ESTIMATED COSTS AND BENEFITS OF POWER GRID INTERCONNECTIONS IN NORTHEAST ASIA

Based on a Presentation Prepared for the

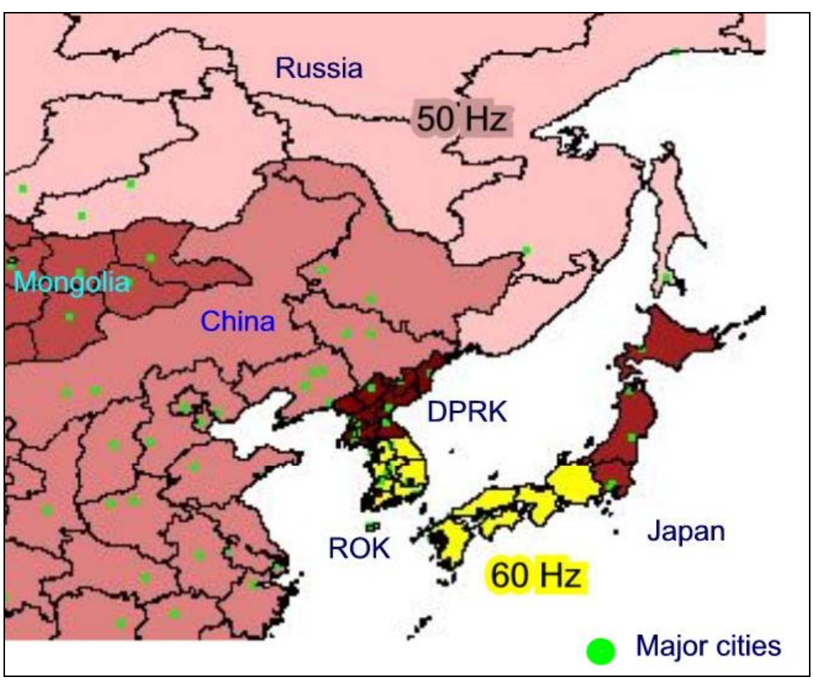
Northeast Asia Grid Interconnection Workshop

Hosted by Nautilus Institute, the State Power International Service Company and the Electric Power Research Institute

Beijing, China, May 14 to 16, 2001

David F. Von Hippel, Nautilus Institute

Draft, 9/28/01



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ABSTRACT

The objective of this paper is to prepare rough estimates of the costs and benefits of connecting the power grids of four of the neighboring countries of Northeast Asia, namely the Republic of Korea (ROK), the Democratic Peoples' Republic of Korea (DPRK), Russia--specifically the Russian Far East (RFE), and China (Northeast China). This paper seeks to approximately establish what the order-of-magnitude capital costs of interconnections of two different types will be, as well as to estimate whether the potential benefits—including economic, environmental, and other benefits—of interconnection are sufficiently high as to justify the investment costs. Investment costs are compared with other energy sector investments designed to reduce environmental impacts.

The paper draws on previous Nautilus work on future energy "paths" for the countries of Northeast Asia, as well as the work of colleagues in the region. This previous and collaborative work is drawn upon to identify major areas in the region with significant electricity demand growth. The overall electricity supply situation in neighboring countries (current and projected) is then reviewed, and estimated costs of interconnection for two specific scenarios are prepared by using capital and operating cost estimates obtained for key transmission line and power generation components. The two scenarios studied in this paper are:

- **Scenario 1**, which assumes a transmission line from the Northeast ROK along the east coast of the DPRK and into China, connecting at Simpo (site of the nuclear reactors built by the Korean Peninsula Energy Development Organization, or KEDO). This transmission line would allow power from the Simpo plants to flow to the ROK or China, and would allows any available baseload nuclear power from the ROK to be routed to China.
- **Scenario 2**, which posits a line connecting the Russian Far East, the ROK, the DPRK and Northeast China. The assumption is that power from the RFE hydroelectric plants flows to the ROK in the summer to meet peak demand there, and to China in the spring and fall. The

linkage also allows power from ROK and./or Simpo nuclear power plants to flow to China in the spring and fall, and to the RFE to meet peak demand there in the winter.

The estimated benefits of interconnection are computed by estimating the economic benefits of transmission links (avoided fuel, capacity costs), estimating the environmental benefits of interconnections in terms of avoided emissions and related impacts, evaluate qualitative benefits for regional security, computing cost-effectiveness indices, and comparing cost-effectiveness with other options for reducing pollutant emissions.

Overall, the Scenario 1 interconnection scheme is estimated to have an annualized net cost (including all nuclear capacity costs) of approximately \$190 million per year, or somewhat less than \$0.02 per kWh transferred. This value computes to about \$13 per tonne of carbon dioxide (CO_2) avoided. Costs are significantly lower if a portion of the nuclear capacity costs are considered "sunk" costs and not recovered in energy sold via the transmission line. Scenario 1 provides CO_2 savings of 15 million tonnes per year, as well as sulfur dioxide emissions reduction of just under 300 thousand tonne. When compared with the positive cost CO_2 emissions reduction measures included in the ROK's compilation of greenhouse gas reduction strategies (the "ALGAS" report), the transmission line concept considered in Scenario 1 provides similar emissions reduction at a lower average cost per tonne of CO_2 saved.

The Scenario 2 interconnection as modeled is estimated to have an annualized net cost (including all nuclear and hydro capacity costs, but only half of the costs of maximum avoided capacity in China, the RFE, and the ROK) of approximately \$50 million per year, about \$0.0033 per kWh transferred, or about \$2.50 per tonne of CO_2. Annual savings of CO_2 using scenario 2 are estimated at about 20 million tonnes, along with 360 thousand tonnes of sulfur dioxides. Scenario 2 thus may be an economic proposition on economic grounds even if environmental benefits are not accounted for, and would likely be quite favorable if significant value were attached to the emissions reduction achieved through the project.

A number of areas for further regional collaborative study and analysis are suggested in the last section of the paper.

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1. Introduction and Background of Study

1.1. Introduction

Electricity demand in several of the countries of Northeast Asia continues to grow rapidly. Despite recent economic downturns, electricity consumption in both China and the Republic of Korea (ROK) has been, on average, very strong throughout the 1990s. Japan's electricity needs have also grown, though at a lower rate in recent years. At the same time, the ROK lacks fossil fuel resources of its own to expand electricity production, and faces land-use and "not in my back yard" difficulties in expanding nuclear generating capacity. China's use of its fossil (particularly coal) and hydroelectric resources for increasing electricity supplies have associated environmental problems that are in some locations quite severe. Japan must import almost all of its energy, and is also facing political problems as it grapples with the question of whether or not to expand the use of nuclear reactors for electricity generation. The Democratic Peoples' Republic of Korea (DPRK) faces a severe electricity shortage that is a result of a number of economic and energy supply problems[1]. The nuclear reactors being built with the aid of the Korean Peninsula Energy Development Organization (KEDO) at the Simpo site in the DPRK are designed to help alleviate electricity shortages, but use of these reactors in the DPRK grid is problematic, at best[2]. Given these constraints, the countries of the region can either import fuels for electricity generation from outside the region, or can work with other countries of the region--in particular the Far East region of Russia (RFE)--to tap and share some of the resources available in the northern part of Northeast Asia.

One form that such resource sharing might take in both the relatively near-term and more distant future is the interconnection of the power grids of some or all of the countries of the region. Interconnections would allow electricity generated in Russia to flow south to China, the ROK, the DPRK, and possibly (eventually) Japan[3]. Grid interconnections would also allow the nations of the region to take advantage of complementarities in the timing of electricity needs and availability between the countries of the region. Finally, grid integration is highly likely to be a practical necessity for the use of the DPRK reactors being installed by KEDO.

The objective of this paper is to present a rough estimate of the costs and benefits of connecting the ROK, DPRK, RFE and Chinese Power Grids in order to establish:

- What the order-of-magnitude capital costs of interconnections—in two specific scenarios—might be
- Whether the potential benefits of interconnection—including economic, environmental, and other benefits—are sufficiently high as to justify the investment costs of the projects, particularly when compared with other energy sector investments designed to reduce environmental impacts

The results of the paper point to other research that is needed in order to more completely evaluate the possibilities of electric power grid integration among the countries of Northeast Asia.

1.2. Background to this Study

This study of the costs and benefits of grid interconnection draws on several ongoing and recent and Nautilus Institute programs and projects.

In the first phase of Nautilus Institute's East Asia Energy Futures (EAEF) Project, Nautilus Researchers assembled "base year" (historic) energy data for a number of east and northeast Asian nations, with the ultimate goal of formulating future scenarios of energy use and evaluating the costs of different "paths" representing distinct approaches to energy development. The countries covered in the first phase of the EAEF work were Japan, China, the ROK and the DPRK, plus Chinese Taipei and Hong Kong (now the Hong Kong Special Administrative Region of China)[4]. This work included compilation of a significant collection of relevant documents, information, and data, plus detailed base year and "reference case" (business-as-usual) projection data sets for each of the countries/areas. The first phase of the EAEF work also included the compilation and analysis of "Maximum Nuclear" electricity generation paths for all countries each of the countries, culminating in an analysis of the regional nuclear waste and waste-handling implications of business-as-usual and Maximum Nuclear paths[5].

A part of the EAEF project's first phase was the development of a reference energy supply and demand path for China, as well as the development and evaluation of a "Clean Coal" electricity supply alternative[6]. The paths were developed within a demand-driven model, with substantial sector/subsector/end-use and fuel detail, and "projection" years to 2020. Within the model, future energy use is expressed as a function of changes in driving activities (physical, economic, and demographic), energy intensities, and the types of fuels used. Energy supplies (including electricity infrastructure) within the model are built up to meet demand for fuels, and the model allows for the calculation of the relative costs of different paths (from a system perspective), as well as the absolute and relative air pollutant emissions from different paths[a].

The "BAU" and "Clean Coal" paths were intended to provide numerical illustrations of:

- Demand for electricity and other fuels in China;
- Potential growth in energy infrastructure;
- Potential growth in air pollutant emissions under a "business-as-usual" energy development scenario; and
- The potential roles of clean-coal technologies, in reducing emissions, and relative costs and benefits of same

The China Clean Coal path effort was also designed to lay the groundwork for future phases of the EAEF project, including the evaluation of energy-efficiency and renewable/alternative fuel paths, of the potential risks and uncertainties associated with particular energy paths, and of the potential role of regional cooperation in addressing problems energy sector development problems.

[a] The LEAP (Long-range Energy Alternatives Planning) software tool was used (and is being used) for the EAEF work. Information about the newest version of LEAP can be obtained from the Stockholm Environment Institute--Boston Center at www.leap2000.org.

A Nautilus project related to the EAEF program has been the Pacific Asia Regional Energy Security (PARES) project[7]. The overall objective of the PARES project was to design an initial framework for the evaluation of internal, external, and security costs of alternative energy development paths. The PARES project involved a group of US and Japanese researchers, and had as its individual goals to:

- Propose a consensus definition of "energy security";
- Develop an analytical framework to address energy security dimensions of choices in energy sector development;
- Prepare two illustrative medium-range energy "paths" for Japan (1995 to 2020);
- Evaluate the energy paths against a suite of energy security criteria using the framework defined; and
- Review the results of the case study for applicability to other countries of the region.

Another area of Nautilus Institute research related to the East Asia Energy Futures program has been an ongoing set of DPRK energy sector analyses and collaborative projects, including the compilation of estimated energy balances for the DPRK, the development of future energy sector scenarios, and a humanitarian village energy project in collaboration with a DPRK counterpart organization[8].

A second phase of the EAEF project has included regional workshops on energy futures in Northeast Asia including workshops in Beijing and in Berkeley, California in June of 2000 and March of 2001, respectively. In addition to exchanges of views and information on energy development in the region, these workshops included the training of a collaborative group of researchers from China, DPRK, Japan, RFE, ROK, in a common energy and environmental analysis tool, and in a conceptual framework for analysis of different energy paths.

In ongoing phases of the EAEF project (phases 3 and 4), goals are to work with the collaborative group of researchers assembled and trained in phase 2 of the project to:

- Generate and evaluate quantitative “reference” and “alternative” scenarios at a country level, with the work done by teams of researchers in each country teams using methodologies common to the project as a whole;
- Share the results and inputs of the evaluation with the collaborating group; and
- Assemble regional scenarios to evaluate costs and benefits of energy sector cooperation.

1.3. Approach in this Study

The overall approach taken in the study reported on in this paper has been to use existing Nautilus energy paths work for the DPRK, ROK, and China (as described briefly above) to identify major areas in the region with significant electricity demand growth. The next step in the analysis was to review the electricity supply situation in neighboring countries (both current and projected).

To estimate the potential costs of grid interconnection in two scenarios, capital and operating cost estimates were obtained for key transmission line components and options, and the costs of transmission links in different configurations were estimated. The benefits of interconnection were evaluated by estimating the economic benefits of each scenario of transmission links (including avoided fuel and generation capacity costs), by estimating the environmental benefits in terms of avoided emissions and related impacts, by estimate the technological diversity benefits from adding electricity imports as a supply option, and by evaluating the qualitative benefits of interconnection for regional security. The costs and benefits of the interconnection scenarios were then weighed by computing a set of cost-effectiveness indices, which were compared (benchmarked) against the cost-effectiveness of other options for reducing pollutant emissions.

1.4. Guide to the Remainder of this Paper

The remainder of this paper is divided into the following sections:

- **Section 2** provides a brief overview of scenarios of future electricity demand in Northeast Asia.
- **Section 3** summarizes the current power supply and demand situation in neighboring Northeast Asian countries that might be involved in electricity grid interconnection.
- **Section 4** presents the results of the analysis of the estimated costs and benefits of two interconnection options.
- **Section 5** offers overall conclusions based on the analysis, and provides comparisons of the cost-effectiveness of the interconnection options with other means of reducing pollutant emissions.
- **Section 6** provides a set of recommendations for research to follow-up and build upon the initial study presented here and on other work related to grid integration carried out by Nautilus Institute and others to date.

2. Future Electricity Demand and Supply in Northeast Asia

2.1. Overall Patterns of Electricity Demand Growth

Growth in electricity demand in many of the countries of Northeast Asia has been impressive over the past decade, and strong growth is likely to continue in some countries. Table 1 presents a combination of historical data on energy demand in the countries (and areas such as Hong Kong) in Northeast Asia, together with Nautilus "base case" projections of electricity demand compiled in 1997[9]. Data on electricity demand in 1999 from the United States Department of Energy's Energy Information Administration (USDOE EIA) show that year 2000 Nautilus estimates for China are likely to be somewhat (though not strikingly) low, estimates for Chinese Taipei (Taiwan) are quite low, and estimates for the DPRK (which postulated an economic recovery starting in the late 1990s) are likely to be substantially high[b, 10]. Nautilus estimates for 2000 electricity demand in Hong Kong appear to be higher than would be expected

[b] Although any estimate of electricity consumption in the DPRK is likely to be highly uncertain, and the author does not know how the USDOE EIA estimate of 1999 electricity use in the DPRK was derived.

based on 1999 consumption, Japanese consumption appears slightly higher than previously estimated, and consumption in the ROK, reduced by the economic crisis of the late 1990s, is somewhat lower than anticipated by figures shown in Table 1. Overall electricity use in the six countries/areas of the region shown in Table 1 appears likely to be slightly, perhaps a few percent, higher in 2000 than the values from the earlier Nautilus modeling effort.

