ROK ENERGY SECTOR AND ROK ENERGY POLICIES, UPDATE AND RESULTS OF THE ROK ENERGY PATHS MODELLING EFFORTS

Report of the Republic of Korea (ROK) Working Group to the Nautilus Institute Regional Energy Security Project

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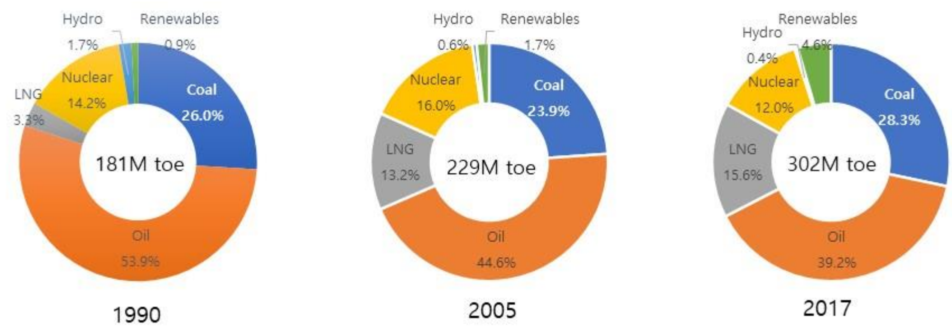
May 23, 2021



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INTRODUCTION

In this Special Report, Chung Woo-jin and Lee Tae Eui, describe the recent history and current status of energy supply and demand in the Republic of Korea (ROK), provide an overview of ROK energy policies, describe ROK involvement in discussions regarding regional energy cooperation, and present and evaluate a set of future scenarios for evolution of the ROK energy sector focusing on the use of renewable and nuclear energy in the electricity sector. Some of the potential short- and longer-term impacts of the COVID-19 pandemic on the ROK energy system are also noted.

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The views expressed in this report do not necessarily reflect the official policy or position of the Nautilus Institute. Readers should note that Nautilus seeks a diversity of views and opinions on significant topics in order to identify common ground.

Banner image: ROK primary energy consumption by source (prepared by the authors based on data from Korea Energy Economics Institute (KEEI, 2019).

I. NAPSNET SPECIAL REPORT BY CHUNG WOO-JIN AND LEE TAE EUI UPDATE ON THE ROK ENERGY SECTOR AND ROK ENERGY POLICIES, AND RESULTS OF THE ROK ENERGY PATHS MODELLING EFFORTS

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CHUNG Woo-jin, and LEE Tae Eui,

ROK Working Group Report prepared for the project

REGIONAL ENERGY SECURITY (RES)

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ABSTRACT

With environmental issues increasing in importance, the current government of the Republic of Korea (ROK) is strongly pursuing energy transition policies to phase out nuclear power and to substantially reduce the use of coal-fired power generation while increasing the use renewable energy and natural gas. Many plans for energy transition measures, programs, and policies have been established and carried out by the government. The energy transition policy, however, is facing strong resistance from many opinion groups including a number of energy experts. It is therefore, not certain that the current energy transition policy will be realized in the coming decades, particularly if the political landscape changes in the future.

For the ROK Working Group's analysis of ROK energy futures using the LEAP (Low Emissions Analysis Platform—formerly Long-range Energy Alternatives Planning) model, five scenarios of ROK energy demand and supply were designed by combining different measures in the three major energy policy areas of nuclear energy, renewable energy, and regional cooperation. The LEAP model analysis indicates that one of the most positive energy policy scenarios for ROK greenhouse gas reduction was the continuing operation nuclear power generation. The use of nuclear power, however, should be reduced because of its own risks, and as a result of replacing nuclear power with fossil-fueled electricity generation, greenhouse gas emissions can increase. These are political issues that the ROK government must resolve. It appears that a significant amount of greenhouse gas reduction is also possible by importing electricity through regional cooperation schemes if the imported power is carbon-free.

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1 INTRODUCTION

The major initial spur of the Republic of Korea's (ROK's) post-war economic development was the launching of the ROK's first five-year economic development plan in 1962. The policy measures included in the plan were designed to increase the country's wealth through the export-oriented industrialization under strong government leadership. These plans have been implemented every five years through the completion of the seventh economic development plan in 1996. During the implementing periods of the economic development plans, the ROK grew from one of the poorest countries in the world to an OECD member country, and was transformed from an agricultural economy to one of the world's major manufacturers. Since the first economic development plan was implemented, energy security (defined as stable energy supplies) and energy efficiency (energy savings) have been the main pillars in the energy policies of the ROK because the country has very limited energy sources and consequently depends on meeting most of its energy demand with resources imported from overseas countries.

In 1997, the ROK experienced a financial crisis in which many companies went bankrupt, with the failed firms holding more than 400% of their capital in debt on average. During that period, almost all of the ROK's companies had the burden of massive debts incurred in securing the investment capital required to increase production to meet rapidly increasing demand for goods and services experienced as a result of (and causing) high economic growth rates. Since then, the ROK economy has pursued a policy of "robust growth" rather than rapid growth. In energy policy, environmental protection and reducing greenhouse gas (GHG) emissions became a new policy pillar in addition to energy security and energy efficiency as climate change has emerged as an international issue. The ROK, which ranked 9th worldwide in per-country GHG emissions as of 1997 (and ranked 7th as of 2018, based on IEA data), should have prepared various measures to restrict the use of fossil fuels. In that sense, nuclear power played a key role in meeting increasing energy demand while reducing GHG emissions. Nuclear power was also an important alternative energy source for alleviating the import costs of fossil energy because the ROK depended (and still depends) almost entirely on fuels imported from overseas countries. Since the ROK constructed its first nuclear power plant in 1978 using technology and equipment from the United States, the country has worked to develop and acquire its own nuclear power technology manufacturing capabilities, ultimately becoming the world's 5th largest nuclear power nation (by generation capacity) built largely with ROK technology. The ROK completed an agreement to export its first nuclear power reactors to the United Arab Emirates in 2015 and is currently constructing four 1400 MW reactors developed in the ROK there. The ROK is also participating in bidding to construct nuclear power plants in several countries, including the United Kingdom.

The new ROK government that took office in May 2017, however, announced the phase-out of domestic nuclear power over the next 40 years. President Moon Jae-in's administration has emphasized that the country is in an unsafe condition because there are too many reactors in a relatively small area, as the ROK is ranked number one in the world in terms of nuclear power density (nuclear power installation capacity divided by national land area). The government, on the other hand, has focused on renewable energy as the key alternative to meet the ROK's increasing energy demand as well as to reduce GHG emissions, and has proclaimed an energy transition policy to increase the shares of renewable energy and natural gas and decrease those of nuclear and coal-fired power. In the case of coal, the government also regards coal-fired power as one of the core PM2.5 (particulate matter of less than 2.5 microns, which is a health risk) emission sources in the ROK.

As a result of the Moon administration's policies, plans to build new nuclear power plants were canceled, and the older coal-fired power plants were decommissioned earlier than the licensed life spans. Some of the plans to build new coal-fired power plants were transformed into plans to construct LNG (liquefied natural gas)-fueled power plants. A far-reaching scheme to expand the supply of renewable energy was established in the Moon administration. But this ambitious energy transition policy has been embroiled in political and social conflicts. The opponents of the scheme insist the energy transition policy could endanger the ROK's energy supply and raise energy prices as the dependency on the technically uncertain renewable energy and expensive natural gas will rise, while reducing electric generation from nuclear and coal-fired power plants that are stable and cheap sources of electricity.

This report explores the structural changes in ROK energy supply and demand over the years and the current controversial energy policies in the ROK, and projects a set of scenarios for the ROK's future long-term energy supply and demand using the LEAP (Low Emissions Analysis Platform, formerly the Long-range Energy Alternatives Planning system) software tool.[1] The scenarios explored here focus on ROK nuclear power policies. The ROK's policies and plans for electricity grid connections with Northeast Asian countries are also introduced, and the impacts of grid interconnection on the ROK's energy supply situation are analyzed with the LEAP model.

2 OVERVIEW OF ROK ENERGY DEMAND & SUPPLY

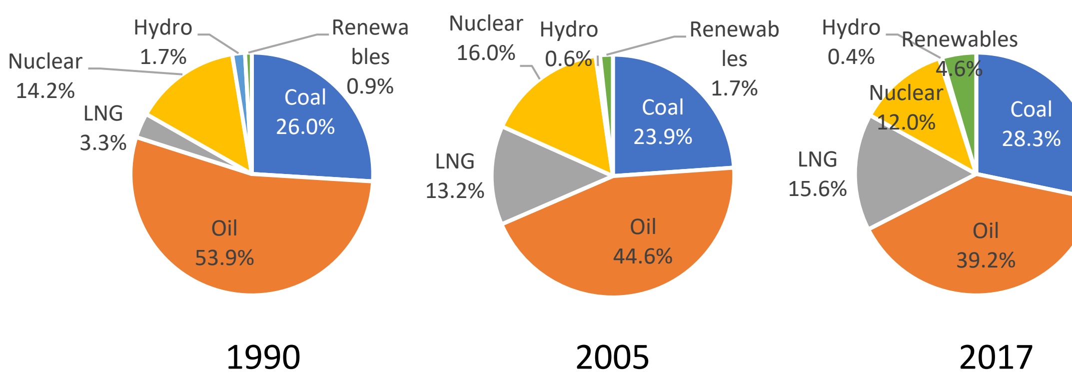
The global domestic product (GDP) of the ROK, when measured at constant prices, grew by a factor of 4.2 between 1990 and 2017. During the same period, the volume of primary energy demand has increased by 3.2 times, from 93.9 million toe to 302.1 million tonnes of oil equivalent (toe) and GHG emissions have increased by a factor of 2.5. The elasticity of energy consumption per unit of GDP growth was 0.762 for the period between 1990 and 2017, which means the growth rate of energy demand in the ROK had substantially slowed when compared with an energy elasticity of GDP of 1.242 between 1980 and 2000, a period during which the country's economy grew at an average of more than 10% per year. Per capita energy use and energy consumption per unit of GDP per 1,000 USD were 5.87 toe and 0.224 toe, respectively, in 2017. The ROK imported 94% of the energy it consumed, at a cost of 109 billion USD, which accounted for 22.8% of the value of total imports to the ROK in 2017.

