coal, and megawatts and megawatt-hours of electricity.

First and foremost, a "Redevelopment" pathway implicitly assumes a major breakthrough in relations with the ROK, and probably with the United States and other nations as well, resulting in some investment in the industrial and energy infrastructure in the DPRK from outside the country, and much-increased foreign development aid. The "Redevelopment" path also assumes, however, that the DPRK government essentially maintains its integrity. If the current DPRK government loses power, rapid reunification of North and South Korea may result, which probably means very large, very fast changes for the DPRK energy sector, providing that the unified Korea can obtain internal and external financing for infrastructure reconstruction in the North. Some of these "collapse" scenarios—which the authors of this report stress that we feel are unlikely—are presented and discussed qualitatively in Chapter 9.

A "**Redevelopment**" pathway for the DPRK would likely be built upon the following assumptions:

- With some political and economic opening, coupled with increased foreign aid, the DPRK economy starts to revive in earnest (for example, in 2022)—but note that the structure of the economy will almost unquestionably evolve along quite different lines than those prevailing in 1990, as the world's markets, and the markets that the DPRK will sell and buy from, are manifestly different in the 2020s than they were in 1990.
- Industrial production increases, particularly in the lighter industries; and there is increased demand for transport.

- There is an increase in household energy use, with trends toward using more electricity, LPG, and kerosene in homes.
- There is a considerable increase in commercial sector activity, and a relatively small increase in military sector energy use.[811]
- Refurbishment of electric transmission and distribution infrastructure takes place, coupled with refurbishment of existing hydro plants, building of new hydro capacity, the re-starting and expansion of the DPRK's east coast refinery, and partial retirement of coal-fired electricity generating capacity.
- Modest improvements in energy efficiency take place.

This pathway, or one very much like it, may in fact be one of the only ways that DPRK infrastructure can be sufficiently rehabilitated to use within the DPRK even some of the power from commercial-sized nuclear reactors such as those that were being built by KEDO until 2002. There is at present no way to use 1000 MW-class reactors within the existing DPRK grid,[812] so to use such a reactor interties to other countries must be constructed, and preferably, from a political and practical perspective, the DPRK grid would need to be totally rebuilt as well, either from the top down or from the bottom up, via establishment of local microgrids (or both). Had the construction of the KEDO reactors at Sinpo continued, interconnection issues could have been both a huge problem that could have led to poor relations between the DPRK and the outside for years to come, or, if handled correctly, could have constituted a huge opportunity for building of economic links (and better relations) between the countries of the region. If construction of the LWRs at Sinpo is taken up again in the future, this technical consideration, and its various solutions and non-solutions, will remain. Given the unresolved nature of the various nuclear-related issues (nuclear weapons, uranium enrichment, the DPRK's stated aim and ongoing program to develop a domestic small light water reactor, and the lingering—although, in practical terms, dwindling—possibility of resuming work on the large Sinpo LWR units with ROK or international assistance), we have chosen to leave large nuclear power units out of the modeling of the Redevelopment path, and also out of the major variant paths described below. We have, however, also prepared preliminary "with nuclear" paths with nuclear power in the DPRK at three different levels of nuclear deployment corresponding to the Redevelopment path and to each of its variants. In those paths, we assume the construction of large (1000 MW) reactors, with the bulk of the power from those reactors, at least initially, exported directly to the ROK through a direct tie-line to the larger, stable ROK grid.

[811] Depending on the nature of the diplomatic breakthrough—which must, for a redevelopment pathway to begin in earnest, include a substantial or full relaxation of UNSC sanctions and reciprocal actions from the DPRK—the degree to which a breakthrough is embraced by the DPRK leadership, and the economic opportunities it offers to North Korean citizens, it is entirely possible that the DPRK armed forces may be partially demobilized, resulting in lower military energy use, although probably offset by greater energy use per soldier due to increased mechanization. Partial demobilization seemed to be under discussion in the DPRK as of about 2002, before tensions between the DPRK and the international community rose again during the United States' George W. Bush administration.

[812] Nuclear safety concerns (back-up power for coolant pumps and controls) and the attributes of a large-capacity nuclear unit operating in a small power grid (the DPRK grid is far below the minimum size to support the KEDO reactors) are key reasons why these reactors cannot operate under current conditions. See D. von Hippel et al (2001), "Modernizing the US-DPRK Agreed Framework: The Energy Imperative", and available as http://nautilus.org/wp-content/uploads/2011/12/ModernizingAF.pdf, as referenced earlier in this report.

8.2.1. Variants on the Redevelopment Path

In the context of collaborative research on regional energy security in Northeast Asia,[813] Nautilus Institute has developed and evaluated alternative paths that provide the same energy services as the Redevelopment path described (in summary) above, but that incorporate features of energy efficiency and renewable energy, as well as strengthened regional cooperation in the energy area. The two main alternative paths evaluated are:

- The "Sustainable Development" Path. This path provides the same energy services as the "Redevelopment" Path—with, for example, the same demographic assumptions, and the same levels of economic output—but applies energy efficiency, renewable energy, and other measures in an aggressive fashion, including upgrading of industrial infrastructure to levels above average standards to high-efficiency international standards, a rapid phase-out of existing coal-fired power plants, and addition of LNG (liquefied natural gas) terminals and gas CC (combined cycle) generating plants.
- The "Regional Alternative" Path. This path resembles the Sustainable Development path, but as a result of regional cooperation, efficiency improvement targets are reached two years earlier than in Sustainable Development path, and at costs that are 10 percent lower. In the fuel supply sector, a gas pipeline from the Russian Far East to the DPRK and the ROK begins operation in 2030, with 10 percent of the pipeline throughput provided for use in DPRK initially, increasing to 20 percent by 2034, and about 33 percent by 2050, with an assumed doubling of pipeline capacity in 2035. The DPRK receives $20 million per year as "rent" for hosting the pipeline. Also, a larger LNG facility is installed over time than in the Sustainable Development path—and is again shared with the ROK. A power line from the Russian Far East through the DPRK to the ROK is included in the Regional Alternative path. Cooperation in renewable energy technologies yields more rapid deployment of those technologies, and a 10 percent reduction in cost of wind and small hydro technologies over time relative to the Redevelopment path. In the Regional Alternative path, all of the DPRK's existing coal-fired plants are retired before 2050.

Some initial results of the evaluation of these three paths are provided below. Note that these results have been updated to reflect the updates to the 1990 through 2020 energy balances described in Chapters 2 and 3 of this report, as well as the updated electricity sector and refined products analyses in Chapters 5 and 6.

8.2.2. Summary Results, Redevelopment Pathway

Figure 8-2 shows final demand by fuel for the Redevelopment Path. Trends here of note after 2021 include the decrease in the use of biomass fuels, the increase in the use of electricity, the decrease in coal use after about 2028, and the introduction of more use of liquefied petroleum gas (LPG) and diesel fuel over time. Coal use increases rapidly between 2021 and the early

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[813] In the Asian Energy Security project, and the related and follow-on East Asia Science and Security and Regional Energy Security (RES) projects, the latter running from 2018 through 2020, collaborating groups of researchers from each of the countries of Northeast Asia have worked together to research the energy security implications of different energy policy choices, both within their countries and regionally. See, for example, "East Asia Science and Security Meeting 2010", at http://nautilus.org/projects/by-name/science-security/workshops/2010-east-asia-science-and-security-meeting/. In these projects, the Working Groups all used common modeling software--the LEAP Low Emissions Analysis Platform (formerly the Long-range Energy Alternative Planning system), available from the Stockholm Environment Institute—United States Center (see https://www.sei.org/projects-and-tools/tools/leap-long-range-energy-alternatives-planning-system/).

2030s, as supply restrictions are lifted and existing basic industries are brought back on line to some extent, but coal use declines after 2035 as households and industries begin switching to other fuels, and a transition away from heavy industry begins. There is an approximately 4.5-fold increase in petroleum products use between 2021 and 2050, led by gasoline and diesel use in (mostly) the transportation sector, but also by the rise of the use of LPG, in particular, in the residential sub-sectors, as LPG is substituted for less-convenient-to-use coal in cooking applications. Diesel use increases in the agricultural sector as agriculture is re-mechanized, and the use of "non-energy" oil products, especially asphalt (for upgrading the DPRK's road infrastructure), but also lubricants and other specialty products, increase as well.

Figure 8-3 shows final demand by sector, showing the increase, in future years, of consumption in the transport, public/commercial (commercial/institutional), and residential sectors relative to the industrial sector. Relative growth in residential sector energy use would appear greater were it not for the gradual phasing out of biomass use in households.

Figure 8-2: Final Energy Use by Fuel, Redevelopment Case

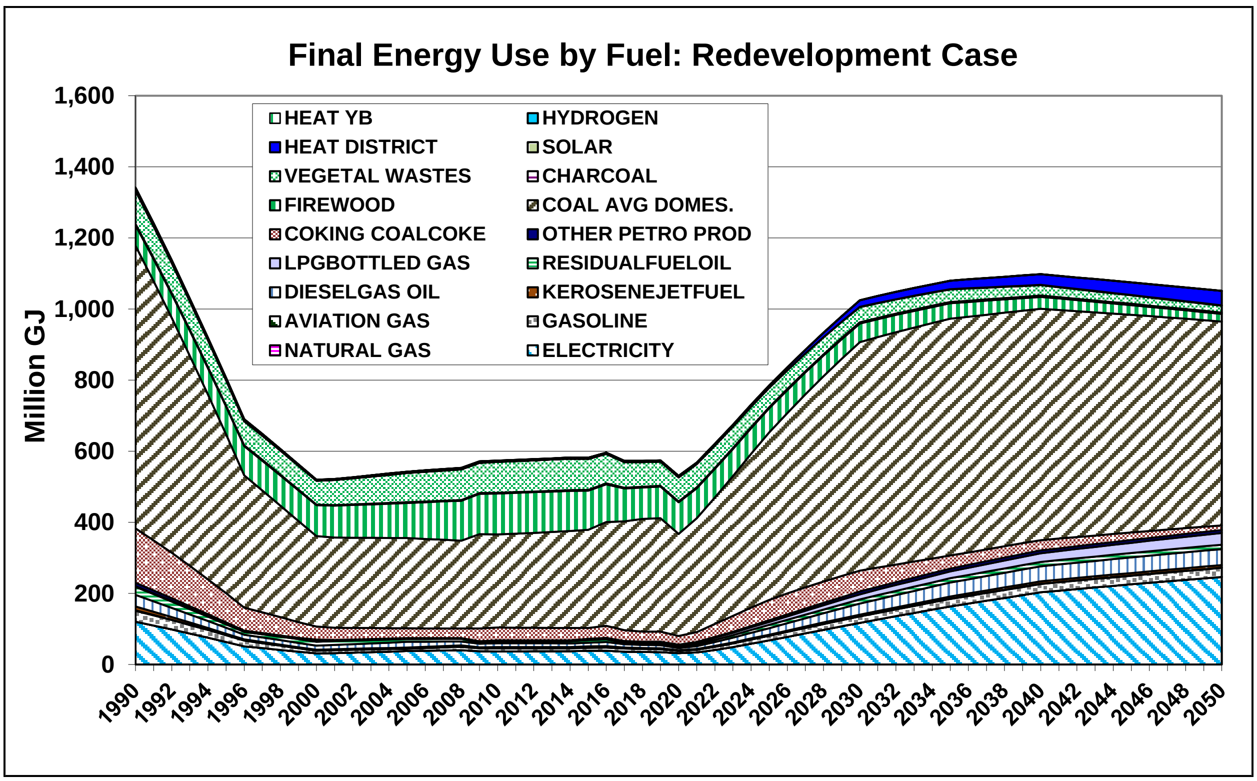


Figure 8-3: Final Energy Use by Sector, Redevelopment Case

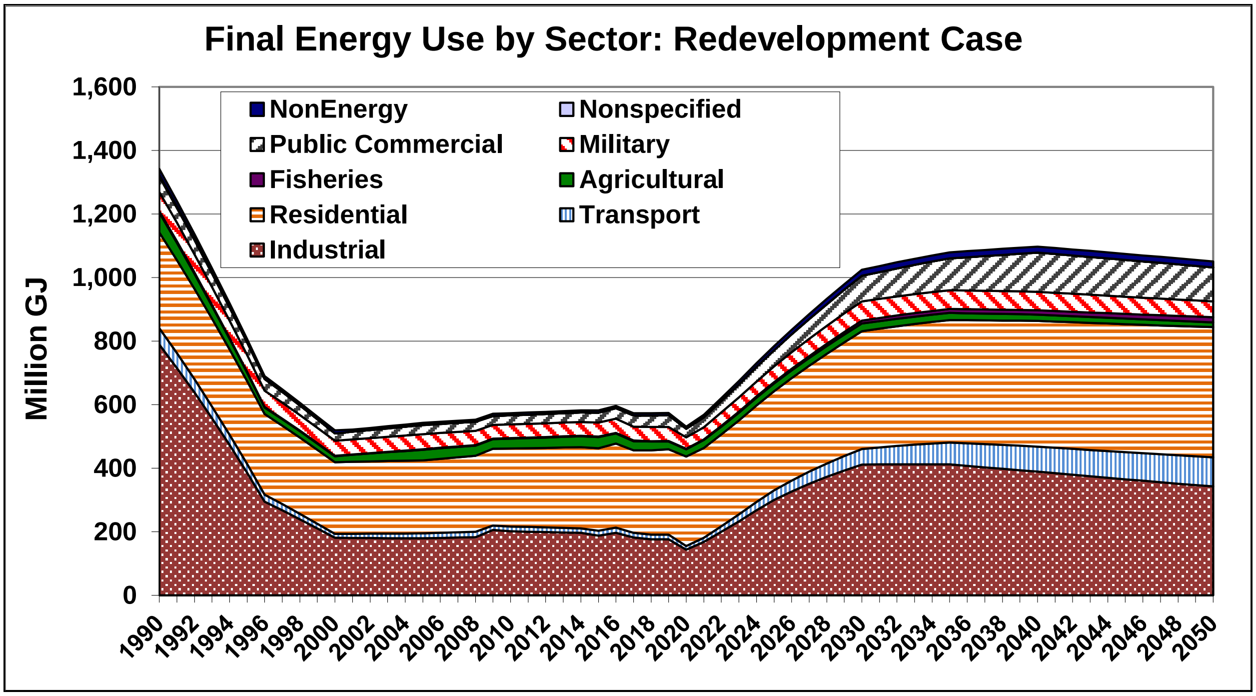


Figure 8-4 shows the trends in demand by sector for electricity under the Redevelopment path. Electricity use increases by nearly a factor of seven between 2021 and 2050, as, particularly, households and public/institutional buildings have access to adequate supplies of electricity and are able to purchase new electricity-using devices and enjoy higher levels of electricity-related energy services.

Figure 8-4: Electricity Use by Sector, Redevelopment Case

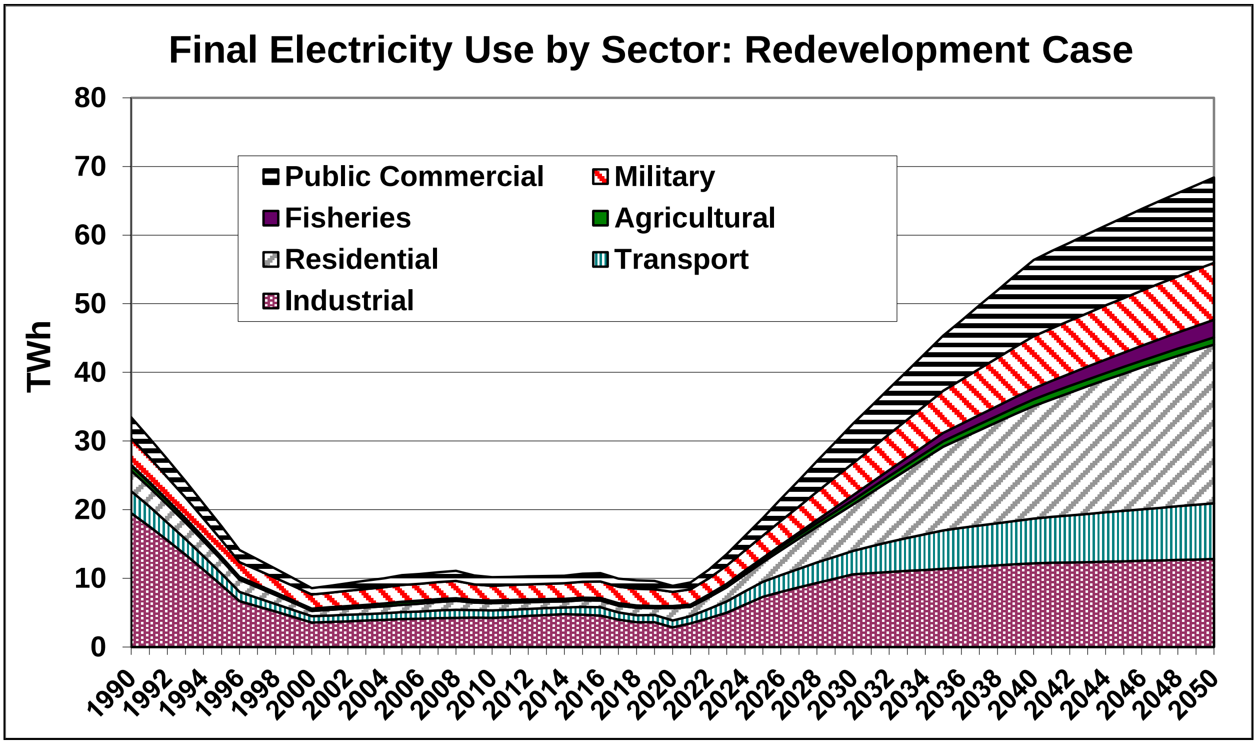


Figure 8-5 shows the pattern of coal use by sector, including coking coal used in steelmaking, under the Redevelopment case. Although coal use never returns to 1990 levels, and does decline slowly starting in the mid-2030s, considerable coal is still used in the DPRK economy, including in the residential sector, as of 2050, underscoring the need for DPRK leadership and international cooperation to focus on reduction of coal use in the DPRK if national and international climate goals are to be met.

Figure 8-5: Coal Use by Sector, Redevelopment Case

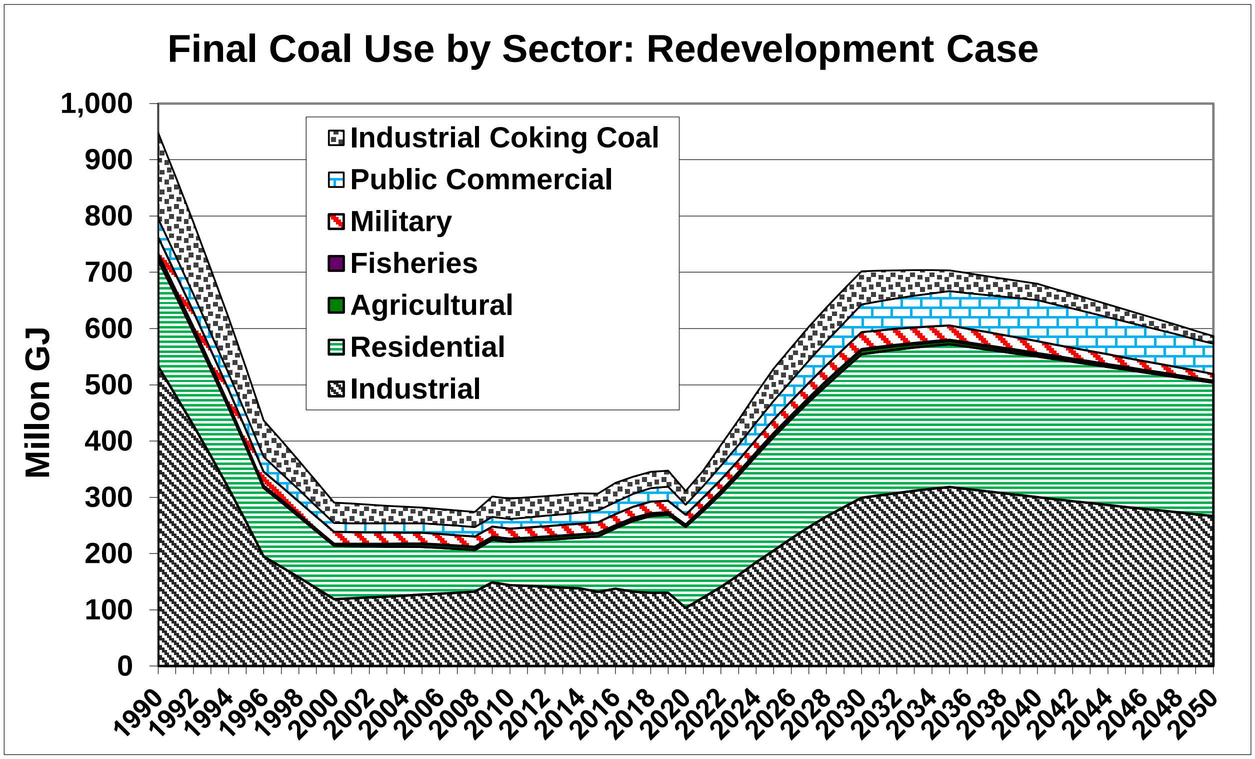


Figure 8-6 and Figure 8-7 show, respectively, the changing patterns of electricity generation capacity and of output by type of generator in the Redevelopment path. Other than hydroelectric generation, renewable energy plays a relatively small role in electricity production, despite the addition of 3 GW of solar PV capacity (and 300 MW of wind power) by 2050, even as the economy redevelops. Existing and some new hydro remains a significant, though declining, portion of total capacity through 2050, but constitutes a smaller portion of output due to the limited capacity factor of hydro facilities (due to seasonal variations in water supply). As older coal plants are phased out, new coal plants and new gas combined cycle plants (fueled with LPG) are brought online, constituting a significant share of capacity, and a larger share of electricity output, by 2050. The projections of capacity of and output from older coal-fired power plants can be thought of as implicitly requiring significant rebuilding over time, as the existing coal-fired plants cannot be expected to continue to provide power at significant levels otherwise.

Figure 8-6: Generation Capacity by Generator Type, Redevelopment Case

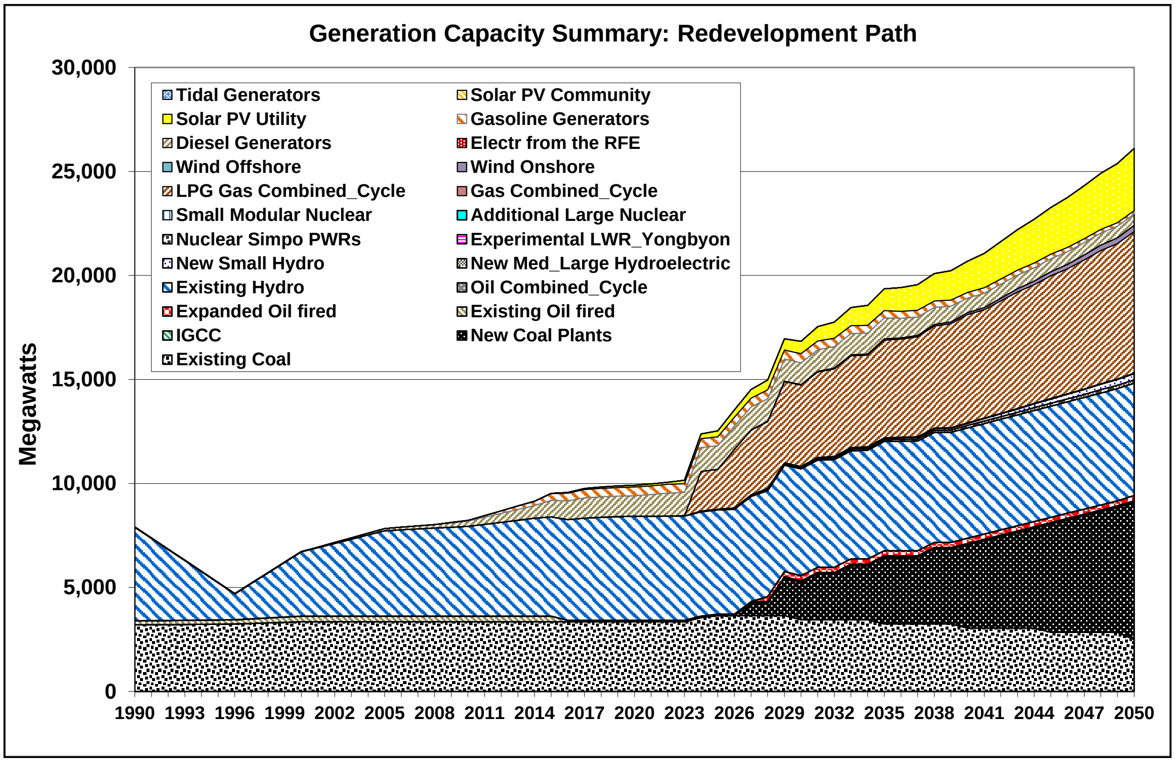
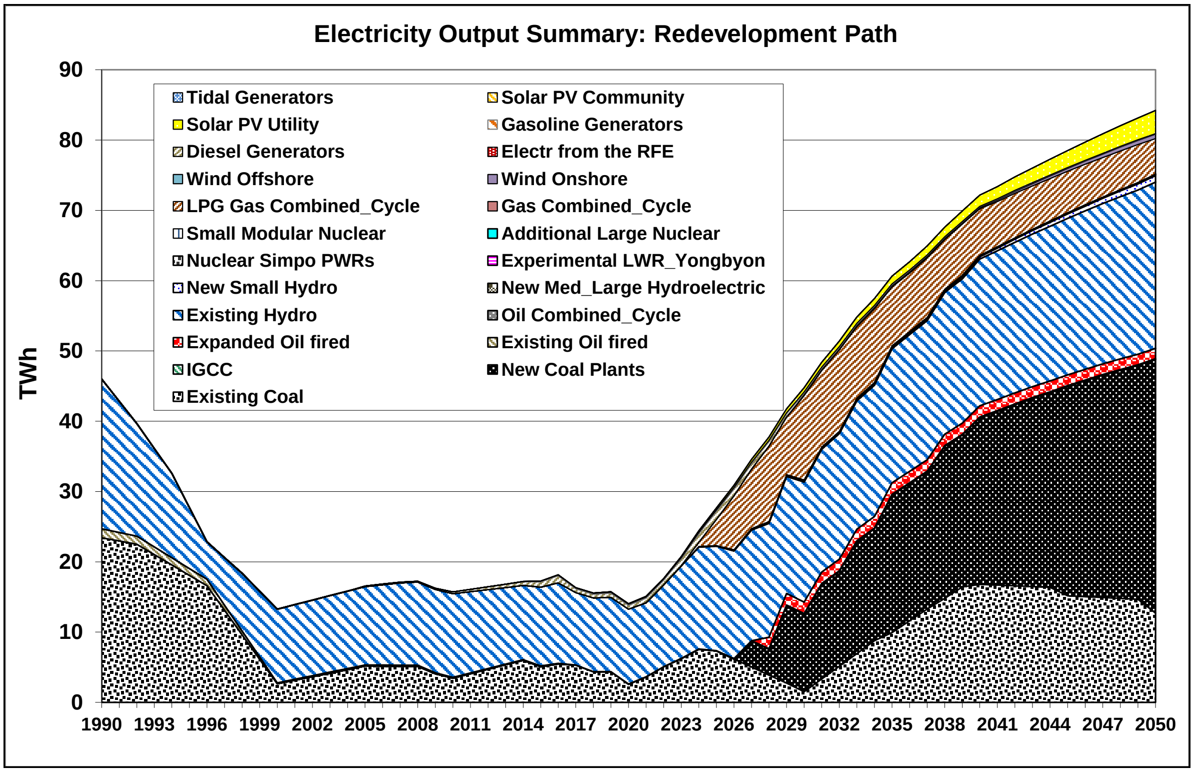


Figure 8-7: Electricity Output by Generator Type, Redevelopment Case



8.2.3. Sustainable Development Path Results

The "Sustainable Development" path is an illustration of the potential impacts of applying a selected set of demand-side energy efficiency measures across the sectors, together with expanded deployment of renewable energy systems (in this case, renewable electricity generation options, particularly solar PV but also wind power). As such, it is designed to provide the same "energy services" (lighting, heating, cooking, transport, and industrial output, for example) as the Redevelopment case, but in a different way. Figure 8-8 and Figure 8-9 show final energy use by sector and fuel, respectively, in the Sustainable Development path. Here, overall energy use rises quickly after 2021, but then plateaus and begins to fall as the increased use of energy services is more than offset by the aggressive application of energy efficiency measures. In addition, there is a stronger transition to electricity and gas use than in the Redevelopment path, including more electricity use in the transportation sector. Both lower energy use because electricity can be used much more efficiently than combustion fuels for most end uses under most conditions (heating in cold weather being a possible exception), and gas can be burned more efficiently than coal or biomass. The direct use of solar energy, in the form of solar water heating, also plays a role by 2050 in the residential subsectors (both urban and rural) and to a smaller extent in the public/commercial sector. Note that in both Figure 8-8 and Figure 8-9 the uppermost wedge (white with grey dots) shows the difference in final fuel use between the Sustainable Development case and the Redevelopment path increasing over time after 2021, ultimately showing nearly a 37 percent decrease in annual fuel use in 2050. It is quite possible, however, that an aggressively applied combination of energy efficiency options, fuel switching, and well thought-out structural changes in the DPRK economy could drive final energy use down even further than indicated in the Sustainable Development case.