Table 1:

Electricity Demand Projections by Country (TWh)

Country	1990	1995	1999*	2000	2010	2015	2020
China**	480	768	1,084	1,050	1,807	2,313	2,838
Chinese Taipei	72	89	130	104	129	144	162
DPRK	41	30	27	39	55	67	82
Hong Kong	24	30	32	42	68	83	102
Japan	747	834	947	931	1,107	1,178	1,260
ROK	99	163	233	265	458	540	626
TOTAL	**1,463**	**1,915**	**2,453**	**2,430**	**3,624**	**4,326**	**5,071**

*1999 Values from USDOE EIA data for provided illustrative purposes.
2000 to 2020 values from Nautilus "Base Case" energy paths for each country.
**Values for China from Nautilus "Clean Coal" paper

Table 2 presents a summary of the growth rates in electricity demand in four countries of the region, again based on earlier Nautilus modeling. Though demand growth in Japan appears likely to be relatively low--between 1.5 and 1.7 percent annually over 2000 to 2010--growth in demand in the ROK, China, and the DPRK (assuming an economic recovery) looks likely to be strong, averaging between 3.8 and 5.1 percent annually over 2000 to 2010, with growth in China and the ROK at a higher rate in the 2000 to 2010 period, but declining in the 2010 to 2020 period as those economies continue to mature.

Table 2:

Estimated Rates of Growth of Electricity Demand

(Percent per year, average over period)

Country	2000 to 2010	2010 to 2020	2000 to 2020
China	5.6%	4.6%	5.1%
DPRK	3.5%	4.2%	3.8%
Japan	1.7%	1.3%	1.5%
ROK	5.6%	3.2%	4.4%

2.2. Overview of Electricity Supply Patterns in Northeast Asia

Table 3 presents estimates, again from earlier Nautilus energy paths work (with historical figures as indicated for 1998 and before), of electricity generation capacity by type in China, the DPRK, Japan, and the ROK. Here, though the projections for the year 2000 appear to have been somewhat low in several countries, the key implications are that significant growth in generation capacity is likely to continue in the ROK and China, and would also occur in the DPRK (particularly after 2010) under an economic recovery scenario. Most of the added generation capacity is likely to be in fossil-fueled thermal power plants, which in China and the DPRK are likely to be largely coal-fired, and might be coal and gas-fired in the ROK (in roughly equal proportions). The combination of the demand projections above, and the capacity projections in Table 3, serve to indicate, at least in a rough way, which countries will benefit most from grid interconnection in the region, and what types of generation capacity might be avoided as power is shared between countries.

Table 3: Historical and Future Generating Capacity in NE Asia (GW)[c]

	1990	**1995**	**1998***	**2000**	**2010**	**2020**
China-Base Case						
Sum of Thermal	101.8	154.7	209.9	206.2	370.5	530.0
Hydro/Other	36.1	49.4	65.3	57.4	96.3	156.4
PWRs	0.0	2.2	2.1	2.7	12.0	23.0
DPRK-Base Case						
Sum of Thermal	4.5	4.7	*4.7*	4.7	5.0	10.8
Hydro/Other	5	5	*5*	5.13	5.3	5.7
PWRs	0	0	*0*	0	2.0	2.0
Japan-Base Case						
Sum of Thermal	130.7	134.9	159.1	143.3	169.1	203.9
Hydro/Other	36.7	38.9	45.4	38.9	42.9	44.9
PWRs	12.0	12.0	**45.2**	13.1	13.1	6.7
BWRs	18.6	24.0		26.6	31.9	28.1
ROK-Base Case						
Sum of Thermal	11.1	20.5	28.3	39.5	75.5	100.5
Hydro/Other	2.3	3.1	3.1	3.9	5.0	6.5
PWRs	6.9	7.9	**12.0**	10.8	14.6	16.6
PHWRs	0.7	0.7		2.6	3.2	3.2
FOUR COUNTRIES						
TOTAL	**366**	**458**	**580**	**555**	**846**	**1138**
Sum of Thermal	**248**	**315**	**402**	**394**	**620**	**845**
Hydro/Other	**80**	**96**	**119**	**105**	**150**	**213**
Nuclear	**38**	**47**	**59**	**56**	**77**	**80**

*See footnote to this table for source of and notes on 1998 data.

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[c] 1998 data shown in Table 3 are from APEC (Asia-Pacific Economic Cooperation) Energy Center database, obtained from www.ieej.or.jp/apec/database during August, 2001. Total generation capacity in 1998 for the DPRK (shown in *italics* in Table 3) is assumed the same as for 1995, though operable capacity is probably much less. Figures for nuclear capacity in Japan and the ROK in 1998 are shown as total nuclear capacity, that is, are not differentiated by type of reactor.

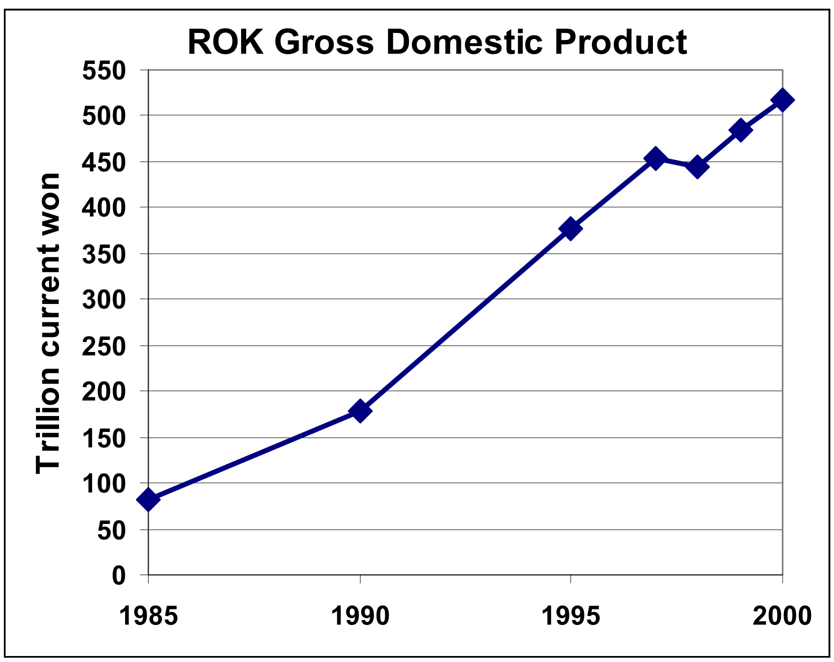
3. Current Electricity Demand and Supply Situation by Country in Northeast Asia: Overview and Trends

To augment the regional overview of electricity supply and demand provided above, summary information on the electricity supply and demand situation in the Republic of Korea, the DPRK, China and the Northeast region of China, and the Russian Far East is provided below.

3.1. The Republic of Korea

The economy of the ROK was hit hard by the regional economic crisis of the late 1990s, and a decline in electricity use accompanied the economic downturn. Both the economy and electricity use have rebounded quickly following the 1998 decline, however, with electricity demand growth increasing at approximately 10 percent annually in 1999 and 2000. The trend in the ROK's GDP is shown in Figure 1[11]. The economic effects of the 1998 financial crisis are evident in the decline in GDP between 1997 and 1998, but a comparison of the changes in GDP from 1998 to 1999 and 1999 to 2000 showed a virtual resumption of the 1990 to 1997 economic growth in the ROK.

Figure 1:



The trend in electricity demand by sector is shown in Figure 2[12]. The share of electricity demand accounted for by the commercial sector has more than doubled in the last two decades, but industry still consumes the majority of electricity (55 percent of total consumption in 2000).

Figure 2:

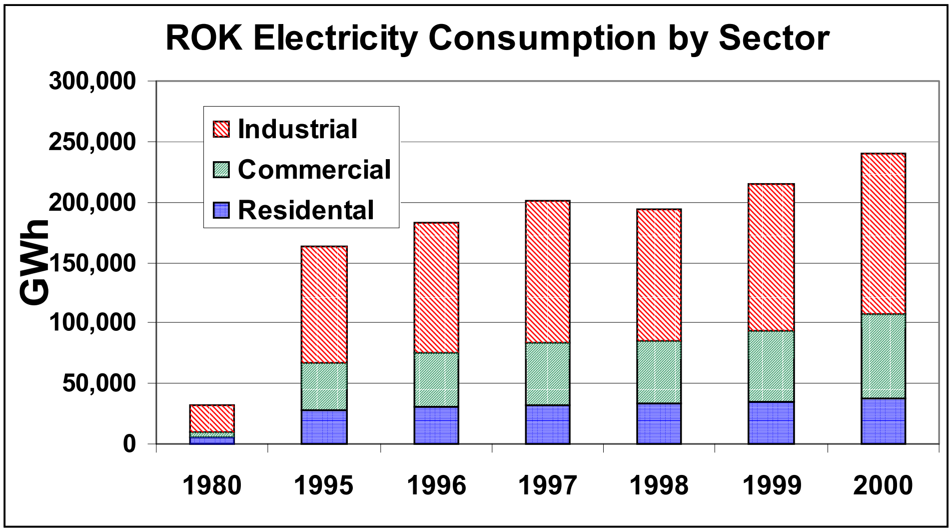
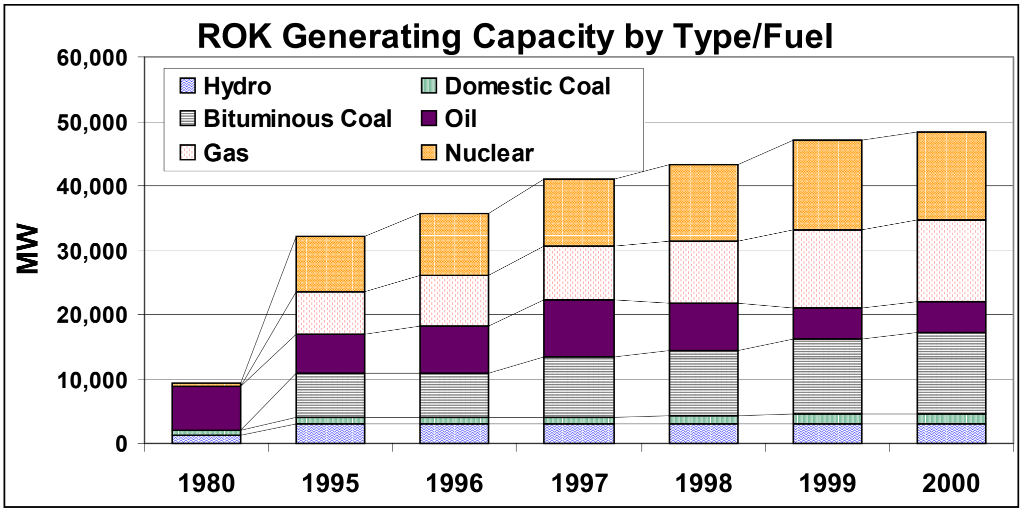


Figure 3 shows the trend of installed generating capacity in the ROK by type of unit and type of fuel[13]. Overall installed capacity was approximately 48.5 GW as of 2000, and generating capacity had expanded at an average rate of 8.5 percent annually. Gas-fired power plants and plants using imported bituminous coal were added at the highest rates during the latter half of the 1990s, followed by nuclear plants. The use of oil for power generation has been decreasing, and the use of domestic coal and hydroelectric power have changed relatively little (hydro is already being used at near its modest resource limits in the ROK).

The ROK electrical system is summer peaking overall, and there is somewhat of an imbalance in the location of most generation, which is in the southern part of the country, and the location of major demand centers in the North. This imbalance, plus a lack of suitable transmission corridors that can be developed, has served as a constraint that must be considered in the planning of future capacity additions in the ROK. Looking further into the future, KEEI (Korea Energy Economics Institute) forecasts suggest that there will be further increases in the share of electricity generated in nuclear power plants (and continued expansion in nuclear capacity). There are, however, significant social and political problems in the ROK related to the siting of new plants beyond the few existing and designated expansion sites, so a considerable additional expansion in nuclear capacity within the ROK may be difficult to achieve. With the exception of its modest domestic coal reserves, the ROK lacks fossil fuel resources, and as a consequence imports the vast bulk of its energy needs.

Figure 3:

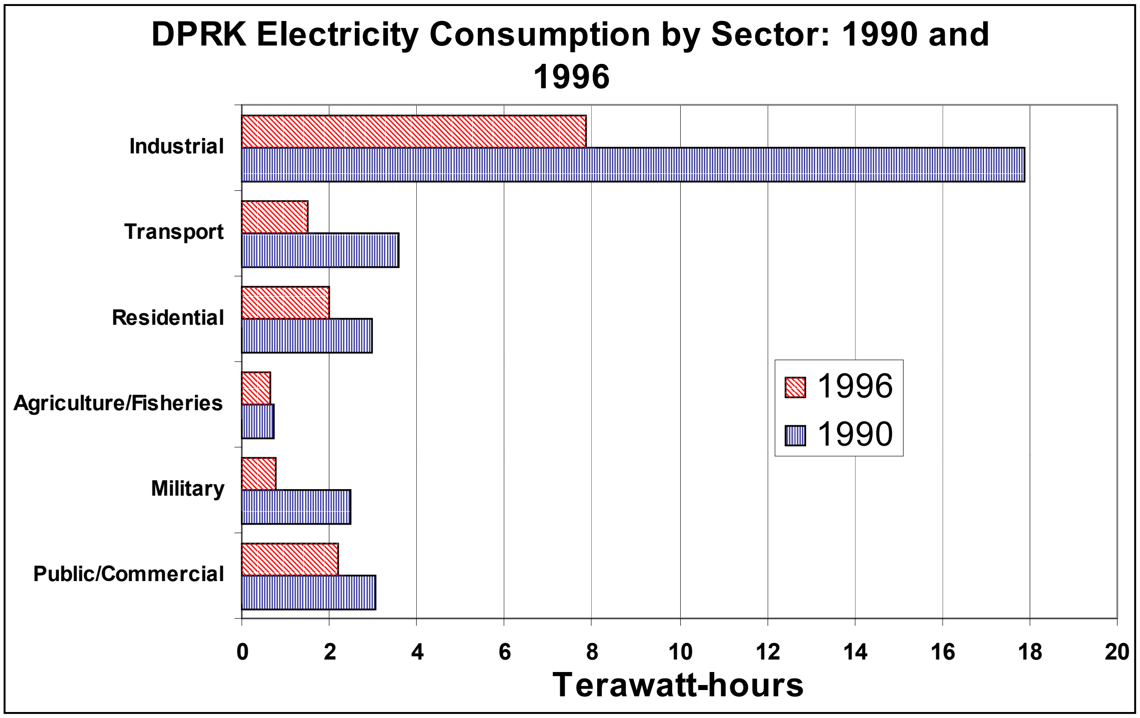


3.2. The Democratic Peoples' Republic of Korea

Starting in approximately 1990, electricity demand in the DPRK has been reduced by the country's economic difficulties, as well as by problems in electricity supply (which have resulted in unmet demand. Figure 4 summarizes Nautilus' estimates of 1990 and 1996 electricity consumption in the DPRK[d, 14]. In both 1990 and 1996, industrial electricity use is estimated to have dominated overall electricity consumption in the DPRK, but with the economic decline in the country, the residential and other sectors are estimated to consume a greater share of the smaller amount of electricity available. Though formal estimates have not yet been compiled for 2000, it is likely that electricity consumption has decreased further since 1996. That said, a combination of economic improvement and rehabilitation of the electricity supply system in the DPRK could easily result in a rapid increase in the demand for electricity in a relatively short time period.