[1] See, Heaps, C.G., 2020. LEAP: The Low Emissions Analysis Platform. [Software version: 2020.1.19] Stockholm Environment Institute. Somerville, MA, USA. https://leap.sei.org.

As of 2017, oil remains the dominant energy form in the ROK, accounting for 39% of total primary energy demand. Coal accounted for 28.3% of primary energy demand, followed by LNG (15.6%), nuclear energy (12.0%), renewable energy (4.6%), hydropower (0.4%). Though oil is the dominant energy resource used in the ROK, its share has steadily decreased since the 1990s under energy policies targeting reductions in the dependency on the oil in energy consumption. On the other hand, the share of LNG has rapidly increased since the first cargo of LNG arrived in 1986 from Indonesia at the ROK port of Pyeongtaek

The share of nuclear energy has also shown a rapid rise but has been a fallen somewhat since 2011 as the consumption of natural gas has increased more rapidly. The share of coal has long been at a 20% level as the second-largest energy source following oil. The share of renewable energy still remains at less than 5%, although it's share is substantially higher than it was in the 1990s, as shown in Figure 2-1.[2]

Figure 2-1: Shares of Primary Energy in the ROK by Source



Source: Yearbook of Energy Statistics, Korea Energy Economics Institute (KEEI), 2019

The Industrial sector consuming more energy than any other sector in the ROK, accounting for 61.7% of primary energy demand in the ROK as of 2017. The transport sector accounted for 18.3%, the residential and commercial sector 17.1%, and the public sector 3.0% of energy use in 2017. Energy consumption by the industrial sector has increased most rapidly, and its share has continued to rise, surpassing the 60% level of total national primary energy consumption since 2015. The share of energy consumption in the residential and commercial sector, on the other hand, has continued to fall from 28.7% in 1990 to 17.1% in 2017. The share of energy used by the transport has remained at 18%~22% for most of the last two decades, though transport use has been falling slightly in recent years.

Final energy consumption in the ROK has increased from 74 million toe in 1990 to 233 million toe in 2018. Oil is also the dominant energy form in the final consumption energy sectors,

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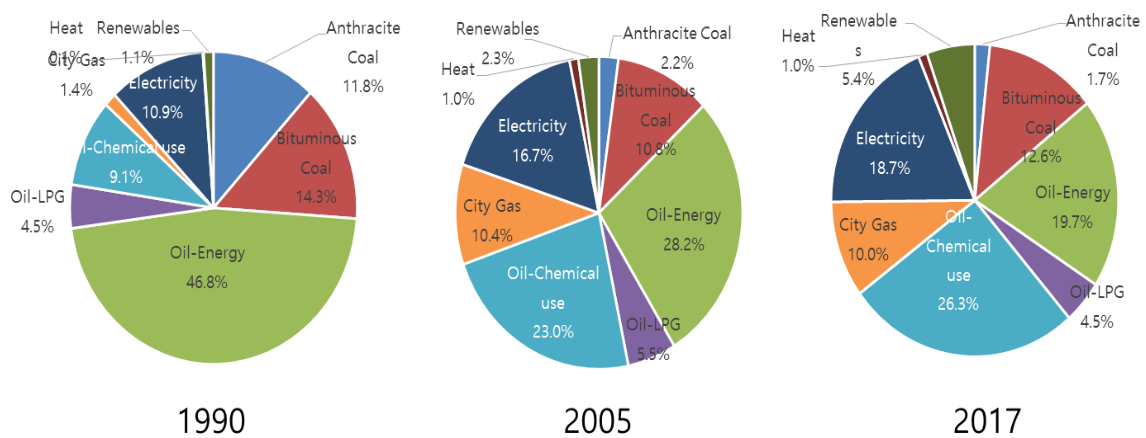
[2] Korea Energy Economics Institute (KEEI, 2019), *Yearbook of Energy Statistics*

accounting for about half of final energy consumption. Since 1990, the share of the oil in final energy consumption has fallen slightly from the 60% to 50% level. The share of oil use as a fuel has significantly decreased; the reason why the overall oil share of total consumption has hardly changed over time is that oil consumption for chemical industry feedstocks has rapidly increased. The share of oil used by the chemical industry has risen from 9.1% in 1990 to 26.3% in 2017, while the share of oil products used as fuels among all energy use has fallen from 51.3% to 24.2% during the same period. The petrochemical industry has grown to be one of the main export sectors in the ROK, selling about half of its production to overseas countries. Electricity consumption accounted for the second largest share among final energy forms, at 18.4% in 2017, and city gas has remained at a 10% level since 2000. Anthracite coal is a domestic energy resource that was a major source of energy in the ROK in the past, particularly in the residential and commercial sectors. The government, however, has phased out coal mining over the years due to growing production costs and significant deterioration in the environment of the residential areas near mines. Consequently, the share of anthracite coal use in final consumption has fallen from 11.2% in 1990 to just 1.4% in 2017. The share of bituminous coal, which is all imported, has long remained at 10%~15% of final energy consumption. Bituminous coal (steam coal) is usually consumed in the industry and power sectors (although note that the coal used in the power sector is not included in the accounting of final energy consumption). Renewable energy usually consumed for water heating in the residential and commercial sector has increased, and its share in the final energy consumption surpassed 5% in recent years, although its share is still small (see Figure 2-2).

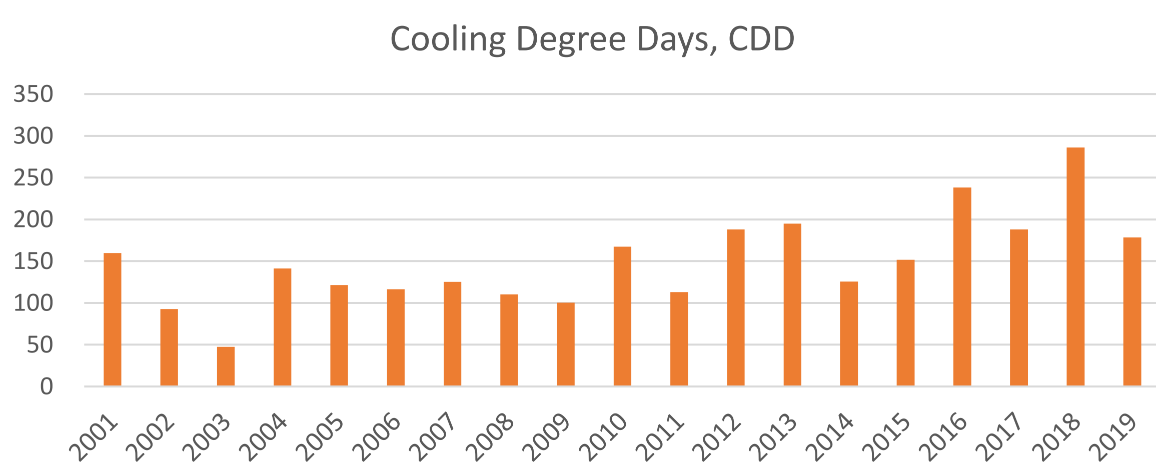
Figure 2-2: Shares of Final Energy Consumption by Source



Source: *Yearbook of Energy Statistics*, Korea Energy Economics Institute (KEEI), 2019

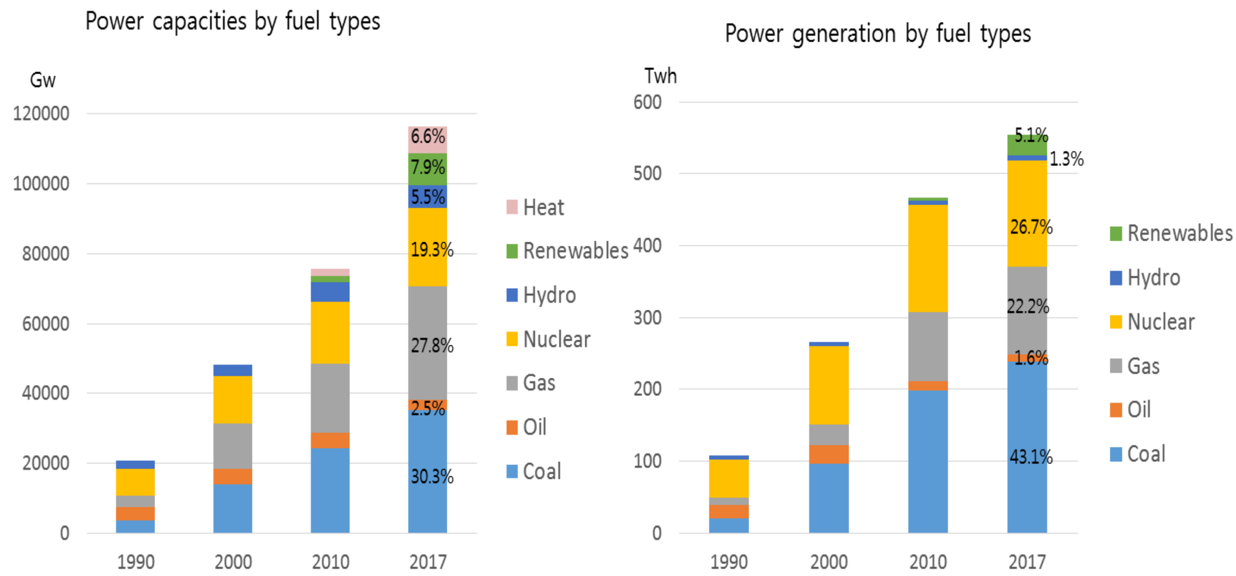
The energy consumed by the electricity sector has increased from 26 million toe in 1990 to 94 million toe in 2017 as electricity uses have been on the rapid increase. During the same period, the volume of electricity generation has jumped more than five-fold, from 107.7 TWh (terawatthours) to 553.5 TWh. Electricity generation per capita has also increased, from 2,516 kWh to 10,759 kWh. Coal-fired and nuclear power have been operated as baseload generation in the ROK, producing 43.1% and 26.7%, respectively, of total electricity output in 2017. The share of nuclear power generation was above 30% for many years, and its load factor was typically more than 80%, and sometimes 90% or more, In 2017, however, the load factor of nuclear generation fell to 71.3% due to strict regulations on nuclear safety, and consequently the share of generation by nuclear power fell to less than 30%. Natural gas power plants produced 22 % of total power generation in 2017, while accounting for 26% of total generation capacity. Both of natural gas generation and capacity have increased faster than those of coal-fired and nuclear power, as the peak demand for electricity in the ROK surged in recent years particularly due to a sharp increase in demand by the air-conditioners during recent unusually warm summers, as indicated by the trend in "cooling degree days" shown in Figure 2-3. Since 2010, power generation from renewable energy has also been on the rapid increase, rising from 4 TWh in 2010 to 28 TWh in 2017, and its share surpassed 5.1% of power generation and approached 8% of total ROK generation capacity. In spite of this rapid increase, renewables still provide only a small portion of the energy mix of power generation in the ROK. In additions, at present most electricity produced from renewable energy sources is generated from waste fuels and bio-energy, and just 25% of the electricity produced by renewable energy sources comes from solar photovoltaic plants and wind power. The load average factors on the ROK electricity system as a whole have improved from 58.4% in 1990 to 74.1 % in 2009, and since then they have remained at a 70% level. But the plant utilization factors (the ratio of the average load over peak load) have declined from 71.2% in 1990 to 54.0% in 2017 as peak electricity demand has sharply increased. Loss factors on the transmission and distribution (T&D) network have been at 3~4%, one of the lowest rates in the world, since 2000. Figure 2-4 shows the trends in generation capacity and electricity generation by fuel type since 1990.