Figure 8-8: Final Energy Use by Sector, Sustainable Development Case

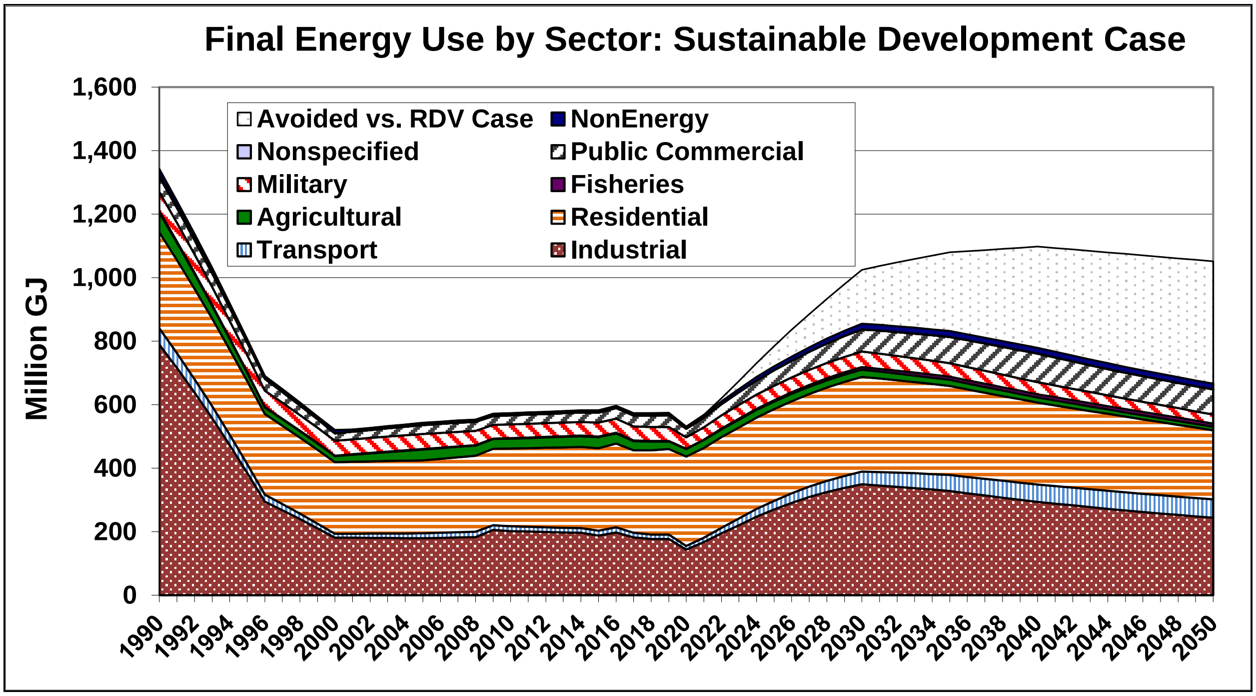


Figure 8-9: Final Energy Use by Fuel, Sustainable Development Case

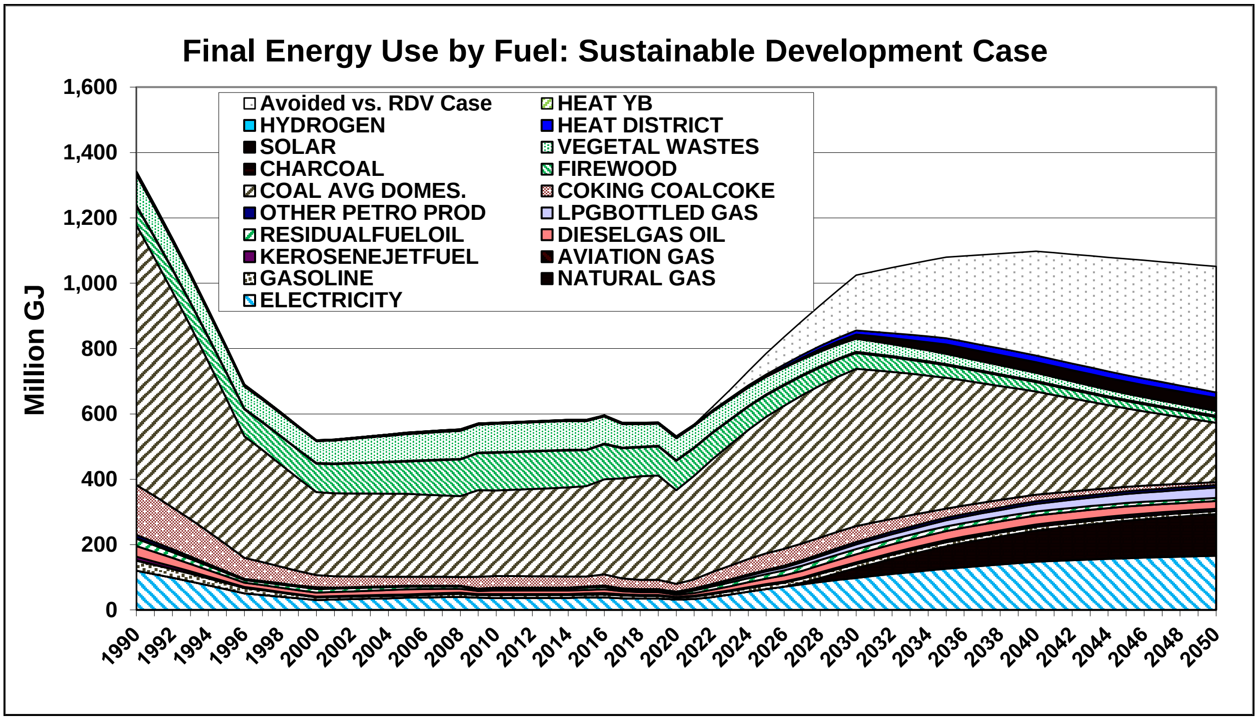


Figure 8-10 shows the trends in demand by sector for electricity under the Sustainable Development Redevelopment path. Electricity use increases by a factor of about 4.5 between 2021 and 2050, but that is significantly less than in the Redevelopment case, even though there is substantially more fuel switching to electric drive in the transport sector and in the military sector (the latter mostly for medium-sized trucks and boats/ships). As in the RDV case, particularly, households and public/institutional buildings have access to adequate supplies of electricity, are able to purchase new electricity-using devices and enjoy higher levels of electricity-related energy services, but energy efficiency improvements throughout the economy make it possible to do so with substantially lower supplies of electricity than in the RDV case. This is significant because it makes it possible to produce the needed electricity at lower cost (including fuel and investment costs) and with more reliance on renewable and other clean fuels, as described below.

Figure 8-10: Electricity Use by Sector, Sustainable Development Case

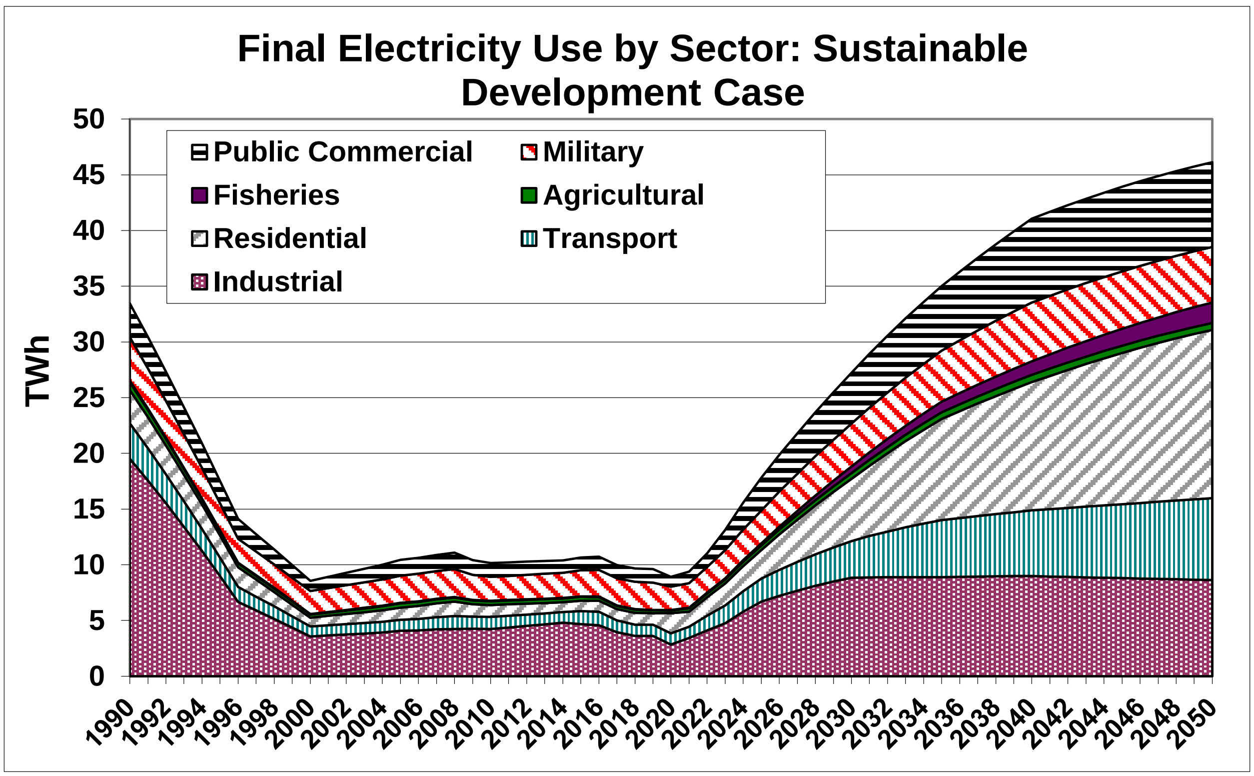


Figure 8-11 show that the changes included in the Sustainable Development case have the effect, in aggregate, of decreasing coal use by 2050 by more than two thirds relative to the Redevelopment case, from about 587 PJ to about 191 PJ. Given the recent pace with which coal use has been declining in many nations (albeit particularly for electricity generation) it is not impossible to think that a concerted effort could reduce coal use in the DPRK by 2050 even more than the results of this path suggest.

Figure 8-11: Coal Use by Sector, Sustainable Development Case

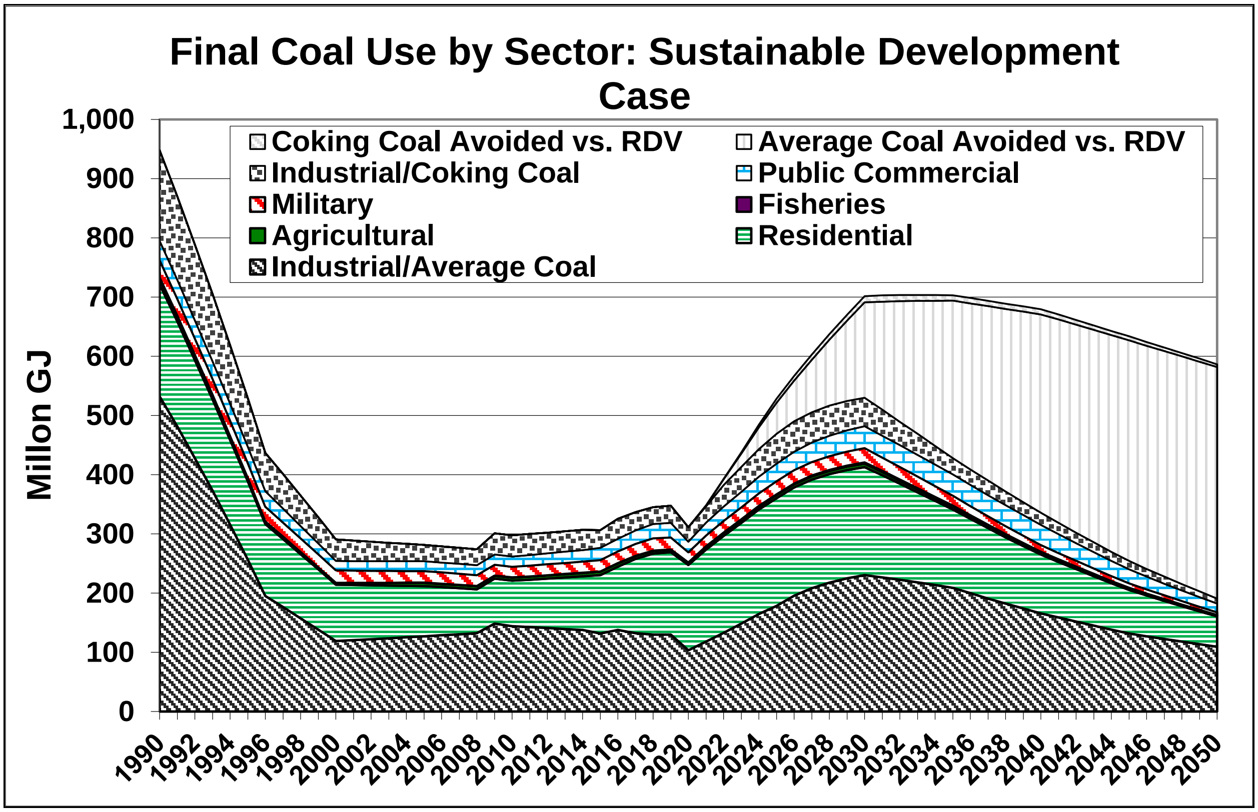
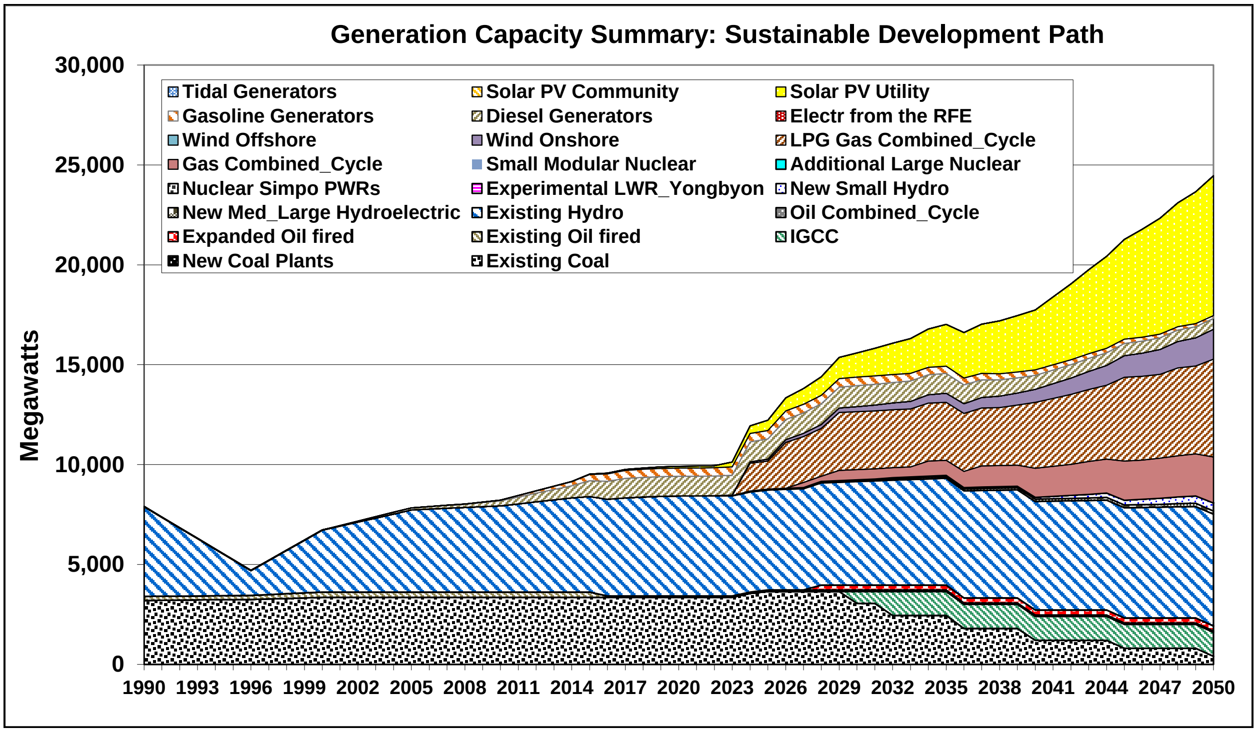


Figure 8-12 provides a summary of the pattern of electricity generation capacity over time for the Sustainable Development path.[814] The Sustainable Development path provides a more diverse set of generation resources, by 2050, than the Redevelopment path, and despite including more renewable generation (wind and particularly solar) that feature, by their nature, lower maximum capacity factors than conventional generation, the overall requirement for capacity is about 650 MW (about 2.6 percent) less, by 2050, than in the Redevelopment path, as a consequence of enhanced demand-side efficiency. The Sustainable Development path also features a more rapid phase-out of existing coal-fired power plants. The Regional Alternative path shows a similar pattern to the Sustainable Development path, but also includes two large additions to capacity representing power from a tie-line to the Russian Far East, though much of the power transmitted through that line would be destined for the ROK, not for the North Korean, grid.

[814] Note that both Figure 8-12 and Figure 8-14 assume that commercial-scale nuclear generation capacity in the DPRK (for example, the reactors at Sinpo that were being constructed under the 1994 Agreed Framework) is **not** completed, though we have prepared variants of these paths that do include nuclear generation, starting operation in approximately 2030, which is probably the very earliest that a plant could possibly come on line given the international situation as of 2021 and the typical recent lead times for nuclear reactor construction. The exclusion of nuclear plants from each of these cases should be considered one of many possible variants in each case, but at present, possibly the more likely variant.

Figure 8-12: Trends in Electricity Generation Capacity Expansion, Sustainable Development Path



8.2.4. Regional Alternative Path Results

The pattern of energy demand by sector in the Regional Alternative case, as shown in Figure 8-13, is very similar to that in the Sustainable Development path, with a shift to lower overall use slightly earlier in time (about one to two years) by the 2030s and 2040s, based on the assumption that regional cooperation accelerates the deployment of energy efficiency and renewable energy measures in the DPRK. This somewhat earlier introduction of demand-side technologies yields a difference between demand in the Regional Alternative case and the Redevelopment case by 2050 of than 38.5 percent, and thus slightly more savings than shown in the Sustainable Development case. An assumption of a more aggressive program of getting energy efficiency and other relevant technologies (including electric vehicles) into the DPRK from nations of the region, for example, through technology transfer programs that lower the cost of high-efficiency devices and equipment in the DPRK and create opportunities for the development of new manufacturing in the DPRK (and foreign investment in same), would accelerate energy efficiency deployment and result in lower fuel use earlier and lower overall fuel use by 2050 than shown here.

Figure 8-13: Final Energy Use by Sector in the Regional Alternative Case

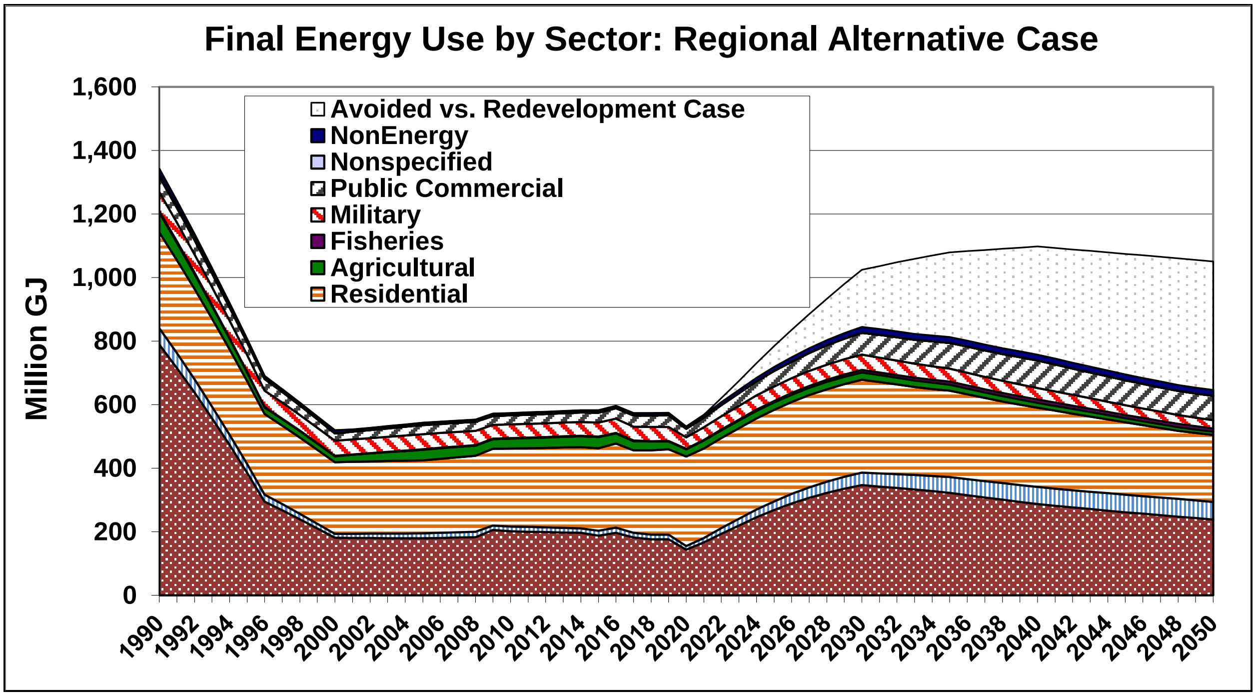


Figure 8-14 shows the pattern of electricity generation capacity over time for the Regional Alternative path. The Regional Alternative path allows a somewhat faster phase-out of existing (although, by the 2040s, likely refurbished) DPRK coal-fired capacity, leaving only an IGCC unit using coal by 2050. The Regional Alternative path includes more gas-fired capacity than in the Sustainable Development path, mostly as an artifact of the way that electricity generation is modeled in the DPRK LEAP dataset, but gas-fired and LPG-fired combined-cycle units are not used as much (have a lower capacity factor) in the Regional Alternative Path, due to the additional renewable generation capacity and the use of a portion of the power from the interconnection with the Russian Far East to meet DPRK domestic needs. Figure 8-15 shows an illustrative routing of a transmission line from the southern part of the Russian Far East, largely following the east coast of the DPRK before heading across the southern DPRK to intersect the ROK border near Seoul. This routing would be on the order of 650 km, including an adder of 10 percent from the linear route as measured on the map. The transmission line is modeled as if the DPRK were the owner of the line, having borrowed money to build it from an international (in practice, likely private/public) consortium, and in effect purchases power coming from the Russian Far East (though in practice, possibly routed in part from elsewhere, such as Mongolia), and sells it to the ROK at a price that allows it to recoup the payments for the line itself plus additional "rent" for hosting the line. In practice, the financing and ownership, and sales arrangements associated with such as power line could involve many different countries and institutions, and will be a matter for detailed negotiations between parties in the region (and outside of it).

Figure 8-14: Trends in Electricity Generation Capacity Expansion, Regional Alternative Path

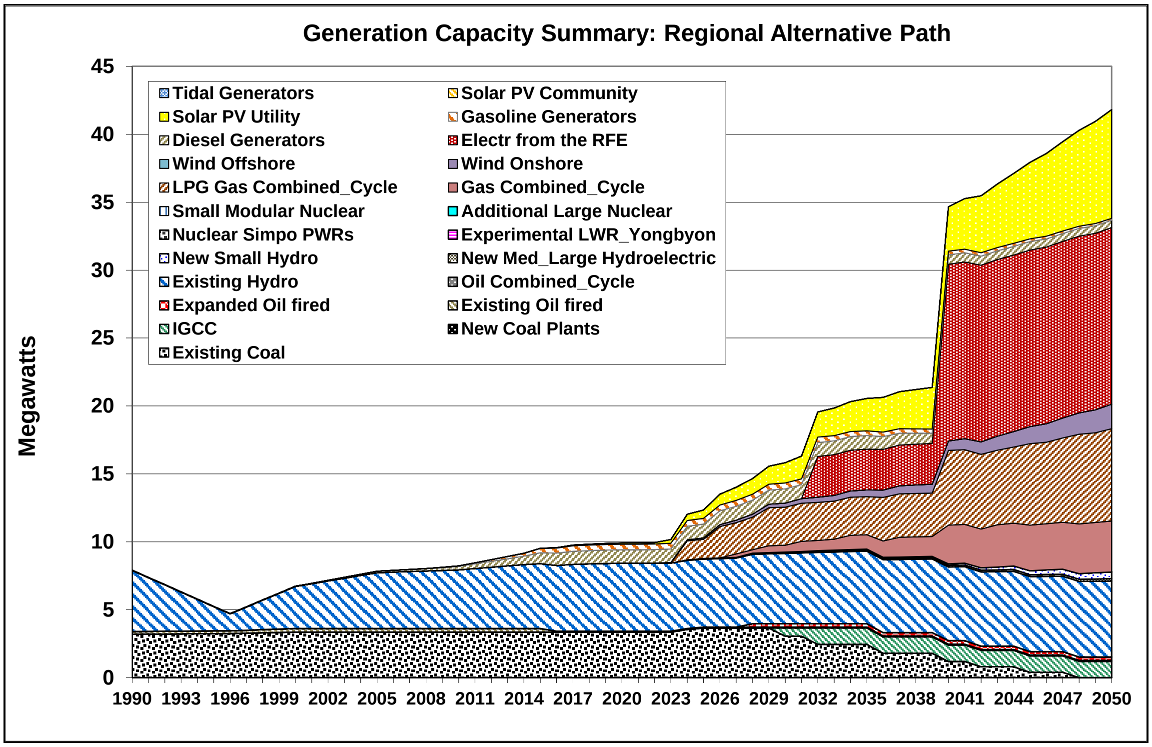
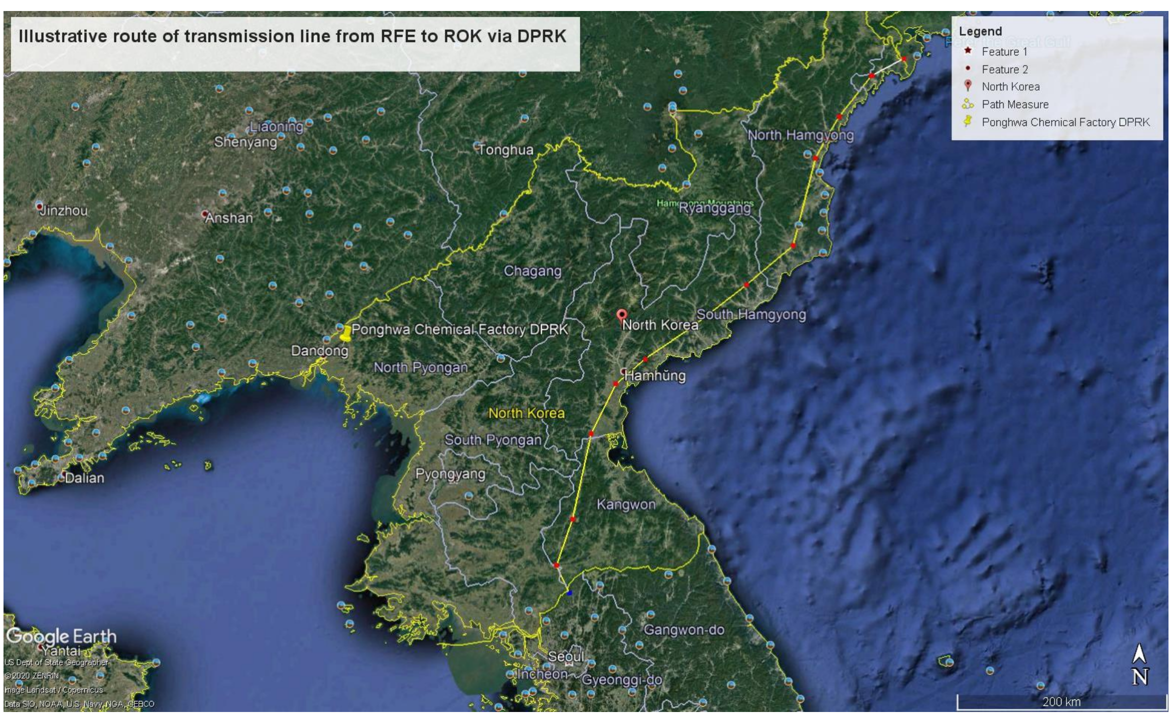


Figure 8-15: Illustrative Route of Transmission Line through the DPRK in Regional Alternative Path (Image from Google Earth Pro, with approximate transmission line routing authors' assumption)



8.3. Implications of a "Recent Trends" Path for the DPRK Energy Sector

Figure 8-16 shows fuel use by sector in the Recent Trends case. This case is very different in concept than the Sustainable Development or Regional Alternative cases, as the Recent Trends case provides a standard of living and economic output by 2050 only slightly improved from that prevailing in 2020, but the overall energy consumed by 2050 is not very different than in the Sustainable Development case, mostly because the Recent Trends case continues to use inefficient demand-side devices, and continues to rely on coal and biomass, which provide less usable energy per unit of fuel consumed (see Figure 8-17).