[d] In the case of the DPRK, electricity consumption technically can very likely not, for most of the last decade, be considered to be the same as electricity demand, as considerable demand has probably remained unmet.

Figure 4:



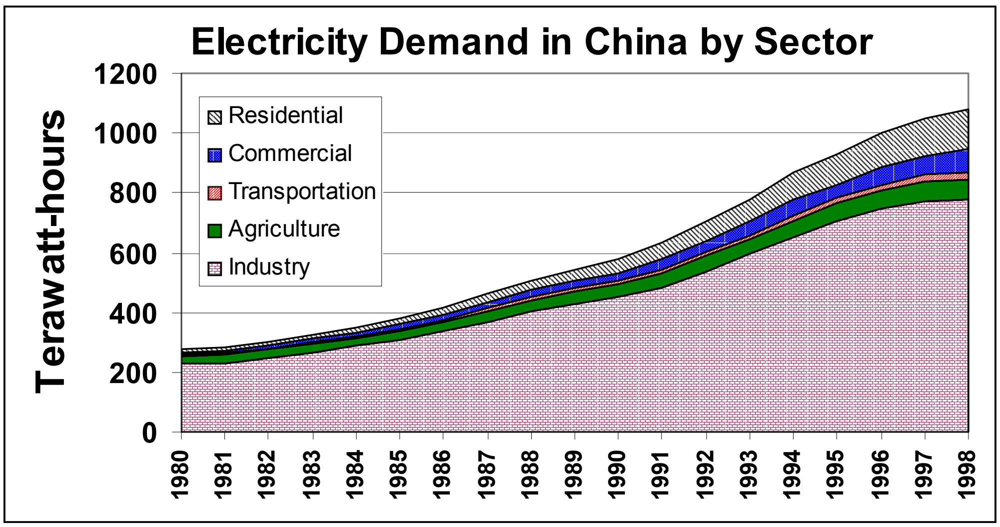
The nominal capacity of the DPRK's electricity generation system is approximately 10 GW, split roughly half and half between coal-fired and hydroelectric units. The currently operable capacity in the DPRK is probably, however, closer to 5 or 6 GW. Operable capacity is reduced by a combination of the lack of availability of spare parts for generators and boilers, damage to hydroelectric facilities caused by floods in the mid-1990s, fuel supply problems (related to both coal mines and transport), and problems with electricity transmission and distribution. The DPRK transmission and distribution (T&D) system itself also suffers from a lack of spare parts. As of the late 1990s the T&D system in the DPRK seems, based on the observation of visitors to the country, to be operating mainly as individual regional grids rather than as a national grid, which means that though some areas (such as Pyongyang) have relatively good electricity supplies, severe shortages exist in other areas. In recognition of the importance of improving electricity supplies, the DPRK government is encouraging the construction of small, local power plants, particularly small hydroelectric plants. Overall, investment capital in short supply in the DPRK, and foreign exchange income is thus a priority.

Few new large power plants seem to be actively under construction in the DPRK at present, with the notable exception being the approximately 2.3 GW (total) nuclear power plants being built at Simpo (or Kumho) by the KEDO consortium. The construction of these reactors is substantially behind the original schedule; current estimates are that the completion date may be between 2007 and 2010.

3.3. China

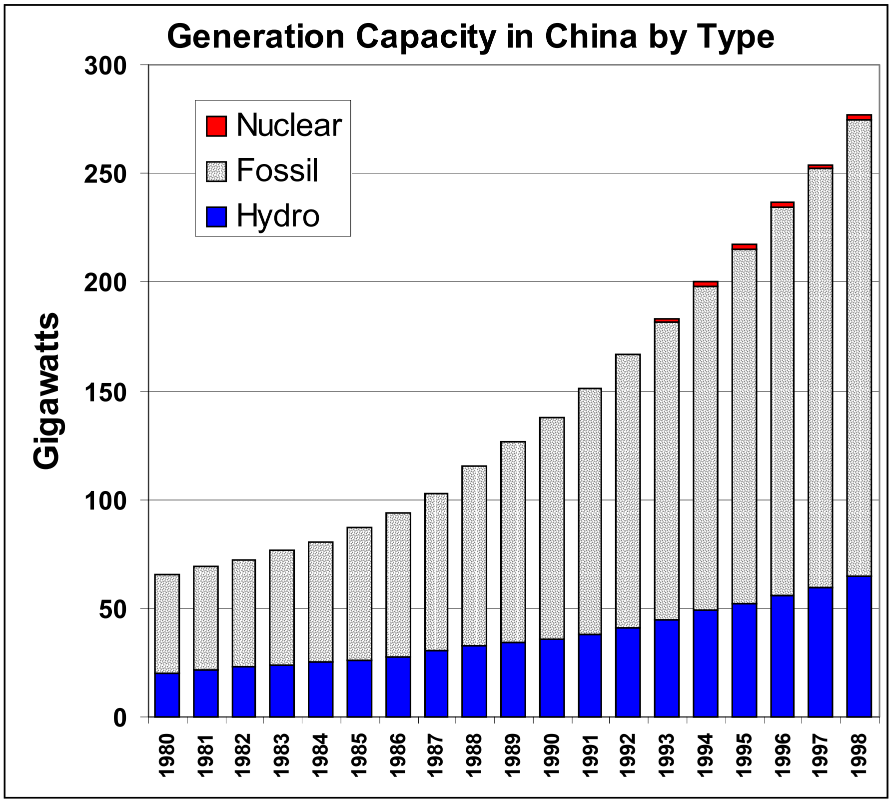
Growth in overall electricity demand in China has slowed somewhat in recent years, but the overall pattern of growth in demand during the 1990s has been very robust. As shown in Figure 5, electricity use in China has historically been dominated by the industrial sector (which in Figure 5 includes electricity use in the construction sector), but consumption in the residential and commercial sectors have been increasing in importance in recent years[15, 16]. Also noticeable in Figure 5 is the trend, in the late 1990s, toward reduced overall growth in electricity consumption in China, though the reduction in demand growth has in part been caused by the regional economic slowdown of the late 1990s.

Figure 5:



At present in China, sufficient supplies of electricity are available in most areas, with thermal (coal-fired) power plants being the main source of electricity. As shown in Figure 6, substantial growth in generating capacity is continuing. China's coal reserves are vast, but the combustion of coal both for end-uses and in power generation is increasingly problematic from an environmental point of view. China's oil and gas reserves are considerable (though not vast), but China has recently become a net importer of oil, and much of its natural gas is in locations relatively remote from population center. Similarly, though significant untapped hydroelectric potential remains in China, much of it is remote from centers of demand and/or, in many cases, would be environmentally and/or socially difficult to develop. Plans are underway, however, to develop the western portion of China, and to send power from the west to cities in the booming southeastern portion of the country.

Figure 6:



Power grids in China are mostly regional at present, but a program of interconnecting regional grids into a national system, over the next two decades or so, is underway. Interconnecting these grids will, however, pose significant engineering challenges, be costly, and, particularly to the degree that deregulation and privatization of China's electricity industry takes place, pose considerable organizational and institutional challenges as well.

3.4. Northeast Area of China

The Northeast area of China—including Heilongijang, Jilin, and Liaoning Provinces, and part of the Inner Mongolia Region—borders both Russia and the DPRK, and as such, is a possible first point of connection in China for transmission interconnections from Korea and the Russian Far East. The 1997 population of Northeast China was roughly 120 million—about 10 percent of the National total. Northeast China has been a major industrial area over much of the last century, with large industrial complexes, some started during the Japanese colonial period, built up to tap the regions rich resources of metal ores. The Northeast China area faces significant environmental problems, mostly related to coal use in industry and to metals smelting. In part in response to environmental problems, as well as to promote economic diversity, industrial restructuring is currently underway in some cities of Northeast China, with an emphasis on value-added manufacturing and commercial sector activities. Though heavy industries are somewhat de-emphasized in development plans for the region, they remain the focus of economic activities for the time being.

Power supplies in Northeast China are sufficient at present. The generating capacity in Northeast China has grown at an average rate of 8 percent annually over the last three years, as shown in Table 4[17]. Approximately 92 percent of total power production in Northeast China was generated in coal-fired thermal power plants as of 1996, and approximately 84 percent of generating capacity was coal-fired (the rest being hydroelectric) as of 1998. Though Heilongijang, Jilin, and Liaoning Provinces have significant coal reserves[e], the region is a net importer of coal from elsewhere in China. Inner Mongolia has huge coal reserves, over 25 percent of the national total, but coal production in Inner Mongolia was only on the order of 5 percent of national production as of 1996. Northeast China has Relatively few additional hydro resources are available in the area.

Table 4: Summary Statistics for Northeast China Power Network

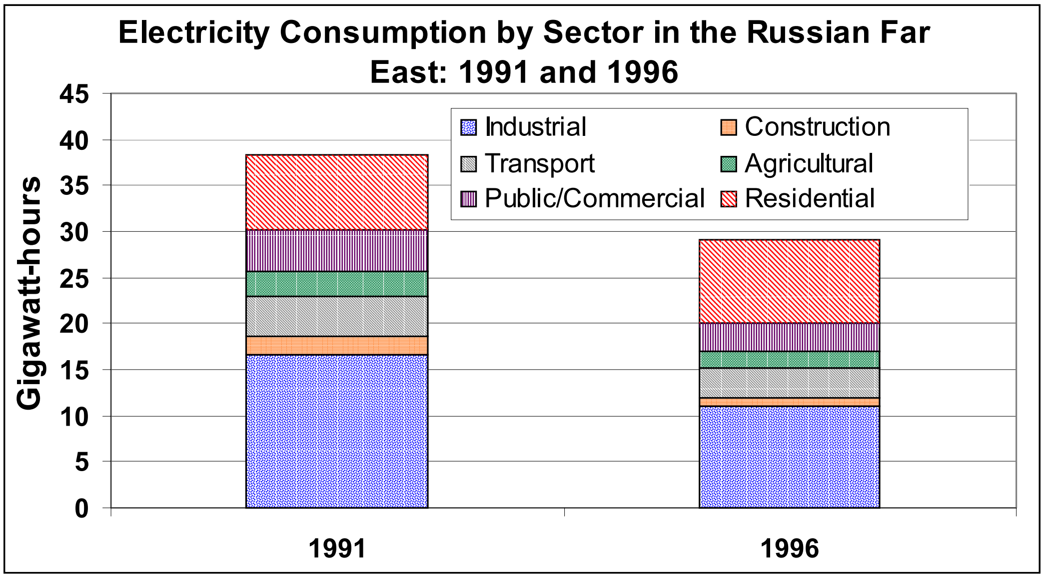
Year	Installed Capacity (MW)	Average Utilization (hours)	Implied Average Capacity Factor	Load Factor (%)
1991	23,012.5	4,763	0.54	85.5%
1993	25,755.9	4,673	0.53	
1994	26,534.4	4,693	0.54	
1995	27,197.5	4,813	0.55	
1996	29,495.3	4,689	0.54	
1997	30,962.2	4,626	0.53	
1998	34,312.1	4,114	0.47	
Ann. Gwth, 91 to 98	5.9%			
Ann. Gwth, 95 to 98	8.1%			

3.5. Russian Far East and Siberia

The Siberian and Far East areas of Russia are vast in territory, rich in natural resources (including timber, oil, gas, coal, and hydroelectric potential) and, for the most part, sparsely populated. In the Russian Far East, the area of Russia that borders Korea and Northeast China, economic decline during the period of restructuring following the breakup of the Soviet Union resulted in a considerable contraction of energy usage during the period from 1992 to 1998. Figure 7 compares electricity consumption by sector in the Russian Far East in 1991 and 1996[18]. The economy of the RFE has begun to recover during the period 1999 to 2000, with electricity consumption rising 6.2 and 4.5 percent in 1999 and 2000, respectively[19]. Electricity consumption in the RFE is projected to rise at about 25 percent above 1990 levels by 2010, though different projections vary considerably[20].

[e] Coal produced in these provinces has been, on average, relatively low in sulfur (0.47 percent, versus a national average of about 1.1percent).

Figure 7:



The electricity generating capacity in the RFE stood at about 11.4 GW as of 1996, of which slightly under three-quarters (8.4 GW) was thermal generation, 48 MW as nuclear capacity, and the rest (2.9 GW) was hydroelectric capacity. Fuel for the thermal power plants in 1996 was provided by coal (71 percent), oil (13 percent) and gas (16 percent). The brown coal found in the Russian Far East is relatively low in sulfur. Due to heating demand during the relatively severe RFE winters, electricity demand in the RFE is winter peaking, with summer peak demand less than 60 percent of winter peak[21].

The vast energy resources of the Russian Far East alone include hydro resources estimated at 1000 TWh (terawatt-hours) per year (and 110 GW), and reserves of coal, oil, and natural gas estimated at approximately 12.5, 1.0, and 2.1 billion tonnes of oil equivalent, respectively. Many resources in the RFE are located at some distance from existing major infrastructure, and the regions climate presents an additional challenge to resource development. Development of energy resources is, however, seen as a key to the economic development of the region. A new hydroelectric plant (called Bureiskaya) is currently under construction, and will have generation capacity of 2.4 GW when its phases are complete. Many thermal power plants are currently being or will be rebuilt. A number of different electricity export options are under consideration in the Russian Far East and other areas of Eastern Russia. Electricity links being considered include Sakhalin to Japan, East Siberia/South Yakutiya to China, and, in the near term, a link from the RFE to Northeast China. A number of different resources have been considered for use in generating electricity for export, including hydroelectric resources, coal, gas, and nuclear power, with variants depending on the scenario being contemplated[22].