Figure 2-3: Cooling Degree Days in the ROK, 2001 through 2019



Source: *Yearbook of Energy Statistics*, Korea Energy Economics Institute (KEEI), 2019

Figure 2-4: The Shares of Power Capacity and Generation by Energy Source



Source: Yearbook of Energy Statistics, Korea Energy Economics Institute (KEEI), 2018

3 THE ROK'S ENERGY POLICIES: AN UPDATE

3.1 ENERGY TRANSITION POLICY

As soon as the Moon administration took power in May 2017, it announced an energy policy focused on phasing out nuclear power and substantially reducing the use of coal-fired generation. Previous plans to construct new nuclear power plants were scrapped, and measures to carry out early shut down of 10 aging coal-fired power plants were also established. This announcement was regarded as a crucial turning point in the country's history of energy policies in that nuclear and coal-fired power have long played roles as the main energy sources to meet fast growing electricity demand at affordable costs, and have been reliable supply sources in the ROK. Coal and nuclear plants are base-load electricity sources that have produced 70~80% of the power generated in the ROK for many years. The government announced that the supply gaps from reducing the use of coal and nuclear plants would be filled by accelerating the development of renewable electricity sources, as well as increasing natural gas-fired generation.

This radical energy policy came in part in response to mounting public anxiety over the safety of nuclear power, as well as over deteriorating air quality in the ROK, especially related to fine particulate matter pollutant emissions (PM2.5), which are produced by coal-fired plants. In 2016 and 2017, successive earthquakes struck Gyeongju and Pohang, which are located in the southeastern coastal regions of the ROK, and which are also areas where nuclear power plant sites are heavily concentrated. The magnitudes of those earthquakes were recorded as 5.8 and 5.4, respectively, and as such were the strongest in the modern history of the ROK. Those earthquakes damaged infrastructure, injured dozens of people, and left thousands of people homeless, though there were no casualties. Those successive earthquakes, along with several aftershocks, reminded people that the country is no longer an earthquake-safety zone. The peoples' anxiety about the earthquakes has triggered renewed public concerns about potential accidents at nuclear power plants, concerns that emerged following the 2011 Fukushima Daiichi nuclear disaster in Japan, and reported by many media outlets. The Korean nuclear power company and many experts, however, insisted that nuclear power plants in the ROK were designed and built to withstand earthquakes with magnitudes ranging between 6.5 and 7, which have rarely occurred in the country over its geological history. The anti-nuclear movements have spread nationwide, and the safety of nuclear power has become a key political issue.

Along with public concern about nuclear safety, "fine dust pollution" has become another major political issue in the ROK as particulate pollution has been a chronic phenomenon during winter and spring in the country, and is alleged to seriously threaten public health. The government has taken many measures to reduce fine dust emissions, including limiting vehicle use, especially diesel cars. The government regarded coal-fired power as one of the main sources of particulate pollution emissions, and so has restricted the operation of coal-fired plants. In the 2017 presidential campaign in the ROK, most candidates pledged to scale down coal and nuclear power amid growing concerns over the safety of nuclear power and highly concentrated fine dust. But there have been many arguments that the energy transition policy of the Moon government to scale back nuclear and coal-fired power is too radical and challenging to implement to be a successful plan, though the direction of the policy is considered by most to be right in the long-term.

The government's energy transition policy was specified through "the 8th Basic Plan for Electricity Supply and Demand"[3] and the "Renewable Energy 3020 Implementation Plan" established at the end of 2017.[4] These energy transition policies and the challenges associated with implementing them are reviewed below.

3.2 DENUCLEARIZATION PLAN OF THE ROK GOVERNMENT

The first nuclear power plant in the ROK, Kori #1, a 75 MW (megawatt) reactor, started operation in 1978. Since then, the country has significantly increased its use of nuclear power, and as of 2019, 24 reactors are in operation with a capacity of 23.9 GW (gigawatts), including 20 pressurized water reactors (PWRs) and 4 CANDU heavy-water reactors (PHWRs), the latter with a combined capacity of 2.8 GW[5]. In the early stages of nuclear power development, the ROK constructed nuclear reactors under turnkey contracts with international nuclear engineering companies like Westinghouse (USA), GEC (England), Parsons (Canada), and Framatome

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[3] Korea Ministry of Trade, Industry and Energy (2017a), *The 8th Basic Plan for Long-term Electricity Supply and Demand (2017-2031)*, dated 2017.12.

[4] Korea Ministry of Trade, Industry and Energy (2017b), *The Renewable Energy 3020 Plan*, dated 2017.12.

[5] Eunjung Lim, South Korea's Nuclear Dilemmas, Journals for Peace and Nuclear Disarmament, volume 2, 2019-Issue 1, The Research Center for Nuclear Weapon Abolition, Nagasaki University (RECNA), April, 2019

(France). Since 1990, the ROK has developed its own nuclear light water reactor designs, the OPR-1000 and APR 1400, and has adapted those technologies to constructing additional domestic nuclear power plants. In 2009, the KHNP, the state nuclear company, contracted to construct the four APR-1400 reactors in the United Arab Emirates (UAE), and is constructing the first nuclear unit at the Barakah site, with completion currently targeted for 2020.

There are four nuclear power sites and one planned site for building new reactors in the ROK and among them, four sites including the new planned site, are concentrated at the southeastern coastal regions, Gyeongju, Pohang, Uljin, and Busan. The one other site is located at the Southwestern coastal area, Youngqwang, as shown in Figure 3-1.

Figure 3-1: Nuclear Sites in the ROK

Source : https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx

The expansion of nuclear power generation has long been a major strategy not only for stable energy supply in the ROK, which has been obliged to import almost all of the energy used as it has to develop its fast-growing economy, but also has served as a strategy for climate change mitigation, which is needed given that the ROK was the world's 7th largest GHG emitter in 2018. Even after the Fukushima nuclear disaster occurred in 2011 in Japan, which is close to the ROK, there was not a significant change in the country's energy policy to depend on nuclear power, although the accident made people more seriously aware of the risks associated with nuclear power[6]. The Energy Master Plan in the ROK provides the primary guidance on all relevant energy sectors, and defines the direction of mid- to long-term energy policies. The Energy Master Plan was newly introduced in 2008 after changing the related law and time span of the plan from those used in past National Energy Plans, which also provided the ROK's long-term energy policies. The second Energy Master Plan was established in 2014 under the immediate previous conservative government.[7] The target shares of nuclear power capacity in the electricity energy mix fell from 41% in the first Energy Master Plan (2008) to 29% in the second Energy Master Plan, reflecting peoples' concerns over potential accidents at nuclear reactors. Although the projected future share of nuclear energy was reduced, the construction of many new nuclear reactors was still planned in order to attain the target share included in the Second Energy Master Plan. 13 reactors, including those under construction (total capacity: 12.3 GW) had been scheduled to come on line through 2029 under "the 7th basic plan for long-term electricity supply and demand", established in 2014 (see Table 3-1).

[6] Yun Sun-Jin, Jung Yeon-Mi, Energy Policy at a Crossroad in the Republic of Korea, Friedrich-Ebert-Stiftung, November, 2017

[7] Korea Ministry of Trade, Industry and Energy (2014), *The Second Energy Master Plan*, dated January 2014.

Table 3-1: Nuclear Reactors in the ROK

No.	Name	Capacity (MW)	Start Year	Close Year	
1	Kori 1	-587	Apr-78	Jul. 2017 (10year expanded)	Shutdown
2	Wolsung 1	-679	4-1978	11-2020	Early Shutdown
3	Kori 2	650	7-1983	8-2023	Under operation
4	Kori 3	950	9-1985	9-2024	Under operation
5	Kori 4	950	4-1986	8-2025	Under operation
6	Hanbit 1	950	8-1986	12-2025	Under operation
7	Hanbit 2	950	6-1987	9-2026	Under operation
8	Hanwool 1	950	9-1988	12-2027	Under operation
9	Hanwool 2	950	9-1989	12-2028	Under operation
10	Hanbit 3	1000	3-1995	9-2034	Under operation
11	Hanbit 4	1000	1-1996	6-2035	Under operation
12	Wolsung 2	700	7-1997	11-2026	Under operation
13	Hanwool 3	1000	8-1998	11-2037	Under operation
14	Hanwool 4	1000	12-1999	10-2038	Under operation
15	Wolsung 3	700	7-1998	12-2027	Under operation
16	Wolsung 4	700	10-1999	2-2029	Under operation
17	Hanbit 5	1000	5-2002	10-2041	Under operation
18	Hanbit 6	1000	7-2002	7-2042	Under operation
19	Hanwool 5	1000	4-2004	10-2043	Under operation
20	Hanwool 6	1000	4-2005	11-2044	Under operation
21	Shin Kori 1	1000	2-2011	5-2050	Under operation
22	Shin Kori 2	1000	7-2012	12-2051	Under operation
23	Shin Wolsung 1	1000	7-2012	12-2051	Under operation
24	Shin Wolsung 2	1000	7-2015	11-2054	Under operation
25	Shin Kori 3	1400	12-2016	2056	Under operation
26	Shin Kori 4	1400	8-2019	2059	Under operation
27	Shin Hanwool 1	1400	2020		Under construction
28	Shin Hanwool 2	1400	2021		Under construction
29	Shin Kori 5	1400	2023		Under construction
30	Shin Kori 6	1400	2024		Under construction
31	Shin Hanwool 3	1400	2022		On hold
32	Shin Hanwool 4	1400	2023		On hold
33	Cheonji 1	1500	2026		Cancelled
34	Cheonji 2	1500	2027		Cancelled
35	Daejin 1	1500	2028		Cancelled
36	Daejin 2	1500	2029		Cancelled

Source: the 8th basic plan for long-term electricity supply and demand, Ministry of Trade, Industry and Energy, 2017[8]

The construction of 6 reactors among the 13 reactors included in the 7th basic plan, however, were canceled or put on hold as a result of the decisions in "the 8th basic plan for long-term electricity supply and demand" established in 2017 under the new progressive government. At that time (2017), among the 7 planned or under-construction reactors not being canceled, 2 reactors (Shin Wolsung #2 and Shin Kori #3) were already under operation and 3 reactors (Shin

[8] Korea Ministry of Trade, Industry and Energy, (2017), *The 8th Basic Plan for Long-term Electricity Supply and Demand (2017-2031)*, dated 2017.12.