Following the trend of fuels use in general, electricity generation in the Recent Trends case rises only modestly after 2020, as the additions of relatively small amounts of hydro and coal-fired capacity, as well as some continued increase in small distributed solar PV systems and diesel and gas generators for businesses and households, combine with maintenance activities that keep older power plants running at closer to the rates we estimate for recent years (Figure 8-18 and Figure 8-19).

Figure 8-16: Final Energy Use by Sector in Recent Trends Path

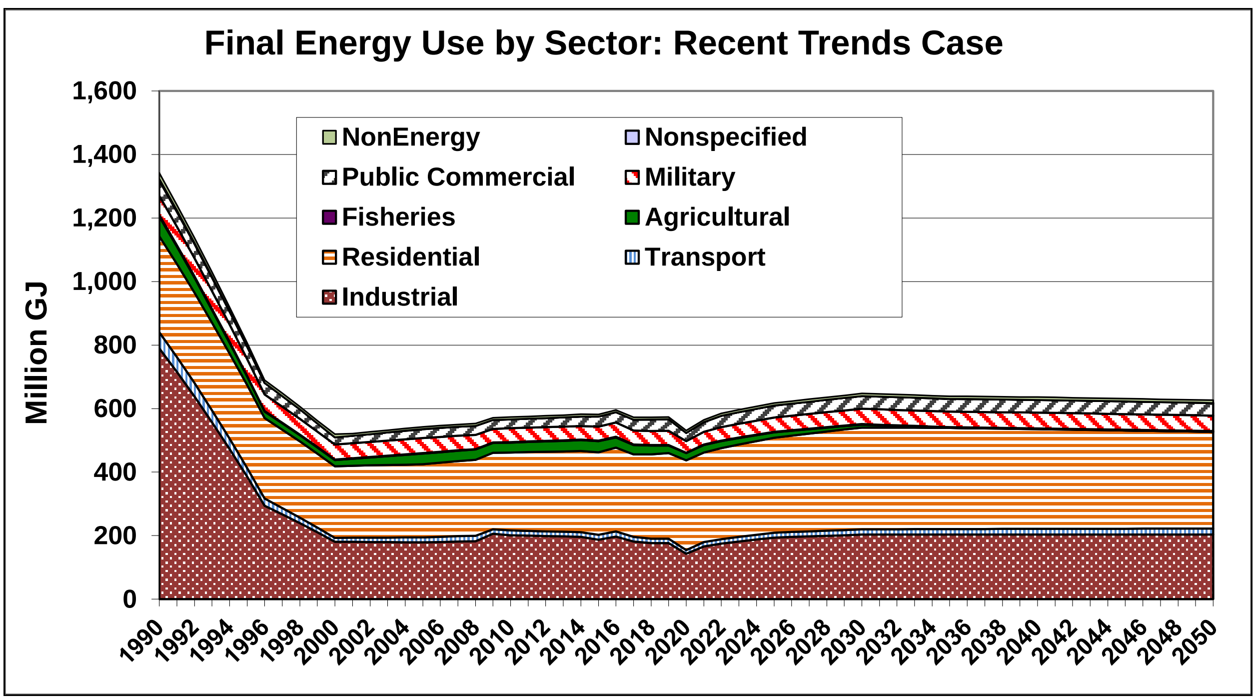


Figure 8-17: Final Energy Use by Fuel in Recent Trends Path

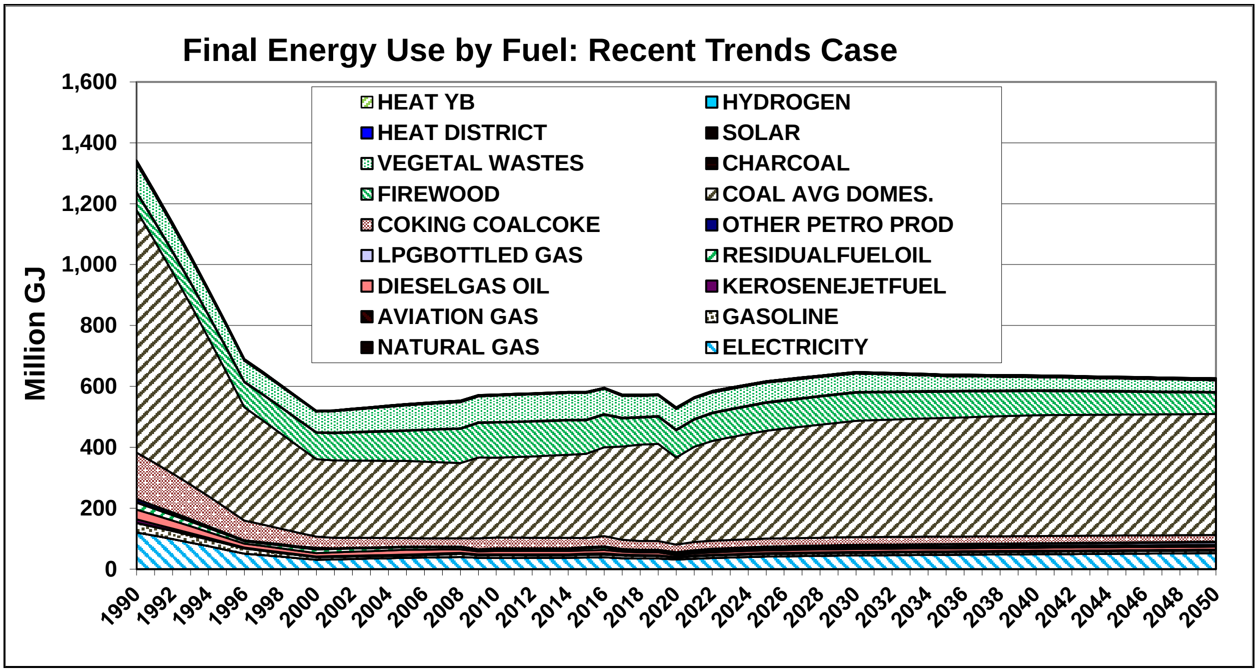


Figure 8-18: Electricity Output by Plant Type in Recent Trends Path

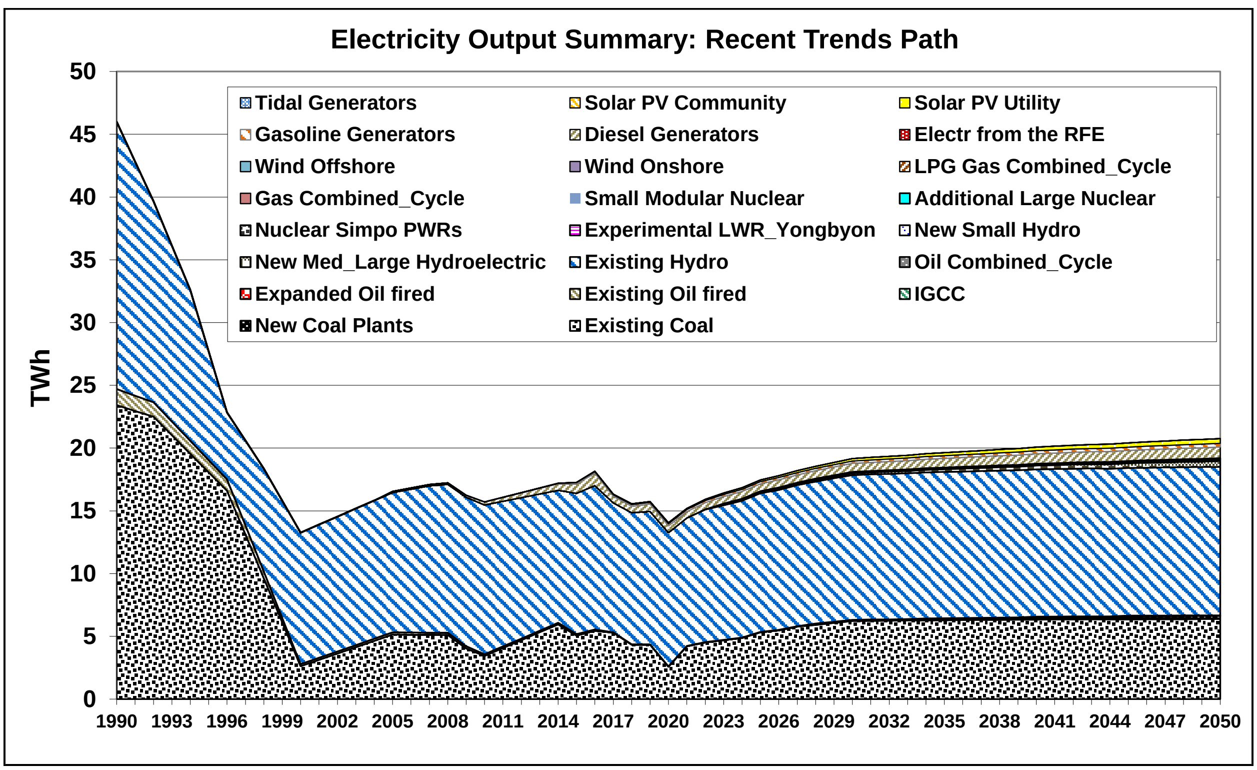
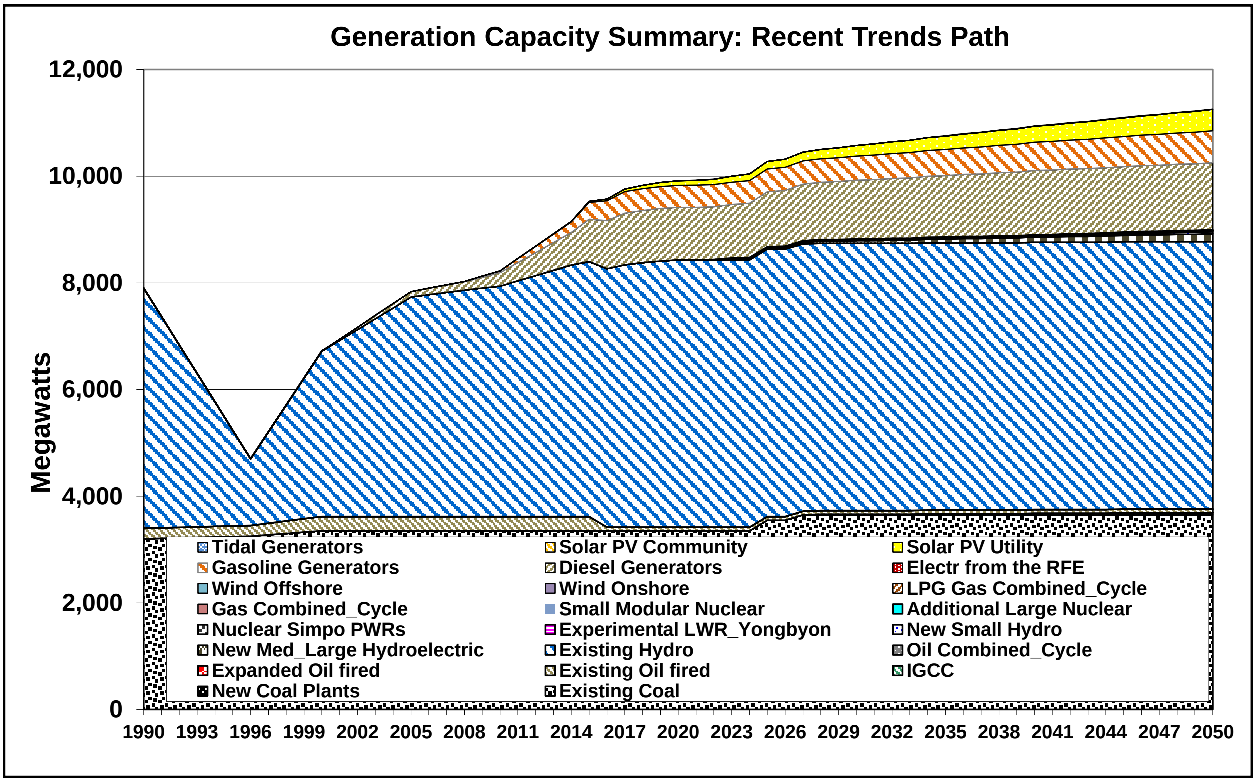


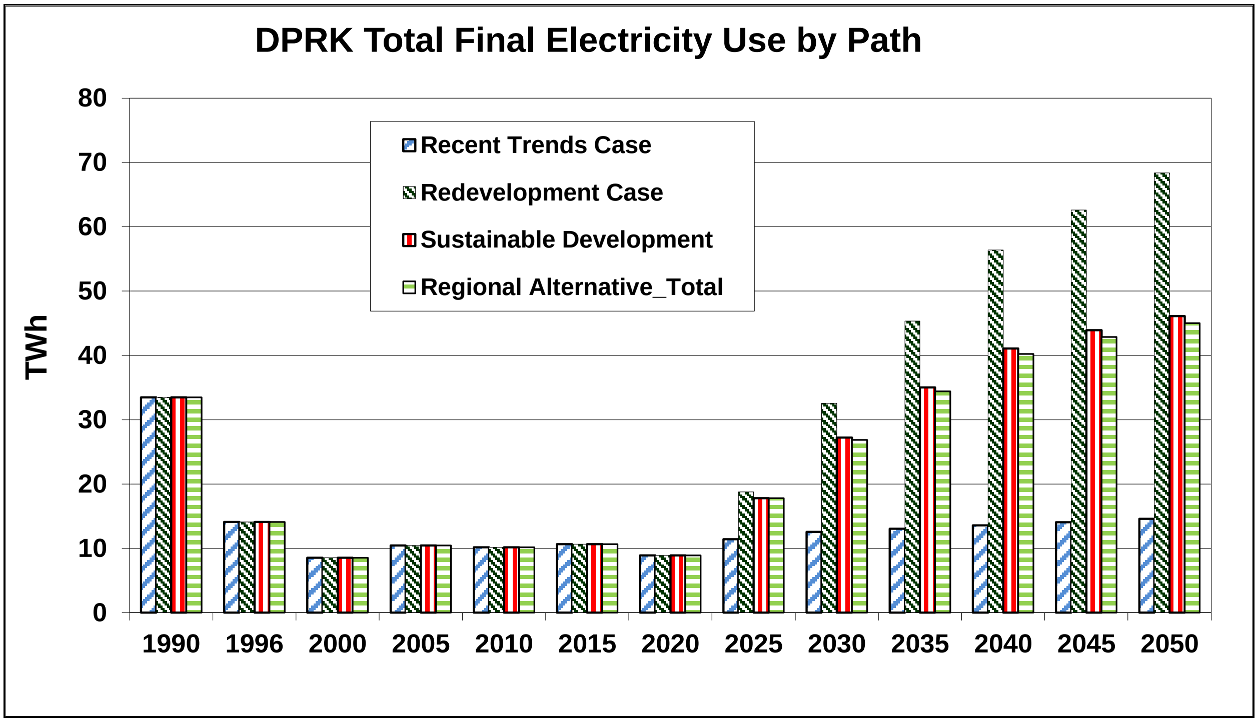
Figure 8-19: Electricity Generation Capacity by Plant Type in Recent Trends Path



8.4. Comparisons between DPRK Energy Futures Paths

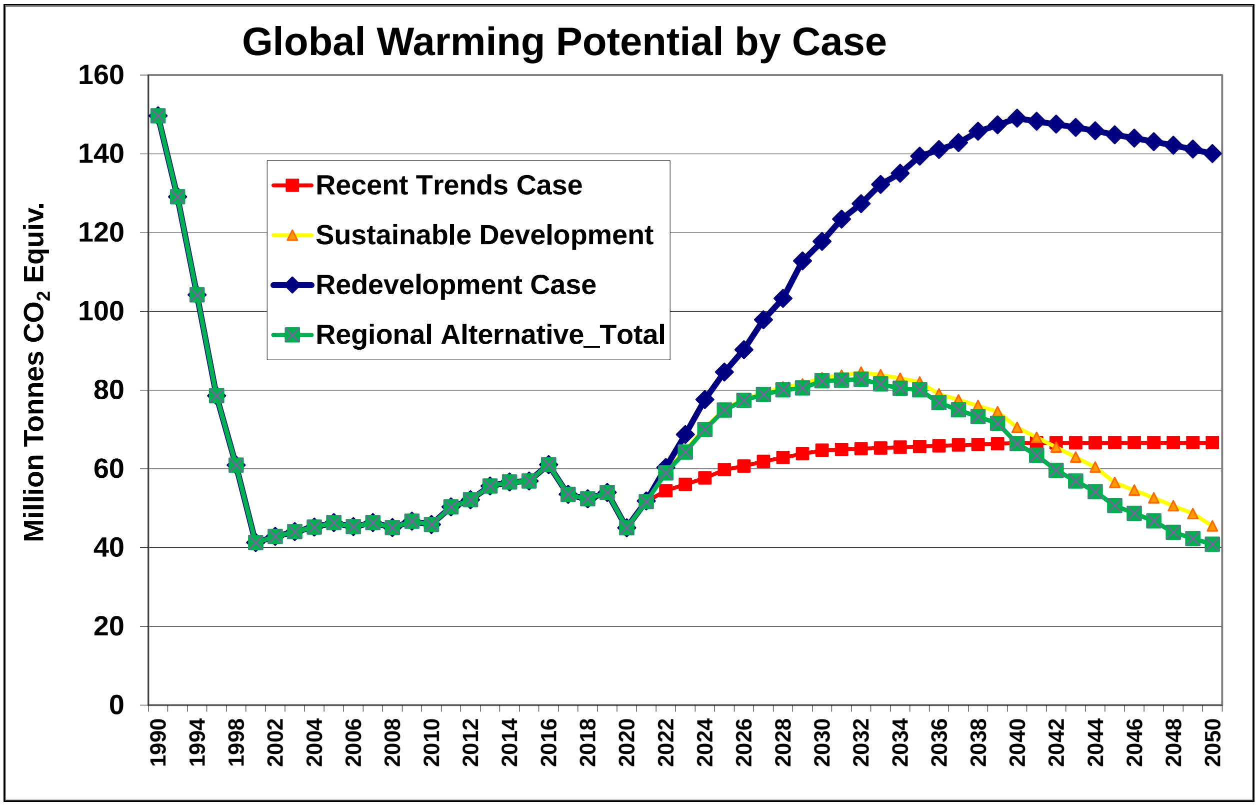
Figure 8-20 compares electricity use over time in the three paths evaluated, as well as in the "Recent Trends" path where a solution to the current impasse over the DPRK's nuclear program is not found, and large-scale economic redevelopment in the DPRK does not occur. Note that due to the aggressive implementation of energy efficiency measures, the consumption of electricity (and thus the need for power generation facilities) is less, by 2050, in the Sustainable Development and Regional Alternative paths (net of the capacity of the interconnection to the Russian Far East and the ROK), relative to the Redevelopment Path, even with the incorporation of more low-capacity-factor renewable power sources.

Figure 8-20: Total Electricity Use by Path



A result of aggressive energy efficiency and renewable energy implementation in the Sustainable Development and Regional Alternative Paths is that air pollutant emissions (including carbon dioxide and other greenhouse gases from the energy sector, as shown in Figure 8-21) are much lower in those paths by 2050. In addition, due to the efficiency gains, fuel switching to natural gas and electricity from coal use, and the substantial phase-out of coal from electricity generation, greenhouse gas emissions in the Sustainable Development and Regional Alternative cases are actually less by about 2040 and on, than emissions in the Recent Trends case, which provides much less in the way of economic output and services to the DPRK populace.

Figure 8-21: Total Carbon Dioxide Equivalent Emissions for Four Future Paths[815]



In addition, the energy efficiency and fuel switching in the Sustainable Development and Regional Alternative paths markedly reduce emissions of local and regional air pollutants relative to the Redevelopment case. For the Regional Alternative path, emissions, for example, emissions of carbon monoxide, sulfur oxides, and nitrogen oxides are estimated to be less than half that in in the Redevelopment case by 2050 (see Table 8-1 and Table 8-2).

Table 8-1: Estimated Local and Regional Pollutant Emissions, Regional Alternative Case

SUMMARY TABLE OF ESTIMATED EMISSIONS, REGIONAL ALTERNATIVE CASE (Thousand tonnes)

	1990	2000	2010	2020	2030	2040	2050
Carbon Dioxide (Fossil Sources)	132,565	35,765	38,566	37,854	70,463	58,056	36,688
Carbon Monoxide	1,610	1,040	1,170	1,106	1,043	657	392
Methane	778	248	331	326	547	383	188
Non-Methane Hydrocarbons	189	116	131	123	120	85	59
Nitrogen Oxides	499	132	160	135	222	198	112
Nitrous Oxide	2.4	1.0	1.1	1.0	1.2	1.0	0.6
Sulfur Oxides	1,414	380	404	403	653	472	235

[815] Global Warming Potential is a measure of how the radiative forcing of air pollutant emissions with direct or indirect impacts on climate compare, on a per unit basis, to that of Carbon Dioxide (CO_2). As such, it allows the tonnes of emissions of different pollutants to be totaled within a common metric, but CO_2 dominates the total.

Table 8-2: Estimated Local and Regional Pollutant Emissions, Redevelopment Case

SUMMARY TABLE OF ESTIMATED EMISSIONS, REDEVELOPMENT CASE (Thousand tonnes)

	1990	2000	2010	2020	2030	2040	2050
Carbon Dioxide (Fossil Sources)	132,565	35,765	38,566	37,854	99,996	127,151	123,077
Carbon Monoxide	1,610	1,040	1,170	1,106	1,333	1,237	1,061
Methane	778	248	331	326	818	1,009	775
Non-Methane Hydrocarbons	189	116	131	123	152	149	134
Nitrogen Oxides	499	132	160	135	358	547	555
Nitrous Oxide	2.4	1.0	1.1	1.0	1.8	2.3	2.2
Sulfur Oxides	1,414	380	404	403	879	1,115	955

Though costs on the demand side (for higher-efficiency equipment) are higher than in the Sustainable Development and Regional Alternative Paths than in the Redevelopment Path, offsetting savings in the transformation sector (mostly due to the reduced need for electricity generation capacity and coal mining, for example) and in resources (avoided fuel production and imports) mean that the Sustainable Development path is only slightly more expensive than the Redevelopment Path from and internal DPRK social cost point of view, and the Regional Alternative Paths is less expensive than the Redevelopment Path, overall, even before any credits are taken for avoided environmental impacts, as shown in Figure 8-22.