4. Scenarios of Grid Interconnection: Analysis and Cost/Benefits Results

4.1. Introduction and Approach

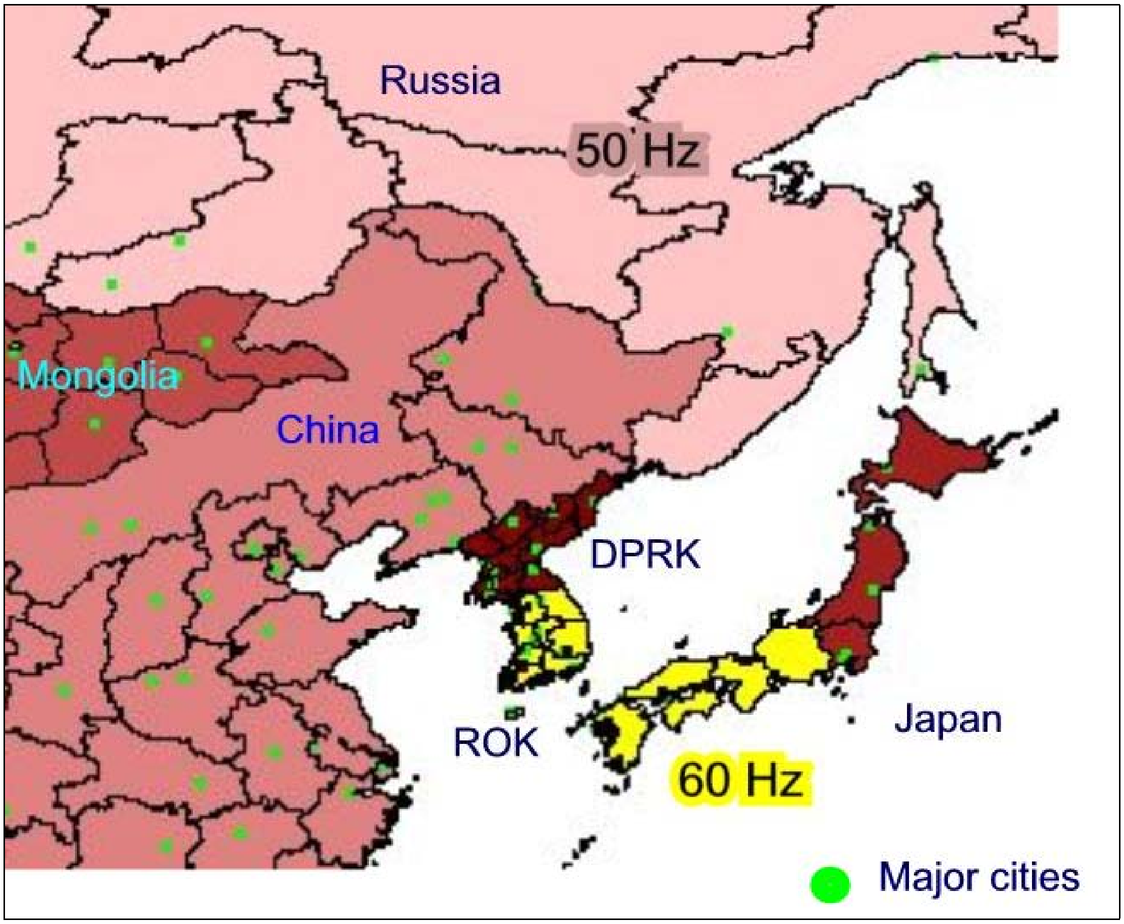
With the goal of estimating the costs and benefits of power sharing, two scenarios of grid integration were evaluated:

- **Scenario 1**—A line from the northeastern part of the ROK running along the East Coast of the DPRK and into Northeastern China; and
- **Scenario 2**—A line (or set of lines) connecting the Russian Far East, the ROK, the DPRK (including the Simpo reactor site) and Northeast China.

Of course, a wide variety of interconnection scenarios are possible and have been proposed. The goal here has been to pick two potential scenarios, with significant differences, and to very roughly estimate the costs and benefits of each interconnection option relative to a situation where no interconnection exists. The assumptions used in evaluating each scenario, together with summary scenario results, are provided below. A printout of the workbook used to evaluate the scenarios is provided in the Annex to this paper. The workbook provides the assumptions and sources of information used in the analysis, as well as detailed results.

A map of the region is provided in Figure 8. Figure 8 indicates the frequency (50 or 60 Hertz) under which the power systems of the region operate. Note that the nominal operating frequency of the DPRK grid is 60 Hertz, but in recent years the actual frequency at which the DPRK grid has operated, though variable, has been closer to 50 Hertz.

Figure 8: Frequency Distribution of the Electricity Grids of Northeast Asia[23]



4.2. Scenario 1: Interconnection of ROK, DPRK, and China

The first scenario postulates a transmission line going from the northeast portion of the ROK along the East Coast of the DPRK, and into Northeast China. Such as line would allow power from the nuclear reactors at Simpo to flow to either to the ROK or to Northeast China, and would also allow any extra baseload (off-peak) nuclear power from the ROK to be routed to China as available.

4.2.1. Line Cost and Capacity Assumptions for Scenario 1

Key assumptions for scenario 1 included the following:

- The transmission line is rated at 500 kV (kilovolts), has a line length of 1080 km, and costs \$270,000 (1999 US dollars) per kilometer[f].

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[f] Please see the Annex to this paper for notes and references on scenario 1 and 2 assumptions. Note that the reference capital cost of a 500 kV line in the United States, about \$340,000 per km, was reduced by 20 percent to roughly account for reduced labor costs in Northeast Asia relative to the U.S..

- The approximate power capacity of the transmission link is 1800 MW (using two 500 kV transmission lines)
- The average capacity factor of the line is assumed to be 65 percent, meaning that 10.2 TWh of electricity is transferred over the line annually.
- A solid state AC-to-DC-to-AC converter station is used at the border with China in order to provide electricity to China at the appropriate voltage and frequency. The converter station is assumed to cost $125 million per GW of capacity.

Note that this scenario implies either that the DPRK and ROK grids are synchronized, or that smaller AC/DC/AC converter stations are used to provide some power from the transmission line to local and/or national grids in the DPRK. Presumably, this transmission line (or lines) could also serve as a source of backup emergency power for the Simpo reactors. The assumption in this scenario is that power from nuclear reactors in the ROK and/or DPRK displaces coal-fired power—and its environmental effects—in Northeast China.

4.2.2. Generation Cost Assumptions for Scenario 1

In order to compute the generation-related costs and benefits of the transmission line described above, it was necessary to estimate capacity and other generation costs. These costs include both the costs of generation that will feed power into the line and the costs of the generation avoided in the country (or region) receiving power from the line. For scenario 1, the following assumptions were made:

- The average capacity costs (in 1995 US dollars) for typical Korean nuclear reactor were assumed to be $2,500 per kW. These costs were assumed to hold both for reactors within the DPRK and for the reactors being built at Simpo in the DPRK.
- All of the capacity costs and fixed O&M costs for the Korean reactors is included in the analysis, though sensitivity analysis (reported on below) was done to determine the effect of considering portions of the fixed costs of the reactors as "sunk" costs.
- The average capacity costs (again in 1995 USD) for typical new Chinese coal-fired plants with scrubbers to remove sulfur oxides are assumed to be $780/kW.
- The cost of coal for Chinese power plants in the Northeast China grid averages $30 per tonne (approximately the prevailing cost in 1999).
- All of the electric power imported to Northeast China is assumed to avoid capacity in China.

4.2.3. Efficiency and Fuel Quality Assumptions

In addition to generation cost parameters, it is necessary to estimate the efficiency with which the avoided generation in Northeast China would operate, and to make some assumptions about fuel quality in order to estimate avoided emissions. It was assumed that the net efficiency (gross efficiency less plant auxiliary power use) of power generation displaced in Northeast China would be 27 percent, approximately a mid-1990s average value for China. The energy content of coal used in power plants in Northeast China is assumed to be 18.7 GJ per tonne, and the coal is assumed to average 56 percent carbon and 1.1 percent sulfur (the latter an average value for China) by weight. The generation displaced by the energy from the incoming transmission line is assumed, for the calculation of the environmental benefits of avoided generation, to be from plants without sulfur scrubbing equipment. The reasoning behind this assumption is that grid operator in Northeast China would probably choose, if power imports were available, to use the imported energy to displace power from older, less efficient power plants that are more expensive to run. That the types of plants assumed to be the sources of the avoided generation and avoided capacity are different is not inconsistent, because the capacity avoided will be standard new power plants (which would likely have scrubbers), while the displaced energy would be from more costly-to-operate older plants (which would not have scrubbers).

4.2.4. Scenario 1 Results: Emissions Reduction and Costs Estimates

Given the assumptions above, the carbon dioxide emissions reduction from the international transmission link in scenario one would be approximately 15 million tonnes/yr (measured as CO_2). The SO_2 emissions avoided are estimated at 295 thousand tonnes annually (measured as SO_2). A substantial reduction in emissions of particulate matter and other pollutants (including methane from avoided coal mining) would also take place as a results of the generation avoided in Northeast China. For both CO_2 and SO_2, actual avoided emissions will depend on the particular power plants whose output is curtailed in Northeast China, and the types and origin of the coal that they are burning. Though avoided CO_2 emissions probably would not vary by more than 20 or so percent from the estimates provided here, sulfur oxide emissions could be a factor of two greater or less than estimated.

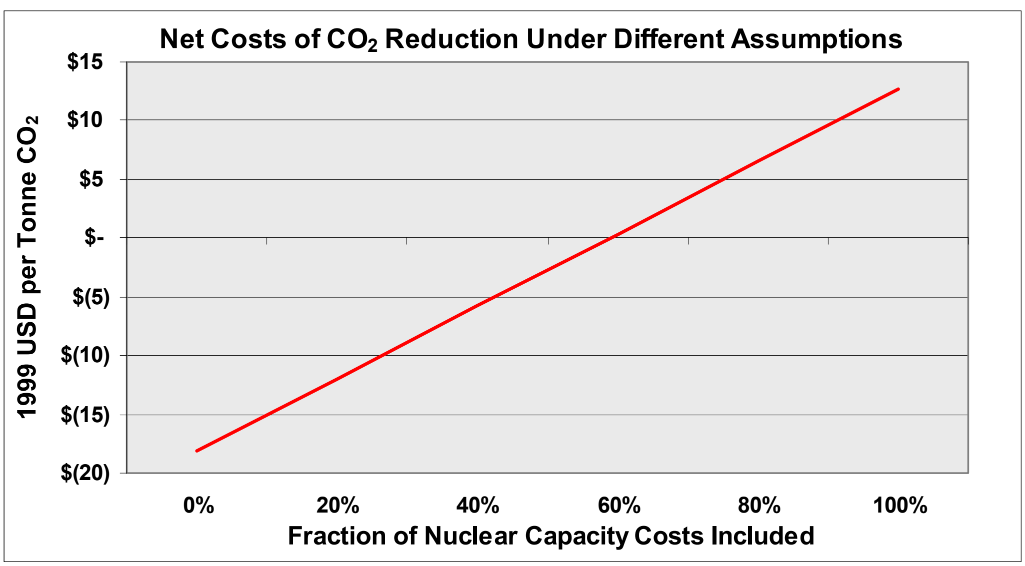
Table 5 provides a summary of the economic costs and benefits of the transmission arrangement described in scenario 1. There is a net cost of power provision of just under $0.02 (again in 1999 USD) all told. This net cost factors in total transmission line (capital and operating and maintenance, or O&M) costs of about 1.2 cents per kWh transferred, plus generation capacity, fixed O&M, and variable O&M costs of about 5.4 cents per kWh. Avoided costs of generation in China total about 4.7 cents per kWh, and are nearly evenly split between generation variable O&M and fuel costs (2.3 cents per kWh) and generation capital and fixed O&M costs (2.4 cents/kWh). The net cost of power provision via the transmission line, when calculated on the basis of carbon dioxide emissions avoided, is approximately $13 per tonne CO_2. On the basis of total annualized cost, the net cost of the transmission line, given the assumptions in scenario 1, is approximately $190 million per year.

Table 5:

Summary of Costs and Benefits of Replacing Coal-fired Power in NE China With Power from a Transmission Line Running from the ROK, Through the DPRK, to NE China, and Supplied by Nuclear Power Plants in the ROK and/or DPRK			
	Annualized Costs/Avoided Costs		
	$/kWh	M$/yr	$/te CO_2
Costs of Providing Power Via Transmission Line			
Line and Converter Station Capital Costs	$ 0.0083	$ 85	$ 5.65
Line O&M Costs	$ 0.0030	$ 31	$ 2.05
Generation Variable O&M and Fuel Costs	$ 0.0090	$ 92	$ 6.12
Generation Capital and Fixed O&M Costs	$ 0.0452	$ 463	$ 30.85
TOTAL	$ 0.0654	$ 670	$ 44.67
Avoided Costs of Power Generation in China			
Generation Variable O&M and Fuel Costs	$ (0.0225)	$ (230)	$ (15.36)
Generation Capital and Fixed O&M Costs	$ (0.0243)	$ (250)	$ (16.63)
TOTAL	$ (0.0468)	$ (480)	$ (31.99)
NET COST OF POWER PROVISION	**$ 0.0186**	**$ 190**	**$ 12.68**

In the discussion provided above, it has been assumed that the full cost of the generating plants used to provide power to the transmission line should be accounted for in the cost-benefit analysis. If this restriction is relaxed, and the costs of the nuclear power plants used to provide power for sale to China can be considered partially or fully amortized (because, for example, they are largely paid for already, or, for the Simpo reactors, using them without the transmission line would be difficult), then the net cost of electricity transferred via the new line, and of the carbon dioxide emissions saved, decreases. A sensitivity analysis showing the net cost of carbon dioxide emissions abatement versus the fraction nuclear capital costs included in the analysis is provided in Figure 9.

Figure 9:



4.3. Scenario 2: Line Connecting Russian Far East, the ROK, the DPRK, and Northeast China

The second scenario analyzed postulates a transmission line connecting the Russian Far East, the ROK, the DPRK (including the Simpo reactor site) and Northeast China. In this case, it is assumed that power from RFE hydroelectric plants (including new plants now being completed) flows to the ROK in the summer to meet summer peak demand there. In the spring and fall, RFE power flows to Northeast China to displace coal-fired generation, and power from nuclear power plants in the ROK and/or the Simpo plants in the DPRK also flows to China, making optimal use of nuclear capacity during the non-peak season in Korea. In the winter, power from the ROK and/or Simpo power would be routed to the RFE to help meet winter peak demand there. During most times of the year, and probably particularly in early and late summer, some power from the line would likely be used in the DPRK. Especially during the early period of the operation of the line (possibly from the year 2006 to 2012 or so), it will likely be very useful to provide power from the line to the DPRK for use in irrigation pumping (for the rice crop) in early summer, and for rice threshing in the late summer.

As a result of the power trading scheme in scenario 2, the generation of electrical <u>energy</u> in coal-fired plants is assumed to be reduced (avoided) by power transfers for all trading partners, but gas-fired (peaking) <u>capacity</u> is reduced in ROK as a result of the transfers, with coal-fired capacity being reduced in other countries. Some of the additional assumptions used in evaluating scenario2 are outlined below, and also presented in the Annex to this paper.

4.3.1. <u>Line Cost/Capacity Assumptions, Scenario 2</u>

Scenario 2 assumes that a set of 500 kV lines each totaling 2040 km in length. This estimates includes approximately 700 km from Yangyang in the ROK through the DPRK to Yanji in Northeast China, another 400 km of line—actually two sets of 200 km lines—within Northeast China to move power from the border to demand centers, and about 600 km from Yanji, China, to Khabarovsk in the Russian Far East. Another 20 percent was added to the line length to compensate for adjustments to topography, yielding the 2040 km estimate. As in scenario 1, the line was assumed to cost $340,000/km in USD, though this cost was reduced by 20 percent under the assumption that labor costs in Northeast Asia will on average be lower than in the United States. The approximate power capacity of the transmission interconnection is 1800 MW, except for the portion of the route that goes into China, which has a capacity of 3600 MW so that Northeast China can receive energy (in the spring and fall) from both the ROK/DPRK and the RFE simultaneously. Also as in scenario 1, the average capacity factor of the line is assumed to be 65 percent, yielding a total for annual energy transferred over the line of 15.4 TWh. A solid state AC/DC/AC converter station is used to accomplish frequency conversion between the 60 Hz (Hertz) ROK/DPRK systems and the 50 Hz Russian and Chinese systems. The converter station is assumed to have a total capacity of 2 GW at a cost of $125 million per GW capacity. It is assumed that frequency and voltage for power exchanges between the RFE and China can be matched without the need for an AC/DC/AC converter.