Kori #4 and Shin Hanwool #1 and #2) were almost complete. The other 2 reactors (Shin Kori #5 and #6, total capacity 2.8 GW) were under construction with about 30% of the process complete. The new government announced these two reactors would also be canceled. But the possible halting of reactor projects already under construction ignited a heated debate. Quite a number of advocates of the nuclear phase-out policy even opposed the cancellation of the construction of the two reactors, saying that it would bring a large economic loss. In response to mounting social conflicts, the government established "the Public Deliberation committee on Shin Kori 5 and 6" in July 2017 to discuss and decide whether to stop the construction of the two Shin Kori units through a public assessment process. The civilian-led committee had nine members from various industries including humanities and the social sector, science & technology, statistical surveys, and conflict management. Energy experts including the nuclear sector were not included as members of the committee. After three months of deliberation, the committee selected 500 ordinary people as jurors to participate in the debates and hearings and would decide the fate of the two reactors. The jurors and experts held a three-day marathon discussion and on 20 October, finally concluded that the construction of Shin Kori 5 and 6 should be resumed, though in the long term, nuclear power generation should be scaled back in the ROK[9]. Following the recommendation of the committee, the government announced the resumption of work on the two Shin Kori reactors.

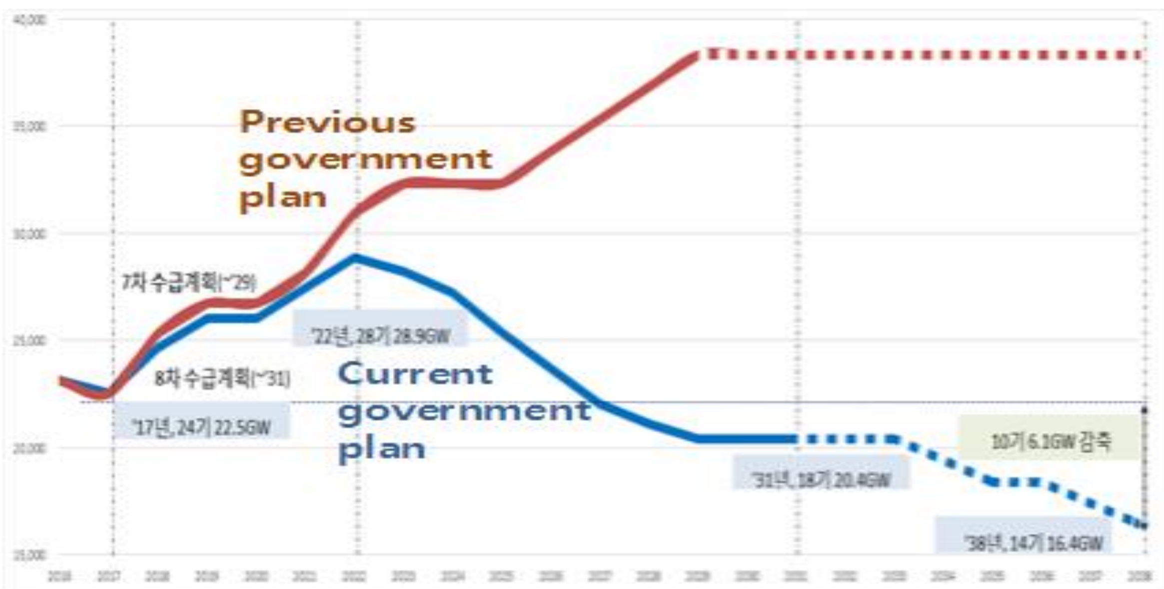
As soon as the new government took power in May 2017, the Kori 1 reactor, the first nuclear reactor in the country, was permanently decommissioned as it had reached the end of its nominal useful life span. At that time, the life span of Kori 1 had already been extended for 10 years. Many nuclear experts stated opinions that application of current technologies could further extend its lifespan, but the government decided to shut down the reactor as a part of the nuclear phase-out policy. Soon after, the government decided to shut down the Wolsung 1 reactor that was also operating under life extension for 10 years until 2022, and the operation of this reactor was permanently halted at the end of 2019, three years earlier than its extended life span would have allowed.

The life spans of many nuclear reactors that began their commercial operations in the 1980s and 1990s are scheduled to run out by 2030 and 2040. As shown in Table 3-1, 10 reactors with a total capacity of 23.5 GW will finish their life spans between 2023 and 2029, and another four reactors with a total capacity of 12.5 GW will also complete their life spans between 2030 and 2040. This means that by 2040, 14 units out of 24 reactors currently operating will be shut down, and only the 4 reactors currently under construction will be phased in because there are no further plans to construct new reactors under the nuclear phase-out policy. A lot of experts in the nuclear and energy sector have long asserted that the life spans of nuclear reactors could be extended for quite a long period without negatively affecting the safety of nuclear facilities. Experts also cited examples of ongoing life-extension in foreign countries like the U.S.A, Canada, Japan, Finland and others. Though the assertions of nuclear supporters in favor of life extension were controversial, all of the previous governments seemed to have had the intention

[9] Ji-Bum Chung, Eun-Sung Kim (2018), "Public perception of energy transition in Korea-Nuclear power, climate change and party preference", Energy Policy 116 (2018).

to extend the life span of nuclear facilities because extending plants' life spans can provide electricity at lower costs than can new power facilities. The life extension of Kori 1 reactor was decided under the previous progressive government in 2007 and the following conservative government also decided to pursue life extension for the Wolsung 1 reactor in 2012. But the current Moon administration announced that existing nuclear reactors would be phased out whenever their current life spans had run out. The result of this policy is that a huge amount of nuclear energy generation, as it is phased out, must be supplemented with other energy sources, and based on the energy transition policy of the government, renewable energy should become the alternative source replacing nuclear energy. Natural gas also is intended to play a partial role as an alternative to phased-out nuclear energy. Figure 3-2 summarizes the changes in plans on nuclear power between the current and previous governments.[10]

Figure 3-2: The Changing Plans on Nuclear Power Capacity in the ROK



Source: Yun, Sun-Jin, Energy Transition and Democracy in Korea, Seoul National Univ., 2018[11]

3.3 Curtailing Reliance on Coal-fired Power Generation

The ROK has 60 operating coal-fired power plants with a total capacity of 35 GW, supplying 43% of the country's electricity as of 2017. Since the mid-1980s, coal-fired power has played a significant role as a pillar of the country's electricity sources along with nuclear power, and since

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[10] YUN, Sun-Jin, and JUNG, Yeon-Mi, "Energy Policy at a Crossroads in the Republic of Korea", Friedrich Ebert Stifung, dated Nov.2017, and available as https://library.fes.de/pdf-files/bueros/seoul/14488.pdf.

[11] Presentation available as https://www.isep.or.jp/wp/wp-content/uploads/2019/01/Yun.pdf.

the mid-2000s the share of coal-fired generation has remained the highest of the types of generation, surpassing nuclear power generation. This has contributed to the ROK becoming the world's fourth-largest coal importer. 61% of the coal used in the ROK is consumed in the power sector, with the other 39% used in the industrial sector. The previous government to the Moon Administration had also planned to add 20 new coal-fired power plants with a total capacity of 18 GW, including some plants that are currently under construction, and due to be completed by 2022. These plants were included in "the 7th basic plan for long-term electricity" established in 2014.

But upon taking office in 2017, President Moon Jae-in announced that his government would phase out coal-fired plants to protect the public health from a growing threat of fine dust pollution. At that time, hazardous levels of fine dust pollution, particularly PM2.5 which is small enough to bypass humans' nose and throat and be absorbed by the lungs and enter the bloodstream, became not only a significant social issue but also a major political challenge. Although almost all candidates in the presidential campaign promised to prepare strong measures for reducing the fine dust pollution, the coal phase-out policy of the Moon administration is regarded as too radical from the points of view of many energy experts and politicians.

The new government policy on coal-fired power plants was concretely revealed in "the 8th basic plan for long-term electricity" established at the end of 2017. In the plan, 10 aging coal-fired plants (totaling 3.3 GW) were to be closed before the end of their rated lifetimes between 2017 and 2022. A total of 4 currently operating coal-fired plants (2.2 GW) and 2 coal-fired plants (1.16 GW) under construction are to be converted to LNG power plants by 2025. Although a number of plants are to be shut down or replaced with LNG plants, the total capacity of coal-fired power in the 8th plan will increase from 36.9 GW in 2017 to 39.9 GW in 2030 due to the addition of newly constructed coal-fired plants. The capacity of coal-fired power in 2030 included in the 8th plan was reduced by comparison with the 43.3 GW of coal-fired power capacity to be operating by 2030 under the previous plan established in 2014, but even so, the volume of coal demand in the power sector will continuously increase through 2030. This means although the government has pledged to significantly reduce fine dust emission, more measures are required to do. In response to this policy need, state-owned power companies are planning not to extend the life spans of coal-fired plants that are close to their rated life, and instead convert them into LNG-fueled power plants. When considering the plans of those power companies, at present, besides 6 coal-fired plants that were already slated to be converted to use LNG, 14 or more additional coal-fired plants may possibly be converted to use LNG, and this change would be reflected in the 9th basic plan for long-term electricity that will be established in 2020.