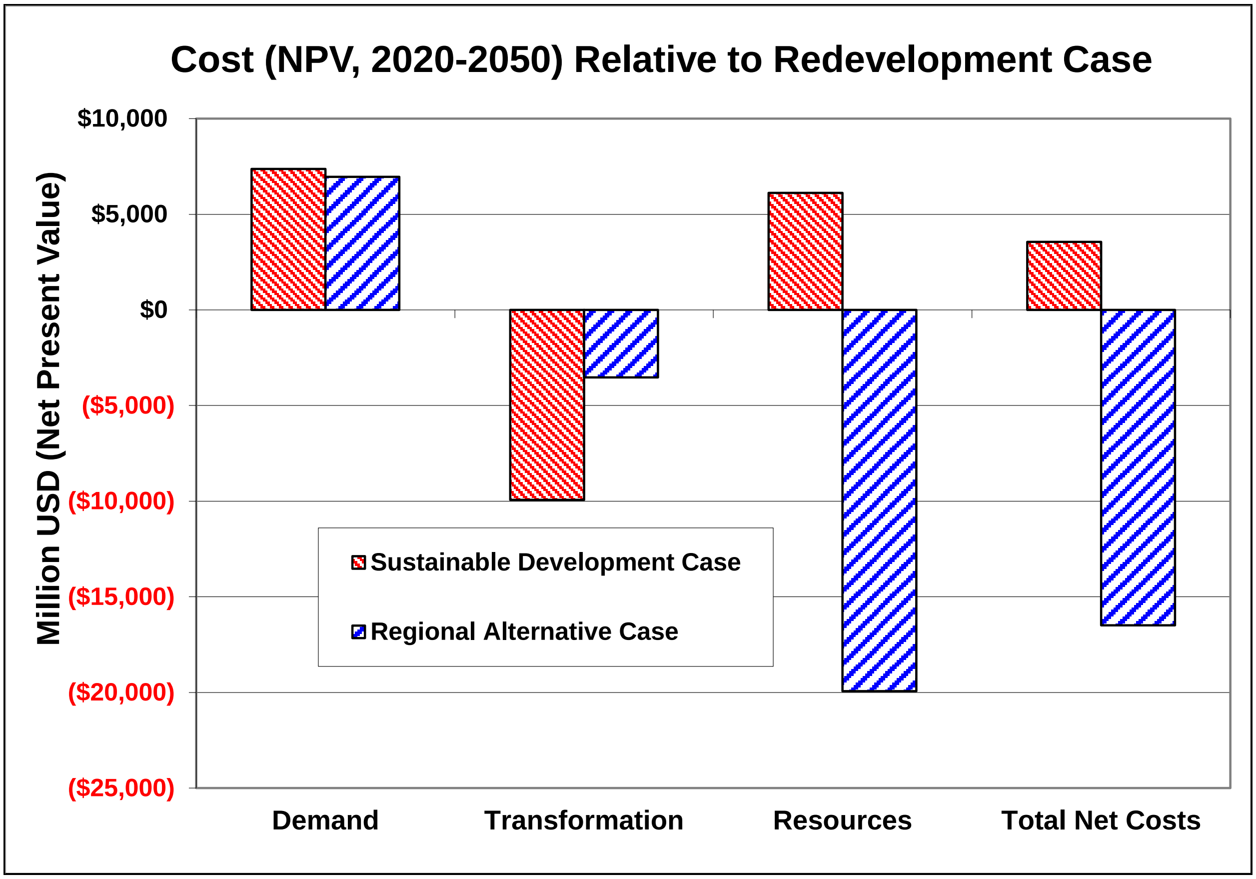
The Sustainable Development Path would in fact be less expensive than the Redevelopment Path but for the assumption in the former is that coal exports are phased out much more rapidly in the Sustainable Development Path, while continuing for longer and at a higher level in the Redevelopment Path. This assumption results in less resource income for the DPRK, as the exports in the Sustainable Development Path to the ROK of natural gas from the LNG terminal developed in the DPRK are less lucrative than coal exports due to a lower assumed price markup for imported LNG relative to the markup over costs of production for coal exported.   Even under these assumptions, however, the Sustainable Development path's net cost relative to the Redevelopment path results in a net discounted cost for avoided DPRK greenhouse gas emissions of about \$2.3/tonne CO_2 equivalent, which was, for example on the order of 14 percent of the price at which carbon allowances were trading on the Korea Exchange as of February 10, 2021, and as such, a relative bargain as an investment in greenhouse gas control, even without taking advantages of significant opportunities for cost optimization.[816]

Relative to the Redevelopment Path, the Regional Alternative Path features a modest reduction (10 percent) in the cost of demand-side energy efficiency measures, savings in (for example) electricity and coal production, resource costs for avoided fuel imports and production, plus net income from sales of electricity from a line from the Russian Far East to the ROK and of gas to the ROK derived from a pipeline from the RFE and from LNG terminals in the DPRK. These changes combine to make the net social costs within the DPRK of the Regional Alternative path significantly less, by \$17 billion on an NPV basis through 2050, than the Redevelopment Path,

[816] Korea Exchange (2021), "[50101] Daily / Closing price", accessed at http://global.krx.co.kr/contents/GLB/05/0506/0506030102/GLB0506030102.jsp on 2-12-2021, showed a price for carbon on the emissions trading system of about 19,000 ROK Won per tonne CO_2 equivalent, or about USD 17 per tonne.

while also reducing year 2050 greenhouse gas emissions in the DPRK by more than a factor of three, and by over 1.6 billion tonnes over 2020-2050.[817]

Figure 8-22: Social Cost Comparison of Three Future Paths



It should be emphasized again that the small number of future paths for DPRK energy sector development considered here are **illustrative**, and not intended to be "optimal" by any particular standard, so that there are many other paths that can and should be explored for the DPRK. Examples might include paths to get to "net zero" carbon emissions by 2050, similar to those recently published for the United States (for example).[818]

[817] In modeling the Regional Alternative and Sustainable Development Paths it was assumed that the shared infrastructure include—LNG terminals, and gas pipelines and electricity transmission lines passing through DPRK territory, would be owned and paid for by the DPRK, and the gas and electricity passing through them would effectively be purchased by the DPRK and sold at a higher price—about 10 percent—to the ROK to pay for a combination of the costs of owning and operating the infrastructure plus some "rent" to the DPRK for hosting the facilities. In practice, a number of other financing options are possible, including that the cost of the infrastructure was paid though some sort of international consortium or by an ROK company, with the DPRK receiving payments of some kind for hosting the facilities.

[818] See, for example, James H. Williams, Ryan A. Jones, Ben Haley, Gabe Kwok, Jeremy Hargreaves, Jamil Farbes, and Margaret S. Torn (2021), "Carbon-Neutral Pathways for the United States", *AGU Advances*, first published 14 January 2021, and available as https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020AV000284. Several other studies on of "net-zero" or "carbon-neutral" pathways for the United States and other nations have also been published recently, including a U.S. National Academies study reported on by John Fialka (2021), "New Report Maps Out the U.S. Road to Net-Zero Emissions" E&E News,

8.5. Energy Security Comparison of Future DPRK Paths

Three of the paths described as above—the Redevelopment path, the Sustainable Development path, and the Regional Alternative path—offer roughly the same energy services and economic development for the DPRK populace, and thus can reasonably be compared in terms of their energy security attributes. Below we apply the framework sketched out in previous work on techniques for energy security analysis by the authors and our colleagues to weigh the relative benefits and costs of the three paths.[819] Before doing so, however, consideration must be given to the perspective from which the comparison is made. Looking at even the broad suite of energy security attributes in our framework from the perspective of the DPRK's leadership (assumed, for the sake of this analysis, to be a continuation of the Kim regime), may yield quite different results from those prepared from the perspective of the international community. In considering the perspective of the DPRK's leadership, we acknowledge that there are, in fact, a number of different factions within the DPRK with different points of view, aspirations, and goals.[820] And further, indeed, the "international community can hardly be considered a monolithic bloc, though the agendas of the DPRK's neighbors and others, notably the United States, are in at least some cases (and probably increasingly, for at least Japan and the ROK, with respect to the US, since the change in US administrations in January 2020), arguably better aligned with each other than with the DPRK, at least where interactions with the DPRK are concerned. As such, in the remainder of this section we evaluate the merits of the Sustainable Development and Regional Alternative paths relative to the Redevelopment path with regard to each of the six energy security dimensions included in our framework, attempting to take the broad perspectives of A) the DPRK's leadership, and B) the international community, meaning the DPRK's neighbors and their allies.

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dated February 5, 2021, and available as https://www.scientificamerican.com/article/new-report-maps-out-the-u-s-road-to-net-zero-emissions/.

[819] The analytical framework for comparing the energy security costs and benefits of future energy paths was developed starting with work done as part of the Nautilus Institute's "Pacific Asia Regional Energy Security" project, including a summary of the PARES energy security analysis approach published earlier (see https://nautilus.org/projects/by-name/pacific-asia-regional-energy-security-1997-1998/), and developed in related articles, as well as articles published in an Asian Energy Security Special Issue of the journal Energy Policy. See, for example, Hayes, P. and D. von Hippel (2006), "Energy Security in Northeast Asia," *Global Asia* 1(1): 91–105; von Hippel, D. F., T. Suzuki, J. H. Williams, T. Savage, and P. Hayes. 2011. "Energy Security and Sustainability in Northeast Asia," Asian Energy Security Special Issue of *Energy Policy*, Volume 39, Issue 11, November 2011, Pages 6719-6730 (https://doi.org/10.1016/j.enpol.2009.07.001); and von Hippel, D. F., T. Savage, and P. Hayes. 2011. "Introduction to the Asian Energy Security Project: Project Organization and Methodologies," Asian Energy Security Special Issue of *Energy Policy*, Volume 39, Issue 11, November 2011, Pages 6712-6718 (https://doi.org/10.1016/j.enpol.2008.01.010). This approach has also been described in Chapter 3 of the *Routledge Handbook of Energy Security*, "Evaluating the Energy Security Impacts of Energy Policies", by David F. von Hippel, Tatsujiro Suzuki, James H. Williams, Timothy Savage, and Peter Hayes, dated December, 2010, and available from https://www.routledgehandbooks.com/doi/10.4324/9780203834602.ch3. Note that an updated version of the Routledge Handbook and of the Chapter is currently in process (as of 2020).

[820] See, for example, the discussion "What Does the DPRK Want?" in David von Hippel and Peter Hayes (2009), *DPRK Energy Sector Assistance to Accompany Progress in Denuclearization Discussions: Options and Considerations*, prepared for the project "Improving Regional Security and Denuclearizing the Korean Peninsula: U.S. Policy Interests and Options", dated October 2009, and available as http://www.ncnk.org/resources/publications/Hipple_and_Hayes_DPRK_Energy_Assistance.pdf.

8.5.1. Energy Supply Dimension

The Sustainable Development (SDV) and Regional Alternative (RALT) paths offer, by 2050, lower annual energy demand, primary energy use, and net imports, and more diversity by fuel type, than in the Redevelopment (RDV) path (see Table 8-3). Although our paths evaluation does not explicitly track the geographic source of all fuel imports to the DPRK, thus rendering impossible the quantitative calculation of a diversification index by supplier, it is virtually certain that the SDV path and, particularly the RALT path would show a more diversified portfolio of energy suppliers than the RDV path, in which energy supplies from China, and to a lesser degree, Russia, would likely continue to dominate, though the fraction of the DPRK's energy imports from China seems likely to decline over time (as overall energy use expands). We do not explicitly track stocks of fuels in the energy paths, as it is difficult to know the full extent of the DPRK's stocks (particularly of oil products) to begin with,[821] but it seems likely that the SDV and particularly the RALT scenarios, with their greater diversity of fuel types and infrastructure, such as LNG terminals, will offer a higher ratio of stored fuel to imports than the RDV scenario.

[821] Although it does not attempt to estimate the stocks of crude oil and oil products that the DPRK is currently holding, the following report provides an estimate of the potential volume of oil storage tanks in the DPRK: David von Hippel, Peter Hayes (2020), *Estimate of Oil Storage Capacity in the Democratic People's Republic of Korea*, NAPSNet Special Reports, August 25, 2020, available as https://nautilus.org/napsnet/napsnet-special-reports/estimate-of-oil-storage-capacity-in-the-democratic-peoples-republic-of-korea/.

Table 8-3: Energy Supply (and Demand) Dimension of Energy Security Comparison of DPRK Paths

Energy Supply Dimension Measure/Attribute	**Annual 2050 Values Relative to RDV**		**Implications of Values Relative to RDV from the Perspective of:**	
	SDV Path	**RALT Path**	**DPRK Leadership**	**International Community**
Total Energy Demand	-385 PJ	-405 PJ	Lower = better	Lower = better (but indirectly)
Primary Energy Use	-661 PJ	-587 PJ	Lower = better	Lower = better (but indirectly)
Fraction of Primary Energy as Imports (net of Exports)	31.0% (RDV 5.1%)	29.6% (RDV 5.1%)	Higher = Worse (more exposure to cost risk)	Mixed (Lower has better overall implications, but higher offers leverage)
Diversification Index (by fuel category, primary energy)	0.21 (RDV 0.55)	0.21 (RDV 0.55)	Lower = better	Indifferent, except with regard to indirect impacts such as on the environment and the regional economy
Diversification Index (by supplier, key fuel types)	Lower	Lower (and lower than SDV)	Lower = better	Mixed (Lower spreads risk among nations, but higher offers more leverage for individual nations)
Stocks as a fraction of imports (key fuels)	Likely Higher	Likely Higher (and higher than SDV)	Higher = better	Mixed (higher improves regional situation, but provides less leverage in the event of conflict)

From the perspective of the DPRK's leadership, lower energy primary and final energy demand, and particularly lower electricity and petroleum products demand, would seem preferable, as leadership would see less of a burden of supplying fuels to the DPRK economy. Lower diversification indices (indicating more diversity of supply) would also likely be preferable to the DPRK's leadership, as the DPRK's dependence on any individual fuel or supplier, and thus the influence that any given supplier or country might have over the DPRK, would be attenuated.

From the perspective of the international community as a whole, higher or lower DPRK energy demand is probably not of great concern in and of itself directly, though lower energy use implies lower environmental impacts, including impacts that cross national boundaries. The major exception here is likely to be the ROK. If one presumes that one day the Koreas will again be united, either officially or de facto, it will be much easier for the ROK to integrate into its economy a DPRK that has a modern, efficient energy supply and demand infrastructure than one that features a haphazard mix of new, older, and derelict equipment. For the international community, a DPRK that uses more different fuels and suppliers both spreads any risk of conflict over energy trades with the DPRK over more nations—which would likely be considered a good thing—but on the other hand could make it harder for the international community to reach consensus on actions restricting energy trade should the DPRK fail to follow up on commitments related to its nuclear weapons program. In addition, the interconnected energy infrastructure elements of the RALT path would improve the energy supply diversity, and thus perceived energy supply security, of neighboring individual countries, probably most notably the ROK.

8.5.2. Economic Dimension

As a result of the emphasis on end-use efficiency and renewable energy, the SDV and RALT paths offer significantly lower total energy system costs, lower fuel costs overall, and lower imported fuel cost (net of the value of fuel exported) than in the RDV path (see Table 8-4). It is likely that the DPRK leadership would see these lower costs as beneficial, as more hard currency could be used for other priorities. From the perspective of the international community, the implications of these lower costs are likely to be mixed, but modest. For example, lower fuel costs might enhance the competitiveness of the DPRK in certain industries (though other barriers to DPRK competitiveness are likely much higher), resulting in (marginally) increased competition for some industries in some nations, while on the other hand lower fuel consumption, particularly of traded fuels, could lower regional prices of some energy products, though this effect would be tiny due to the DPRK's small market relative to other nations in the region.

Table 8-4:: Economic Dimension of Energy Security Comparison of DPRK Paths

Economic Dimension Measure/Attribute	**Present Value 2020 through 2050 Relative to RDV (2020 USD)**		**Implications of Values Relative to RDV from the Perspective of:**	
	SDV Path	**RALT Path**	**DPRK Leadership**	**International Community**
Total Net Energy System Internal Costs	+$3.6 B	-$16.5 B	Lower = better	Indifferent (except in how differences in DPRK expenditures for specific goods are affected)
Total Net Resource Costs	+$6.1 B	-$19.9 B	Lower = better	Largely indifferent (Reduced or increased DPRK demand likely to have a negligible impact on regional prices, which are driven by demand from much larger economies)
Import Fuel Costs	Higher	Higher	Lower = better	
Economic and Employment Impact of Fuel Price Increase	Additional diversity in fuel types and sources helps insulate economy from increases in prices of individual fuels		Lower = better	Improvement in DPRK economic stability in the face of price increases would likely be seen as a positive
Economic and Employment Impact of difference between paths	Mixed, for example, coal mining sector lower, high-tech higher. In RALT, construction higher (pipelines, powerlines)		Mixed: implications depend on political power of individual groups affected	Probably positive, in that SDV and RALT paths will bring more North Koreans in contact with foreigners than RDV path

Reduced fuels demand, and thus costs, for domestically consumed fuels in the SDV and RALT paths, together with a greater diversity of energy sources in those paths, would likely render the DPRK economy less sensitive to price increases for individual fuels, which would be seen as a benefit by the DPRK leadership. Reduced fuel demand and increased diversity of fuel use would also, though indirectly, be seen as a benefit by the international community, which would prefer to see a more economically resilient DPRK, assuming that it was a DPRK that was also not threatening other nations. The SDV and RALT paths shift outputs between some DPRK industrial sectors, relative to the RDV path. For example, coal production would be decreased, the use of renewable fuels increased, and trades that worked on regional energy infrastructure—LNG terminals, gas pipelines, and transmission lines—would also benefit. The degree to which these changes would be perceived as positive by the DPRK leadership would depend upon which industries are more influential with DPRK leadership. The international community would probably see the shifts in economic emphasis under the SDV and RALT plans as a positive, as both, and particularly the RALT plan, offer more opportunities for teachers, engineers, technicians, and officials from outside the DPRK to engage with DPRK actors.

8.5.3. Technological Dimension

Table 8-5 provides our assessment of the relative merits of the SDV and RALT paths from a technological risk point of view. In general, the SDV and RALT provide greater diversity in terms of new technologies used (though this difference is not much reflected in the indices in Table 8-5, which do not distinguish between new and older technologies), which would probably be considered a benefit by DPRK leadership, but also offer some exposure to technologies with which the DPRK is not familiar. From the perspective of the international community, the DPRK's technological choices per se are probably not a large issue in a direct sense, though they may be of concern for other reasons, such as environmental risk or risk of nuclear weapons proliferation. The SDV path, with its greater diversity of technologies, is likely to improve the DPRK's adaptability to climate change risk or other stresses, though the addition of large regional infrastructure in the RALT case might arguably reduce the DPRK's ability to adapt to conditions favoring different energy technologies.

Table 8-5: Technological Dimension of Energy Security Comparison of DPRK Paths

Technological Dimension Measure/Attribute	**Value Relative to RDV**		**Implications of Values Relative to RDV from the Perspective of:**	
	SDV Path	**RALT Path**	**DPRK Leadership**	**International Community**
Diversification Indices for Electricity Generation Industry (as of 2050)	0.1907 (RDV 0.1977)	0.1888 (RDV 0.1977)	Lower = better due to demonstrated national capability in more technologies	Lower = generally preferred as developing DPRK markets for newer technologies
Diversity of R&D Spending	Higher in these paths than in RDV		Higher likely to be seen as better by leadership in most cases	Diversified DPRK R&D probably would be welcomed, particularly if it diverted funds from nuclear R&D
Reliance on Proven Technologies	Lower in these paths than in RDV		Lower might be seen as higher risk by DPRK leadership	Probably not a large issue for international community, as "new" technologies will not seem unproven outside the DPRK
Technological Adaptability	Likely higher in SDV path than in RDV path, though arguably somewhat lower in RALT than SDV due to inclusion of large infrastructure		Higher likely to be seen as better, though adaptability in the face of threats from other nations is likely to be considered as well as adaptability to environmental and other stresses	Improvement in DPRK resilience would likely be seen as a positive, assuming that the DPRK was no longer a military threat

8.5.4. Environmental Dimension

The Sustainable Development (SDV) and Regional Alternative (RALT) paths have much lower attendant annual emissions of greenhouse gases, acid gases, and "criteria" air pollutants (including sulfur and nitrogen oxides and particulate matter) in 2035 than does the Redevelopment (RDV) path (see Table 8-6). Other air and water pollutants would likely be reduced as well. The variants of the SDV and RALT paths without nuclear power would have less generation of nuclear waste and spent fuel than the RDV path, in which the DPRK pursues its domestic reactor program. For the variants that include large nuclear power units, generation of spent fuel and nuclear wastes would be much higher, but it is presumed that a precondition of construction (done mostly by organizations from outside the DPRK) and operation of new, large, modern LWRs (or small modular reactors, if that evolving technology is used in the DPRK) would be an agreement as to stringent monitoring and handling of spent fuel.

Table 8-6: Environmental Dimension of Energy Security Comparison of DPRK Paths

Environmental Measure/Attribute	**Annual 2050 Values Relative to RDV**		**Implications of Values Relative to RDV from the Perspective of:**	
	SDV Path	**RALT Path**	**DPRK Leadership**	**International Community**
GHG emissions (tonnes CO_2 equiv.) (RDV 140 Mte)	45 Mte	41 Mte	Lower = better (national image, CDM opportunities)	Lower = better
Acid gas emissions (ktonnes) (RDV 955 kte SO_x, 555 kte NO_x)	274 kte SO_x, 137 kte NO_x	235 kte SO_x, 112 kte NO_x	Lower = better (local impacts, national image)	Lower = better
Local Air Pollutants (tonnes)	Lower	Lower	Lower = better	Lower = better (but not a major concern)
Other air and water pollutants (including marine oil pollution)	Lower	Lower	Lower = better	Lower = better (primarily for neighbors)
Solid Wastes (tonnes coal ash)	Lower	Lower	Lower = better	Lower = better (but not a major concern)
Nuclear waste/spent fuel generation (tonnes or Curies, by type)	Lower (except variants with nuclear power)	Lower (except variants with nuclear power)	Mixed (less waste to manage, but less potential fissile material in the event of a breakdown in rapprochement)	Lower = better (variants with nuclear power would presumably include/require stringent IAEA management of spent fuel)

From the perspective of the DPRK leadership, the reduction in greenhouse gas emissions is likely to be seen as an enhancement in the DPRK's international stature, as well as an opportunity for profiting by implementing greenhouse gas reduction measures under the clean development mechanisms (CDM) provision of the Kyoto Protocol. Though they might be less of concern to the DPRK leadership than in other nations, reductions in acid gas and local air and water pollutants, and their attendant impacts, would likely be seen in a favorable light, and would probably be recognized as an achievement by the Kim Jong Un regime. Though the variants of the SDV and RALT paths without large new nuclear plants would generate less nuclear waste and spent fuel than the RDV path, which assumes completion of the small Experimental LWR unit that has been under construction at Yongbyon, that might be seen by the DPRK leadership as both good (less waste to dispose of) and bad (less potential fissile material, in case bets on continued improvements in relations with the international community need to be hedged).

From the perspective of the international community, the reduced greenhouse gas and acid gas emissions in the SDV and RALT paths would be seen as a positive, since emissions of these potentially transboundary pollutants could have impacts beyond the DPRK. Other air pollutant emissions reductions, though local in nature, might make them less of a concern, except, for example, in immediately adjoining regions of neighbors' territories (the ROK, China, and Russia) that share waterways and other environmental resources with locations in the DPRK. The reduction in nuclear waste/spent fuel production between the RDV and the SDV/RALT paths would be considered significant positive by the international community.

8.5.5. Social and Cultural Dimension

From the perspective of the DPRK's leadership, the SDR path, which implies significantly greater interaction between a wide range of DPRK citizens and an equally wide range of actors from outside the DPRK, would likely be seen as substantially riskier than the RDV path, though even the RDV path involves significant interaction with the outside world, albeit in perhaps a less-planned way. The DPRK's leadership would probably see those interactions as threatening because they would further weaken leadership's ability to control the flow of information and ideas, exacerbating the potential for internal conflict. The addition of the requirement to work jointly with foreigners to manage international infrastructure in the RALT path probably, from the perspective of DPRK leadership, adds to that risk, although it offers monetary and other benefits that would be considered attractive.

The international community, on the other hand, would see shifts from the RDV to the SDR and, especially, the RALT path as a positive for an almost opposite set of reasons—namely that exposure of DPRK citizens to ideas and people from outside the DPRK would reduce the risk of conflict between the DPRK populace and foreigners by increasing the understanding that DPRK citizens have for the outside world. The view of the shift from the RDV path to the other paths as being advantageous will likely be shared by most other nations, but may be tempered, in the case of China and Russia, by fears that a DPRK populace that knows more about the outside world might be more likely to run for their borders in the event of an internal crisis in the North.

8.5.6. International Military/Security Dimension

From the perspective of the leadership of the DPRK, it is likely that the SDV path, which depends more on other nations for technological know-how, and requires the DPRK to allow probably a wider range of visitors to a wider range of places than the RDV case, would be seen as offering greater exposure to military security risks. The RALT path would have similar features, but would also include the double-edged sword of major shared energy facilities, which would both provide a weapon to the DPRK via the potential threat of interrupting the flow of energy to/from the other partners sharing the infrastructure, and would also provide a vulnerability in that the other partners could also threaten to shut down the flow of gas or electricity, with impacts both on the DPRK energy sector and on the national budget. The RALT path might require the DPRK to spend more, for example, on guards and monitoring equipment, to securing the portion of the shared infrastructure that passes through the DPRK than it otherwise might need to spend to secure its own infrastructure.

The international community would likely see the SDV path, with its increased engagement between the DPRK and other nations, as reducing military/security risks by giving the DPRK more reasons to avoid confrontation with other nations. The RALT path would likely be seen as going even further in the direction of encouraging interaction, and discouraging confrontation, by increasing the drawbacks (in the form of forgone income and available resources) to behaviors that would upset the other members of the consortium. To the extent that, over time, the SDV and RALT paths would result in a reduction in military tensions in the region, they would also result in a reduction in the requirement for military-related spending, both by the DPRK and by others, though it is likely that the partners in shared international energy infrastructure under the RALT path would, like the DPRK, need to allocate funds to guard and monitor the pipeline, powerline, and LNG facilities included in the path.

8.6. Internal Policy and Legal Reforms to Stimulate and Sustain Energy Sector Rebuilding in the DPRK

There are several areas in which DPRK policies must be revised if the DPRK energy sector is to be rebuilt within a more open economy. The ROK and other nations could assist in the process of learning and phasing in the types of reforms that will be necessary. Some of the areas in which policy reform is called for are described briefly below.

8.6.1. Reform of energy pricing practices and the physical infrastructure to implement them

Hand in hand with rebuilding of energy supply infrastructure should go the rebuilding of end-use equipment, but accomplishing the former in a cost-effective manner is in large part dependent on making sure that new end-use equipment is purchased and operated with an eye toward efficiency. The economic levers of prices, in a market economy, are important tools for helping to make sure that energy is used wisely, as has been frequently underlined by Professor William Brown of Georgetown University and other analysts.[822]

Before adopting market style pricing of energy commodities, ***the modification of existing incentives facing plant managers and relevant officials*** is needed to encourage more efficient use of energy. Some of these reforms have begun in the DPRK, but the process remains in its infancy, and issues related to corruption by officials and "black market" activity may well have to be addressed as reforms are implemented. Despite some problems, quota management and administrative measures were key to China's success in eliminating many of the worst energy

[822] See, for example, William Brown (2018), "Special Report: North Korea's Shackled Economy (2018)", *The National Committee on North Korea*, dated March, 2018, and available as https://www.ncnk.org/resources/briefing-papers/all-briefing-papers/special-report-north-koreas-shackled-economy-2018.

inefficiencies in its industrial sector, and in stimulating adoption of relatively more advanced techniques and technologies. Although inappropriate to a market economy, a well-designed program of administrative measures would effectively utilize the strengths of the DPRK's current form of government, and would be a first step toward a more efficient energy economy[823].

Reforming energy pricing is a longer-term goal. Before market forces of any kind can help to spur the implementation of energy efficiency measures (or choices of efficient, rather than the cheapest, equipment on the supply side), the prices for energy products in the DPRK must be adjusted towards their actual costs of production. This adjustment must include products that are currently not priced at all. Pricing of some energy products, particularly electricity, will require the implementation of metering and billing systems (some of these changes are reportedly underway, at least in the Pyongyang area of the DPRK, as noted in previous chapters in this report). To be effective, parallel reforms that sensitize local decision-makers to prices (that is, that allow, for example officials responsible for purchase of industrial equipment to benefit from energy cost savings by retaining the savings for their organization) must be implemented.

One way to modify existing disincentives for energy efficiency is to ***promote changes in physical infrastructure that will facilitate energy decision-making.*** In previous reports (and in brief above), we have discussed some of the types of energy-using equipment and other infrastructure in the DPRK that could be targeted for replacement or rehabilitation. What has been emphasized relatively less, but is at least as important, is the need to invest in equipment that allows flows of energy to be controlled and quantified adequately. Such equipment includes electricity, heat, and hot water meters; steam and process control valves and shunts; and dimmers and other equipment for controlling lighting. Applications for such equipment exist throughout the residential, commercial/public/military, and industrial sectors. Without such equipment--which typically is inexpensive and relatively easy to install and operate--any attempt to institute price signals in energy markets, or even to reward reduced energy use in other ways, will be futile, as end-users will lack the ability to control energy flows, the quantitative feedback that tells them whether efforts to reduce energy use have succeeded, or—worst of all—both.

8.6.2. Training for energy sector actors

Recovery of the DPRK economy, and modification of the DPRK’s energy and industrial infrastructure, will require that a wide spectrum of energy sector actors—from analysts in planning institutions to building maintenance personnel—receive training on topics varying from long-range energy planning (as noted above) to operation and maintenance of commercial boilers. Here, regional cooperation will be helpful in making experienced personnel available to train their counterparts in the DPRK.

In particular, if energy efficiency and renewable energy are to be successful in the DPRK—and these may be the areas where, given stated interest on the part of the DPRK government, and the

[823] That the DPRK is aware of this need for managerial reform is suggested by a recent article in the newsletter North Korea Today, number 65, published by Good Friends, and dated 3/28/07 (in Korean—available as http://www.goodfriends.or.kr/download/newsletter/newsletter65.pdf). The article on the DPRK electricity situation notes that Kim Jong Il has stressed the need to increase the rate at which new hydroelectric and thermal power generation capacity is built, and that the DPRK is looking for aid and/or investment to help solve the energy shortage, but at the same time realizes that there are problems of management inefficiency that might hamper reform of the power sector, and is in the process of replacing the managers currently running the electricity and water facilities in the DPRK with "experts"—presumably meaning managers with more technical training and background in the specific industries. (Content of article paraphrased by Tim Savage of Nautilus Institute).

potential small unit size of assistance efforts, it will be possible to start the earliest energy cooperation projects with the DPRK—it will be necessary to ***provide specific information and training to local actors.*** Training of a very specific and practical nature must be provided to personnel at the local level. Examples here are factory energy plant managers, boiler operators in residential and commercial buildings, power plant and heating system operators, and new job classifications such as energy-efficiency equipment installers and energy auditors. The departure of Soviet/Russian assistance after 1990 (or at least much of it) has left a vacuum of technical expertise that, according to some observers, very much persists to this day. The sort of training described above is therefore both badly needed and a necessary complement (or, more probably, precondition) for any other type of technical assistance to the DPRK energy sector.