4.3.2. Power Cost Assumptions for Scenario 2

As in scenario 1, it is assumed that the average capacity costs (in 1995 USD) for a typical Korean nuclear reactor is $2,500/kW in scenario 2. In computing the costs of power provided via the transmission line, the full capacity cost of both the Korean reactors and RFE hydroelectric plants (at $1200/kW) are included, and fixed O&M costs for these units in the Korea and in the RFE are included as well. In computing avoided capacity costs, it is assumed that in the ROK a portion of the capacity of the transmission line displaces gas-fired power plants in the ROK that would have cost $580/kW, and displaces coal-fired plants with scrubbers in Russia and China that would have cost $780/kW. It was assumed that 50 percent of the import capacity provided could be considered avoided capacity in each importing country.

In computing the avoided operating costs of the power plants whose generation was displaced by power imports, it was assumed that the cost of coal for Chinese and Russian coal-fired plants was $30/te, and that the cost of coal for ROK plants was $42.5/tonne (the average cost of imported coal in the ROK as of 1998).

4.3.3. Scenario 2: Efficiency and Fuel Quality Assumptions

Also as in scenario 1, the net efficiency of power generation displaced in Northeast China was assumed to be 27 percent. In the ROK and RFE, displaced coal-fired generation was assumed to be 31 percent efficient. Table 6 provides the assumptions as to coal energy content and elemental composition used in the calculations. The power generation displaced in the RFE and Northeast China is assumed to be from coal-fired plants without scrubbers, while 50 percent of the generation displaced in the ROK is assumed to be from plants with FGD (flue gas desulfurization) equipment.

Table 6: Coal Composition Assumed for Avoided Generation in Scenario 2

Avoided Generation in:	Net Heating Value (GJ/te)	Elemental Composition by Weight: Carbon	Sulfur
Northeast China	18.7	56%	1.10%
Russian Far East	15	38%	0.50%
Republic of Korea	25.4	61%	1.00%

4.3.4. Scenario 2 Results: Emissions Reduction and Cost Estimates

As modeled, the operation of the transmission interconnection described in scenario 2 reduces regional CO_2 (as CO_2) emissions by 20 million tonnes per year, and results in SO_2 emissions reduction of 360 thousand tonnes/yr (as SO_2). Substantial reduction in emissions of particulate matter, methane, and other pollutants can be expected as well (though these have not yet been quantified).

Table 7 provides a summary of the costs, avoided costs (benefits), and net costs of the operation of the scenario 2 international transmission interconnection. The net cost of the interconnection as modeled is just barely positive, at \$0.0033 (1999 USD) per kWh transferred, or about 50 million dollars in net costs per year. This results in a net cost of saved CO_2 of about \$2.50 per tonne, which does not, of course, include the value of the avoided emissions of SO_2, CO_2, or other pollutants. On the cost side, the capital and operating costs of the transmission line sum to about 1.2 cents per kWh, generating and O&M costs for nuclear reactors in the ROK and/or DPRK total about 2.7 cents/kWh, and the capital and operating expenses for hydroelectric facilities in the RFE at about 1.3 cents/kWh. On the avoided costs side, the avoided costs of capacity and generation in China total about 2.3 cents over all of the kWh transferred over the transmission line, avoided power provision costs in the ROK total about 1.0 cents/kWh, and generation-related costs in the RFE total about 1.3 cents/kWh.

Table 7:

Summary of "Scenario 2": Power Trade to China (spring/fall) from RFE and ROK/DPRK, to ROK from RFE (summer) and From ROK to RFE (winter), with supplies from RFE Hydro Plants, Nuclear Power Plants in the ROK and/or DPRK			
	Annualized Costs/Avoided Costs		
	\$/kWh*	M\$/yr	\$/te CO_2
Costs of Providing Power Via Transmission Line			
Line and Converter Station Capital Costs	\$ 0.0089	\$ 137	\$ 6.76
Line O&M Costs	\$ 0.0030	\$ 46	\$ 2.27
Generation Variable O&M and Fuel Costs, ROK/DPRK	\$ 0.0045	\$ 69	\$ 3.39
Generation Capital and Fixed O&M Costs, ROK/DPRK	\$ 0.0226	\$ 347	\$ 17.08
Generation Variable O&M Costs, RFE (Hydro)	\$ 0.0005	\$ 8	\$ 0.38
Generation Capital and Fixed O&M Costs, RFE (Hydro)	\$ 0.0126	\$ 194	\$ 9.53
TOTAL	\$ 0.0521	\$ 801	\$ 39.40
Avoided Costs of Power Generation in China			
Generation Variable O&M and Fuel Costs	\$ (0.0150)	\$ (230)	\$ (11.33)
Generation Capital and Fixed O&M Costs	\$ (0.0081)	\$ (125)	\$ (6.14)
Avoided Costs of Power Generation in ROK			
Generation Variable O&M and Fuel Costs	\$ (0.0037)	\$ (57)	\$ (2.83)
Generation Capital and Fixed O&M Costs	\$ (0.0062)	\$ (96)	\$ (4.72)
Avoided Costs of Power Generation in RFE			
Generation Variable O&M and Fuel Costs	\$ (0.0044)	\$ (67)	\$ (3.31)
Generation Capital and Fixed O&M Costs	\$ (0.0113)	\$ (174)	\$ (8.55)
TOTAL	\$ (0.0488)	\$ (750)	\$ (36.88)
NET COST OF POWER PROVISION	**\$ 0.0033**	**\$ 51**	**\$ 2.52**
* Expressed per kWh of total annual power carried by interconnection (all countries)			

5. Conclusions and Comparisons

5.1. Introduction

The results presented above suggest several conclusions:

1. Given resource distribution in the different parts of Northeast Asia, grid interconnections could provide significant contributions toward reducing pollutant emissions, and reducing associated environmental impacts. At the same time, Northeast Asian grid interconnections, depending on how they are configured, could make important contributions to economic development (for example, in the RFE and DPRK), and could help to overcome technical problems (the use of the Simpo reactors in the DPRK grid), social constraints (transmission line and power plant siting in the ROK), and even political difficulties (by fostering international cooperation) in the region.
2. Though there are a considerable number of different interconnection options that could be evaluated, and only two have been investigated in this paper, the cost-effectiveness analysis presented above indicates that grid interconnections are at least close to cost-effective even without considering their environmental benefits.
3. The analysis presented here has of necessity included a number of simplifying assumptions. Each of these assumptions should be investigated further to reduce the uncertainties in the analysis. Additional research in a number of areas, as indicated in section 6 of this paper, will be needed in order to determine which interconnection options are the best near-term candidates.

In order to obtain a sense of the cost-effectiveness of grid interconnection in reducing the impacts of electricity generation in the region, it is useful to compare the costs and environmental benefits of grid interconnection options with other means of reducing pollutant emissions. In addition, grid interconnection offers a host of other benefits that have not yet been described in this paper. Subsection 5.2, below, present a comparison of the cost and CO_2 emissions savings of the grid interconnection options with the cost and savings of other measure of reducing greenhouse gas emissions. A discussion of some of the additional benefits of grid interconnection is provided in subsection 5.3.

5.2. Comparison of CO_2 Savings and Costs from Interconnection Scenarios with Costs and Savings from Other Measures

Most, if not all, of the countries in Northeast Asia participated in the ALGAS (Asia Least-cost Greenhouse Gas Abatement Strategy) project, administered by the Asian Development Bank for the Global Environment Facility and the United Nations Development Programme. The country reports generated by the ALGAS project usually included a "cost of saved carbon" curve like that presented in Figures 10 and 11. These curves (actually step functions) show the cost and savings in CO2 emissions estimated to be achievable through the implementation of a number of different measures. Figure 10 presents ALGAS result for the ROK, overlaid with a line showing the approximate cost and savings expected from the international transmission line described in scenario 1, above[24]. This comparison shows that the total positive-cost CO_2-reduction measures in the ROK (measures 7 through 19 in figure 9) avoid

17 million tonnes of CO_2 per year at cost of $307 million per year, which is very similar in <u>performance</u> (CO_2 savings) to Scenario 1 (15 million tonnes). Scenario 1, however, would cost approximately $100 million per year <u>less</u> than the combination of the positive-cost measures.

Comparing scenario 1 savings to CO_2 emissions reduction measures included in the China ALGAS study, as shown in Figure 11, indicates that the net cost of saving CO_2 via a transmission line could be comparable, for example, to the net cost of greenhouse gas abatement by reconstruction and renovation of thermal power plants, or by expanding the use of nuclear power[25]. Although the scenario 1 CO_2 savings from the transmission line option constitute a much smaller fraction of the ALGAS savings in China than they do in the ROK, if CO_2 reduction opportunities in China are assumed scale with population, 15 million tonnes of CO_2 saved constitutes a significant contribution for Northeast China.

Scenario 2 saves 2.6 million tonnes of CO_2 in the ROK, and more than 18 million tonnes of CO_2 in China and the RFE, at a net cost of $50 million per year, or about $2.50 per tonne of CO_2. As such, the transmission line postulated in scenario 2 is even more cost-effective than the line in scenario 1, relative to ALGAS mitigation options, in reducing greenhouse gas emissions.

Figure 10: Comparison of Scenario 1 Costs and Benefits with Results from ROK ALGAS Project

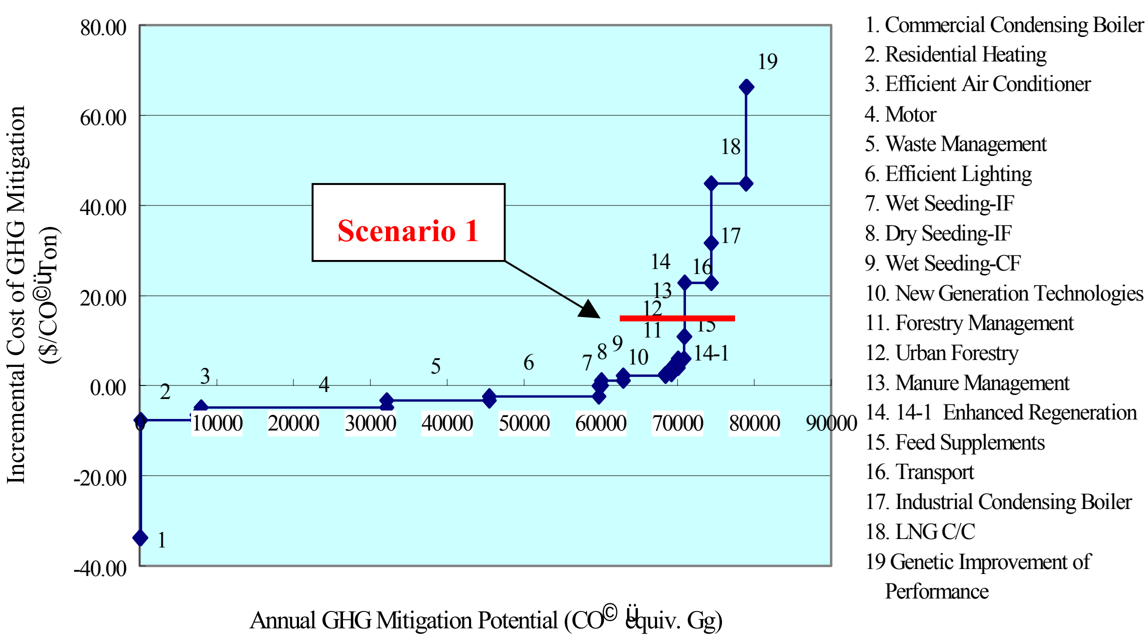
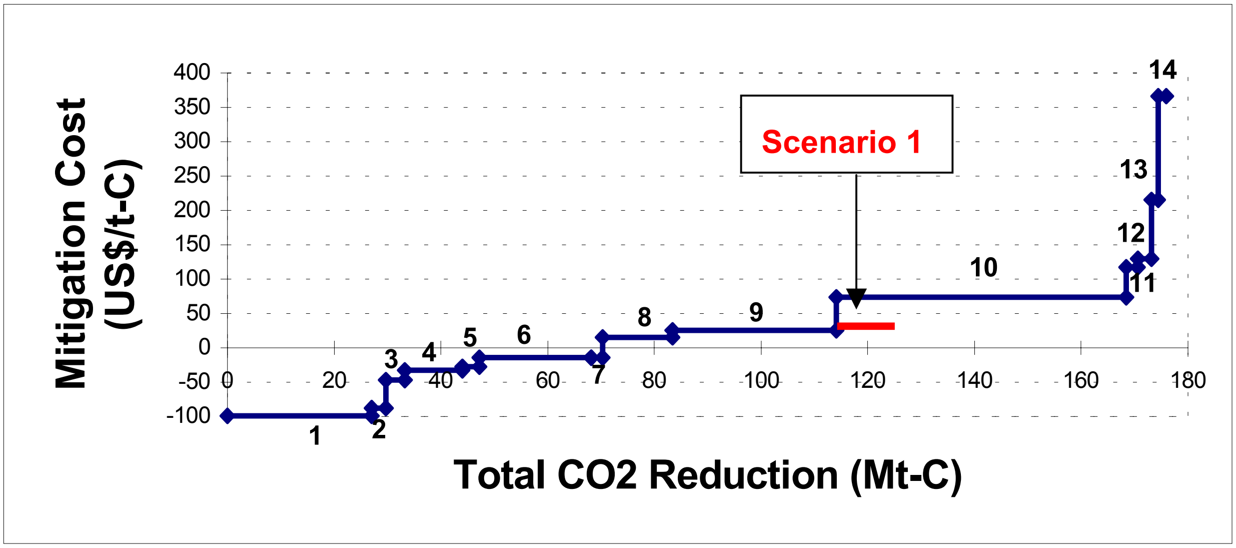


Figure 11: Comparison of Scenario 1 Costs and Benefits with Results from China ALGAS Project



The numbers used to mark the mitigation technology options in Figure 11 refer to the measures listed below:

1. Technical renovation of motor for general use
2. Reducing ratio of iron/steel in steel & iron industry
3. Renovation of kilns for wet cement production
4. Energy-saving lighting
5. Comprehensive process renovation of synthetic ammonia
6. Renovation of industrial boilers
7. Continues casting of steel making
8. Renovation and reconstruction of conventional thermal power plant
9. Nuclear power
10. Hydro power
11. IGCC and other advanced thermal power generation technologies
12. Biogas and other biomass energy
13. Wind power
14. Solar thermal

The degree to which transmission line options are cost-competitive with other GHG reduction options depends principally on whether capital costs for generation supplying the line are paid for or not. If the capacity used to provide power exported via the transmission line is arguably "surplus" (would not be used as much if a means of power export were not available), the costs of GHG reduction (as shown, for example, in Figure 9) are negative, and transmission line options are even more competitive alternatives to other emissions mitigation measures.

Given the significant benefits that transmission lines could provide in reducing greenhouse gas emissions, it seems reasonable that such projects might be considered for cost-sharing opportunities such as the proposed Clean Development Mechanisms (CDM). As the greenhouse gas emissions savings, however, and their related costs, accrue to more than one country in grid interconnections, it is an open question, at this point, how CDM mechanisms would be applied. How would greenhouse gas savings and project costs be assigned and credited in a shared project like this one? In the mind of the author, at least, there is no clear answer to this question at present, but at scenarios of transmission line interconnections in Northeast Asia are further developed, it will likely become increasingly important to understand how (if at all) CDM-type arrangements might help to defray or raise capital for the substantial cost of the transmission links.