In an additional measure to reduce fine dust emissions, the government enacted a rule to limit the operation of coal-fired plants to 80% of their full capacity when the concentration of PM2.5 particles exceeds a concentration of 56 ug/m^3 in nearby areas. Also, the government planned to temporarily halt the operation of older (over 30 years) coal-fired plants during the spring. As another effort to restrict coal use in the generation of power, an act of "environmental power dispatch" was passed in the parliament and introduced as an electricity business law.

Environmental power dispatch is a trading rule that stipulates that impacts on the environment (including emissions of fine dust, greenhouse gases, and other pollutants), as well as the economy, must be reflected at the time that the dispatch order for power plants is decided in the electricity exchange market. The enforcement ordinance of this act is expected to come into force after a detailed design process to incorporate the external costs of environmental emissions into electricity trading rules that will include hearing the opinions of many expert on how the trading rules should be modified.

The tax regime for fossil fuels was also adjusted to have higher taxes on coal in order to provide incentives for industries and power producers to reduce coal consumption. Before the tax adjustment was carried out, the tax on LNG was four times the tax on coal on a per-unit-energy basis. To increase the use and share of LNG, it was necessary to change the energy tax systems to include environmental costs in electricity bills. The tax benefit is applicable only to LNG used in electricity generation, not LNG/natural gas used in the household sector or in other industries. Though the gap in tax rates between coal and LNG for power generation was reduced, generation costs for coal-fired plants is still estimated to be lower than that for thermal power plants fueled with LNG, thus even though the tax revision narrowed the fuel cost gap between the two fossil fuels, the revision has not yet been sufficient to give LNG a cost advantage over coal as a fuel for producing electricity. Table 3-2 shows major recent policy measures related to coal-fired power in the ROK.

Table 3-2: Major Measures Related to Coal-Fired Power in the Energy Transition Policy

By Plans	Measures	Contents
The 8th basic plan for long-term electricity	Early Decommissioning	10 older coal-fired plants will be shut down early by 2022 (Total capacity: 3.3 GW)
	Converting to LNG power	4 operating older coal-fired plants and 2 plants under construction will be converted to LNG-fired power (Total capacity: 3.36 GW)
Plans of state-owned generating companies	Converting to LNG power	The state-owned generating companies plan to convert about 14 coal-fired plants to LNG use.
Other measures	Restricted operation of coal-fired plants	Coal-fired plants are restricted to 80% of their capacity when the ambient concentration of $PM_{2.5}$ particles surpasses $56 ug/m^3$.
		Operation of older (over 30 years) coal-fired plants will temporarily cease in the spring.
	Enacting environmental power dispatch	The government introduced into the electricity trading rule the requirement that environmental costs as well as the economy are reflected at the time the dispatch order of power is decided in the electricity exchange market.
	Fuel tax adjustments	The tax on coal use for power generation was raised from 36 won/kg to 46 won/kg while the tax on LNG was cut from 91.4 won/kg to 23 won/kg.

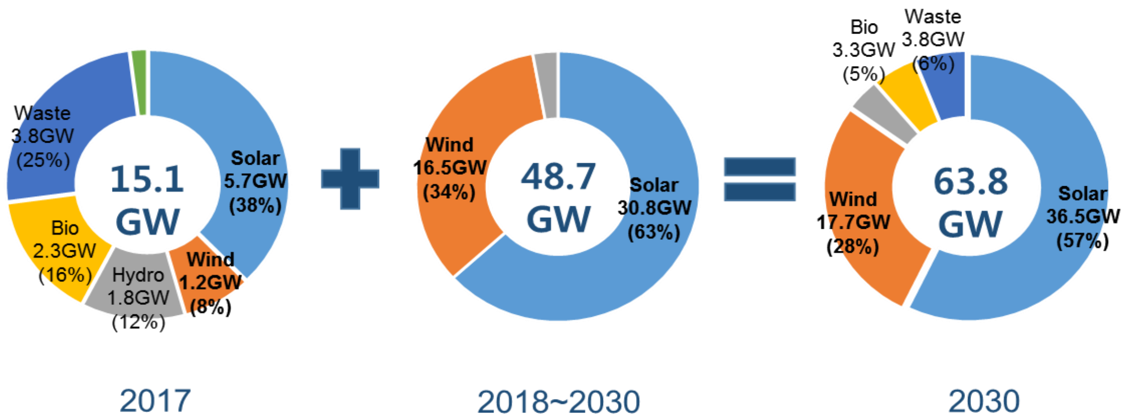
Source: The, 8th Basic plan for long-term electricity 2017, and other various sources including news medias

3.4 STRENGTHENING THE ROLE OF RENEWABLE ENERGY

The ROK, which imports almost all of its energy from overseas and simultaneously aspires to be a global leader in the fight against climate change, has long put an emphasis on increasing its supply of renewable energy as a key measure to address the country's energy challenge. In particularly, President Lee's administration, which held power from 2008 to 2012, strongly drove policies to increase renewable energy development and use, pursuing " low carbon, green growth" as the national agenda. In "the first energy master plan", carried out in 2008 during the early months of the Lee administration, the target share of renewable energy in primary energy was set at 10.7% in 2030. The target share seemed aggressive when compared with renewable energy's share of 2.2% in 2008, and at that time a lot of energy experts were skeptical about whether the ROK could meet the renewables target. In retrospect, renewable energy policies have made slower-than-expected progress since then. Renewable energy accounted for 5.2% of the primary energy and 5% of total power generation as of 2017, and most renewable electricity has been produced from waste (60%) and bioenergy (22%). The shares of solar photovoltaic (PV) and wind power in 2017 were just 9.6% and 2.9%, respectively, of the total renewable energy used.

The Moon government has proclaimed that the policies of nuclear-free and shifting away from coal should be accompanied by accelerated development of renewable energy in order to supplement the contraction of nuclear and coal-fired generation. To sharply increase renewable energy is also a core area in the energy transition policy that the current government is pursuing. In line with this policy, in December 2017, the government established "the Renewable Energy 3020 Plan" that aims to increase renewable energy's share of power generation to 20% by 2030. This compares favorably with the 11.7% target share of renewable energy by 2029 that was included in the previous basic plan for long term electricity, which was published in 2014. To reach the 20% target, the generation capacity of renewable energy must increase from 15.1 GW in 2017 to 63.8 GW in 2030. In addition to increase, the target capacity of 63.8 GW has to be attained not mainly from growth of the use of the waste and bioenergy plants currently dominating the supply of renewable energy in the ROK, but from growth in solar PV and wind power, which account for just a small fraction of generation capacity at present. Following the 3020 plan, solar PV and wind power are to account for 57% and 28%, respectively, of the renewable energy by 2030, and this means that the capacity of solar PV should increase 7- fold from 5.7 GW in 2017 to 36.5 GW in 2030, and wind power capacity should increase 15-fold from 1.2 GW to 17.7 GW during the same period, as shown in Figure 3-3.

Figure 3-3: Renewable Capacity Targets in the 3020 Plan



Source: "Renewable Energy 3020", Ministry of Trade, Industry and Energy, 12, 2017

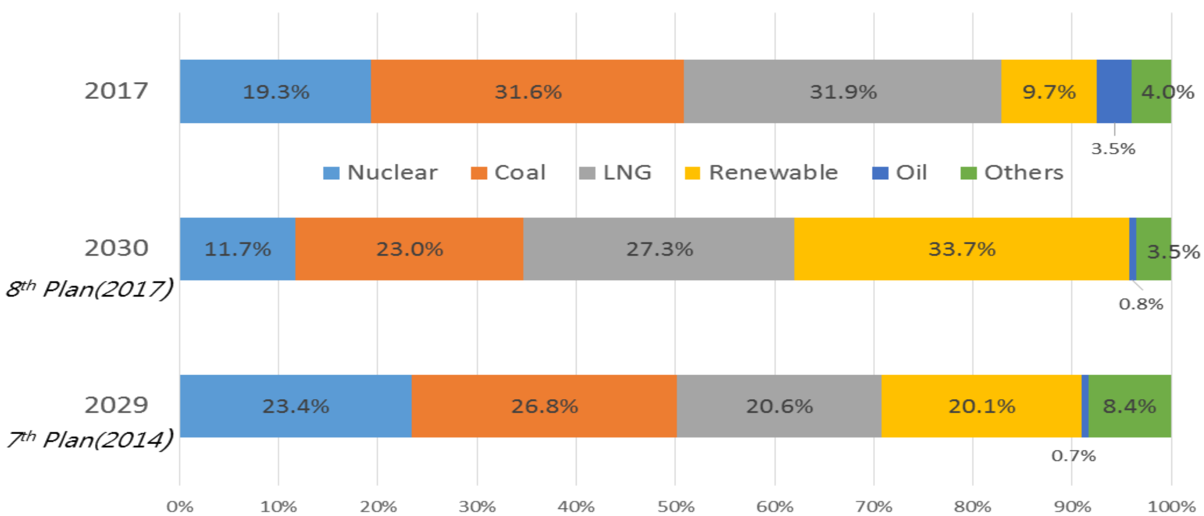
To reach this target capacity for solar and wind generation, many facilitating measures are to be implemented based on the 3020 plan. First, the government is to promote invest in private solar power facilities in urban areas by citizens and corporations, as well as in the development of solar power generation in rural areas, by providing with various investment incentives. One of the incentives is to introduce a FIT (Feed-in Tariff) program for small-scale businesses (demand less than 100 kW) for a certain period of time (less than five years). A second measures is to allow local governments to select and secure lands suitable for renewable energy power generation of the direct participation of local residents. The profits of businesses developing renewable generation facilities in local areas must be shared with both developers and local governments. A third measure is to allow private and public companies to promote and invest in large-scale renewable energy projects by helping those companies to secure access to large sites such as the land around nuclear power plants and decommissioned coal-fired power, areas for siting ocean solar PV (such as protected bays), and sites for ocean wind farms. To accelerate large scale investment, the government is raising the generation company's RPS (Renewable Portfolio Standard) requirements (fraction of generation that must come from renewable sources) so that the power companies are required to either increase their own renewable power generation or to purchase additional electricity produced from the renewable generation by other companies. In addition to these measures, the government has unveiled various plans to help in reaching its renewable generation target, including public support for and investments in renewables, easing permit regulations, and strengthening R&D for renewable generation technologies. Despite these efforts by the government, there remain many obstacles to developing renewable energy in the ROK, including the lack of sites, residents’ opposition to new facilities, and local authorities who are reluctant to permit renewable businesses.