8.6.3. Strengthening regulatory agencies and educational/research institutions in the DPRK

There is and will be a definite need to strengthen a variety of North Korea's government institutions through a combination of provision of information, persuasion of leaders, training of personnel, and supplying institutions with needed equipment. Many of these tasks have been started (or at least attempted) through initiatives of the United Nations Development Programme (UNDP) and other ongoing programs.

One general area in which DPRK institutions could be strengthened is in their ability to ***develop and implement practical standards, and to enforce them.*** DPRK officials have made general statements about their support for energy efficiency and environmental protection. The next step is to codify these in terms of quantitative standards for the efficiency of new appliances and equipment, as well as effluent/emissions standards for new—and perhaps eventually, existing—factories, power plants, residential heating boilers, vehicles, and other major sources of pollution. Once standards are set (or adapted/adopted from other nations), it will be necessary to create the capability to enforce them by recruiting and training enforcement personnel and supplying them with the tools necessary to do their job (measurement and testing equipment, and adequately equipped analytical labs, for example) and the high-level administrative and political support needed for credible implementation of sanctions.

Standards for specific energy consumption (for example, the amount of energy needed to produce a unit of physical, and sometimes economic, output) have long been used in China to gauge performance of and within industrial and other enterprises. Issued nationally, and often tailored to conditions specific to individual enterprises, these standards have been used to measure progress in improving efficiency and have formed the basis of a system of financial and other awards. It is, in effect, a system of performance evaluation that parallels that evaluations based on output levels and product quality. This system is losing its effectiveness as China's transition to a market-oriented economy has progressed (although it has recently been revived somewhat as a tool for greenhouse gas emissions reduction in China) and the central planning apparatus becomes less important, but it may still be quite appropriate for the DPRK at this time, if temporarily during a transition toward a market system.

There is not as yet in the DPRK, a single ***center of technical excellence*** that is devoted to the study and promotion of *energy efficiency and renewable energy* opportunities, although there are various institutes tasked with issues in these areas. We would encourage the formation of such an institution, which could be modeled on existing institutions like the Beijing Energy Conservation Center and a similar Center in Russia. The Center in China was established jointly with the Battelle Pacific Northwest Laboratory and the Lawrence Berkeley National Laboratory (both U.S. government-sponsored organizations with extensive experience in energy demand issues), and the Center in Russia was founded with Battelle.[824] It is possible that the Center for the Rational Use of Energy (CRUE), formed during the early 1990s within the existing DPRK Institute of Thermal Engineering under a UNDP project, could be strengthened through a combination of North Korean and extramural support into such a center of excellence. The first step will be to start training current CRUE staff in the fundamentals of energy-efficient technologies and analysis.

8.6.4. Involving the private sector in investments and technology transfer

Much of the money and other assistance necessary to help the DPRK toward recovery will have to come from the more flexible and fast-moving private sector. If substantial private-sector financing for DPRK projects is to be forthcoming, it is likely that inducements and guarantees—possibly supplied by other governments of the region—will be necessary in order to mediate, at least initially (but perhaps for years), the risks of dealing with the DPRK. Chinese entrepreneurs have already established many operations in the DPRK, though it is not clear to what extent the Chinese government has provided support for these ventures.[825] ROK businesses and organizations have also, during the last decade, started businesses and joint ventures in the DPRK, with mixed (and sometimes transitory) results.

One way that the governments of the region, including the DPRK government, and governments of other countries with an interest in what happens on the Korean Peninsula (including the United States) can help in this regard is to *promote joint ventures and licensing agreements*. The government of the DPRK, and other interested parties, should promote joint ventures and licensing agreements between DPRK concerns (governmental or otherwise) and foreign firms with energy-efficient technologies to produce. Compact fluorescent light bulb factories were at one time a commonly cited example of potential energy technology transfers,[826] [827] and our understanding is that in the 2000s a factory for local production of CFLs has been set up in the DPRK. As technology has moved on, at this point, joint venture manufacturing of LED lighting in the DPRK might be an interesting choice, though the key electronic components of LED lamps would probably need to be imported for at least several years before a workable modern electronics industry could be built in the DPRK, as well as a stable electricity grid to power both the manufacturing and the lighting products it would produce. Solar photovoltaic panel manufacturing is another potential obvious joint venture, and one with some historical precedent, as there have apparently been examples of factories that (probably) assemble PV panels from solar cells imported from China.[828]

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[824] Chandler, W. U., Z. Dadi and J. Hamburger (1993), U.S. - China Cooperation for Global Environmental Protection. Pacific Northwest Laboratory, Richmond, Washington, USA. Chandler, W. U. (1993), AISU's China Program Update June 1993. Battelle, Pacific Northwest Laboratory, Richmond, Washington, USA.

[825] Judging from anecdotal reports of some Chinese businesses that have had difficulty reaching profitability in trading with the DPRK, it is unclear to what extent the Chinese government actively supports these ventures.

[826] Sathaye, J., R. Friedmann, S. Meyers, O. de Buen, A. Gadgil, E. Vargas, and R. Saucedo (1994), "Economic Analysis of Ilumex: A Project to Promote Energy-Efficient Residential Lighting in Mexico". Energy Policy, February 1994, pp. 163 - 171.

[827] We have been told by a delegation from the DPRK that a CFL factory has been set up in the DPRK, though it is not clear to us whether this factory is a joint venture or a domestic DPRK enterprise.

[828] See, for example, James Pearson (2015), "In North Korea, solar panel boom gives power to the people", *Reuters*, dated April 21, 2015, and available as https://www.reuters.com/article/us-northkorea-solar/in-north-korea-solar-panel-boom-gives-power-to-the-people-idUSKBN0NC2FG20150422.

As examples of technology transfers, a wide variety of efficient industrial equipment and controls (including adjustable-speed drive motors and improved industrial and utility boilers), efficient household appliances and components, and efficient building technologies have already been introduced to China through commercial channels, and are being widely manufactured there—and, indeed, exported to the world. A similar process for similar devices is possible for the DPRK.

Wind turbine-generators are another intriguing possibility, given the apparent success of such ventures in former East-bloc nations and China,[829] and the North Koreans' historical emphasis on machinery manufacture. Foreign firms that have successfully transferred efficient and renewable technologies to China, Russia, and Eastern European nations represent a valuable repository of experience that could be applied to similar efforts in the DPRK. Depending on how fast the Tumen River Economic Development Zone develops (infrastructure in the area is not yet adequate to support major industry, and relatively little progress in fulfilling the initial plans for the Zone has occurred in recent years, though bilateral action between China and the DPRK and Russia and the DPRK has occurred around ports and other transport facilities in the region in recent years), this area could be the location most acceptable to the DPRK for the first such ventures, along with the Kaesong Industrial Zone in the southern DPRK. It is likely that the foreign companies that would participate in joint ventures in the DPRK will require guarantees not only from the DPRK government, but also from their own government or another industrialized-nation or a multilateral donor, and will require those guarantees for years until the DPRK's legal and regulatory systems evolve to operate consistent with the practices of typical industrialized nations.

Before any of these types of ventures can be initiated, however the DPRK will have to implement, and show the international community that it is adequately enforcing, laws to protect the intellectual property and investments of foreign companies doing business in the DPRK. A description of all of the areas in which such laws are required, and the reasons why they are needed, is, however, beyond the scope of this report.

[829] Martinot, E. (1994), *Technology Transfer and Cooperation for Sustainable Energy Development in Russia: Prospects and Case Studies of Energy Efficiency and Renewable Energy*. Energy and Resources Group, University of California at Berkeley, Berkeley, California, USA. [Summary of a Ph.D. Dissertation - Draft]

9. DPRK "Collapse" Pathways: Implications for the Energy Sector and for Strategies of Redevelopment/Support

9.1. Introduction[830]

The prospect for the DPRK (Democratic People's Republic of Korea) and its leadership remains unsettled. The succession of power to Chairman Kim Jong Un following his father Kim Jong Il's death appears to have proceeded relatively smoothly, albeit with expected forced changes in upper-tier leadership as the younger Kim has consolidate his political power. There is as yet little sign, however, given the economic and energy sector situation described in the earlier chapters of this report, that the economic poverty of the vast majority of DPR Koreans will change for the better in the near future. The external powers continue, as of 2021, to squeeze the DPRK with sanctions over its nuclear weapons program, and even the change in administrations in the US in early 2020 may not markedly change the sanctions regime without some sort of diplomatic breakthrough. Inflation occurred in the aftermath of the currency redenomination failure of 2010, and droughts and floods have continued to plague DPRK agriculture even through 2020.[831] External aid will be minimal so long as the nuclear weapons issue remains unresolved.

This dismal future does not mean the DPRK is about to collapse. "Collapsists" have been arguing since the end of the Cold War that the DPRK "is about to collapse."[832] Many scenarios, including a persistent, slow recovery and gradual modernization of the DPRK, are possible.[833] The continued survival against all apparent odds of the DPRK is not regarded as refutation of the collapsist prediction. Nor apparently does the DPRK's regime pose a longevity worthy of investigation and explanation. Apparently, the only way to prove the prediction is to wait for the predicted outcome, at which time the prediction has a *post-ad hoc* character of truth after the fact. Thus, we should tread warily when it comes to claims about the prospective nature of collapse in the DPRK.

There is a reason, we suggest, that the DPRK has outlasted every other statist, personalized regime since the end of the Cold War. The DPRK is different, it is unique, and it represents a sample of one. It is hard to conduct authentic social science with a sample of one, especially from a distance. Moreover, this sample of one is intimately connected with and arguably

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[830] Much of the text presented in this chapter was developed for a paper originally prepared as part of The Korea Project, co-organized by the Korean Studies Institute at the University of Southern California and the Office of the Korea Chair at the Center for Strategic and International Studies, Washington D.C., and presented at the conference "The Korea Project: Planning for the Long Term" Conference, August 20-21, 2010, Los Angeles, USA. Versions of that paper are available as http://csis.org/files/publication/101215_Collapse_Pathways_North_Korea.pdf and as http://nautilus.org/napsnet/napsnet-special-reports/dprk-collapse-pathways-implications-for-the-energy-sector-and-for-strategies-redevelopmentsupport/.

[831] See, for example, Benjamin Katzeff Silberstein (2020), "The North Korean Economy: Assessing the Flood Damage", *38 North*, dated October 16, 2020, and available as https://www.38north.org/2020/10/bkatzeffsilberstein101620/.

[832] See, for example, Bryan Kay, staff reporter: "Is Collapse of NK Regime Imminent?" *Korea Times*, November 15, 2009, at: http://www.koreatimes.co.kr/www/news/nation/2010/08/120_55550.html, and Aidan Foster-Carter, "The Gradualist Pipe-Dream: Prospects and Pathways for Korean Reunification," in ed. A. Mack, *Asian Flashpoint: Security and the Korean Peninsula*, Canberra: Allen & Unwin, 1993, 159-175.

[833] J. Witt, *Four Scenarios for a Nuclear DPRK*, US-Korea Institute, Working Paper 10-01, February 2010, at: http://uskoreainstitute.org/bin/s/g/USKI_WP10-01_Wit.pdf

inextricably linked with the status of United States policies towards the DPRK. The DPRK and the US national security state were born in war with each other; they have remained at war for nearly six decades; they are at war today. In our view, one cannot analyze the prospects for change in the DPRK without simultaneously analyzing the rates and types of change in US foreign and military policy.

Rather than outright collapse in the next decade, far more likely is either a "slow burn" by which we mean continuing slow degradation of the economy and consequent adaptation at local levels to tighter scarcity constraints; or a very slow recovery nurtured by economic reforms, buttressed by external support from and trade with China, and large-scale labor exports; or a faster recovery based on rapprochement with the ROK and the integration of DPRK state-owned-enterprises with the ROK's chaebols.

In an overall spectrum of possibility, we estimate that the non-collapse pathways dominate, covering roughly 95 percent or more of the policy spectrum. In this 95 percent plus range, the primary question is what support and reconstruction policies are available to avoid outright collapse, the outcome that is most likely to lead to loss of control of fissile material, nuclear warheads, people, and escalation to war via civil war or cross-DMZ war. Many, perhaps most, of the policy responses needed to avoid collapse are the same as will be needed in the case of outright collapse.[834] The main difference in the post-collapse pathways is greater scale and speed and therefore cost needed to re-establish stability rather than to merely maintain it. Perhaps there is an obvious lesson in economics of policy choice in that difference.

The biggest single qualitative difference between non-collapse and collapse pathways will be in the military dimension after a DPRK regime collapse. Obviously, the highest velocity policy response in the case of DPRK collapse will be the moves by the ROK military (in particular, its special forces) to occupy and control key leadership posts, military bases, critical infrastructure, and transport chokepoints. How long this intervention would last is impossible to know in advance, but it could be held in place for many months or even years, depending on the degree to which local populations comply with the legitimacy of the occupying forces as against rebel against perceived injustices inflicted during the takeover. This policy response has its energy implications, both in its execution, and in its implications for energy sector reconstruction and immediate humanitarian assistance to the DPRK population. We do not cover, however, the military-energy aspects of establishing post-collapse control of the DPRK in this chapter, although we review the implications for post-war reconstruction of how a war might be fought with the DPRK.

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[834] We have outlined in detail appropriate policy options for this goal in, for example, von Hippel, D.F., and P. Hayes (2009), "DPRK Energy Sector Development Priorities: Options and Preferences", Asian Energy Security Special Issue of *Energy Policy*, and available as http://dx.doi.org/10.1016/j.enpol.2009.11.068; von Hippel, D.F., and P. Hayes (2007), *Fueling DPRK Energy Futures and Energy Security: 2005 Energy Balance, Engagement Options, and Future Paths* (Nautilus Institute Report, available as http://nautilus.org/wp-content/uploads/2012/01/07042DPRKEnergyBalance.pdf); von Hippel, D.F., and P. Hayes (2007), "Energy Security for North Korea", Science, volume 316, pages 1288 – 1289, June 1, 2007; von Hippel, D. F., P. Hayes, J. H. Williams, C. Greacen, M. Sagrillo, and T. Savage, 2008, "International energy assistance needs and options for the Democratic People's Republic of Korea (DPRK)". *Energy Policy*, Volume 36, Issue 2, February 2008, Pages 541-552; and D. von Hippel and P. Hayes, *DPRK Energy Sector Assistance to Accompany Progress in Denuclearization Discussions: Options and Considerations*, produced as part of the project "Improving Regional Security and Denuclearizing the Korean Peninsula: U.S. Policy Interests and Options.", organized by Joel Wit of Columbia University's Weatherhead Institute for East Asia and the U.S.-Korea Institute at the Johns Hopkins University School of Advanced International Studies, Washington, D.C., and available as http://nautilus.org/wp-content/uploads/2011/12/vonHippel.pdf.

In spite of these caveats and our best judgment that collapse is unlikely, it is conceivable and therefore should be addressed. Indeed, we have observed situations in the DPRK where the fabric of rural life was literally coming apart, and the demands on individuals and social units were beyond what would in most conditions be considered the bounds of human endurance. By collapse, however, we have a specific meaning in mind in this chapter, namely, the complete breakdown of central government in Pyongyang. Given the number of interacting internal and external variables that affect the probability of DPRK collapse in the long-term (ten plus years), that probability is simply unknowable. Thus, we will concentrate largely on the short to medium- term in our analysis.

Whether precipitated by war, coup, or simply continuing slow economic decline, it will be incumbent on the international community to help to provide services and support to stabilize North Korea in the unlikely event of outright collapse. Fortunately, many of the measures that would for stabilization are the same as should be undertaken in the non-collapse pathways. Among the many likely needs of the North Korean population following a collapse—food, clean water, heath care, and economic development among them—the need to promptly provide the population with reliable and demonstrably improving access to energy services (heat, light, mechanized transportation, and so on) will be a key to stabilizing the country, meeting other post-collapse needs, and readying the DPRK for eventual smooth (one hopes) integration with the ROK. In this paper, we begin, in a largely qualitative way, the exploration of the implications of various DPRK "collapse" pathways for the energy sector of the North Korea, and for the approaches that the Republic of Korea and other interested parties will need to take to rebuild and redevelop the DPRK energy sector, and in planning for same.

The remainder of this Chapter is organized as follows:

- **Section 9.2** provides a summary of the background on the status of the DPRK energy sector relevant to the prospects of a DPRK "collapse", drawing on the materials presented in earlier chapters of this Report.
- **Section 9.3** provides a summary of Nautilus Institute's approach to evaluating the impact of "collapse" pathways, and presents our illustration of four potential pathways that could lead to the collapse of the government of the DPRK, ranging from a quick collapse brought on by a "shooting war" or a West-friendly coup to a collapse from continued isolation and slow decline, which could take years or decades.
- **Section 9.4** describes our assessment of the implications of collapse pathways for the DPRK energy sector, and for provision of energy services (including energy supply and demand infrastructure) in the DPRK. For each collapse pathway, we identify key measures that the international community—including but hardly limited to the ROK and the US, would be obliged to or could take to help the DPRK transition toward eventual reunification with the ROK (whether official or *de facto* through economic integration).
- **Section 9.5** summarizes key overall lessons from our preliminary analysis of collapse pathways, focusing on near-term initiatives and planning efforts that the international community might carry out and support that would help to manage, smooth, and make easier the post-collapse transition for the DPRK populace, independent of how collapse actually occurs.

9.2. Background: The DPRK Energy Sector since 1990, and Nautilus Analytical Approaches

When the Soviet Union was dissolved in 1990, the DPRK lost not only its major supplier of crude oil and of parts for its power plants and factories, but also the markets for the bulk of the goods that its factories were designed to produce. The rapid economic and resource contraction, compounded by a series floods and droughts that affected both agriculture and energy production, plus economic isolation resulting from the international reaction to the DPRK's nuclear weapons program, resulted in a downward economic spiral of reduced energy availability and reduced industrial energy demand as the country's infrastructure fell into disrepair and markets dried up. By 2000 the DPRK's use of coal and production of electricity had fallen (by our estimates—see above) to almost a quarter of its 1990 levels, and overall energy end use had fallen to less than 40 percent of what it had been a decade before. Since this period, the DPRK's energy sector has been sustained primarily by an annual half-million tonnes (possibly somewhat more, in the 2010s) of crude oil from China, modest imports of refined oil products, Korean tenacity and ingenuity that have kept some of its coal mines and aging power and coal production infrastructure running, and the substitution of wood and other biomass for coal and oil products to provide subsistence energy use. Much of the DPRK's major energy and industrial infrastructure dates to the 1950s, '60s, and '70s, with some, including major hydroelectric plants, dating to the 1920s Japanese occupation era.

Since 2000 there have been modest improvements in the DPRK economy and energy sector, with some power plant repairs, new small hydroelectric facilities, and new mining activity underwritten, in large part, by Chinese investment. DPRK citizens have started to provide their own energy supplies by adopting diesel and gasoline-powered generators and using (mostly) small solar panels to provide lighting and power small electronic devices. Still, shortages of power, district heat, and coal persist, with blackouts even in Pyongyang, and much more tenuous power supplies in other areas. In effect, the North Korean electricity system, though it is nominally a nationwide transmission and distribution grid, is a patchwork of a few regional and some local grids, centered around major and smaller power plants. Most of the large thermal (almost all coal-fired) power plants and heating plants are only partially in operation due to damage of various kinds to one or more boilers/generating units, and/or to transformers, substations, or other parts of the transmission and distribution system. This means that even if large amounts of fuel or electricity were suddenly to be available to the DPRK, distribution of that energy would be problematic.

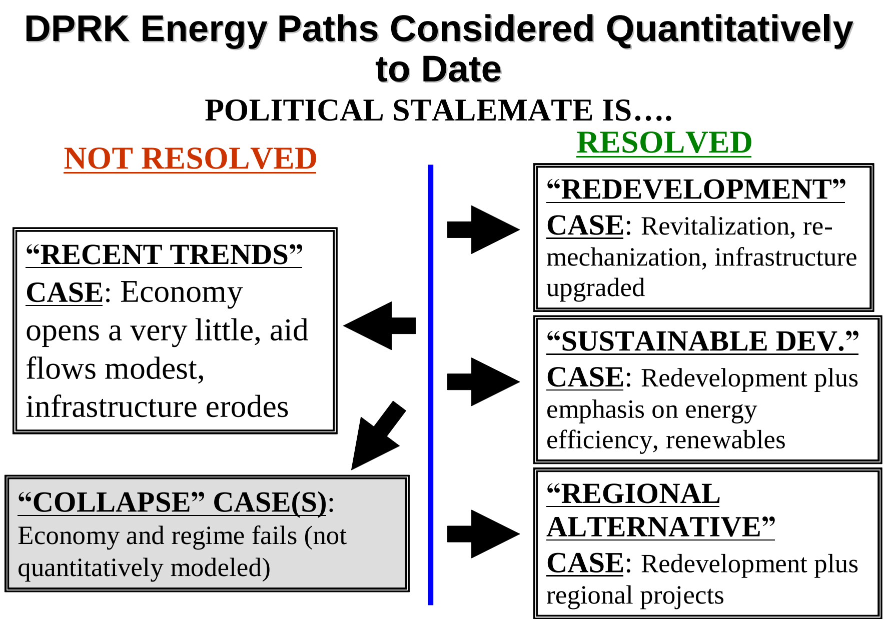
The combination of erosion in its energy system and industrial infrastructure, together with similar erosion in its transport infrastructure in many (not all—Pyongyang and Nampo being exceptions) areas and lack of investment capital, means that the DPRK will not be able to substantially reconstitute, or perhaps more accurately, redevelop, its energy system and economy in general without outside help. Rebuilding power plants—most of which, remember, were built with major components imported from the USSR or elsewhere—could not be done, at least for many years, using materials "made from scratch" in the DPRK because the industrial infrastructure to make the required power plant components either is no longer operating or, in fact, was never present in the DPRK. Similarly, decades of relative isolation have left the DPRK substantially without the capabilities in metallurgy, electronics, and other fields that would allow it to develop new industries. This means that the DPRK cannot redevelop its infrastructure sufficiently to develop a sustainable, peaceful economy without outside help.

Even for the DPRK economy to remain at its current "subsistence" level, help from other nations has been required. As noted above, the DPRK receives sufficient crude oil from China to keep one of its two oil refineries running, though at well below full capacity. This oil was, at least until the middle of the 2010s when China ceased to report crude oil trades with the DPRK, paid for at market prices, but the DPRK runs an annual trade deficit with China. China could provide more crude oil to the DPRK, and has done so in the past (in some years during the 1990s), but the fairly constant flow of oil from China to the DPRK for the past two decades or so suggests that China has determined the amount of oil that the DPRK economy needs to receive to fuel basic economic functions, and is providing that amount.[835] This suggests to us that although China is willing to provide fuel to keep the DPRK economy (and society) from failing, it is unwilling, until the DPRK can afford the additional imports on its own, to provide sufficient assistance to actually redevelop the DPRK economy.

Starting from the estimated energy balances presented in earlier Chapters, we prepared future scenarios of energy-sector development for the DPRK, using the Low Emissions Analysis Platform energy/environment software tool or LEAP, as reported in Chapter 8.[836]   In that work, as shown in Figure 9-1 (as well as in Chapter 8), we compare a "Redevelopment" path, implying significant opening of the DPRK economy to outside investment and assistance, but without significant emphasis on energy efficiency improvement, with a "Sustainable Development" path emphasizing energy efficiency and (to a lesser extent) renewable energy, and a "Regional Alternative" path also including DPRK participation in several types of regional energy infrastructure (for example, LNG terminals, gas pipelines and electricity trading). An additional path modeled, the "Recent Trends" path, assumed that a substantial solution to the DPRK nuclear issue was not forthcoming, and recent trends in the DPRK economy continued.   Not modeled quantitatively, as indicated in the shaded box in Figure 9-1, are the "collapse" cases that are the subject of this Chapter.

[835] This in addition to technical reasons for maintaining flow through the pipeline—see section 6 of this Report.
[836] The LEAP software tool is developed and maintained by Stockholm Environment Institute—United States. Please see https://leap.sei.org/Default.asp for information about the LEAP tool.

Figure 9-1: DPRK Energy Paths



9.3. Potential "Collapse" Pathways

9.3.1. Analytical Approach and Listing of Pathways Considered

Our general approach to the analysis of potential pathways of DPRK regime collapse is as follows. First, we define several significantly different, illustrative regime collapse pathways. We make no predictions about the relative likelihood of any of these paths, and freely admit that the four paths we illustrate have been chosen out of a universe of many possible options. The second step in the analysis is to think about the impacts of regime collapse, for each path, on the DPRK energy sector, and, by extension on energy and related infrastructure that supports the DPRK economy. Third, we consider how the ROK, the US, and the rest of the global community might or would need to respond to energy needs following each different type of collapse. Finally, we identify "robust" planning approaches that, if pursued now or soon, would prove useful in the event of any type of collapse pathway.

We consider four possible paths of regime collapse. These paths are described briefly below, and in more detail in the section that follows:

- **War**: A brief but very destructive war occurs between the DPRK and the ROK and its allies, precipitated by a military incident that rapidly escalates, and leads to essentially immediate unification.
- **Regime Implosion Leading to New Authoritarian Regime:** Death, incapacitation, or some other significant event befalls Chairman Kim Jong Un before a firm leadership succession plan is in place, leading to regime replacement in the DPRK, with the new regime being modernizing, but leaning toward China and Russia for economic support, and away from the ROK and its Western allies.

- **Regime Change by Palace Coup Leading to ROK-installed Regime**: While not immediately leading to unification, this collapse path would lead to modernization that in turn would lead to at first de-facto economic unification, then, somewhat later, political unification with the ROK.

- **Slow Collapse Leading to Regime Change through Internal Conflict**: In this path, the Kim family and/or other leaders continue the current (largely) isolationist policies, which leads eventually, though perhaps not for many years, to the collapse of the DPRK state, with the ROK and its allies obliged to "pick up the pieces".

9.3.2. The "War" Path

The "War" path of regime collapse assumes that a shooting war between the DPRK and the ROK (and its allies), once set off by a military incident of some kind, quickly escalates. Given the proximity of DPRK artillery to the ROK border, we assume that this path results in considerable destruction in the Northern ROK (including the parts of the Seoul area close enough to the DMZ as to be within range of DPRK artillery and rocket fire—to the extent that DPRK ground-launched weapons capacity is not suppressed by ROK and US counter-fire), and also in considerable destruction in many areas of the DPRK, especially in areas associated with military installations, but perhaps sparing areas near the DPRK's northern borders (for reasons touched on below). Based on previous work (see text box below), our rough estimate is that the DPRK would not be able to sustain a conflict long (probably for weeks, or at most, a month or two) due to lack of fuel supplies. This assumes that China does not somehow step up fuel deliveries to the DPRK, which seems unlikely if the DPRK is seen as the aggressor in the conflict.

We assume that war leads to ROK (assisted by US and others) administration of the DPRK. We further assume that the ROK's administration of the DPRK is managed in such a way that significant dissatisfaction with the administration on the part of the North Korean population is avoided. This is a crucial assumption, as an insurgency related to popular local dissatisfaction with ROK administration of the DPRK would set DPRK rebuilding and redevelopment back years, as has been the case following the US wars in Iraq and Afghanistan. Would the DPRK population welcome ROK/US victors with open arms? Iraq/Afghanistan provide cautionary tales, but an analysis of that particular issue, though it has potentially significant ramifications for what types of energy infrastructure improvements will be possible/effective, is beyond the scope of this Chapter. Clearly, however, one of the lessons of Iraq is that the degree to which the administration quickly ramps up the provision of the essentials of life—food, clean water, health care, electricity, waste treatment, jobs—to the populace will play a huge role in how well the populace adapts to its new government.