5.3. Other Grid Interconnection Benefits

In addition to cost savings and reduction of pollutant emissions, there are a number of other benefits of grid interconnection that cannot be treated in detail in this paper, but deserve mention.

- <u>Generation of Foreign Exchange</u>: Depending on how it configured, grid interconnection in Northeast Asia could provide opportunities for the DPRK and the RFE to establish income streams from sales of power to the ROK and China—and perhaps, eventually, Japan.
- <u>Confidence Building between Nations</u>: The buying and selling of power across borders is a non-trivial exercise from virtually every point of view. The international transparency (in terms of sharing of data on power generation and costs) and the coordination needed to accomplish technical and economic power exchanges will help build confidence between the trading partners. This confidence in the nations with which power is traded can be expected to have a positive impact on relations between the countries involved as a whole. Sharing a common power system also provides an economic link powerful incentive for countries to resolve other differences in a peaceful manner.
- <u>Use of Grid Interconnection to Support International Economic Development</u>. It may be possible to link the creation of a regional grid inter-connection with activities in the Tumen River economic development zone shared by China, Russia, and the DPRK. Such a linkage could mean using power from the line to provide electricity for industrial and other facilities in the Tumen River area. Alternatively, the negotiations required for the implementation of the transmission line could serve as a template or boost to the development of the Tumen area (or vice-versa).
- <u>Supply Diversity Enhancement</u>. The development of grid interconnections in the region will enhance the diversity of electricity supply in the countries of the region. The degree of diversity enhancement can be calculated for each country involved and for the region as a whole, and should be a part of further analysis of grid interconnection options.
- <u>Emergency Power and Grid Access for the Simpo Reactors</u>. As noted briefly elsewhere in this paper, grid interconnection that involves a power line running through the DPRK is a key option (perhaps one of only a few short-term options) for providing needed emergency back-up power for the nuclear reactors being built at Simpo in the DPRK. Such a line would also provide—again at least in the short term, until the DPRK electric grid can be rehabilitated—

options for the economic disposition of power from the KEDO-built reactors. It also seems likely that the presence of a grid interconnection that runs through the DPRK would help to move forward the process of improvement of the DPRK grid and electricity supply system, as improvements needed to connect to the international transmission line in the DPRK will likely lead to other electricity sector improvements.

6. Areas for Further Research and Analysis

As noted above, this paper has provided only a first- (perhaps "zeroth-") order attempt at the analysis of grid interconnection options. Further research and analysis is required in a number of areas in order to bring grid interconnections in Northeast Asia closer to reality. Some of these areas include:

- **Forecasts of Power Demand and Supply Situations**: Researchers from China, together with others as appropriate, should work together to prepare forecasts and projections of the rate of growth in power demand and of power capacity deficits in under different supply scenarios in Northeast China as well as in nearby areas of China. Similar work should be undertaken in the ROK, the DPRK, and the Russian Far East.
- **Timing and Types of Capacity Surpluses**: Researchers the countries involved should work together to determine the current status and future potential timing and types of capacity surpluses in the ROK and the RFE. How well do seasonal load factors in the ROK and RFE match? What is the magnitude of any potential seasonal surplus capacity, and what types of power plants are likely to have extra capacity in some seasons? How will the capacity picture change in each country in the future, factoring possible rates of load growth and current patterns of capacity addition?
- **Options for Operation of Simpo Reactors**: A key area of research yet to be completed is to undertake much more detailed analyses of feasible options for operation and connection to the DPRK, and other national grids of the reactors being built by KEDO at Simpo in the DPRK. What are the options for the disposition of power from those reactors when they are complete? How can emergency power to supply electricity for plant auxiliaries and coolant pumps be provided, and what might the role of international transmission lines be in providing that power? What needs to be done in order to connect the Simpo plants to part or all of the DPRK grid itself, and how much will modifications to the grid cost?
- **Comparison with Other Emissions-Reduction Options**: Transmission lines are capital intensive and time-consuming to build. Before large commitments to such projects are made, more detailed comparisons of the relative costs and benefits of grid interconnection schemes with other options for greenhouse gas emissions reduction in NE Asia should be carried out. These additional comparisons will be and particularly if financing alternatives such as climate change-related Clean Development Mechanisms are to be considered as means to partially finance grid interconnections.
- **Consideration of Other Pollution Reduction Benefits**: The analysis provided here has considered only reductions of CO_2 and SO_2 emissions as a result of power trading in the region. Incorporation of consideration of other direct and indirect pollution reduction benefits—including the impacts of reduction of SO_2 and nitrogen oxides emissions and

impacts on acid rain in China and elsewhere in the region, impacts on urban and local air quality associated with reduced power plant coal combustion, and full fuel cycle impacts in China and elsewhere—should be done in order to obtain a more complete picture of the full benefits (or costs) of interconnection.

- **Updated Review of DPRK Electric Sector Needs**: The energy sector needs and capabilities of the DPRK play a crucial role in determining what interconnection options make sense and will be feasible. An updated review of the need for power in the DPRK—including both the current status of power demand, options for power distribution, and the need for T&D upgrades—should be undertaken. Part of this update would be a careful re-assessment of alternative scenarios for near- and mid-term economic and energy-sector development in the DPRK, and of the ramifications of those scenarios for international power trading options.
- **Pre-feasibility consideration of potential international transmission routes**: Substantial work has been done by many groups, including groups in Russia, China, the ROK, and Japan, on power line alternatives that would interconnect some or all of the countries of the region. There is a need to collect all of the available studies, and use them as input to pre-feasibility consideration of potential power line routes and configurations. It is important that this consideration of different alternatives be on a consistent basis, making sure that assumptions are comparable across the alternatives considered.
- **Transmission Line Engineering Options and Constraints**: Once pre-feasibility studies have indicated the most promising options for interconnection projects, it will be necessary to carry out detailed consideration of transmission line engineering options and constraints through a process of initial power line design and detailed power systems modeling.
- **Study of Political and Economic Considerations**: Parallel to the detailed consideration of engineering options for interconnection of regional grids, it will be necessary to undertake a more detailed consideration of the political feasibility of transmission interconnections. This consideration, involving key researchers and, ultimately, officials from each country, would try and anticipate the political problems that might (or will) be encountered in international power line development and operation. Related tasks of such a team of researchers (or of separate, similarly constituted teams) will be to try and work out in advance at least the broad parameters of how the pricing of internationally traded electricity will take place, how payments between countries (or electricity users within countries) will be made, and how international control over cross-border transmission lines will be administered. These political, economic, and organizational tasks should not wait to be initiated until a final engineering design is settled upon, as they may well take fully as long to investigate, decide upon, and put into place as the transmission hardware itself.
- **Consideration of the Costs of Power Generation and Transmission**: As input to several of the studies suggested above, a more detailed and accurate consideration of the current and future costs of power generation and transmission in the ROK, the DPRK, the Russian Far East, and China will be needed. These cost figures may well be hard to obtain, but will be necessary for the accurate modeling of interconnection options. A working group of researchers and possibly officials from throughout the region will probably be needed to assure that the relevant data can be obtained.

- **Detailed Feasibility Study**: The research suggested above would likely serve to inform a process where the initial feasibility of a number of power line options can be undertaken, and a small number of highly promising options can be decided upon. The next step after this process would be the commissioning of detailed engineering and economic feasibility studies of the two or three most promising interconnection options. These studies, which will likely cost hundreds of thousands or millions of dollars each, should be commissioned only when there is reasonable assurance that the options to be studied are likely to be practical from the engineering, economic, and political points of view.

As a final note, the author would like to stress that no interconnection options can be expected to come to fruition without the cooperation of each of the countries of the region. This means, first, that each country must come prepared to share information relevant to transmission interconnections in an open and transparent manner, and second, that working groups investigating the areas above should be as inclusive as possible of representatives from each country. In some cases, it will be necessary to provide country representatives with training in the various analytical disciplines (engineering analysis, power system modeling, economic analysis, policy analysis, and financial analysis, to name a few) involved so that those representatives can participate in a full and meaningful manner in the analytical work.

7. Endnotes

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ANNEX: WORKPAPERS FOR CALCULATION OF TRANSMISSION LINE COSTS AND BENEFITS

A.1. Line Costs, Scenario 1

**ROUGH ESTIMATE OF TRANSMISSION LINE COSTS
FOR LINE RUNNING FROM NORTHEAST ROK
ALONG THE EAST COAST OF THE DPRK AND INTO CHINA**

Prepared by:	David Von Hippel, Nautilus Institute
Date Modified:	2-May-01

Estimate for 500 kV Line(s), Single Circuit

COST ASSUMPTIONS/CALCULATIONS *(Note 1)*

Total Capital Cost of 500 kV, single circuit line:	$317,000	per kilometer (1996 dollars)
Consumer Price index, late 1999	499	(from US Bureau of Labor Statistics WWW site
Consumer Price index, late 1996	469.9	http://146.142.4.24/cgi-bin/surveymost. Data for urban consumers)
Total US Capital Cost of 500 kV, single circuit line:	$336,631	per kilometer (1999 dollars)
Fraction of capital cost as labor	50%	(at US labor prices, including construction equipment)
Ratio of cost of ROK/DPRK/Chinese labor to US labor, including equipment:	60%	(Guess)
Cost of AC/DC/AC converter needed to change from ROK 60 Hz to China 50 Hz:	$125	per kW

(see Note 4) . Operating and maintenance costs of the converter station are assumed to be minimal relative to capital costs. Labor is assumed to be a minor component of converter station costs.

LENGTH OF LINE ASSUMPTIONS/CALCULATIONS FOR SCENARIO 1 *(Note 2)*

Length of 500 kV to be built:	700	km (Yangyang, ROK to Yanji, China)
plus	200	km additional in China
Adding	20%	for topography (guess--though existing right of ways are probably available),
Total length of line needed is:	1080	km

LINE CAPACITY ASSUMPTIONS/CALCULATIONS *(Note 3)*

Rough power capacity per line:	900	MW (assumes line is in two pieces, with KEDO plants in middle)
Desired Capacity of Line	2000	MW
Number of lines needed	2	(rounded)
Total estimated cost of 500 kV lines to serve desired capacity:	**$ 582**	Million 1999 $US
Total estimated cost of AC/DC/AC converters to serve desired capacity:	**$ 250**	Million 1999 $US

ESTIMATED PER-UNIT COST OF POWER TRANSFERRED OVER LINE

Average capacity factor of line	65%	(guess--consistent with average Chinese capacity factor)
Annual power transferred	10,249	GWh
Interest rate for computing annual cost of line and AC/DC/AC converter ownership	8%	
Estimated lifetime of power line and converter	20	years (lifetime of loan)
Fixed charge factor (computed from lifetime, interest rate)	10.19%	
Capacity cost of transmission line and converter station:	$ 0.0083	per kWh

Notes/Sources:

1 *Capital cost figure and labor fraction estimates obtained from Peter Donalek of Harza Engineering (Personal communication, 3/14/2000). These estimates are roughly consistent with per-mile costs for 500 kV lines in rolling terrain used for preliminary transmission line cost estimates by the Bonneville Power Administration in the Northwest United States. Costs do not include land costs for right-of-ways (which would be c. 50 m wide), though it is probable that lines would follow existing right-of-ways.*

2 *Based on rough measurements along indicated power line right-of-ways from Defense Mapping Agency Aerospace Center Maps ONC G-10 and ONC F-9.*

3 *Power carrying capacity per line is a function of line length (and other parameters). Capacity per line decreases with line length. 900 MW is an estimate obtained from Peter Donalek (see above), and could be somewhat high (though probably by only a few percent) for a 500 km span.*

4 *Order-of-magnitude cost estimate obtained in conversation (1997) with G. Jutte of Siemens Power Transmission and Distribution, Limited. 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 DPRK side, the distance over which the power must be transferred, and many others.*

A.2. Line Costs, Scenario 2

ROUGH ESTIMATE OF TRANSMISSION LINE COSTS
FOR LINE RUNNING FROM NORTHEAST ROK
ALONG THE EAST COAST OF THE DPRK AND INTO CHINA
JOINED BY A SECOND LINE PROVIDING A LINK TO THE
RUSSIAN FAR EAST

Prepared by:	David Von Hippel, Nautilus Institute
Date Modified:	7-May-01

<u>Estimate for 500 kV Line(s), Single Circuit</u>

<u>COST ASSUMPTIONS/CALCULATIONS *(Note 1)*</u>

Total Capital Cost of 500 kV, single circuit line:	$317,000	per kilometer (1996 dollars)
Consumer Price index, late 1999	499	(from US Bureau of Labor Statistics WWW site
Consumer Price index, late 1996	469.9	http://146.142.4.24/cgi-bin/surveymost. Data for urban consumers)
Total US Capital Cost of 500 kV, single circuit line:	$336,631	per kilometer (1999 dollars)
Fraction of capital cost as labor	50%	(at US labor prices, including construction equipment)
Ratio of cost of US labor to ROK/DPRK/Chinese labor, including equipment:	60%	(Guess)
Cost of AC/DC/AC converter needed to change from ROK 60 Hz to China/Russia 50 Hz:	$125	per kW

(see Note 4) . Operating and maintenance costs of the converter station are assumed to be minimal relative to capital costs. Labor is assumed to be a minor component of converter station costs.

<u>LENGTH OF LINE ASSUMPTIONS/CALCULATIONS FOR SCENARIO 1 *(Note 2)*</u>

Length of 500 kV to be built:	700	km (Yangyang, ROK to Yanji, China)
plus	400	km additional in China (200 km x double capacity)
plus	600	km (Yanji, China to Khabarovsk)
Adding	20%	for topography (guess--though existing right of ways are probably available),
Total length of line needed is:	2040	km

<u>LINE CAPACITY ASSUMPTIONS/CALCULATIONS *(Note 3)*</u>

Rough power capacity per line:	900	MW (assumes line is in several pieces, with substation at Simpo)
Desired Capacity of Line	2000	MW
Number of lines needed	2	(rounded)
Total estimated cost of 500 kV lines to serve desired capacity:	**$ 1,099**	Million 1999 $US
Total estimated cost of AC/DC/AC converters to serve desired capacity:	**$ 250**	Million 1999 $US

<u>ESTIMATED PER-UNIT COST OF POWER TRANSFERRED OVER LINE</u>

Average capacity factor of line	65%	(guess--consistent with average Chinese capacity factor)
Months in which power transferred from Russia to China	6	
Months in which power transferred from ROK/DPRK to China	6	
Months in which power transferred from ROK/DPRK to Russia	3	
Months in which power transferred from Russia to ROK/DPRK	3	
Annual power transferred (total)	15,374	GWh
Annual power transferred, RFE to China	5,125	GWh
Annual power transferred, ROK/DPRK to China	5,125	GWh
Annual power transferred, ROK/DPRK to Russia	2,562	GWh
Annual power transferred, Russia to ROK/DPRK	2,562	GWh
Interest rate for computing annual cost of line and AC/DC/AC converter ownership	8%	
Estimated lifetime of power line and converter	20	years (lifetime of loan)
Fixed charge factor (computed from lifetime, interest rate)	10.19%	
Capacity cost of transmission line and converter station:	$ 0.0089	per kWh

Notes/Sources:

1 Capital cost figure and labor fraction estimates obtained from Peter Donalek of Harza Engineering (Personal communication, 3/14/2000). These estimates are roughly consistent with per-mile costs for 500 kV lines in rolling terrain used for preliminary transmission line cost estimates by the Bonneville Power Administration in the Northwest United States. Costs do not include land costs for right-of-ways (which would be c. 50 m wide), though it is probable that lines would follow existing right-of-ways.