3.5 ENERGY TRANSITION POLICIES IN CONFLICT

The new energy transition policy directs that the shares of nuclear and coal-fired capacity are to be reduced while that of renewable energy is to be substantially increased by 2030, based on the requirements of the “8th Basic Plan for Long-term Electricity" established at the end of 2017. The share of LNG power in total generation is to fall slightly at the same time, but its capacity will increase from 37.4 GW to 47.5 GW. In terms of its share of available capacity, LNG generation is set to increase from 34.7% in 2017 to 38.6% in 2030 because the 58.6 GW installed capacity of the renewable energy in 2030 falls into just 8.8 GW when counting it in terms of effective capacity—because the sun doesn’t always shine and the wind doesn’t always blow. The 8th Basic Plan shows a significantly different electricity mix from the one that appeared in "the 7th Basic Plan for the Long-term Electricity [Market]" set up under the previous government in 2014.

As shown in Figure 3-4, the most prominent difference between the 2014 and 2017 plans appear in the shares of nuclear and renewable energy. The share of nuclear power is scheduled to fall from 19.3% in 2017 to 11.7% in 2030 in the 8th Plan, but it had been slated to rise to 23.4% in 2029 in the 7th Plan. On the other hand, the share of the renewable energy's power generation capacity will surge from 9.7% in 2017 to 33.7% in 2030 based on the 8th Plan, but the 7th Plan showed it rising only slightly to 20.1% in 2029. In the 7th Plan, the capacities of nuclear and coal-fired power rose from 20.7 GW and 25.1 GW in 2014, respectively to 38.3 GW and 43.3 GW in 2029. On the other hand, in the 8th Plan, the capacity of nuclear power plants falls from 22.5 GW in 2017 to 20.4 GW in 2030, and the capacity of coal-fired power plants will increase from 36.9 GW in 2017 to 42.0 GW in 2022 before falling to 39.9 GW in 2030.

Figure 3-4: Generation Mix Outlooks under the 2014 and 2017 Basic Plan



Source: "The 7th, 8th Basic Plans for Long term Electricity”, Ministry of Trade, Industry and Energy, 2014, 2017

The current government's energy transition policy is facing strong resistance from many opinion groups including the political opposition parties, conservative news media, and many energy experts. These groups argue that, although the energy transition is the right direction for the ROK to pursue as a future energy scheme, the government has been (and/or plans to be) too hasty in implementing the transition policies, and this haste could bring about many negative effects for the ROK. The first of the negative effects that critics of the plan warn about is an energy price rise. The critics insist that electricity rates will inevitably climb if coal and nuclear energy are replaced by the more expensive LNG-fueled generation and renewable energy. The increase in electricity bills caused by the energy transition policies have been estimated to vary across a range of about 20%~300% depending on the analytical assumptions used to estimate the impact. Actually, the state-owned electricity retailer KEPCO has suffered large-scale operating losses since 2017. The government announced that these losses were due to rising prices of fossil fuels, but opponents of the administration energy policies claimed that the loss has occurred due to the lower operation rates of nuclear power plants. The nuclear power plants' operating rates have been lowered from 80~90% to 55~75% as the government has strengthened safety standards in the nuclear power plants since 2017. The lowered operating rates of coal-fired plants, a measure to reduce fine dust emissions, were also indicated as a cause of the expansion of KEPCO losses. Critics of the policy also suggest that if LNG prices rise with crude oil prices (LNG prices and crude oil prices are often linked in spot markets and in long-term contracts), once many nuclear reactors and coal-fired plants have been decommissioned, electricity rates and bills will sharply rise, potentially putting a significant burden on many ROK electricity consumers. The generation costs for renewable electricity were assumed to fall by 35.7% by 2030 in the analysis that was used to produce the 8th Plan, but Plan opponents have been skeptical of this cost reduction and insist that the more renewable energy generation is used in the ROK electricity system, the more investment in transmission lines and various backup facilities will be required, which will in turn push up the generation costs of renewable energy and consequently raise electricity rates.

The ROK's land area is small and is 70 % mountainous. Renewable energy facilities usually require large spaces. In addition, the mountainous terrain makes it difficult to connect new renewable facilities to the grid even if renewable energy sites can be secured. Residents' resistance to the siting of renewable energy facilities in their local areas (NIMBY, or "not in my backyard") also poses significant obstacles to the expansion of renewable energy power systems. Local governments have the authority to permit the construction of renewable energy facilities, but they are usually reluctant to provide licenses for the construction of those facilities due to resistance and complaints by residents. In the ROK, it has been said that the most difficult thing for the renewable energy businesses is securing permission to construct the facilities from the local government because the local governors are elected by the local residents. Accordingly, opponents are skeptical of securing sufficient sites to supply the amounts of electricity expected to come from renewable energy generation under the 8th Plan. Plan opponents warn that the inability to secure sites could bring about disaster in electricity supply if increasing the reliance on renewable energy power generation becomes too difficult while nuclear and coal-fired power are together reduced.

The third negative effect that opponents of the 8th Plan are concerned about is that the energy transition policy could worsen the GHG emission problem. The expansion of nuclear power has long been the major policy forwarded to mitigate GHG emissions in the ROK. Like nuclear power, renewable energy also does not emit GHGs. But, even as renewable energy use increases, the accelerated decommissioning policy for nuclear reactors under the 8th Plan could increase the total amount of GHG emissions in the country, due to the lower capacity factors of renewable generators. There are arguments that much of the reduced amount of nuclear electricity output under the phase-out policy could be replaced by LNG- or even coal-fired power generation, rather than renewable energy generation. In its "Emissions GAP Report 2019" published in November 2019, UNEP also projected that the ROK's contemplated emissions reduction from the power sector would be reduced from 64.5 $MtCO_2e$ per year to 23.7 $MtCO_2e$ per year, with the reduced mitigation mainly attributable to the current government's nuclear policy. In addition to this, the agency put the ROK together with Brazil, Canada, and the United States of America on the country group that is projected to have emissions 15% or more above its NDC (Nationally Determined Contribution) target. In the UNEP report, the group to which the ROK belongs was classified as the worst in terms of UNEP's assessment of progress toward NDC targets[12].

The ROK government and environmentalists set forth a strong counterargument against the assertions by the opponents of the energy transition policy. In particular, they emphasize the safety issues associated with having so many nuclear plants densely packed into the ROK's small land area. According to the analysis of the government and its allies, there are 11 locations with more than 6 reactors among the 187 locations where nuclear reactors operate in the world. In the ROK, however, all its nuclear plants locations have more than 6 reactors, which means the risks related to nuclear are more intense and more concentrated in the ROK. Furthermore, most of the ROK's sites for nuclear plants are located close to each other. Professor Yun of the Seoul National University published a paper pointing out that the nuclear density of the ROK is 224.2 kW per km^2, making the ROK the world's most nuclear dense area. This is more than twice the nuclear densities of France (98.1 kW/km^2) and Japan (103 kW/km^2), both of which have nuclear generation capacity more than twice that of the ROK. Environmentalists also have different views from the Plan opponents' assertion that the energy transition policy could raise electricity bills and exacerbate GHG emissions problems, with the environmentalists' views mostly based on an anticipation of fast progress in the evolution of (and cost reductions in) renewable technologies.

The government's policies on energy transition and nuclear phase-out have been escalating into a keen political issue in the ROK. It is therefore not certain that the current energy transition policy, including the proposed gradual reduction of nuclear capacity, will in fact be realized in the coming decades, particularly if the Conservative Party (the current opposition party) takes

[12] UN environment program, "Emissions Gap Report 2019, November 11, 2019

power after the next presidential election. It is not also completely guaranteed that the gradual phase-out policy can be fully implemented even if the Progress Party (the current ruling party) continues to hold power due to the growing resistance of the public opinion to the nuclear-free policy. So, at present, the ROK's energy policy stands at a crossroads.

4 ROK Involvement in Discussions on Regional Power Sharing

The issue of electricity grid connections among the Northeast Asian countries emerged not long after Russia and China opened their economies to the Western countries. In 1998, Energy System Institute (ESI) located in Irkutsk, in East Siberia, proposed the Northeast Asian Super Grid scheme to connect long-distance transmission lines from the Russian Far East including Sakhalin to China, Mongolia, the two Koreas and Japan. This proposal prompted the discussion of many other ideas related to grid interconnections not only focusing on super grid connections in the Northeast Asia region but also grid connections between countries within the region. After the Fukushima nuclear accident in 2011, Japan's Softbank CEO, Son Masayoshi proposed an Asian Super Grid scheme that would produce electricity in the Gobi desert of Mongolia using renewable energy such as solar photovoltaic and wind power and transmit it to the countries in Northeast Asia and Southeast Asia.[13] Some research agencies including IRENA (the International Renewable Energy Agency) have estimated that the Gobi desert has a huge renewable energy potential, enough to produce more electricity than the total volume consumed in the Northeast Asian countries, including Russia.

The ROK has long been interested in the idea of electricity imports from neighboring countries, especially the East Russia regions, because the ROK is obliged to pay high costs for building power plant capacity exceeding its electricity demand in order to prepare for potential supply shortages (that is, to provide an adequate generation “reserve margin”). If the ROK can import a substantial volume of electricity from Northeast Asian countries, the current administration’s policy of nuclear phase-out would be more supportable in the eye of the public because with available imports the ROK can use imported power when domestic electricity supply is unstable. Before 2014, discussions on importing electricity from the Northeast Asian countries had taken place mostly among researchers and scholars, rather than between governments or in government-affiliated agencies. Since 2015, however, the public transmission companies of the ROK (KEPCO), China (SSGC) and Russia (ROSSTI) have begun to discuss both bilateral and multi-nation grid connection concepts. Softbank in Japan has been included in the dialogues with those public transmission companies, although it is not an electricity company

[13] Gaye Christoffersen (2018), "The Asian Super Grid in Northeast Asia and China's Belt and Road Initiative", SWP Working Paper, Oct. 2018.