How the war is prosecuted by the ROK/US side will have a significant bearing on the tasks needed to reconstruct the energy system. For example, will the ROK/US alliance choose to:

- Destroy power plants wholesale, or just render plants relatively temporarily unusable with surgical strikes on key, relatively easily-replaceable (at least post-conflict) components?

- Destroy the DPRK's operating refinery, or just cut refined products supply lines?

- Destroy coal mines, or just cut power to them, rail lines from them?

DPRK Energy Supply during a War

Several years ago, we carried out, and more recently updated, a rough calculation that suggested that it would take about three months of DPRK refinery output, at current levels, to resupply the gasoline and diesel fuel that the military would use in the first month of an active conflict. By the end of the first month of conflict, it would take about two months of total refinery production plus imports (assuming current levels) of gasoline and diesel to operate for an additional month of war the DPRK military vehicles that we estimate might remain operable after the initial 30 days of conflict.

This calculation includes several simplifying assumptions, each with significant to considerable degrees of uncertainty. First, it assumes that 50 percent of DPRK military ground vehicles and armaments would be inoperable after 30 days of conflict, and that 90 percent of the DPRK's navy and 100 percent of its air force would be similarly inoperable or in deep storage. Given the superior firepower, particularly from the air, of the ROK/US alliance, these assumptions seem reasonable to us. Second, it assumes that the DPRK does not have many months of fuel stored in deep bunkers. Here, we have no direct information one way or another, but suspect that the relatively constant fuel shortages over the past decade and more have probably eroded stocks, at least somewhat. Third, it assumes that the one operating refinery continues to provide fuel at current levels, and that the second major DPRK refinery, at Sonbong on the DPRK's northeast coast (currently and recently inactive) is not reopened. The degree to which the currently-operating refinery, in the DPRK's northwest and connected by pipeline with China, maintains its output depends largely on the degree to which China continues supplying crude oil. Refineries are easy military targets, but it seems unlikely to us that the ROK-US forces would attack a facility so close to China. Whether China might increase or decrease the flow of crude oil to the refinery is an open question—our guess is that they might not do either. Reopening the Sonbong refinery would likely take much too long to help much in the event of a conflict, and it is unclear where the crude oil to fuel it would come from. Fourth, we assume that the current (mostly minor) sources of imported refined products would not increase or decrease much in a conflict. If anything, it seems to us that it would be more difficult, not easier, to import oil by truck, train, or small tanker ship in the event of an armed conflict.

These caveats notwithstanding, the essential finding from our calculation is that the DPRK military would quickly—in a matter of weeks or certainly months—run short of fuel in any major armed conflict. With regard to the "War" path to regime change discussed in this Chapter, this finding has (at least) two implications. First, the major part of a war between the DPRK and the ROK and its allies is likely to be over, at least in terms of participation of large fuel-using vehicles, aircraft, and vessels by the DPRK, within two or so months. Second, knowing that a war is likely to be brief, the ROK and its allies might be more inclined NOT to inflict difficult-to-reverse damage on major DPRK energy facilities.

We assume that, given that ROK/US air power superiority will provide control of the skies within days, the ROK/US military command can be prevailed upon to knock out energy infrastructure surgically. War planners will probably deem it necessary to knock out electrical grid to deny power to munitions and armaments factories and other military installations (although the latter will likely have their own power sources). Doing so by wholesale destruction of the transmission and distribution (T&D) grid and major power plants, however, would make it much harder to redevelop the DPRK energy sector in a timely fashion, and probably is not necessary. Targeting and destroying, for example, substations at power plants, which are already in poor shape, will knock the power plants offline indefinitely, and be much easier to fix than would major damage to the power plants themselves. It seems unlikely that ROK/US forces would try to destroy or permanently disable the DPRK's one major operating (Northwest) refinery, as it is so close to China (and tied to China by pipeline), but they might seek to bomb major rail and road links that would be used to provide fuel to the front, and possibly sink or disable some coastal tankers used to transport petroleum products, and/or target petroleum fuel depots. Disrupting the provision of power to DPRK coal mines would knock most coal production offline, but again, targeting rail links would inflict damage that would be relatively easy (once the war ended) to fix, but still effective in reducing the DPRK's supply of fuel to the front lines of the war. Probably some war damage would be sustained in DPRK seaports, especially those that host submarines or Special Forces that use naval craft. Due to concerns about humanitarian impacts, plus effects on ROK water resources (rivers that flow across or near the DPRK/ROK border) and on China (for rivers in the northern part of the DPRK), we assume that ROK/US forces would avoid damaging hydroelectric facilities, at least the dams, but might, again, choose to knock hydropower stations off line (except probably, the several Supung and other power stations shared by the DPRK and China that are located along northern border rivers) by destroying key substations.

The descriptions of the "War" path above, and analysis of the energy implications of the War path provided below, assume that Russia and especially China stay out of the conflict. If they do not stay on the sidelines, at least in a military sense, the ROK/DPRK conflict becomes a very different and much more dangerous altercation, to say the least, with possible global consequences.

9.3.3. "Regime Implosion Leading to New Authoritarian Regime" Path

In the second path considered here, a new regime takes over from the Kim family as a result of the death of Chairman Kim Jong Un or his successor, or as a result of some internal coup. The new regime is authoritarian but modernizing and is dominated by military and technocratic elements. Despite its modernizing elements, the new regime continues to spurn the ROK and the West. Rather, the modernizing approach implies much higher than recent rates of investment (from non-ROK, non-Western sources), and as a result energy infrastructure is rebuilt/redeveloped in close cooperation with China and Russia. For the most part, international governmental organizations and international financial institutions are also excluded by the new regime from the DPRK modernization process.

The elites of the new regime serve themselves by modernizing the DPRK economy enough to modestly improve the lot of the general population but do so in the process of establishing businesses that mostly emphasize export of the DPRK's mineral and labor resources, with China and Russia as major partners. The elites of the regime operate the export companies, and thereby install themselves as a Korean equivalent of the Russian oligarchs of the 1990s. The ROK remains locked out of DPRK economy in the short and medium-term but may in the longer term obtain regional network integration (via agreements on and construction of electricity interties and gas pipelines) by paying rent to the DPRK government for energy infrastructure and transport corridors through the DPRK to resources in Russia and markets in China and beyond.

9.3.4. "Regime Change by Palace Coup Leading to ROK-installed Regime" Path

In this path, following, for example, an act by Chairman Kim Jong Un or his successor that is considered the "last straw", a group of cosmopolitan younger DPRK diplomats and technocrats backed by young officers in the KPA takes power, and immediately establishes links with the ROK, the United States, and their allies. The result, initially, is an authoritarian regime that sympathetic to the ROK and the West. The regime slowly, perhaps very slowly, installs elements of democracy in the DPRK, but focuses first on economic reforms. These economic reforms place an emphasis on planning a DPRK economy that complements the ROK economy. For example, initially, economic reforms would likely emphasize development of the DPRK mineral resource base to help provide raw materials for ROK industry and would utilize cheap labor in the DPRK to compete in industries (for example, textiles, and basic electronics) that have been moving out of ROK to lower-cost suppliers such as China, and subsequently Vietnam, India, and other nations. To fund these economic reforms, significant investment is drawn from the ROK, and probably from the US and elsewhere as well.

As with the China- and Russia-leaning elite in the "Regime Implosion Leading to New Authoritarian Regime" path, the new, ROK-leaning regime elites in the DPRK seek to serve themselves but do so possibly by setting up ROK-style chaebol that they control, and that interface with/draw investment from analogs in the South. Such a regime might be amenable to large-scale virtual exports of DPRK labor via the internet, for example, for Korean language records processing for the insurance, medical, and telecommunications industries, or for software development.

9.3.5. "Slow Collapse Leading to Eventual Reunification" Path

In this variant of "Regime Implosion", either Chairman Kim Jong Un or a successor from the Kim clique maintains control, or another regime (perhaps run by a "regent" governing the country in the name of a Kim successor) takes power. In either case, however, there is a failure to modernize or open the DPRK significantly to the outside world. Aided by continued isolation, the national regime's control over the country becomes progressively less effective due to continued erosion of energy and other infrastructure, and its inability to provide food and other essentials for the population as a whole. It is possible that this type of process would be brought on or at least encouraged by the kind of international sanctions regime that was in place as of early 2021.

As this erosion continues, possible situations between national control and total collapse of authority might include the effective fragmentation of the DPRK into "fiefdoms" run by powerful party or military (or criminal) leaders, perhaps supported individually by national neighbors (China, Russia, Japan?) or large foreign investors such as Chinese companies.

We assume that this scenario will lead to eventual reunification of the DPRK with the ROK. Control of information coming into the DPRK would breaks down as the power of the central authority to impose order wanes,[837] which, coupled with continued declines in living standards, leads eventually to disillusionment on the part of the majority of the population (for which, crucially, access to information from outside the DPRK has gradually been increasing), internal conflict, civil disorder, and possibly even civil war in DPRK. A "Civil War" situation may be difficult to conceive of, given the lack of significant ethnic or religious divides in the DPRK, but a possible mechanism might occur in a "fiefdom" situation where rival warlords controlling (for example) different provincial areas, and using arms smuggled from different friendly nations/groups, begin to struggle for territory/key assets (mines would be an example, with analogs in Africa and elsewhere) or power.

Overall, the process of decline under this path may be very slow, taking years or even decades to play out, but would likely end with a rapid collapse at the end stage that requires urgent intervention by the ROK and its allies, and possibly others on the DPRK's northern borders to stem/support a flood of refugees leaving the DPRK.

9.4. Implications of Collapse Pathways for the DPRK Energy Sector and for Provision of Energy Services in the DPRK

Each of the four "collapse" pathways outlined above has its own implications for how the DPRK energy sector will be affected. As such, each of the pathways implies different ways in which those in the international community with the wherewithal to help might provide or plan to provide energy services to the DPRK population and economy in response to, or to soften the effects of, regime collapse. What follows are our initial thoughts on the energy sector and energy assistance implications of each of the paths described above.

9.4.1. "War" Path

As noted above, a major military conflict between the DPRK and the ROK (and its allies) would, depending significantly on the military strategy that the ROK/US alliance chooses to pursue, eliminate considerable energy and industrial infrastructure in the DPRK, though much of it is already failing and/or obsolete. If a "surgical" military approach is used, the minimum short-term requirements to supply basic energy services to the DPRK and to start to build a peaceful DPRK economy would likely be:

- Replace virtually all substation equipment, including both equipment that was war-damaged and equipment that has simply become inoperable (or close to it) over time, as most substation transformers and related equipment are reportedly in poor condition.
- Establish emergency electricity generation and provide fuel for the stock of existing generation that has grown substantially during the 2010s, initially fueled with diesel oil or possibly liquefied petroleum gas (LPG, a mixture of propane and butane). Larger-scale generation under this approach might take the form of power barges in coastal areas or where

[837] Some would say that, due to the advent of cell phone usage in the Chinese border region and in Pyongyang, and more recently nationwide, coupled with the dissemination of South Korean music, films, TV shows, and other content in the DPRK via flash drives, control of information in the DPRK is breaking down already. See, for example, Jeremy Hsu (2018), "How the USB Taught North Korea to Love K-Pop", *Discover*, dated April 6, 2018, and available as https://www.discovermagazine.com/technology/how-the-usb-taught-north-korea-to-love-k-pop.

river transport is possible, and package diesel or portable combined heat and power plants in inland areas.

- Try to get major coal-fired power stations restarted, and restart or stabilize output from coal mines to supply them, while undertaking temporary transmission repairs sufficient to get electricity onto the local or regional grid on a semi-reliable basis.
- Ramp up petroleum products production in ROK refineries to substitute for whatever DPRK fuel production/transport capacity was destroyed in the war, with additional fuel provided to supply emergency generation facilities. ROK refining capacity is large enough that it could easily supply the ROK and the DPRK together today, though possibly not both the ROK and DPRK at ROK per-capita levels of consumption. Given the status of DPRK fuels demand infrastructure (such as its road vehicle fleet), however, the DPRK would not reach ROK levels of consumption for many years. As such, overall refined products supplies might not be a problem in a suddenly reunified Korea (though some products will be easier to supply than others), but the infrastructure to move supplies to where they are needed in the DPRK—port facilities, rail facilities, and roads—will need upgrading even if they not damaged by war.
- Try to get major hydroelectric facilities restarted, including required transmission repairs and/or repairs to dams.
- Provide critical power and fuel for agriculture. The urgency of doing so will, of course, depend on the season in which the conflict occurs, but planning for supporting DPRK agriculture as much as possible will be a priority in any circumstance to reduce the quantity of food aid that will inevitably be required.

If a surgical military approach is NOT used by the ROK and its allies, supplying basic services and economy-building in the DPRK would be more difficult. For example, immediate replacement of most power plants would be needed, meaning more "triage" solutions to restart parts of energy facilities however possible, and more provision of emergency generation. Significant emergency civil engineering work will be also needed to shore up damaged infrastructure, repair ports, rail facilities, roads so that emergency supplies of refined products can be brought in.

A key complication of the "War" path is that it will somehow be necessary to rebuild/develop the DPRK at the same time as the considerable damage to the ROK infrastructure (and society) is being repaired. This complication argues for the need for countries beyond the ROK and US to take very active roles in DPRK reconstruction, as a great deal of ROK rebuilding effort will necessarily be domestically focused. The need to support/rebuild both Koreas will make coordination, even amid post-war chaos, even more necessary if citizens both south and north of the 38th parallel are to get needed services in a timely manner. All these factors underline the need for detailed and coordinated pre-crisis planning.[838]

In any post-war path there will be a need to quickly ramp up capacity-building for energy, environment-related, and other occupations. Capacity-building will be needed in part because

[838] We assume that at least some significant planning for DPRK collapse has been undertaken by ROK government agencies, but if these plans have been reported in the public literature, we have not yet seen them.

trained people will be needed for reconstruction and redevelopment, but also because the DPR Korean population will need gainful, useful, peaceful employment. This is especially true for those officials and technicians associated with sensitive industries (for example, military industries and nuclear weapons programs) in today's DPRK. A key focus of early capacity-building efforts should be on providing skills and technologies that encourage the growth of local economies (for example, at the county level) that are capable, to a large degree, of providing essentials such as food and energy services for themselves. As concrete example, training should be provided for redeployment of scientists and technicians working at the Yongbyon nuclear weapons complex and military missile development/production programs so as to make sure their skills are directed toward productive and peaceful activities, rather than having their skills diverted to serving threatening states or organizations.[839]

In the medium- and longer-term, several types of actions will be needed under a collapse via the "War" path:

- Plan for and start to build an integrated ROK/DPRK grid, probably starting with extending ROK grid into areas in the southern part of the (current) DPRK and building local/regional grids (including microgrids) in other areas for eventual hook-up to national grid.
- Make sure to replace damaged (or otherwise unserviceable) energy demand infrastructure with the most energy-efficient devices that are widely available, so as to lessen the requirements for new or rebuilt energy supply infrastructure.
- Make sure to choose energy-efficient devices for all of the new housing, commercial, and industrial developments that will be built as the North's economy and living standards start to gain on those of the South.
- Evaluate which industrial facilities need to be developed (or in rare cases, rebuilt), and plan for evolving supply systems for fuels (such as electricity, gas, heat) to serve the evolving economy.   In this case, serving the "evolving economy" means, for example, putting supply systems where people will be, factoring in elements like re-mechanization of agriculture and shifts in economic composition toward the services sectors, and away from heavy industry, and probably toward cities and away from the countryside. That is, don't plan to necessarily put facilities where the people happen to be located now (or where they are shortly after collapse) as they work in the planned economy and in survival-level cottage industries.
- Work with the Russians to reconstruct–or, more likely, construct a new–Sonbong refinery, related port facilities, and the combined heat and power facilities associated with and serving the refinery and the local area in the DPRK's far Northeast.
- Work with the Russians to bring gas supplies and gas transmission and distribution infrastructure into and through DPRK to the ROK, and/or work with the Russians and DPRK to develop new liquefied natural gas (LNG) import, storage, and regasification facilities (again, with associated gas T&D facilities) somewhere near the 38th Parallel (for example, in or near Nampo in the DPRK). LNG facilities would likely be shared to serve both the North

[839] See, for example, David F. von Hippel (2010), "Possible Energy, Economic, and Other Engagement/Assistance Activities to Combine with Yongbyon Decommissioning/Conversion", dated January, 2010, and available as http://nautilus.org/wp-content/uploads/2011/12/Yongbyon-Decommissioning-and-Conversion.pdf.

and South, particularly in the early years as DPRK gas distribution capacity and demand is still being built.

- Consistent with global needs for evolving energy systems to address climate change, and with the opportunity offered by the need for substantial energy sector redevelopment in the DPRK in a "War" path (and, in fact, in essentially any path for the DPRK that involves substantial change, collapse-driven or not) emphasize the development of renewable energy sources in the DPRK, including micro-grids powered with solar (and possibly wind) energy and with electricity storage using batteries, small pumped-storage hydro, or other technologies.

9.4.2. "Regime Implosion Leading to New Authoritarian Regime" Path

In the "Regime Implosion Leading to New Authoritarian Regime" Path, the technocratic regime would presumably assess the country's energy needs, and attempt to focus internally on energy infrastructure redevelopment, taking advantage of largely Chinese and Russian technical help. Energy infrastructure development would be focused on serving raw materials export industries, and as such might be focused on areas in the North and West of the DPRK, leading to somewhat geographically and sectorally-unbalanced energy systems. For example, if the regime is focused on maximizing income from raw materials and labor exports, it might give limited attention to improving energy supplies to and infrastructure in urban areas (outside of areas where elites live) or to rural areas (outside of where minerals are found).

The ROK and West would be expected to have limited short and medium-term influence under this path. The main options the ROK and West might have to influence the DPRK energy sector might be to try and work through the Russians and Chinese to provide capacity-building, and thus affect patterns of change in DPRK energy infrastructure at the margin, and also to look for opportunities for joint ventures with Russians on regional infrastructure (for example, in electricity and gas networks, and on oil refining). Working through the Chinese and Russians, however, may be complicated by the bottom-line focus of Chinese and Russian trading companies operating in the DPRK, which may leave little room for modifications in approach that would help an eventually-reunified Korea. In general, the ROK and West could offer capacity-building on energy and related topics as a lever to start opening the DPRK economy to other influences, but how those overtures might be received by the new DPRK regime, under this path, is hard to predict.

In the longer-term, assuming an eventual gradual or sudden opening of the regime, the ROK/West will need to focus on providing energy infrastructure in areas and populations left underserved by export-oriented infrastructure.

9.4.3. "Regime Change by Palace Coup Leading to ROK-installed Regime" Path

The implications for the energy sector under the "Regime Change by Palace Coup Leading to ROK-installed Regime" path are similar in many ways to those under the "surgical strike" variant of "War" path, but with less DPRK destruction/dislocation to address, and without the need to rebuild infrastructure in the ROK

As such, short-term needs under this path would include:

- Making a full assessment of the status of the North Korean electricity grid (T&D and generation) and other major energy and related infrastructure, including mines, refineries, rail facilities, and ports.
- Replacing virtually all electrical substation equipment, starting with failed and failing units.
- Establishing emergency electricity generation, initially, on a city scale, with diesel or possibly LPG-power barges in coastal areas, and package diesel or combined heat and power plants in inland areas, and on a village/town scale with microgrids powered mostly by renewable energy, focusing where power supply is particularly inadequate, in order to build social stability in those areas and stem out-migration.
- Where possible, applying quick repairs to keep the best of the major coal-fired power stations going for a few years while the national power grid is being replaced.
- Look for ways to upgrade existing hydroelectric facilities to improve their safety of operation, efficiency, and generation capacity.
- Ramping up ROK refined products production to supply currently unmet demand for transport fuels in the DPRK, plus diesel fuel needs for temporary generation.
- Providing critical power, fuel, and equipment for farming.

In the medium- and longer-term, one priority under this path will be to assess coal supply infrastructure to determine if any existing mines will be cost-effective to operate in the longer-term; and to shut down and abandon (and remediate) mines with poor prognosis. Poor prognosis for North Korean mines may occur as a result of a damaged mining infrastructure that would be too difficult to repair, unsafe mining conditions, a poor or depleted resource base (in terms of coal quantity and/or quality), or simply poor mine economics (which could be a function of many factors, including all of the above, plus coal transport and other considerations). Even under this path, it would not make sense to abandon mines immediately as the regime changes, given the importance of coal to the existing infrastructure and the importance of the coal industry as an employer, but the coal mining sector should be reviewed soberly and shrunk if needed in favor of importing coal from major international low-cost producers if the assessment so indicates, and/or working to adopt substitute fuels. A second major priority will be to evaluate which industrial facilities need to be developed, based in large part, on demand for DPRK-located facilities as indicated by the willingness of private sector actors (in the DPRK, the ROK, and beyond) to invest. In addition, in the medium- and longer-term, plans need to be developed for evolving supply systems for fuels (electricity, gas, heat, and refined products or renewable fuels) to serve the evolving Northern economy.

Again, in the medium- and longer-term, under the path leading to an ROK-friendly regime, a key requirement will be to establish markets for fuels, and the regulatory authorities to oversee them, with an eye toward merging markets and regulatory authorities in a unified Korea. For markets, the DPRK could in fact lead (or at least go arm-in-arm with) the ROK into the world of "smart grids" and smart electricity meters. This could include, for example, widespread use of time-of-demand pricing, local generation, and renewable generation. Demand for electricity in the DPRK under this path could be expected to increase rapidly, accompanied by an opportunity (not to be missed) to build a very modern, very high-efficiency supply and demand-side electricity sector. Hand-in-hand with this effort should go development of progressively tighter building energy efficiency regulations and build human capacity to enforce building energy efficiency and other regulations, and to design and construct high-efficiency buildings.

As with other paths, it will be desirable to work with Russia, and possibly with China and other nations, to explore and extend regional electricity and gas grids, and to partner on a new Sonbong refinery. It will also be necessary to develop gas use infrastructure (demand-side and distribution) for all sectors, including electricity generation and combined heat and power, for a number of reasons, including reducing the greenhouse gas emissions in a unified Korea, and providing energy services as cleanly and efficiently (in terms of overall fossil fuel use) as possible.   As in other paths, another priority will be to explore extending gas grids north from ROK and building shared (North/South) LNG facilities.

Last, but certainly not least, this path will provide both the opportunity and need to do aggressive capacity-building on a vast host of topics, starting as soon as possible. This will mean sending the best North Korean students to the ROK, the United States, Australia, Europe, and elsewhere for study, and providing them with incentives to return to work in the DPRK, but also, just as if not more importantly, building up North Korean educational institutions at all levels.

9.4.4. “Slow Collapse Leading to Eventual Reunification” Path

In the “Slow Collapse Leading to Eventual Reunification” path, energy infrastructure continues to slowly decay, following the general pattern—albeit occasionally partially reversed by isolated repair projects and new developments—over the last two decades. As infrastructure decays it continues to become more inefficient over time, and also loses capacity (for example, electricity generation capacity, transport capacity, heat production capacity, and so on) as the performance of individual units continues to decline, and as units fail altogether. In this path, scavenging for metals to sell for scrap may take an increasing toll on important energy infrastructure (such as electricity T&D) systems and other infrastructure (such as rail lines) as well.

In the “Slow Collapse…” path, the DPRK’s efforts to keep infrastructure running will continue, but will run up against diminishing returns due to a lack of replacement parts (for infrastructure originally manufactured outside the DPRK) and of outside expertise that can only be acquired with scarce foreign exchange dollars. Exceptions to the pattern of decaying infrastructure may be infrastructure that is required to support export ventures with outside investors, for example, Chinese companies (especially, recently, mines), where outside investors have a vested interest in making sure that key infrastructure is operable.

From the perspective of the ROK and its allies, actions to usefully help to address DPRK energy sector and related needs in the short-to-medium term are limited. So long as a central regime hostile to the outside remains in power in North Korea, little can be done but to take advantages of the (likely) rare opportunities that occur for engagement and capacity building. As the central regime loses power, there may be more opportunities for small, local engagement projects addressing energy sector needs, but such projects will be difficult and potentially hazardous to carry out and may more likely be the province of non-national groups such as non-governmental or international organizations. If an era of “fiefdoms” occurs during the slow collapse, arranging any type of regional project (electricity interties, gas pipelines, or rail interconnections) will be difficult due to shifts in who is in charge or in power in areas transited by proposed infrastructure at any given time.

In the longer-term, when the collapse of the state is complete, with or without an interim "fiefdom" era, the types of measures required of the ROK and its partners following reunification-by-default are the same as in the "Regime change by palace coup" path, but with a significant difference. Continued degradation of energy infrastructure, leading (in part) to extreme scarcity and suppressed demand, is likely to make eventual reconstruction/redevelopment and recovery the DPRK a progressively larger and larger long-term issue for the ROK, with growing complexity and expense.

Also in the longer-term, relative to a more immediate collapse, the Slow Collapse path implies that full assessments of DPRK energy and related infrastructure will not be possible for some time. Full, on-the-ground assessments of infrastructure needs, energy demand, and other key factors that are needed to plan effective energy sector assistance will be stymied by lack of access for years. As a result, the countries and organizations that would need to step in to provide energy services and rebuild energy infrastructure under a collapse scenario will not be able to fully assess the slowly deteriorating situation until actual collapse occurs, at which point needs (for food, water, electricity, waste treatment, health care, jobs, and other essentials) will likely be more urgent than they would have been had collapse occurred sooner.

The lack of access to the DPRK to perform a full energy sector assessment means that planning for energy sector support, and increasingly, as time passes, redevelopment, will need to continue to be informed by fragmentary information. This underlines the need for the international community to A) coordinate and share information on the DPRK whenever possible, B) use that information to formulate and regularly update plans for energy sector triage and rebuilding under a collapse scenario, even if collapse is long in coming, and C) provide resources to consistently support both A) and B). Gathering and making sense of energy sector information will require coordination by interested parties in data gathering and analysis. Considerable persistence and patience will also be required of those in the ROK and the international community who must prepare for DPRK regime collapse by keeping energy sector assistance and contingency plans updated, and remaining in readiness to effectively activate plans when needed.

9.5. Lessons from Collapse Pathways for Near-term Initiatives and Planning Efforts

Our initial consideration of the energy sector implications of potential DPRK regime collapse pathways suggests that there are several initiatives that those in the ROK, the United States, and the broader international community who are interested in the future of the Korean peninsula can undertake to be ready to assist in the event of a DPRK regime collapse. Possible initiatives include:

- Do capacity building on lots of topics whenever possible. Capacity-building is cheap, useful, and necessary in any path, and has many ancillary benefits. Required capacity building topics include technical training in electricity generation, energy efficiency, oil refining, renewable energy, environmental remediation, waste treatment, reforestation, and other similar disciplines. In addition, training will be needed in running commercial enterprises, including economic analysis, building an operating regulatory and legal systems, and many other organizational topics. Ancillary benefits of capacity building include engagement on the individual and organizational level, opening minds to new ways of thinking, increasing the availability of competence and personal connections for application at key movements of transition, as well as availability of in-country trainers to rapidly expand training as needed.

- Plan now for the wholesale rebuilding of the transmission and distribution system, likely with the dissemination of microgrids using largely renewable energy in the short- and medium-term, followed by knitting those microgrids together to restore a national grid. Doing so will be necessary sooner or later. An initial step might be to stockpile key components, such as transformers and substation switchgear, for rapid installation as needed.
- Assess the ROK's current refining capacity versus the petroleum products needs of a reunified (in fact if not in deed) Korea. Start talking with Russians about possibility of rebuilding and expanding the Sonbong refinery to be ready to rapidly start a refinery project when conditions permit. In a world that is addressing climate change through, for example, reducing/replacing the use of petroleum products in motor vehicles, it may be that today's petroleum refining capacity—particularly considering the ROK's huge refining base—will suffice essentially indefinitely.
- In order to reduce the burden on energy supply infrastructure (including reducing the amount of new energy supply infrastructure needed), have the discipline to provide high-efficiency energy demand (and supply) devices when rebuilding the DPRK economy. Provide high-efficiency demand and supply devices rather than, for example, marketing secondhand appliances, industrial motors, power plants, automobiles, and other devices to the DPRK from China, the ROK, and/or Japan, so as to make sure that the DPRK has a better chance of "catching up" with technology in the ROK, yielding better outcomes from social, resource conservation, environmental, economic/infrastructure integration perspectives.
- Think through how markets for energy goods can be established so as to spur private sector investments.
- Plan integrated energy infrastructure/economic development demonstration projects, for example, on a county scale, and try to get some integrated projects implemented even before collapse.
- Network with other interested parties to provide the best assessment possible of DPRK energy sector status and needs, and collaborate (including the participation of DPRK actors, if and when possible) on concrete plans so as to be able to swiftly and effectively address those needs when an opening occurs.