2 Based on rough measurements along indicated power line right-of-ways from Defense Mapping Agency Aerospace Center Maps ONC G-10 and ONC F-9.

3 Power carrying capacity per line is a function of line length (and other parameters). Capacity per line decreases with line length. 900 MW is an estimate obtained from Peter Donalek (see above), and could be somewhat high (though probably by only a few percent) for a 500 km span.

4 Order-of-magnitude cost estimate obtained in conversation (1997) with G. Jutte of Siemens Power Transmission and Distribution, Limited. 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 DPRK side, the distance over which the power must be transferred, and many others.

A.3. Greenhouse Gas Reduction Benefits, Scenario 1

ROUGH ESTIMATE OF GREENHOUSE GAS EMISSION REDUCTION BENEFITS FOR TRANSMISSION LINE RUNNING FROM NORTHEAST ROK ALONG THE EAST COAST OF THE DPRK AND INTO CHINA

Prepared by:	David Von Hippel, Nautilus Institute
Date:	2-Jun-00

Assumptions as to Electricity Production and Consumption in Northeast China

				Notes/Sources:
Fraction of Electricity Produced from Coal in NE China:	92%			*1*
Fraction of power displaced by power from trans. line that would have been coal-fired:		100%		
Average net efficiency of coal-fired (Thermal) power production in NE China:	27%			*4*
Average carbon content of coal used for power generation in NE China:	56%			*3*
Average net heating value of coal used for power production in NE China:	18.7		GJ/te	*2*
Estimated carbon dioxide emissions reduction per GWh power imports:	1,464		tonnes	
Average sulfur content of coal used for power generation in NE China:	1.10%			*5*
SO_x emission control efficiency for plants fitted with scrubbers in NE China:	80%			*6*
Fraction of coal-fired electricity production displaced by imports that has scrubbers:		0%		
Estimate sulfur dioxide emissions reduction per GWh power imports:	28.76		tonnes	
Assuming that power exported to China is from nuclear plants (and thus no GHG emissions are produced when exported power is generated), total annual emissions savings are estimated to be:	15.0		million tonnes CO_2	
and annual SO_2 emissions savings of	295		thousand tonnes	

Notes/Sources:

1 Based on 1996 regional electricity production statistics for "Northeast China" from p. 217 of China Energy Annual Review, 1997. Department of Resources Conservation and Comprehensive Utilization, State Economic and Trade Commission, PRC.
2 China Energy Databook, page 18. Average value for China.
3 As used in LEAP data set.
4 China Energy Databook, page IV-62 gives average value for China in 1992 as 25.3%.
5 As used in LEAP data set for China as a whole.
6 Rough estimate for domestic Chinese equipment

A.4. Greenhouse Gas Reduction Benefits, Scenario 2

ROUGH ESTIMATE OF TRANSMISSION LINE COSTS FOR LINE RUNNING FROM NORTHEAST ROK ALONG THE EAST COAST OF THE DPRK AND INTO CHINA JOINED BY A SECOND LINE PROVIDING A LINK TO THE RUSSIAN FAR EAST

Prepared by:	David Von Hippel, Nautilus Institute
Date:	2-Jun-00

Assumptions as to Electricity Production and Consumption in Northeast China				Notes/Sources:
Fraction of Electricity Produced from Coal in NE China:	92%			1
Fraction of power displaced by power from trans. line that would have been coal-fired:		100%		
Average net efficiency of coal-fired (Thermal) power production in NE China:	27%			4
Average carbon content of coal used for power generation in NE China:	56%			3
Average net heating value of coal used for power production in NE China:	18.7	GJ/te		2
Estimated carbon dioxide emissions reduction per GWh power imports:	1,464	tonnes		
Average sulfur content of coal used for power generation in NE China:	1.10%			5
SO_x emission control efficiency for plants fitted with scrubbers in NE China:	80%			6
Fraction of coal-fired electricity production displaced by imports that has scrubbers:		0%		
Estimate sulfur dioxide emissions reduction per GWh power imports:	28.76	tonnes		
Assuming that power exported to China is from nuclear plants (and thus no GHG emissions are produced when exported power is generated),				
total annual emissions savings are estimated to be:	15.0	million tonnes CO_2		
and annual SO_2 emissions savings of	295	thousand tonnes		

Assumptions as to Electricity Production and Consumption in Russian Far East				Notes/Sources:
Fraction of Electricity Produced from Coal in RFE:	37%			7
Fraction of power displaced by power from trans. line that would have been coal-fired:		100%		
Average net efficiency of coal-fired (Thermal) power production in RFE:	31%			8
Average carbon dioxide emission factor for lignite coal (US value):	93.19	kg/GJ		11
Average net heating value of coal used for power production in RFE:	15	GJ/te		9
Estimated carbon dioxide emissions reduction per GWh power imports:	1,068	tonnes		
Average sulfur content of coal used for power generation in RFE:	0.50%			10
SO_x emission control efficiency for plants fitted with scrubbers in RFE:	80%			As in China
Fraction of coal-fired electricity production displaced by imports that has scrubbers:		0%		
Estimate sulfur dioxide emissions reduction per GWh power imports:	14.01	tonnes		
Assuming that power exported to RFE is from nuclear plants (and thus no GHG emissions are produced when exported power is generated),				
total annual emissions savings are estimated to be:	2.7	million tonnes CO_2		
and annual SO_2 emissions savings of	36	thousand tonnes		

Assumptions as to Electricity Production and Consumption in the ROK			Notes/Sources:
Fraction of Electricity Produced from Coal in ROK:	35.1%		12
Fraction of power displaced by power from trans. line that would have been coal-fired:	100%		
Average net efficiency of coal-fired (Thermal) power production in RFE:	31.5%		12
Average carbon dioxide emission factor for bituminous coal (US value):	88.45	kg/GJ	11
Average net heating value of coal used for power production in ROK:	25.4	GJ/te	12
Estimated carbon dioxide emissions reduction per GWh power imports:	1,011	tonnes	
Average sulfur content of coal used for power generation in ROK:	1.00%		*Assumption*
SO_x emission control efficiency for plants fitted with scrubbers in ROK:	85%		*Assumption*
Fraction of coal-fired electricity production displaced by imports that has scrubbers:	50%		*Assumption*
Estimate sulfur dioxide emissions reduction per GWh power imports:	9.49	tonnes	
Assuming that power exported to RFE is from nuclear plants (and thus no GHG emissions are produced when exported power is generated), total annual emissions savings are estimated to be:	2.6	million tonnes CO_2	
and annual SO_2 emissions savings of	24	thousand tonnes	

Summary of Emissions Reduction

	Mte CO_2	kte SO_2
Emissions Reduction in China	15.0	295
Emissions Reduction in RFE	2.7	36
Emissions Reduction in ROK	2.6	24
TOTAL	20.3	355.0

Notes/Sources:

1 Based on 1996 regional electricity production statistics for "Northeast China" from p. 217 of China Energy Annual Review, 1997. Department of Resources Conservation and Comprehensive Utilization, State Economic and Trade Commission, PRC.

2 China Energy Databook, page 18. Average value for China.

3 As used in LEAP data set.

4 China Energy Databook, page IV-62 gives average value for China in 1992 as 25.3%.

5 As used in LEAP data set for China as a whole.

6 Rough estimate for domestic Chinese equipment

7 1995 figure from V. Kalashnikov (1997), ELECTRIC POWER INDUSTRY OF THE RUSSIAN FAR EAST: STATUS AND PREREQUISITES FOR COOPERATION IN NORTH-EAST ASIA. Draft Report Prepared for the Working Group Meeting on "COMPARISONS OF THE ELECTRICITY INDUSTRY IN CHINA, NORTH KOREA AND THE RUSSIAN FAR EAST", Organized by the East-West Center, Honolulu, Hawaii, 28-29 July 1997.

8 From reference in Note 7, page 17. Reference does not specify whether stated average RFE efficiency (31.4 percent) is measured on a net or gross basis.

9 Source as in Note 7 presents a range of heat contents from RFE brown coal of 10 to 19 GJ/tonne.

10 V. Kalashnikov (2000), National Energy Futures Analysis and Energy Security Perspectives in the Russian Far East. Presented at the workshop on "Regional Collaboration for Energy Futures and Energy Security in China and Northeast Asia", organized by Nautilusi Institute and Tsinghua University, Beijing, China, 14-15 June, 2000. Source gives a range of 0.13 to 0.87 percent sulfur in brown coal in the Russian Far East.

11 B.D. Hong and E. R. Slatick (1994), "Carbon Dioxide Emission Factors for Coal". Energy Information Administration, Quarterly Coal Report, January-April 1994, DOE/EIA-0121(94/Q1) (Washington, DC, August 1994), pp. 1-8. Source gives US average emission factor for lignite coal of 216.3 lbs/MMBtu.

12 Korea Energy Economics Institute (1999), Yearbook of Energy Statistics. Page 155 gives fuel consumption for generation, page 153 gives power generation by source fuel. 1998 values used here. Fuel energy content calculated from 1998 value on page 155.

A.5. Generation Costs and Avoided Costs, Scenario 1

ROUGH ESTIMATE OF GREENHOUSE GAS EMISSION REDUCTION TOTAL AND UNIT COSTS FOR TRANSMISSION LINE RUNNING FROM NORTHEAST ROK ALONG THE EAST COAST OF THE DPRK AND INTO CHINA

Prepared by:	David Von Hippel, Nautilus Institute
Date:	4-Jun-00

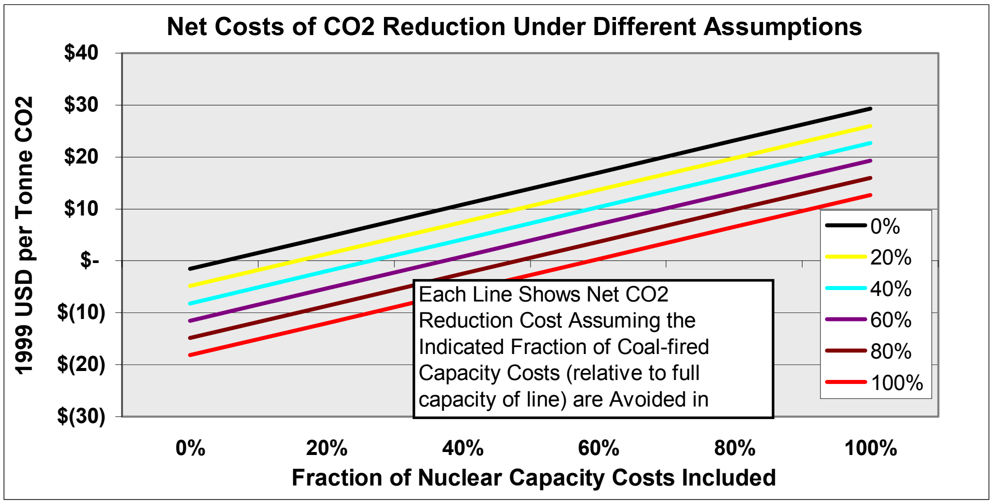
Assumptions as to Costs and Avoided Costs of Power Transmission and Generation:

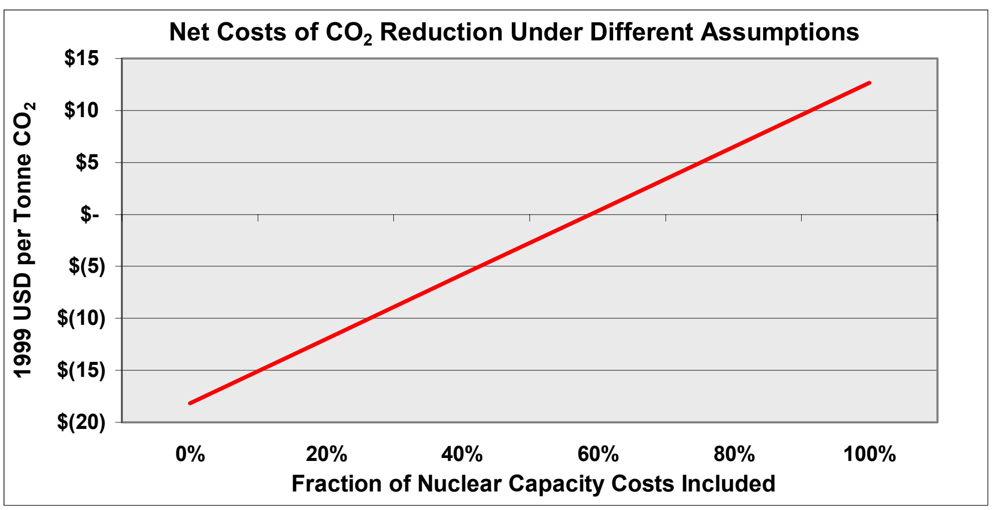
						Notes/Sources:
Unit Annualized Capacity Cost of Transmission Line:	$ 0.00827	per kWh	1999 $			1
Annualized ($99) per-unit operation and maintenance costs for transmission line			$ 0.0030	per kWh		2
Variable O&M cost of Nuclear Power Generation	$ 0.0002	per kWh	1995 $			3
Fuel cost of nuclear power generation	$ 0.0080	per kWh	1995 $			3
Capacity factor for nuclear power generation:	80%					*Rough Estimate*
Average capacity costs ($95/kW) for typical Korean nuclear reactor:			$2,500			*Rough Estimate*
Lifetime of Korean reactor:	30	years				
Interest rate used to determine annual capital cost of nuclear plants:			10%			*Rough Estimate*
Fixed charge factor used to determine annual capital cost of nuclear plants:			10.61%			
Fixed O&M cost for typical Korean nuclear Reactor	$ 47.00	per kW/yr.	1995 $			3
Fraction of capacity costs and fixed O&M costs for Korean reactors included in analysis:					100%	*Input Assumption*
Capacity of power line reaching China:	1800	MW				1
Fraction of import capacity provided that can be considered avoided capacity in China:					100%	*Input Assumption*
Estimated avoided capacity in China	1800	MW				
Average capacity costs ($95/kW) for typical new Chinese coal-fired plant w/ scrubber:					$ 780	4
Cost of coal for Chinese plants	$30	per tonne (1999 cost)				5
Lifetime of Chinese coal-fired plant:	30	years				
Interest rate used to determine annual capital cost of coal plants:			12%			7
Fixed charge factor used to determine annual capital cost of coal plants:			12.41%			
Average fixed O&M costs ($95) for typical new Chinese coal plant with scrubber:			$ 30.00	per kW/yr.		4
Variable O&M cost of Coal-fired Power Generation (with FGD):		$ 0.0020	per kWh	1995 $		3
Variable O&M cost of Coal-fired Power Generation (without FGD):		$ 0.0010	per kWh	1995 $		6
Consumer Price index, late 1995	456.5					8
Escalation factor, 1995 to 1999 dollars	1.0931					