In 2015, KEPCO carried out joint research on grid connections between the ROK and Russia with ROSSTI. In 2016, KEPCO established a formal task force for Northeast Asian grid connections and carried out a pre-feasibility study on grid connections linking the ROK, China, and Japan under an MOU (Memorandum of Understanding) with SSGC, ROSSTI and Softbank. At the ROK-China Business Forum, which was held on 13 December 2017, China's Global Energy Interconnection Development and Cooperation Organization (GEIDCO) signed a cooperation agreement with SGCC and KEPCO. This agreement aims at carrying out a joint study on the technical feasibility, benefits, and costs of the grid connections between China and the ROK.

According to KEPCO's feasibility study report on grid connections to the ROK's neighboring countries, China, Russia, and Japan, as submitted to the ROK parliament as of December 2018, the total costs to build power grid lines to the three counties is estimated to be over 7 trillion won (US$ 6.2 billions). In the case of a grid connection to China, KEPCO reviewed a proposal to link a transmission line from the western port of Incheon in the ROK via undersea power cables to the eastern port of Weihai, China. Such a line would cover some 370 km and have an associated construction cost of 2.9 trillion won. KEPCO is negotiating to connect that grid line with the transmission network operated by the SSGC. It is also estimated that an investment of 2.4 trillion won would be needed to link Vladivostok in the Russian Far East, via the DPRK, to the northern part of Gyeonggi province in the ROK using an overland transmission line, which would cover approximately 1,000 km. To connect grids with Japan, the report proposed linking Goseong in South Gyeongsang Province with either Kitakyushu or Matsue, both on the northern coasts of the southern part of the Japanese archipelago. This connection via undersea cables is expected to cost around 1.9 trillion to 3.3 trillion won to build.

The ROK government expressed its expected dates for the initiation of electricity trade with neighboring countries in "the 8th Basic Plan for long-term electricity supply and demand" established in 2017. The ROK expects to start importing electricity in 2025 through a 2.4 GW grid line from Weihei, China to Incheon, ROK, but the date when the line will be operational will depend on the outcomes of negotiations between the two countries. The country also hopes to start operation of a 3 GW grid line from Russia to the ROK via the DPRK in 2027, though the timing of this project could change dramatically depending on the political and military situation between the two Koreas. The ROK also hopes that it can import electricity from Mongolia and export electricity to Japan (including power flowing through the ROK from Mongolia) by 2027. Figure 4-1 shows interconnection grid schemes involving the ROK as conceptualized by KEPCO.

Figure 4-1: KEPCO's Grid Scheme in Northeast Asia

Source: the 8th Basic Plan for Long-term Electricity Supply and Demand

5 THE IMPACTS OF COVID-19 ON THE ROK'S ENERGY SYSTEM

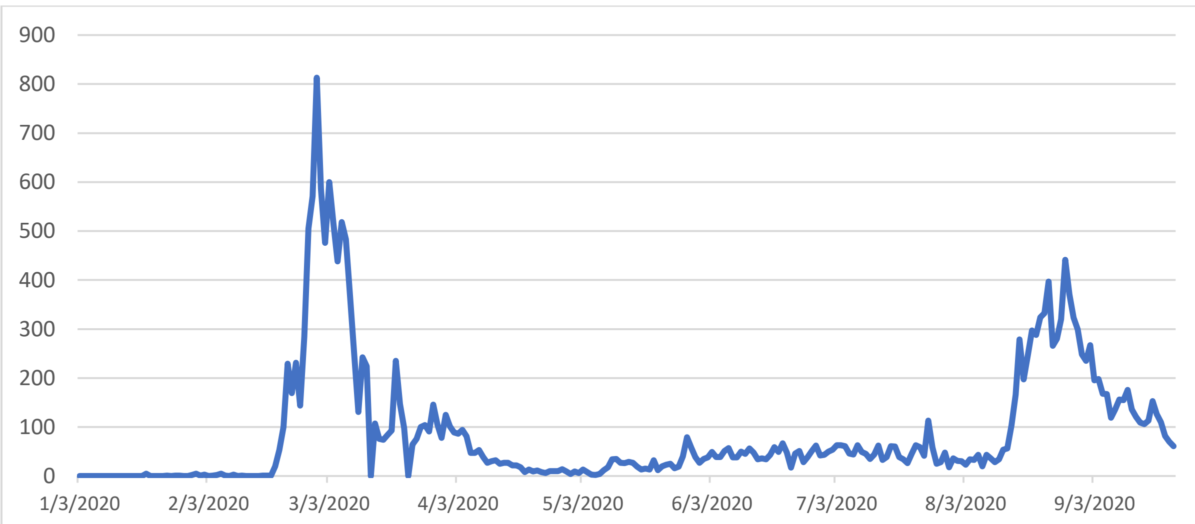
5.1 THE COVID-19 SITUATION AND SOCIAL DISTANCING RULES

1. Outbreak Timeline

The ROK was one of the first countries outside of China to experience a COVID-19 infection, with the first case identified as a Chinese woman who came from Wuhan, and reported on January 20, 2020. The first Korean national to be infected was reported three days later, a person who worked in Wuhan and returned to the ROK with flu symptoms. The government established an emergency response committee within days of the first cases becoming known and controlled the spread of the virus relatively well for the first month of the outbreak. The number of confirmed cases ranged from zero to two per day and the cases were mainly found in Seoul and its neighboring area until a cluster of infections was identified in Daegu, a city of 2.5 million, located in south-eastern Korea about 200 km from Seoul. The cluster, which first appeared as 20 cases on February 19, was tied to religious events held at the Shincheonji Church of Jesus, at which multi-day events that involved more than 10 thousand church members were held. One of the members who had symptoms and later was confirmed to have the virus (dubbed patient No. 31) had participated in the events after her diagnosis. The gatherings triggered a drastic escalation of the spread of COVID-19 throughout the country because the religious events were typically held with people in a very close proximity and included physical contact of the members of the gathering in an indoor space. Just three days after the cluster was identified, the number of new confirmed cases jumped to 229 and thereafter daily confirmed cases rose rapidly and reached a peak of 813 on February 29, which made the ROK the second most infected country in the world after China by early March.

The government designated Daegu City as "a Special Management Zone" and the Prime Minister took direct control of measures to restrict the spread of infection in the city. Residents were advised to stay home and minimize movement outdoors for weeks. But the city was not locked down and almost all stores remained open. Figure 5-1 shows the timeline of COVID-19 outbreaks in the ROK through September 2020.

Figure 5-1: Timeline of the Outbreak of COVID-19 in the ROK



Source: World Health Organization

Thanks to the efforts of central and local governments and resident's cooperation, the number of daily confirmed cases steadily declined to nearly below 100 one month after the peak. Thereafter, daily new cases were kept near 50 until August 15, although there was a minor resurgence in mid-May when the government relaxed social distancing rules and new clusters tied with attendance at nightclubs emerged.

A large-scale anti-government protest led by far-right groups took place illegally on August 15, 2020. This movement, during which the protesters included many people wearing no masks, gathered in downtown Seoul, and triggered again an escalation of the spread COVID-19 in the ROK. The infection spread rapidly nationwide because at that time, the protesters came from many local places as well as from the Seoul area, and brought the virus back to their home communities when the protest ended. This created a situation in which it was more difficult to prevent a spreading of COVID-19 than it was to manage the first cluster that occurred in Daegu on February 19. The number of new daily confirmed cases jumped again to about 200 on August 20 and continued to rise to a peak of 441 on August 27. The government strengthened social distancing rules to the level 2.5 in which 12 types of crowded businesses, including coffeehouses like Starbucks, health clubs, and private cram schools, were ordered to be shut down, and one-third of all employees in the government, state-run agencies and public institutions were required to work from home. By application of strong policies to restrict the spread of the virus, the number of new COVID-19 cases fell to about 100 by one month later. The social distancing rule at level 2.5 was implemented for two weeks and then eased to level 2.0. As of September 20, the number of cumulative cases of COVID-19 was 22,975 and the cumulative number of deaths was 383 in the ROK. The number of daily new cases was about 60~120 between September 20 and 25. The level 2 of distancing rule is still being implemented as of this writing, a rule under which indoor gathering of more than 50 people are banned along with outdoor gathering of more than 100 people.

2. Social distancing rules

As the first cluster of COVID-19 occurred in Daegu, the government began to implement strong social distancing campaigns to contain the spreading of the disease. Facilities were required to conduct temperature checks for fever at entry points and in offices, public and multi-purpose facilities were temporarily shut down, and schools and universities were closed, with only on-line classes permitted. Visa waivers were suspended and all of the people entering the ROK were required to comply with a 14-day quarantine protocol. The ROK adopted a three-level policy of social distancing rules triggered by thresholds in the number of daily confirmed COVID-19 cases nationally (level-1: less than 50 cases, level-2: 50-100 cases, and level-3: exceeding 100 daily cases for 14 straight days). Under level-1, ordinary economic, social activities are allowed to proceed but mandatory mask-wearing and electronic visitor logs are required for high-risk businesses. Under level 2, the 11 categories of high-risk facilities would be required to suspend all operations, including bars, karaoke rooms, and large after-school academies. Moderate-risk facilities such as religious establishments, movie theaters, wedding halls, and public baths are required to adhere to disease prevention rules. Under Level 3, all schools and kindergartens are required to implement online classes or shut down completely. All gatherings of 10 or more people would be prohibited apart from attendance of family funerals or essential public and business activities.

While the government introduced enhanced physical distancing so as to prevent diffusion of the virus, the ROK did not introduce a full lockdown on any city or region. The authorities recommended the temporary suspension of the operation of religious meetings, as well as indoors sports and entertainment facilities, and also urged citizens to stay at home and work remotely.