Finally, medium- and long-term regional energy projects such as a regional electric grid tie-lines and/or regional gas pipelines should be implemented in ways that provide China, Russia, the ROK and perhaps energy suppliers/users not immediately adjacent to the DPRK, such as Mongolia and Japan, with some leverage over the reconstruction agenda should the DPRK collapse. This leverage may be needed, in part, to ensure that the ROK hands over all fissile material and nuclear weapons-related hardware and knowledge to the IAEA and/or to nuclear weapons states in the scenario where such hardware and knowledge is obtained/inherited by the ROK from DPRK sources after the collapse of the DPRK. Meanwhile, policymakers should focus on the measures needed to stabilize the DPRK to avoid collapse of the DPRK in the short- and medium-term.

10. Redevelopment of the DPRK Energy Sector: Assistance Approaches and Project Options

10.1. Introduction

When and if negotiations between the DPRK and the involved players in the international community (formerly constituted as the Six-Party Talks and the diplomatic venues that emerged to replace them) resume, negotiations will center on the dismantling of the DPRK's nuclear weapons program, and on the incentives that will be offered by the international community to induce the DPRK to do so.[840] Chief among the incentives will be energy sector assistance to the DPRK. This chapter outlines a number of generic policy areas where assistance would be in order, as well as some ideas for cooperation activities in specific energy sectors. Neither set of suggestions is intended to provide an exhaustive list of the opportunities for cooperation, and neither is intended to provide a "schedule" of any kind to guide the development of a package of options to offer the DPRK. Development of such a package is necessary (and is a critical need), but is beyond the scope of this Report, and must necessarily involve consultations among key policy actors in the ROK, the US, China, Russia, the EU, and other nations, as well as, to the extent that such conversations are possible, the DPRK.

10.2. Potential for International Cooperation to Assist in the Redevelopment of the DPRK Energy Sector

Key economic resources for the DPRK, as noted earlier in this Report, include a large, well-trained, disciplined, and eager work force, an effective system for dissemination of technologies, the ability to rapidly mount massive public works projects by mobilizing military and other labor, and extensive reserves of minerals. What the DPRK lacks are modern tools and manufacturing methods, fuel, arable land (though the land it does have might be just sufficient to feed its population with improvements in agricultural methods), and substantial financial capital and the means to generate it. The lack of capital is largely a function of the DPRK's historical economic isolation from most of the international economy but has certainly been exacerbated under the international sanctions regime that has been imposed during the last few years (to 2021). In part to make up for the lack of ways to earn foreign exchange through typical international trade, DPRK has earned money to by allegedly selling weapons (sometimes through barter for fuel or other goods) and by implementing a range of alleged illicit activities, including cyber-crime, and, until recently (that is, until the practice was mostly halted due to UNSC sanctions), through remittances from North Koreans working abroad.[841] As a

[840] For a perspective on the views of DPRK officials regarding energy assistance options and nuclear weapons dismantlement, see Siegfried Hecker, "Energy Dialog with DRPK Officials Aug. 23-27, 2005 Visit to DPRK", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA. Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Hecker.ppt.
[841] See, for example, US Department of Justice (2021), "Three North Korean Military Hackers Indicted in Wide-Ranging Scheme to Commit Cyberattacks and Financial Crimes Across the Globe", dated February 17, 2021, and available as https://www.justice.gov/opa/pr/three-north-korean-military-hackers-indicted-wide-ranging-scheme-commit-cyberattacks-and.. See also Michelle Nichols and Raphael Satter (2021), U.N. experts point finger at North Korea for $281 million cyber theft,

consequence, given the energy sector problems outlined above, a coordinated program of assistance from the ROK, the United States, and other countries that builds upon these skills will be needed. Providing key assistance in a timely manner will enhance security in Northeast Asia, accelerate the process of North Korean rapprochement, and help to position the countries and firms as major suppliers for the DPRK rebuilding process.

The nature of the DPRK's energy sector problems, however, mean that an approach that focuses on one or several massive projects—such as a single large power plant—will not work. A multi-pronged approach on a several fronts is required, with a large suite of coordinated, smaller, incremental projects addressing needs in a variety of areas. Installing a large power plant in the DPRK without addressing problems of fuel supply, end-use efficiency, and electricity transmission and distribution, and without helping the DPRK to develop the means to peacefully earn the money to pay for the plant plus its operating expenses, is "putting the cart before the horse". Providing a power plant with no fuel supply, or a power plant with fuel supply but no workable grid, or fuel supply and an upgraded grid but no power plant, or even a power plant with fuel supply and an upgraded grid but no efficient end use equipment (or no end use equipment at all) with which to use the electricity, are neither cost-effective nor even feasible options in the DPRK and will not improve the security situation in the long term. A coordinated approach is necessary.

Below, we identify priority areas where we see DPRK energy sector assistance as both necessary and in the best interests of all parties.[842] All of these interventions would put foreign (US, ROK, or other) engineers, trainers, consultants, and other program staff in direct contact with their DPRK counterparts and with DPRK energy end-users. In our own experience working on the ground in the DPRK, visitors working hard to help and to teach North Koreans has great effectiveness in breaking down barriers between our peoples. Actions speak louder than words or missiles in negotiating with the DPRK.

Many of the options described below are also consistent with the key areas for international cooperation to assist in developing the DPRK energy sector and the broader DPRK economy outlined in 2006 by Dr. Ji-Chul Ryu of the Korea Energy Economics Institute in his presentation for the DPRK Energy Experts Working Group Meeting entitled "Energy Crisis in DPR Korea and Cooperation Issues".[843] We summarize Dr. Ryu's key areas for cooperation as:

1. Abandoning the DPRK's self-reliance economic policy, including opening the energy system to commercial energy supply from overseas.
2. Establishing market mechanisms for distribution of energy, and creating energy markets, including introducing energy pricing and tax systems and reforming energy legal structures.

KuCoin likely victim", *Reuters*, dated February 9, 2021, and available as https://www.reuters.com/article/us-northkorea-sanctions-cyber/u-n-experts-point-finger-at-north-korea-for-281-million-cyber-theft-kucoin-likely-victim-idUSKBN2AA00Q.

[842] See also Peter Hayes, "Options for DPRK Energy Sector Engagement", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA. Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Hayes_Options.ppt.

[843] Ji-Chul Ryu, "Energy Crisis in DPR Korea and Cooperation Issues", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Ryu.ppt.

3. Promoting active regional/international cooperation, including for rehabilitation of the existing energy facilities, and expansion of the energy system through accommodating foreign investments.
4. Adopting cost-effective energy options in rebuilding the DPRK energy sector, including increasing the role of petroleum in the DPRK's energy mix while at the same time pursuing in parallel the development of new and renewable energy in the short term, and development of natural gas in the medium-long term goals.
5. Strengthening the energy policy-making capability in the DPRK by improving energy statistics and modeling infrastructure, and through training of energy experts and scientists.

ROK--DPRK cooperation in many of these areas has already, at least at times, been underway, as reported by Dr. Kyung Sool Kim of KEEI in his 2006 presentation "Current Situation and Prospects of Energy Cooperation between Two Koreas". Though Dr. Kim noted that the cooperative interactions between the ROK and the DPRK at that time had been "very limited", they had included the supply of oil for a railroad interconnection, the supply of materials for road building, the development of the Gaesung (Kaesong) industrial district, and humanitarian aid related to the 2004 rail accident. Dr. Kim noted that possibilities for "Major Inter-Korean Energy Cooperation Projects", including transmission lines and gas pipelines involving the Russian Far East as well as the two Koreas, similar to those described in Chapter 8 of this report with reference to a future "Regional Alternative" energy path for the DPRK.[844]

10.2.1. Provide technical and institutional assistance in implementing energy efficiency measures

Focusing in particular on energy efficiency, regional cooperation would be useful to help the DPRK to:

- ***Provide the DPRK with access to energy-efficient products, materials and parts***. Since these items will probably, at least initially, be imported, this will entail a loosening of restrictions on exports to the DPRK. China, the DPRK's largest trading partner, would be a good source of efficient technologies and equipment that may be more easily absorbed (and more affordable) than those available from most other countries. The flow of such equipment from China to the DPRK China has in fact stepped up in recent years, as noted above, as the rapid growth of trade in televisions, bicycles, electric scooters, solar PV panels, and generators (to name just a few products) attests. China is the DPRK's major energy supplier, and thus may have an interest not only in marketing equipment, but in reducing the DPRK's dependence on (in some cases, reportedly subsidized) energy imports from China, particularly given China's own recently tight energy supplies in the wake of trade disputes

[844] Kyung Sool Kim, "Current Situation and Prospects of Energy Cooperation between Two Koreas", presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/KEEI.ppt. Dr. Kim also presented information on the potential cost, capacity, and other features of these and other options, placed possible cooperation on these projects in the context of the goals of the 6-Party Talks, and reviewed an agenda for cooperation opportunities in other sectors, including non-physical capacity building, capacity building in the energy market system, and cooperation in the coal, oil, electricity, gas, new and renewable energy, and other sectors.

with the US, Australia, and other nations, as well decreases in coal imports from the DPRK due to UNSC sanctions.[845]

- ***Pursue sector-based implementation of energy efficiency measures.*** One point made forcefully by early studies of East European economies "in transition"[846] is the need to pursue energy efficiency opportunities on a sector-by-sector basis, as opposed to through an overarching "Least Cost Planning"-style of analysis as has been practiced for electric and gas utility service areas.[847] It is people at the sectoral level who must work with energy-using equipment daily to do their jobs who are most likely to be interested in energy-efficiency opportunities, rather than planners in a central ministry.

  One way to gain support for energy efficiency measures is to emphasize those that achieve multiple goals. Energy-efficient technologies can be combined with building retrofits that increase the comfort of residents, the rebuilding of factories to improve output, the renovation of power plants to cut down on forced outages, and other upgrading efforts that have little--explicitly--to do with energy efficiency. China, in the 1980s, introduced a major process improvement to the steel industry—continuous casting—primarily as an energy efficiency measure, and supported its introduction with funding from the national program of efficiency investments. In China's other energy-intensive industries, such as chemicals and cement manufacturing, measures to increase energy efficiency have typically resulted in greater product output and higher product quality as well, resulting in high rates of adoption once the benefits of the measures have been appreciated by other manufacturers.

  To the ultimate users of energy efficiency measures, the relative costs per unit of energy savings of the various possible industrial process, transport, and energy supply improvements is less than meaningful--what matters is how energy efficiency opportunities stack up to other potential uses for the investment funds that they have available (for example, investment funds allocated from the central government). In addition, it is often counterproductive to charge personnel from the typically supply-oriented energy sector with equipment decisions in end-using sectors of the economy, because they would bring with them a strong supply-side bias.

- ***Carry out demonstration projects***. The most effective way to convince decision-makers in the DPRK—both at the national and local levels—that energy efficiency measures and programs are worthwhile will be to show that they work in specific North Korean situations. Carefully designed, effective demonstrations of energy efficiency and renewable energy

[845] See, for example, Chuin-Wei Yap (2021), "China's Coal War With Australia Fuels Shortage at Home: The trade dispute has forced Chinese buyers to pay steep premiums for imports amid a supply crunch", *Wall Street Journal*, dated February 10, 2021, and available as https://www.wsj.com/articles/chinas-coal-war-with-australia-fuels-shortage-at-home-11612953005.

[846] Schipper, L. and E. Martinot (1993), *Energy Efficiency in Former Soviet Republics: Opportunities for East and West*. International Energy Studies, Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33929. Prepared for U.S. Department of Energy. A version of this work is available for purchase from https://www.inderscienceonline.com/doi/abs/10.1504/IJGEI.1994.063544.

[847] Schipper and Martinot also point out two disadvantages of least-cost planning in the context of the former Soviet Union that are probably equally relevant to North Korea. First, stable energy markets and prices (which are inputs to Least Cost Planning) do not exist as they do (for the most part) in the West, and data on energy end-uses, as noted above, as well as cost data for domestic and imported equipment, are problematic. Second, Least-cost planning is sufficiently similar to the system of planning formerly in use in the USSR (and still, apparently, used in the DPRK) that it would provide a comfortable and familiar retreat for central planners, and thus could be considered a step away from, rather than towards, economic reform.

technologies that involve local actors as much as possible are likely to catch the interest of North Koreans. Given the good system for technology dissemination in the DPRK, this approach is likely to lead to the adoption of energy efficiency measures into the North Korean way of doing things. One word of caution here is to make sure that any demonstration projects carried out can be replicated elsewhere in the DPRK—measures unique to one or a few specific industrial plants, for example, are not likely to be widely replicated.

The authors of this Report have over the years prepared several concepts for demonstration engagement projects centered around energy-efficiency and/or renewable energy, designed to meet the political and energy service needs of constituents in the DPRK and beyond. Most recently, we have prepared a concept, to be published shortly, that we summarize as follows:

"A consortium-led humanitarian/capacity-building/engagement project, focusing on the installation of energy-efficiency measures in the Democratic People's Republic of Korea (DPRK) buildings sector and mini-grid systems powered by renewable energy for electricity generation, could potentially be deployed rapidly and would meet the requirements of a substantial pilot engagement project that would contribute toward cooperative threat reduction on the Korean Peninsula. The project would offer positive attributes such as highly visible symbolic improvements for the DPRK energy sector, consistency with DPRK stated interests, limited potential for military diversion, affordability, scalability, humanitarian and economic development elements, and large scope for face-to-face interactions between North Koreans and the international community. It would also provide a demonstrable model for both future direction in the DPRK energy sector and for productive and cooperative future engagement between the parties as they work toward threat reduction. In order for such a project to be deployed rapidly, it is likely that a consortium of third parties—that is, non-governmental organizations—in the international community will need to plan, organize, and deliver the project, albeit, of course, with the approval and support of the governments involved." Our publication on this concept provides a summary of our estimates of DPRK energy supply and demand (which is updated in earlier chapters of this report), a description of what the goals of and challenges faced by a cooperative project would be, and an illustration of what the project might include, how it might be organized, what organizations and skills would be needed, and an example project budget and timeline, plus thoughts on the types of organizations might be involved in a project consortium and overall conclusions.[848]

In addition, in 2012 one of us (von Hippel) worked with colleagues from an ROK government institute to prepare a document entitled *Development of an Energy-Independent Village in the DPRK: Scoping Study for Pilot Project* that illustrated of an engagement project whereby a chosen village or small town in the DPRK would be host to a project that included an energy needs survey, development of local industries, provision of humanitarian services, and environmental benefits using a combination of energy efficiency, renewable energy, and other technologies and approaches. That report was prepared for publication,

[848] David von Hippel And Peter Hayes (2021), *Provision of Humanitarian Energy Efficiency, Renewable Energy, and Micro-Grid Measures to The Democratic Peoples' Republic of Korea (DPRK) as Complementary to Engagement-Focused Cooperative Threat Reduction Activities*, Paper prepared in September 2020 for the Asia Pacific Leadership Network (APLN), and forthcoming as an APLN Special Report (https://www.apln.network/analysis/special-report).

and even printed in book form, but never distributed by the sponsoring institute. We plan to update and publish it soon.

10.2.2. Promote better understanding of the North Korean situation in the ROK

South Koreans have a deep and natural interest in what goes on in the DPRK but have no better access to information on the DPRK than those in other countries. It will be important in particular to involve South Korean actors—to the extent allowed and desired by the DPRK and ROK—in the types of research and training activities mentioned above. This suggestion follows partly from the proximity of the two countries, and from the considerable economic support and technical know-how amount that the South can offer the North. In addition, given the premise that the two countries will ultimately reunify, we believe that the more contact officials from the two countries have, and the more they know about each other, the less painful will be the process of reunification.

10.2.3. Work to open opportunities for Independent Power Producer companies to work in the DPRK

As noted above, the scale and complexity of the energy sector problems in the DPRK mean that the most reasonable way to address those problems is on a local and regional level. Though the ROK (and US, for example) governments might reasonably provide technical assistance and limited direct humanitarian aid, as well as support for international efforts, it is probably unreasonable to expect other countries to directly underwrite the renovation of DPRK infrastructure on even a county scale. What the other governments can do, however, is pave the way for companies such as Independent Power Producers (IPPs) to operate in the DPRK. In this liaison role, the governments could provide assistance to firms in identifying, negotiating with, and working with DPRK counterparts, underwrite performance guarantees, and provide low-interest financing. The governments can also help by providing North Korean counterparts with training in the economics of project evaluation and in international contract law, both of which are, as noted above, at present alien concepts in the DPRK. The goal would be to assist IPP firms in working with DPRK authorities to set up with local and regional infrastructure (for example, power plants of less than 50 MWe) using small hydro installations, wind farms, solar PV installations, or possibly small or mid-sized coal-fired plants, for example, using gasification technology. In most cases, infrastructure projects would need to be coupled with the initiation or re-establishment of local revenue-generating activities so that IPP products and services can be compensated. A necessary condition for the implementation of IPP projects is the development of markets for electricity in the DPRK that would allow IPP companies to recover their costs and profit from their investments.

10.2.4. Cooperation on technology transfer for energy efficiency, renewable energy

A number of suggestions for beginning to work with the DPRK on confidence-building measures in the realm of energy efficiency and renewable energy were listed in our initial (1995) report on the topic,[849] as well as in subsequent publications. Briefly, these include:

[849] Von Hippel, D. F., and P. Hayes (1995), *The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options*. Nautilus Institute for Security and Sustainable Development, Berkeley, CA, USA. December 1995.

- Provide information and general training in energy efficiency to high-level government officials.
- Provide specific information and training to local actors (such as power plant managers, industrial energy plant overseers, and building boiler operators).
- Encourage and support implementation and enforcement of energy efficiency standards.
- Assist in establishing a program of grants and concessional loans for energy efficiency investments to industrial organizations and others.
- Encourage the modification of existing incentives that thwart energy efficiency improvements.
- Assist in and encourage the reform (or establishment) of energy pricing.
- Provide training in the design and implementation of micro-grid focused on using renewable energy systems such as solar PV systems. Nautilus provided well-received training to a delegation from the DPRK as a part of our December 2019 Regional Energy Security Project meeting in Ulaanbaatar, Mongolia.[850] Ultimately, implementation of local mini-grids to provide electricity needs in villages, towns, and counties, then, later, integrating those mini-grids into a rebuilt national grid system in the DPRK, may prove the most effective and cost-effective way to restore provision of electricity to much of the country.
- Promote and support joint ventures and licensing agreements between the DPRK and foreign firms, possibly as part of development of the Rajin-Sonbong Free Trade Zone (Rason Special Economic Zone), or the further development/restarting of the Kaesong Industrial Park.[851]
- Initiate a program of exchange focused on methods of and training in energy planning (and the data gathering needed to make such planning relevant), including consideration of the environmental and economic impacts of energy choices.

10.3. Key/attractive energy sector technologies and processes for energy sector redevelopment in the DPRK

10.3.1. Rebuilding of the transmission and distribution system

The need for refurbishment and/or rebuilding of the DPRK T&D system, and the types of materials and equipment that will be required, have been identified briefly earlier in this Report. The most cost-effective approach for international and ROK assistance in this area will be to start by working with DPRK engineers to identify and prioritize a list of T&D sector improvements and investments, and to provide limited funding for pilot installations in a limited area—perhaps in the Tumen River area, in counties where key industries for earning foreign exchange (such as mines) are located, or in the Kaesong area. Ultimately, it will be necessary to engage the World Bank as a leader in DPRK power sector refurbishment, likely with funding from the Japanese government. It is possible, as noted above, that an approach involving

[850] See Chris Greacen (2020), *Integrating Mini Grids into National Grids: Technical And Organizational Aspects*, NAPSNet Special Reports, dated September 22, 2020, and available as https://nautilus.org/napsnet/napsnet-special-reports/integrating-mini-grids-into-national-grids-technical-and-organizational-aspects/.

[851] Relatedly, for example, Won Bae Kim, in a 2008 presentation for the DPRK Energy Experts Working Group Meeting, March 8 and 9, 2008, Beijing, China, entitled " Design of Infrastructure Development in North Korea: A Practical Approach", available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/WBKim.ppt, advocated focusing on industrial zones in the "four corners" of the DPRK for infrastructure development to serve as a catalyst for overall DPRK economic redevelopment.

implementation of mini or microgrids in the short-to-medium term could be the most practical and cost-effective path to providing reliable electricity service across the DPRK. Local solutions could be focused on projects that would help the DPRK earn foreign exchange in acceptable manner, such as repairing or replacing T&D infrastructure and local power plants in specific areas so that facilities such as key mines can operate.

The box below presents a "Microgrids for Mines" engagement/development project concept that we hope to have a chance to expand and discuss further with DPRK and other colleagues in the future.

Illustrative Project for DPRK Denuclearization Engagement: "Microgrids for Mines"

Summary

The Democratic People's Republic of Korea (DPRK) possesses abundant mineral resources, and economic development based on minerals extraction is a key priority for the DPRK government. A lack of mining technology in general, and of electricity to run mines in particular, significantly limits the degree to which the DPRK can develop minerals resources without outside investment. An offer of a demonstration project that builds a "micro-grid"—a small electrical grid to run the mine and nearby settlements using mini-hydro, solar PV, and other technologies—for a mining complex could well be of keen interest to the DPRK, and could serve as a means for engaging in denuclearization dialog with the DPRK.

Minerals and Electric Power in the DPRK

As noted in Chapter 7 of this Report, the DPRK possesses significant, and in some cases world-class, reserves of many minerals and metal ores, including gold, silver, iron, zinc, lead, copper, magnesite, rare earth minerals, and many others. These resources have attracted attention from the Republic of Korea, with its massive industrial structure but a general lack of resources, but although inter-Korean mining projects have been proposed, successful implementation has been lacking. Chinese investors, particularly from the Northeastern provinces, have developed joint ventures in many DPRK mines, with mixed success. Although the DPRK has limited supplies of modern mining equipment, a key impediment to development of mines is the lack of reliable electricity supplies from the central grid. Since the fall of the USSR in 1990, the DPRK's electricity and transmission and distribution (T&D) assets have generally eroded, with the development of new, mostly smaller, mostly hydroelectric plants insufficient to make up for the gap between electricity supply and demand, which is exacerbated by high T&D losses.

The DPRK has a system of prioritizing supplies that allows some key mines to receive power, sometimes directly from power plants, as much as 24 hours per day, but many installations receive much less, hardly any (2-3 hours per day) or indeed no power from the grid. Mines require nearly full-time power to be reasonably productive, and in some cases lack of power for key end uses—such as pumping water out of mining areas—results in significant setbacks. In addition, some mine operators must pay significant tariffs (reportedly between $0.10 and $0.15 per kWh) for the electricity they receive from the grid. As such, many mine developers have taken to installing equipment to produce their own electricity, typically either with mini-hydroelectric power plants, with diesel generators (although use of these has been more limited as sanctions have reduced oil supplies), or with small coal-gasifier-powered generator units.

Microgrids for Mines Concept

The "Microgrids for Mines" concept proposes offering to undertake a collaborative project with the DPRK that would develop a microgrid and related systems to power a mine in the DPRK, the output of which would be sold internationally. The project and the ability to sell mine output would be a part of a bargain with the DPRK to induce participation in denuclearization talks and first steps—such as allowing IAEA inspectors back to some key DPRK nuclear facilities—toward reaching agreements. The microgrid could be applied to one or more mines and could be adjusted in terms of cost and power output to meet the needs of the mine and the needs of negotiations. A 2018 article by ROK authors envisioned a solar microgrid for a large existing zinc and lead mine at Gumdeok with an output capacity of 7.5 million tonnes of ore annually,[852] but smaller installations are also possible due to the scalable nature of microgrids.

Like the grid electricity they supplant, microgrids for mines would need to provide power for a range of end-uses, including conveyors and elevators (motive power), air compressors for drills and jackhammers, hydraulic drilling equipment, water pumping, ore grinding and classifying, lighting for mines, and lighting and plug loads for offices and workers' quarters, although the latter demands are quite small. The microgrid could also be extended to nearby villages, providing a humanitarian benefit and additional rural economic development opportunities (for education, agricultural processing, local manufacturing, and other needs). A mining operation would likely need power 12-16 hours per day, for most of the year (possibly with a hiatus in winter). Sources of power for microgrids would include solar photovoltaic panels, mini- and micro-hydro installations, and wind power (some areas of the DPRK have good wind resources, particularly in the far Northeast and along the high ridges in the center of the country). These could be augmented with fossil-fueled units such as electricity generators and coal gasifier-fueled generating units. For microgrids based on solar power, in particular, solar output would need to be stored, with the two most likely technologies being battery storage—the cost of which has been falling rapidly (and of which the ROK is a leading producer), and pumped-storage hydro, which pumps water uphill when excess power is available, and routes water back down to turn a turbine when needed. Pumped-storage hydro may be a good match to the DPRK's rugged terrain in many places.

Examples of Scales of Microgrids for Mines

Two examples of mines where microgrids might be applied are shown below to illustrate the potential scales of such systems, although they represent neither the largest nor the smallest grids that are possible.

- In the Gumdeok mine example provided by the ROK authors referenced above, electricity requirements of 255 GWh (million kWh) per year were estimated, requiring on the order of 250 MW of solar PV power to provide all of the power needed for the

[852] Myeongchan Oh, Sung-Min Kim, Young-Hyun Koo, and Hyeong-Dong Park (2018), "Analysis of Photovoltaic Potential and Selection of Optimal Site near Gumdeok Mine, North Korea", *New & Renewable Energy* 2018. 9 Vol. 14, No. 3, available as https://doi.org/10.7849/ksnre.2018.9.14.3.044.

mine, or less than that if other power sources are used as well. The authors estimate a cost of about $200 million for the PV systems, although that A) is based on ROK costs (probably from 2 years ago, at this point), which may be high if panels are purchased from China, for example, and B) the cost does not appear to include storage for electricity, which would be required, particularly if solar was the main power source. As such, a range of $150 to $300 million is probably a reasonable assumption for this installation.

- Another example, which might be applicable, for example, to a smaller gold mine (which typically would produce other metals as well), would require about 500 kW of power on a fairly continuous basis (12-18 hours per day), about 200-250 days per year. Depending on the types of power supplies used for the microgrid, one would expect a microgrid for such an installation using renewable energy to cost on the order of $3 million to $7 million or more including microgrid elements such as generation, storage, distribution lines, transformers, and control equipment. Oil- or coal-fired generators would be considerably less expensive (though distribution costs would not change) but would incur costs for continuous fuel inputs and for the systems supplying those fuels.

Additional Considerations

This illustrative example has provided a necessarily brief treatment of the "Microgrids for Mines" concept. Much would need to be done to negotiate, plan, and implement such a project in the DPRK, requiring many types of expertise. Among the additional considerations to be addressed, and additional possibilities to consider, are:

- Will restrictions be placed on who the DPRK can export the mine output to, and/or how the proceeds from sales of the output would be used? For example, would there be an insistence that funds from the sale of minerals commodities go toward humanitarian uses?
- Relatedly, the mine targeted for a microgrid would need to be carefully considered. Gold and silver mines, for example, produce instantly and globally saleable output, but perhaps offer less opportunity to control the use of the output, if that is an issue.
- It is to be expected that the choice of the mine or mines to be included in a microgrids project will be neither random nor straightforward, and will require North Koreans to consult a number of internal constituencies even as the project is discussed as a part of talks.
- The timing of the project will need to be coordinated with agreements made during talks, and probably will require the project to be mounted and delivered quickly once the parties get to "Yes". This means that significant initial planning and development of at least conceptual project options, including identification of potential project delivery mechanisms and participants, will need to be done well in advance.
- This type of project is consistent with the DPRK's own stated priorities for economic development in general, minerals sector development in particular, development of stand-alone power sources, and development of sources of renewable energy, some of which have been highlighted by Kim Jong Un himself. As such, a Microgrids for Mines project would be expected to have considerable symbolic and demonstration value to the DPRK.