Summary of Costs and Benefits of Replacing Coal-fired Power in NE China With Power from a Transmission Line Running from the ROK, Through the DPRK, to NE China, and Supplied by Nuclear Power Plants in the ROK and/or DPRK

	Annualized Costs/Avoided Costs		
	$/kWh	M$/yr	$/te CO_2
Costs of Providing Power Via Transmission Line			
Line and Converter Station Capital Costs	$ 0.0083	$ 85	$ 5.65
Line O&M Costs	$ 0.0030	$ 31	$ 2.05
Generation Variable O&M and Fuel Costs	$ 0.0090	$ 92	$ 6.12
Generation Capital and Fixed O&M Costs	$ 0.0452	$ 463	$ 30.85
TOTAL	$ 0.0654	$ 670	$ 44.67
Avoided Costs of Power Generation in China			
Generation Variable O&M and Fuel Costs	$ (0.0225)	$ (230)	$ (15.36)
Generation Capital and Fixed O&M Costs	$ (0.0243)	$ (250)	$ (16.63)
TOTAL	$ (0.0468)	$ (480)	$ (31.99)
NET COST OF POWER PROVISION	**$ 0.0186**	**$ 190**	**$ 12.68**

		Sensitivity Analysis--$ per tonne CO_2 Reduction Under Different Combinations of Assumptions					
		Fraction of Nuclear Plant Capital Costs Included					
	[redacted]	0%	20%	40%	60%	80%	100%
Fraction of Chinese Coal Plant Capital Cost Avoided	0%	$ (1.54)	$ 4.63	$ 10.80	$ 16.97	$ 23.14	$ 29.31
	20%	$ (4.87)	$ 1.30	$ 7.48	$ 13.65	$ 19.82	$ 25.99
	40%	$ (8.19)	$ (2.02)	$ 4.15	$ 10.32	$ 16.49	$ 22.66
	60%	$ (11.52)	$ (5.35)	$ 0.82	$ 6.99	$ 13.17	$ 19.34
	80%	$ (14.84)	$ (8.67)	$ (2.50)	$ 3.67	$ 9.84	$ 16.01
	100%	$ (18.17)	$ (12.00)	$ (5.83)	$ 0.34	$ 6.51	$ 12.68





Notes/Sources:

1 *From Line_Cost_S1 sheet*
2 *Rough estimate*
3 *From 1998 Working Draft PNL document (see LP_Chin7.XLS)*
4 *As used in NI "Clean Coal" paper, and based roughly on PNL and DOE data.*
5 *Rough estimate based on range of prices given for 1996/7 in China Energy Annual Review, 1997. Department of Resources Conservation and Comprehensive Utilization, State Economic and Trade Commission, PRC. Prices of coal in China are highly variable by region.*
6 *Very rough estimate. These costs are undoubtedly lower than for plants with FGD, but also undoubtedly non-zero. At present no variable non-fuel O&M costs are included in the NI "Clean Coal" paper analysis.*
7 *As used in NI "Clean Coal" paper.*
8 *Same source as for 1996, 1999 factors in "Line_Cost_S1" sheet.*

A.6. Generation Costs and Avoided Costs, Scenario 2

ROUGH ESTIMATE OF TRANSMISSION LINE COSTS
FOR LINE RUNNING FROM NORTHEAST ROK
ALONG THE EAST COAST OF THE DPRK AND INTO CHINA
JOINED BY A SECOND LINE PROVIDING A LINK TO THE
RUSSIAN FAR EAST

Prepared by:	David Von Hippel, Nautilus Institute
Date:	7-May-01

Assumptions as to Costs and Avoided Costs of Power Transmission and Generation:

	Value	Unit	Year	*Notes/Sources:*
Transmission Line				
Unit Annualized Capacity Cost of Transmission Line:	$0.00894	per kWh	1999 $	*1*
Annualized ($99) per-unit operation and maintenance costs for transmission line	$ 0.0030	per kWh		*2*
Nuclear Power Generation, ROK/DPRK				
Variable O&M cost of Nuclear Power Generation	$ 0.0002	per kWh	1995 $	*3*
Fuel cost of nuclear power generation	$ 0.0080	per kWh	1995 $	*3*
Capacity factor for nuclear power generation:	80%			*Rough Estimate*
Average capacity costs ($95/kW) for typical Korean nuclear reactor:	$2,500			*Rough Estimate*
Lifetime of Korean reactor:	30	years		
Interest rate used to determine annual capital cost of nuclear plants:	10%			*Rough Estimate*
Fixed charge factor used to determine annual capital cost of nuclear plants:	10.61%			
Fixed O&M cost for typical Korean nuclear Reactor	$ 47.00	per kW/yr.	1995 $	*3*
Fraction of capacity costs and fixed O&M costs for Korean reactors included in analysis:	100%			*Input Assumption*
Hydro Power Generation, RFE				
Average capacity costsfor typical RFE Hydro power station:	$1,200	per kW		*Rough Estimate*
Lifetime of Hydro Station:	40	years		
Capacity factor for RFE hydro power generation:	75%			*Rough Estimate*
Interest rate used to determine annual capital cost of hydro plants:	12%			*Rough Estimate*
Fixed charge factor used to determine annual capital cost of nuclear plants:	12.13%			
Fixed O&M cost for typical RFE Hydro Station:	$ 20.00	per kW/yr.		*Rough Estimate*
Fraction of capacity costs and fixed O&M costs for RFE Hydro included in analysis:	100%			*Input Assumption*
Variable O&M cost of Hydro Power Generation in RFE	$ 0.0010	per kWh		*Rough Estimate*
Avoided Capacity and Energy in China				
Capacity of power line reaching China from ROK/DPRK:	3600	MW		*1*
Fraction of import capacity provided that can be considered avoided capacity in China:	50%			*Input Assumption*
Estimated avoided capacity in China from power from ROK/DPRK/RFE	1800	MW		
Average capacity costs ($95/kW) for typical new Chinese coal-fired plant w/ scrubber:	$ 780			*4*
Cost of coal for Chinese plants	$30	per tonne (1999 cost)		*5*
Lifetime of Chinese coal-fired plant:	30	years		*Assumption*
Interest rate used to determine annual capital cost of coal plants:	12%			*7*
Fixed charge factor used to determine annual capital cost of coal plants:	12.41%			
Average fixed O&M costs ($95) for typical new Chinese coal plant with scrubber:	$ 30.00	per kW/yr.		*4*
Variable O&M cost of Coal-fired Power Generation (with FGD):	$ 0.0020	per kWh	1995 $	*3*
Variable O&M cost of Coal-fired Power Generation (without FGD):	$ 0.0010	per kWh	1995 $	*6*
Consumer Price index, late 1995	456.5			*8*
Escalation factor, 1995 to 1999 dollars	1.0931			
Avoided Capacity and Energy in ROK				
Avoided capacity of summer peaking power in ROK	1800	MW		
Fraction of import capacity provided that can be considered avoided capacity in ROK:	50%			*Input Assumption*
Capacity cost for summer peaking power in ROK (gas combined-cycle or similar)	$ 583.00	($96)/kW		*9*
Lifetime of peaking plant	20	years		
Average fixed O&M costs for ROK gas-fired combined cycle plant ($1996)	$ 21.80	per kW/yr.		*9*
Interest rate used to determine annual capital cost of peaking plants:	12%			*Assumption*
Fixed charge factor used to determine annual capital cost of gas-fired plants:	13.4%			
Cost of coal in ROK	$ 42.50	per tonne (1998 cost)		*12*
Variable O&M cost of Coal-fired Power Generation in ROK (with FGD):	$ 0.0033	per kWh		*10*

Avoided Capacity and Energy in RFE				
Avoided capacity of winter peaking power in RFE	1800	MW		
Fraction of import capacity provided that can be considered avoided capacity in RFE:	50%		*Input Assumption*	
Capacity cost for winter peaking power in RFE (coal-fired)	$ 1,291	per kW		*11*
Lifetime of coal-fired plant	30	years		
Interest rate used to determine annual capital cost of RFE coal-fired plants:	12%		*Assumption*	
Fixed charge factor used to determine annual capital cost of gas-fired plants:	12.4%			
Cost of coal for RFE plants	$30	per tonne	*Assumed similar to Chinese costs*	
Average fixed O&M costs ($96) for typical new RFE coal plant with scrubber:	$ 33.00	per kW/yr.		*11*
Variable O&M cost of Coal-fired Power Generation in ROK (with FGD):	$ 0.0033	per kWh		*10*

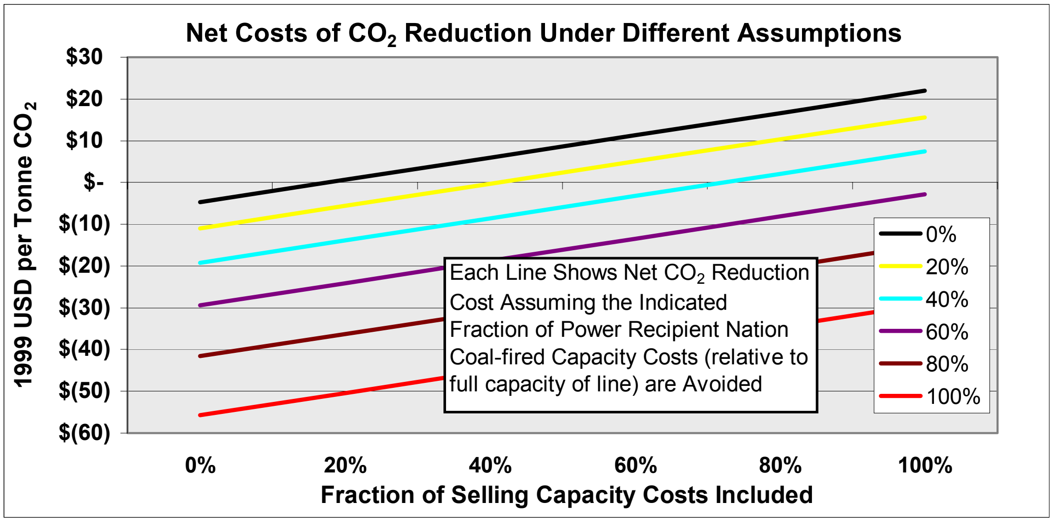
Summary of "Scenario 2": Power Trade to China (spring/fall) from RFE and ROK/DPRK, to ROK from RFE (summer) and From ROK to RFE (winter), with supplies from RFE Hydro Plants, Nuclear Power Plants in the ROK and/or DPRK	Annualized Costs/Avoided Costs		
	$/kWh*	M$/yr	$/te CO_2
Costs of Providing Power Via Transmission Line			
Line and Converter Station Capital Costs	$ 0.0089	$ 137	$ 6.76
Line O&M Costs	$ 0.0030	$ 46	$ 2.27
Generation Variable O&M and Fuel Costs, ROK/DPRK	$ 0.0045	$ 69	$ 3.39
Generation Capital and Fixed O&M Costs, ROK/DPRK	$ 0.0226	$ 347	$ 17.08
Generation Variable O&M Costs, RFE (Hydro)	$ 0.0005	$ 8	$ 0.38
Generation Capital and Fixed O&M Costs, RFE (Hydro)	$ 0.0126	$ 194	$ 9.53
TOTAL	$ 0.0521	$ 801	$ 39.40
Avoided Costs of Power Generation in China			
Generation Variable O&M and Fuel Costs	$ (0.0150)	$ (230)	$ (11.33)
Generation Capital and Fixed O&M Costs	$ (0.0081)	$ (125)	$ (6.14)
Avoided Costs of Power Generation in ROK			
Generation Variable O&M and Fuel Costs	$ (0.0037)	$ (57)	$ (2.83)
Generation Capital and Fixed O&M Costs	$ (0.0062)	$ (96)	$ (4.72)
Avoided Costs of Power Generation in RFE			
Generation Variable O&M and Fuel Costs	$ (0.0044)	$ (67)	$ (3.31)
Generation Capital and Fixed O&M Costs	$ (0.0113)	$ (174)	$ (8.55)
TOTAL	$ (0.0488)	$ (750)	$ (36.88)
NET COST OF POWER PROVISION	**$ 0.0033**	**$ 51**	**$ 2.52**

* Expressed per kWh of total annual power carried by interconnection (all countries)

Sensitivity Analysis Input Data	
Fraction of Country of Origin Power Plant Capital Costs Included	100%
Fraction of Recipient Country of Power Plant Capital Costs Included	50%

Sensitivity Analysis--$ per tonne CO_2 Reduction
Under Different Combinations of Assumptions

		Fraction of Country of Origin Power Plant Capital Costs Included					
	$ 2.52	0%	20%	40%	60%	80%	100%
Fraction of Recipient Plant Capital Cost Avoided	0%	$ (4.67)	$ 0.65	$ 5.97	$ 11.29	$ 16.61	$ 21.93
	20%	$ (10.97)	$ (5.65)	$ (0.32)	$ 5.00	$ 10.32	$ 15.64
	40%	$ (19.22)	$ (13.90)	$ (8.58)	$ (3.26)	$ 2.06	$ 7.38
	60%	$ (29.44)	$ (24.12)	$ (18.80)	$ (13.48)	$ (8.16)	$ (2.84)
	80%	$ (41.63)	$ (36.31)	$ (30.99)	$ (25.67)	$ (20.35)	$ (15.03)
	100%	$ (55.78)	$ (50.46)	$ (45.14)	$ (39.82)	$ (34.49)	$ (29.17)



<u>Notes/Sources:</u>

1 From Line_Cost_S2 sheet
2 Rough estimate
3 From 1998 Working Draft PNL document (see LP_Chin7.XLS)
4 As used in NI "Clean Coal" paper, and based roughly on PNL and DOE data.
5 Rough estimate based on range of prices given for 1996/7 in China Energy Annual Review, 1997. Department of Resources Conservation and Comprehensive Utilization, State Economic and Trade Commission, PRC. Prices of coal in China are highly variable by region.
6 Very rough estimate. These costs are undoubtedly lower than for plants with FGD, but also undoubtedly non-zero. At present no variable non-fuel O&M costs are included in the NI "Clean Coal" paper analysis.
7 As used in NI "Clean Coal" paper.
8 Same source as for 1996, 1999 factors in "Line_Cost_S1" sheet.
9 Stockholm Environment Institute--Boston Center, <u>Techology and Environment Database (TED)</u>. Data for technology branch "Electricity generation/Natural Gas/Combined Cycle/NEA IEA/Korea LNG Low NOx burners. Data for this branch in TED taken from <u>Projected Costs of Generating Electricity</u> by Nuclear Energy Agency and International Energy Agency, 1998.
10 Data from TED (see above), technology branch "Electricity generation/Coal/Conventional Steam/AEO1999/Scrubber" Data based on assumptions used in developing the 1999 edition of the U.S. DOE/EIA's Annual Energy Outlook.
11 Stockholm Environment Institute--Boston Center, <u>Techology and Environment Database (TED)</u>. Data for technology branch "Electricity generation/Coal/Conventional Steam/NEA IEA/Russia FGD. Data for this branch in TED taken from <u>Projected Costs of Generating Electricity</u> by Nuclear Energy Agency and International Energy Agency, 1998.
12 Korea Energy Economics Institute (1999), <u>Yearbook of Energy Statistics</u>. Page 121 gives costs and quantities for coal imports (most coal used in the ROK is imported).