■	The DPRK’s endowment of rare earth minerals ores, sources of elements (examples are yttrium and neodymium) important for but used in small quantities in the production of high-tech products, should be of strategic interest to the US and others, as China currently produces on the order of 97% of these elements. Rare earth resources are found in many places, including the US, so there may be synergies with microgrids and development of rare earth mines in the DPRK that could provide experience that would also benefit US producers.

10.3.2. Rehabilitation of power plants and other coal-using infrastructure

Rehabilitating existing thermal power plants, industrial boilers, and institutional/residential boilers will result in improved efficiency so the coal that is available goes further, will reduce pollutant emissions, and will improve reliability so that the lights and heat stay on longer. Accomplishing these upgrades will require a combination of training, materials (especially control systems), and perhaps assistance to set up and finance manufacturing concerns to mass-produce small boilers and heat-exchange components.

An initial focus, in the area of boiler technology, should be on improvements in small, medium, and district heating boilers for humanitarian end-uses such as residential heating and provision of heat and hot water for hospitals, schools, and orphanages, many of which have reportedly had little or no heat, or have used biomass fuels for heating, in recent years. If possible, it would be optimal to provide such upgrades in areas of the country away from Pyongyang, those hardest hit by the DPRK's economic difficulties.

The DPRK building stock, even in rural areas, tends to make extensive use of masonry and concrete, with leaky windows and doors, and minimal insulation. A program of boiler upgrades should go hand-in-hand with a program of "weatherization" (insulation, caulking, weatherstripping, and window replacement). Even minimal weatherization measures promise significant savings, with attendant reductions in coal use (making the supply go further), and in local and regional pollution.

Another early focus should be on rehabilitation of boilers in key industries that could help the DPRK to "bootstrap" the civilian economy. As a specific example, the DPRK has one of the world's largest deposits of the mineral magnesite, which is used in making refractory (furnace-lining) materials. Helping to rebuild the boilers or kilns that are used to produce magnesite, along with the fuel- and ore-supply chains that feed them, would help to boost magnesite production, and would bring much-needed additional foreign exchange into the country. We suspect that with international and ROK government participation and guidance, a private sector partner from the ROK or elsewhere could be found to assist with this type of rehabilitation, and to share in the profits of a joint-venture firm.

In the short run, it may also be useful for the international community to provide the DPRK with coal for selected power plants (to the extent that they are operable) in areas now poorly served by the existing coal and electricity supply systems. Providing such supplies would help restore humanitarian services and assist in economic revival while other energy sector upgrades are underway. In general, assuming an agreement is reach with regard to the DPRK’s nuclear weapons and related programs, it is likely that improvements in coal-fired power and heat will be largely short-to-medium term measures to provide energy service while the DPRK (and the world) transitions to cleaner, low/no-carbon fuels.

10.3.3. Rehabilitation of coal supply and coal transport systems

Strengthening of the coal supply and transport systems (again for the short-to-medium term) must go hand in hand with boiler rehabilitation if the amount of useful energy available in the DPRK is to increase. Foreign coal industries—in the United States and Australia, for instance, as well as China and Russia—have significant expertise to assist with evaluating and upgrading coal mines in the DPRK, including helping with improvements in mining technologies and equipment, in evaluation of coal resources, in mine ventilation systems, and in mine safety. The needs in this sector are so extensive, however, that no one should expect that substantial rehabilitation of the coal sector will happen quickly. For example, even once power is restored to mines, electrical and other equipment has been replaced or upgraded, and in-mine life support systems are adequate, in many mines it may take literally years before many coal galleries are pumped sufficiently free of water to be worked again. Coal processing to remove ash and improve fuel value could be another focus of assistance, as could the tapping of coalbed methane for use as a fuel[853] (and to improve mine safety).

In parallel with any mine upgrades, rehabilitation of the coal transport network must also take place. This involves making sure that train tracks between mines and coal users are operable, that locomotives have electricity or diesel fuel to operate, and that working coal cars are available. In turn, this may mean providing or helping to set up a remanufacturing facility for steel rails, providing or helping to renovate factories for rail car and locomotive parts, and other types of assistance.

10.3.4. Development of alternative sources of small-scale energy and implementation of energy-efficiency measures

The North Koreans we have worked with have expressed a keen interest in renewable energy and energy-efficiency technologies. This interest is completely consistent with both the overall DPRK philosophy of self-sufficiency and the practical necessities of providing power and energy services to local areas when national-level energy supply systems are unreliable at best. Such projects should be fast, small, and cheap. Some of the key areas where the United States and partners could provide aid (some of which have been noted in earlier Chapters in this Report) are:

- Small hydro turbine-generator manufacturing: Much of the rugged topography of the DPRK is well suited to small, mini, and micro-hydroelectric development, and the DPRK government has given its blessing for local authorities to undertake hydro projects. The DPRK does manufacture some small turbine-generator sets (see Figure 10-1), but it is clear that assistance would be helpful to produce more reliable and cost-efficient units, as well as to expand mass production.

[853] Methane is the chief component of natural gas. Once processed to remove water, CO_2, and other impurities, coalbed methane can be used in the same way and with the same equipment as natural gas and can be injected into existing natural gas pipelines.

Figure 10-1: DPRK-made Mini-Hydroelectric Turbine-Generator[854]

- Wind power: Likewise, the dissemination of wind turbines is a both a national goal and, from our first-hand observations, a keen interest of individuals in the DPRK. As noted in section 5.2.2, the barren ridges of the interior of the country and some areas along the northern border are likely to be excellent wind power sites. The DPRK-manufactured wind generators and control components that we saw in 1998/2000, however, are at best grossly inefficient, and more likely non-functional, and although improvements have been made since then, it is still not clear that the DPRK has a significant capability for manufacturing serviceable wind power turbines. Design assistance and joint venture manufacturing of wind power systems are needed. A first phase might be the manufacture of lower-technology water-pumping windmills (see Figure 10-2).

[854] Figure from David Von Hippel and Jungmin Kang, "Updated DPRK Energy Balance (Draft) and Work to Be Done" as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DvHKang.ppt.

Figure 10-2: Water-pumping Windmill Installed by Nautilus and DPRK Engineers at Unhari in the Year 2000[855]

- Agricultural equipment efficiency measures: Helping North Koreans to feed themselves should be a high priority. The rice harvest in the DPRK has for most of the last two decades been, based on our observations in the "rice basket" of the country, a nearly completely manual process. To increase productivity, improvements are needed in tractor design and maintenance (including spare parts manufacture) to make sure that the diesel fuel that is used in agriculture goes further. Improvements in motors and drives for electrically-driven agricultural equipment, such as rice threshers and mills, will stretch supplies of electricity.
- Building Envelope Improvement/Building Energy Efficiency. As noted in section 4.5, the thermal efficiency of building envelopes in the DPRK—the efficiency with which buildings

[855] Photo by Nautilus Institute.

keep heat in and cold out, or vice versa (depending on the season), is generally quite poor. Existing multi-unit residential buildings and commercial/institutional buildings in the DPRK are typically made of precast concrete or reinforced concrete pillar construction, with the walls filled in with concrete blocks and mortar. Few such building have any substantial insulation, and those that do may have some insulation made of lightweight concrete, which has far less insulation value than modern insulation materials. Cooperation on building energy efficiency including production (or, initially, import) and use of insulating materials, collaboration on development of building designs in the residential and commercial/institutional sectors with excellent thermal properties, and production or import of key building components that would contribute to high-efficiency buildings (doors, windows, radiators, heat controls, and other components) is one of the most important options to pursue from the energy savings, economic, environmental, and humanitarian perspectives. It is also an option very much of interest to the DPRK, as witnessed, for example, by a presentation provided by a DPRK delegation at the 2008 DPRK Energy Experts Working Group Meeting, March 8 and 9, 2008, Beijing, China, entitled "Introduction of the Building Sector in DPR Korea", and including conceptual designs of energy-efficient buildings (see Figure 10-3) among other details.[856]

Figure 10-3: Conceptual Residential Building Design from 2008 DPRK Presentation

- Residential lighting improvements: Three or four times as many households (or more) can be supplied with much higher quality light with the same amount of electricity if DPRK incandescent and tube fluorescent bulbs are replaced with LED light bulbs, or with the older CFL technology. As noted above, at least for CFLs, this measure has reportedly been taken up by the DPRK government, with distribution of CFLs to many households. Ultimately,

[856] Presentation available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/DPRKBuilding.ppt.

joint venture manufacturing (or at least assembly) of LEDs in the DPRK could be undertaken, but until then provision of LEDs of robust quality should accompany any local power supply or T&D improvement initiative. In our work in the DPRK in 1998 and 2000, we found the provision of modern (at the time) lighting products to be invaluable for securing grassroots support, as it provided a direct and tangible improvement in the lives of ordinary Koreans (see Figure 10-4), as residents have found the improvement in light quality in their homes from installing CFLs to be considerable.

Figure 10-4: Compact Fluorescent Light Bulb Installed in DPRK Residence During the Unhari Project, 1998[857]

- Industrial and irrigation motors: The opportunities for efficiency improvement in large electric motors and motor drive systems are estimated to be considerable. Imports of efficient motors, pumps, air compressors, and other motor-related equipment may be the first

[857] Figure from David Von Hippel and Jungmin Kang, "Updated DPRK Energy Balance (Draft) and Work to Be Done" as prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA).

step (once power quality has been improved sufficiently), followed by assistance in setting up facilities to manufacture or assemble equipment in the DPRK. Improving the reliability and efficiency of irrigation pumps will help the DPRK move toward feeding its populace.

- Humanitarian measures: Even the best orphanages, hospitals, and schools in the DPRK are cold and bleak today. Providing on-site power (preferably with renewable energy systems), water purification equipment, and efficient lighting and other end-use devices are necessary and highly visible first steps toward meeting humanitarian needs in the DPRK.

10.3.5. Rehabilitation of rural infrastructure

The goal of a rural energy rehabilitation program would be to provide the modern energy inputs necessary to allow DPRK agriculture to recover a sustainable production level, and for the basic needs of the rural population to be met. The priority areas for rehabilitation would be those for which energy shortfalls most seriously affect agricultural production, human health, and fundamental quality of life. These areas include maintenance of soil fertility, farm mechanization, irrigation and drainage, and lighting, heating, cooking, and refrigeration for households and essential public institutions such as clinics and schools.

A comprehensive rehabilitation program for rural areas would feature a combination of short to medium-term energy supplies from imports and medium to long-term capital construction and rehabilitation projects. Components of an import program would include fertilizer, tractor fuel, and electricity at levels sufficient to enable agricultural recovery in the shortest attainable time. Some imports of tractors themselves may be necessary, as many of the DPRK tractors have suffered for years from lack of spare parts and poor fuel quality. Piloting the use of electric tractors, as a component, for example, of projects in which rural micro-grid play a role, would be a means of accelerating the deployment of both reliable and sustainable re-mechanization of DPRK agriculture.[858] A capital construction program for rural energy would include projects necessary to achieve the sustainable rehabilitation of the North Korean rural energy sector in the medium term (approximately 5 years). It is possible to outline some of the main elements of such a program: rehabilitation of the rural electricity transmission and distribution grid, development of reliable local power generation, improving the energy efficiency of the irrigation and drainage system, modernizing fertilizer and tractor factories, and improving the transportation of agricultural inputs and products. Many of these projects have already been proposed in the context of UN-sponsored agricultural reconstruction studies. An integrated, county-level project of rural rehabilitation would be more useful, and a more useful example for similar work in other areas of the country, than piecemeal efforts in many locations.

Another key element of rural rehabilitation with links to the energy sector is rehabilitation of the agricultural sector. The United Nations AREP (Agricultural Recovery and Environmental Protection) project in the DPRK noted a number of agricultural sector problems that, if

[858] See, for example, "Lindsay Campbell (2020), "Going Green: Can Electric Tractors Overtake Diesel", *Modern Farmer*, dated March 28, 2020, and available as https://modernfarmer.com/2020/03/going-green-can-electric-tractors-override-diesel/. A company called Solectrac based in the United States, is one of the first manufacturers to provide a range of electric tractors (see https://solectrac.com/), but major manufacturers such as US-based John Deere are also working on electric tractor commercialization (see, for example, Sam Francis (2019), "John Deere showcases autonomous electric tractor and other new tech", Robotics and Automation News, dated November 19, 2019, and available as https://roboticsandautomationnews.com/2019/11/19/john-deere-showcases-autonomous-electric-tractor-and-other-new-tech/26774/.

addressed, would likely help to improve consumable crop production per unit energy input, including reducing post-harvest losses and early crop consumption, ensuring that field operations (tilling, planting, fertilization) occur at the right time of year (and have the inputs available to do so), optimizing fertilizer application (amount, type, and timing),improving seed stocks, and other improvements.[859] Post-harvest crop losses and early crop consumption alone have been estimated to reduce usable crop production by 20 percent in the DPRK.

10.3.6. Electricity grid interconnections

Although hardly either a quick fix or a short-term project, it is imperative and attractive, from the perspectives of virtually all countries in the region, to move ahead with the consideration of electricity grid interconnections involving the ROK, the DPRK, Russia, and possibly China and Mongolia as well (as described in Chapter 8, above).[860] As of 20 years ago, a driving force for the implementation of such interconnections would have been the need to provide a means of safely "turning on" reactors built by KEDO on the Simpo site, as the reactors would have been (and will be until the DPRK is stable and much larger) too large for the DPRK grid, even if the grid were fully operational. As of now, in the (probably unlikely) event that construction is resumed, once the nuclear units are complete (at this point, probably no earlier than 2028), the interconnection would more likely serve mostly as a means of getting power through the DPRK to the ROK from Russia, or possibly (through Russia or China) from Mongolia, as described in Chapter 8. An international connection would also be needed to provide a means of transferring significant amounts of power from the ROK to the DPRK, as was proposed by the ROK in 2005, although doing so would probably require both reinforcement of the ROK grid in certain places and reconstruction of the DPRK grid to allow the latter to accept significant amounts of power.

10.3.7. Gas supply/demand infrastructure

Little or no gas is used in the DPRK at present. Given, however, the keen interest in Russia and the ROK in extending a gas pipeline from the vast resources of Siberia and the Russian Far East to the consumers of South Korea (see Chapter 8), it may be worthwhile to start to establish an appreciation for the benefits of gas on the part of the DPRK. Initial steps might be to build small demonstration power plants fired, for example, with liquefied petroleum gas imported to small (probably coastal) storage facilities, and also to use gas piped from such facilities to provide essential humanitarian services and residential fuel (for cooking, space and water heating, and other uses) to a small surrounding area. If these types of small, local gas distribution systems can be established, it may be possible to build a small LNG terminal in the DPRK, as described as part of the “Sustainable Development” and “Regional Alternative” paths investigated in

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[859] Hugh Bentley, “Trends in the DPRK Agricultural Sector & Implications for Energy Use”, presentation prepared for the DPRK Energy Experts Working Group Meeting, June 26th and 27th, 2006, Palo Alto, CA, USA). Available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2012/01/Bentley.ppt.

[860] See, for example, Alexander Ognev and Ruslan Gulidov, “Russia – DPRK Electricity Cooperation: the Role of INTER RAO UES Company at Current Stage”, prepared for the DPRK Energy Experts Working Group Meeting, March 8 and 9, 2008, Beijing, China, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/RussiaDPRK.ppt, Yoon Jae-young, “Analysis on DPRK Power Sector Data & Interconnection Option”, prepared for the same meeting, and available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/Yoon.ppt, and another presentation by the same author, entitled “Analysis on DPRK Power Industry & Interconnection Options”, prepared for the 2010 DPRK Energy and Minerals Working Group Meeting, September 21st-22nd, 2010, Beijing, China, available as http://nautilus.wpengine.netdna-cdn.com/wp-content/uploads/2011/12/01.-Yoon.ppt.

Chapter 8, above, and, as gas consumption increases and a local pipeline network begins to coalesce, consider, as a next step in energy relations between the DPRK and its neighbors, an international pipeline. As a relatively clean fuel, and one that is relatively resistant to diversion for most military purposes, it may in at least the medium run (assuming eventual global efforts to bring carbon emissions down to near-zero) prove worth the ROK's effort to begin the process of introducing gas as a fuel in the DPRK.

10.3.8. Engagement on Nuclear Energy with the DPRK

The DPRK's current and planned use of nuclear technologies may present severe problems related to nuclear security and safety. Of most concern is possible loss of control of nuclear materials and/or nuclear weapons due to instability in the DPRK itself associated with a leadership transition or occurring during a conflict. Short of such disorder in the DPRK itself, the DPRK's "routine" nuclear security on fuel cycle sites and its nuclear material- and weapons-related sites is likely to be very stringent. Nonetheless, it may be important to engage the DPRK to ensure that its domestic legislation is fully developed with respect to the obligations that all states must observe regarding UN Security Council resolution 1540 (passed in 2004). Measures related to 1540 compliance, and training in same, may be useful confidence-building activities in the early stages of engagement of the DPRK to denuclearize its nuclear weapons program.

With regard to nuclear safety, it is understood that the DPRK electric power system in general operates with very low standards for technical performance and maintenance, in large part due to the DPRK's many decades of isolation from the international community, and also due to the related lack of spare parts and materials, leading to remarkable improvisation but also to a system prone to constant breakdown. Similar practices were observed at Yongbyon nuclear sites during the period of US and IAEA monitoring in the 1990s, and there is little reason to think that this proclivity to take short cuts, conduct speed campaigns, and proceed with regard for worker health and safety that is typically lower than international norms has changed. There is certainly reason to be concerned about the DPRK's construction practices in its construction of the experimental LWR (ELWR) at Yongbyon that has been in process for most of the last decade.

The experimental LWR core could also be disabled accidentally due to poor design, operator error, or hardware failure, but it is too small a thermal mass to lead to a fuel meltdown as occurred at Fukushima, Chernobyl, or Three Mile Island. If some other accident or attack disabled the reactor, however, it could release a relatively small amount of radioactive material, but the plume will affect mostly local areas close by Yongbyon.[861]

There are many ways to engage the DPRK on safety and nuclear fuel security, once a realistic framework for denuclearizing the DPRK's weapons program is agreed to and being implemented. Although nuclear engagement with the DPRK may not appear attractive to the international community, it is likely that the DPRK will continue, as it has in the past, to see an opportunity to pursue a nuclear energy future, at least at some level, as a required element of an

[861] See David F. von Hippel and Peter Hayes, *Illustrative Assessment of the Risk of Radiological Release from an Accident at the DPRK LWR at Yongbyon*, NAPSNet Special Reports, May 06, 2014, http://nautilus.org/napsnet/napsnet-special-reports/illustrative-assessment-of-the-risk-of-radiological-release-from-an-accident-at-the-dprk-lwr-at-yongbyon-2/.

agreement with the international community on its nuclear weapons program. Such an engagement could entail some or all of the following steps:[862]

- Helping the DPRK to make or contribute to production of low-enriched uranium (LEU) to convert and fuel the DPRK's IRT research reactor (possible, for example, for use in medical isotope production),[863] and/or, in the future, to supply LEU for small stationary or barge-based LWRs;
- Jointly designing with the DPRK a made-in-DPRK small reactor that meets international safety and manufacturing standards, possibly in a joint project with ROK LWR manufacturing firms. This could include designing and deploying (or importing) a small barge-mounted reactor (possibly Russian, if imported) to provide power in a coastal DPRK town, though recent Russian experience suggests that such deployment will take years and may face significant obstacles;
- Undertaking power system planning for the rational development of a national grid capable of supporting a fleet of small LWRs over a decade;
- Creating a multilateral financing scheme (possibly linked to a regional grid connecting the ROK with the Chinese and Russian Far East grids) for the manufacturing and construction of small LWRs in the DPRK (or, more likely, jointly with the ROK, with components made in both nations) over time, starting with a survey of DPRK manufacturing capabilities capable of contributing to or being upgraded to international standards required for safe, reliable LWR production;
- Creating a regional enrichment consortium involving Japan, the ROK and the DPRK (among other possible partners) whereby DPRK enrichment capacities are either incorporated into a safeguarded scheme, possibly operated as part of a multinational facility, in return for which the DPRK would reveal all its enrichment acquisition history;
- Development of a small reactor export program as part of an inter-Korean nuclear export push;
- Provision of a program of training and institutional development needed to support each of the above activities, which is likely currently almost completely missing in the DPRK today; and
- Development of alternative functions and missions—ranging from nuclear safety, nuclear facilities dismantlement and cleanup, and nuclear materials disposal and/or packaging for transfer to the US or its allies, to environmental monitoring and other productive activities—to redeploy and employ scientists and technicians currently working at Yongbyon. Providing such opportunities as a part of cooperative threat reductions can help to minimize

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[862] These and other approaches are outlined in more detail in David von Hippel and Peter Hayes, *Engaging the DPRK Enrichment and Small LWR Program: What Would It Take?*, NAPSNet Special Reports, December 23, 2010, http://nautilus.org/napsnet/napsnet-special-reports/engaging-the-dprk-enrichment-and-small-lwr-program-what-would-it-take/.

[863] See, for example, David Albright and Serena Kelleher Vergantini (2016), *North Korea's IRT Reactor: Has it Restarted? Is it Safe?*, dated March 9, 2016, available as https://isis-online.org/uploads/isis-reports/documents/IRT_Reactor_March_9_2016_FINAL.pdf; and

opportunities for leakage of nuclear weapons expertise to other nations as DPRK denuclearization proceeds.[864]

An engagement on nuclear energy issues including the types of activities described above cannot occur in a vacuum. LWR engagement should be accompanied by engagement on a host of other policy, economic, and humanitarian issues, but most importantly it must be accompanied by engagement on a wide range of other DPRK and regional energy sector issues such as those described above.

10.4. Cooperative Threat Reduction through Engagement on Energy Issues: An Example

As noted earlier in this Report, a key reason for the Democratic Peoples' Republic of Korea's (DPRK's) development of nuclear weapons and missile systems has been the DPRK's *energy insecurity*, that is, its lack, since the breakup of the Soviet Union, of access to key fuels—particularly crude oil, oil products, and electricity—at affordable prices and in sufficient quantities to develop its economy. A consortium-led humanitarian/capacity-building/engagement project, focusing on the installation of energy-efficiency measures in the Democratic People's Republic of Korea (DPRK) buildings sector and mini-grid systems powered by renewable energy for electricity generation, could potentially be deployed rapidly and would meet the requirements of a substantial pilot engagement project that would contribute toward cooperative threat reduction on the Korean Peninsula.

The authors have presented an outline of this type of cooperative threat reduction project in a recent publication for the Asia Pacific Leadership Network (APLN).[865] Such a project would offer positive attributes such as highly visible symbolic improvements for the DPRK energy sector, consistency with DPRK stated interests, limited potential for military diversion, affordability, scalability, humanitarian and economic development elements, and large scope for face-to-face interactions between DPR Koreans and the international community. It would also provide a demonstrable model for both future direction in the DPRK energy sector and for productive and cooperative future engagement between the parties as they work toward threat reduction. In order for such a project to be deployed rapidly, it is likely that a consortium of third parties—that is, non-governmental organizations—in the international community will need to plan, organize, and deliver the project, albeit, of course, with the approval and support of the governments involved.

A consortium-led, third-party-funded Pilot Energy-efficiency Renewable Energy Cooperative Threat Reduction "plus" (EE/RE CTR+) DPRK engagement project would be designed to have the following elements and attributes:

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[864] See, for example, the documents available from National Academies of Science, Engineering, and Medicine Committee on National Security and Arms Control, "Redirecting North Korean Nuclear Scientists", http://sites.nationalacademies.org/pga/cisac/pga_085529.

[865] David von Hippel and Peter Hayes (2021), *Provision of Humanitarian Energy Efficiency, Renewable Energy, and Micro-Grid Measures to the Democratic Peoples' Republic of Korea (DPRK) as Complementary to Engagement-Focused Cooperative Threat Reduction Activities*, Asia Pacific Leadership Network Special Report, March 2021, available as https://cms.apln.network/wp-content/uploads/2021/03/David-Von-Hippel-and-Peter-Hayes_DPRK-Energy.pdf and from www.nautilus.org.

- A focus on **energy efficiency**, starting with building envelope/system efficiency (including in apartment buildings in Pyongyang, to enhance project visibility within the DPRK), but also potentially including, to a lesser extent, elements such as residential lighting improvements, improved industrial and irrigation motors, and heating system and agricultural equipment efficiency measures.
- A second focus on **renewable energy**, emphasizing solar photovoltaic (PV) power and microgrids, but also potential including small hydroelectric and wind power installations where applicable.
- Humanitarian measures in homes/schools/clinics (for both the EE and RE measures), and possibly in one or more rural villages (combined EE and renewable energy systems) where economic development is a need.
- Job creation in the DPRK during the project and afterward, both through the local expanded availability of energy services provided by the project and through replication of project successes elsewhere in the DPRK. This could include job creation for military and nuclear-sector workers whose current jobs could be displaced by a threat reduction agreement. For example, positions for technicians and researchers in the Yongbyon Nuclear Complex could be developed to allows those workers to provide research and development on energy efficiency and renewable energy topics, to investigate environmental problems in the DPRK (and their solutions), and to work on safeguarding DPRK nuclear material with the involvement and oversight of international colleagues (for example, from the International Atomic Energy Agency).
- CO_2 emissions reductions, which, depending on how the project is structured, Clean Development Mechanism (CDM) rules, and ROK laws, could possibly result in carbon credits for the ROK if ROK firms invest in the project.
- Materials provision to the DPRK that is not likely to violate the spirit of United Nations Security Council sanctions.
- The positive image of cooperation, which can be pointed to by both ROK/US and DPRK leaders, of cargo ships headed north across the line of demarcation bearing insulation and other EE/RE products for installation in the DPRK.

The timeline of an EE/RE CTR+ DPRK Engagement project, like the scope of the project itself, could be scalable to meet the needs of threat reduction negotiations. For example, an initial rapid demonstration project including a limited number of measures could be carried out in 9 to 12 months, assuming good agreement and active/timely participation from all parties, with a more substantial and economic development-focused project carried out over five years or more, consistent with a negotiated timeline for nuclear weapons threat reduction by the DPRK and reduction/elimination of sanctions, economic and energy assistance, and other measures by the international community.

10.5. Conclusion

In this report we have provided our best estimate of DPRK energy supply and demand in the years 1990, 1996, 2000, 2005, 2008 through 2010, and 2014 through 2020. Despite what some observers report as a turn-around in the DPRK economy in the early years of the decade of the

2000s, and in some more recent years as well—at least in some areas of the country, and particularly in the mid-2010s, before the application of the more stringent UNSC sanctions—our estimates are that on a nationwide basis the DPRK's energy supplies of commercial fuels, and probably wood and biomass as well, remain extremely limiting. In addition, key infrastructure, especially in the power sector, continues to erode, with only modest improvements in isolated cases running counter to the trend. We have also reviewed the status of the electricity sector in particular, and of refined product imports, exports, and domestic production, and have reviewed the DPRK's considerable mineral resource base and its infrastructure for minerals production. We have quantitatively explored and quantitatively and qualitatively compared several of the universe of different future energy pathways for the DPRK and explored the energy sector implications of a range of "collapse" pathways for the DPRK, though we emphasize that we think the regime collapse in the DPRK is quite unlikely. Finally, we have suggested initiatives and cooperative activities that we believe, assuming the right approach and open, consistent dealings on the part of all of the nations and agencies involved, could provide a means of confidence-building while providing tangible benefits at the local level to DPRK citizens.