5.2 IMPACTS OF COVID-19 ON THE ROK ECONOMY

Covid-19 triggered a deep recession in the ROK, just as it has in many other countries worldwide. According to recent statistics from the Korea Development Institute (KDI) ,[14] GDP fell 1.3%, and 3.2% respectively in the first and second quarters of 2020 (measured quarter on quarter). Exports dropped 1.4% and 16.6%, and imports declined 3.6% and 6.7% in the first and second quarters (q-o-q). On the production sides, the situation has worsened in the second quarter of 2020. Output in the agriculture, forestry, and fisheries sector dropped 9.5 percent compared to the previous quarter, and manufacturing fell 8.9 percent due to weak production (and purchases) of transportation equipment, computers, electronic products, and optical products. Construction contracted 0.3 percent as building construction declined. Services fell 0.9 percent as wholesale and retail and hotels and restaurants activity declined, with additional declines in transportation, entertainment and leisure services, and other services.

Private consumption fell 6.5% in the first quarter but rose 1.5% in the second quarter due to large scale government distribution of coronavirus relief funds to all Korean people during April, 2020. The number of people employed also declined 1.5% and 1.3% in the first and second quarters of 2020, respectively. Table 5-1 compares selected quarterly ROK economic statistics for 2018, 2019, and the first two quarters of 2020.

The ROK economy has been sharply shrunk by the COVID-19 pandemic, but the country was able to avoid the extensive lockdowns endured by many other countries. This has limited the damage to the domestic economy and output has contracted less in the ROK than in other OECD countries. But as the ROK economy is heavily dependent on global business, both exports and imports, it could be damaged more than the economies of other countries if the worldwide recession caused by the pandemic persists for a long time.

[14] Korea Development Institute (KDI, 2020), "Economic News Briefing", ROK Economic Bulletin, vol 4 No.9, 2020.9.

Table 5-1: Percent Change of Major Economic Indicators in the ROK (units: %)

	2018					2019					2020	
	Year	Q1	Q2	Q3	Q4	year	Q1	Q2	Q3	Q4	Q1	Q2
GDP	2.9	1.1	0.6	0.6	0.9	2.0	-0.3	1.0	0.4	1.3	-1.3	-3.2
Agriculture, forestry & fisheries	0.2	1.4	-2.1	-3.4	2.8	0.3	5.8	-5.5	2.9	-1.5	3.7	-9.5
Manufacturing	3.3	1.0	1.4	1.9	1.1	1.3	-2.9	1.0	1.8	1.8	-1.0	-8.9
Construction	-2.8	1.4	-2.0	-4.3	0.1	-2.5	-1.2	3.1	-3.7	3.7	0.2	-0.3
Service	3.8	1.6	0.5	0.7	0.8	2.9	0.6	0.8	0.5	1.3	-2.4	-0.9
Private consumption	3.2	1.3	0.3	0.5	0.5	1.7	1.7	0.7	0.4	0.7	-6.5	1.5
Exports	4.0	3.7	1.0	4.2	-1.6	1.7	-3.1	1.9	4.5	0.6	-1.4	-16.6
Imports	1.7	5.4	-2.2	-0.8	1.0	-0.6	-3.2	2.9	1.2	0.4	-3.6	-6.7
Employed Persons	0.4					1.0			1.4	1.6	1.1	-1.5

Note: percent changes are from the previous period

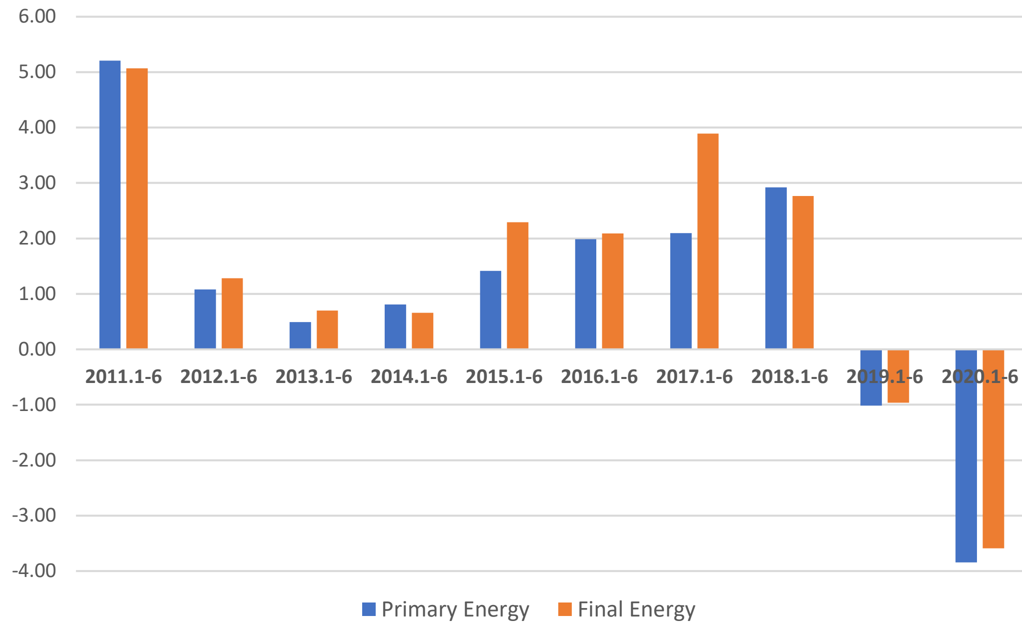
Source: Korea Development Institute, 2020.9

5.3 COVID-19 IMPACTS ON ENERGY SYSTEMS IN THE ROK

1. Changes in Energy Consumption Due to the Pandemic

As the economy was hit hard by COVID-19, the ROK energy market also contracted significantly. Primary energy consumption in the first half of 2020 fell by 3.8% compared to the same period of 2019. Final energy consumption showed the same trend, falling by 3.6% relative to 2019. The decline of energy consumption in the ROK experienced in 2020 was the first for the country, except for a slight decline in 2019, since the financial crisis in 1998 (see Figure 5-2). In 2019, though the ROK economy grew by 2%, energy consumption slightly decreased due to recession in the heavy energy consumption industries such as the petrochemical and steel sectors. Most other industries expanded their energy use in 2019, but all of the ROK's industrial subsectors showed a reduction in their energy consumption in the first half of 2020 due to COVID-19 and the measures applied to contain the pandemic.

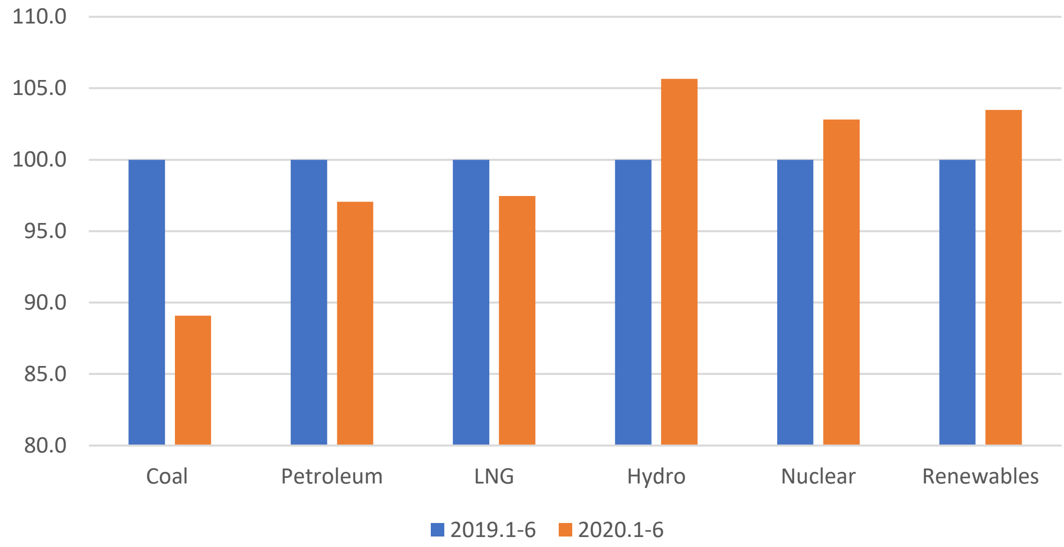
Figure 5-2: Change Rates of Energy Consumption in the ROK Compared to Previous Years (%)



Source: *Monthly Energy Statistics*, Korea Energy Economics Institute (KEEI), September, 2019

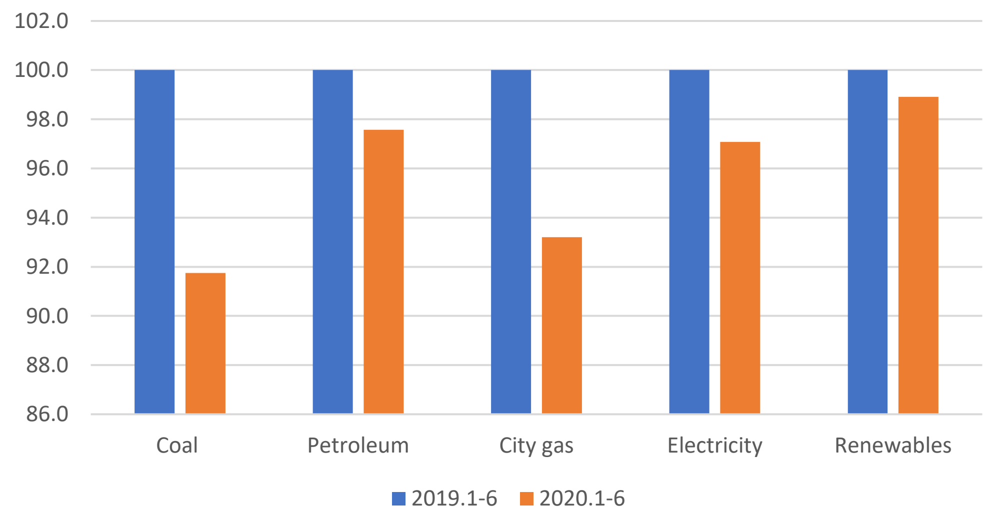
Among energy forms, the ROK's consumption of fossil energy decreased in 2020, but on the other hand the use of hydro, nuclear, and renewable energy increased. Among the fossil fuels, the rate of decline of coal use was the steepest (about 12%), and those of oil and LNG were less, with both falling 3-4 percent in the first half of 2020 relative to the same period in 2019 (see Figure 5-3). Though the consumption of renewable energy increased in the first half of 2020, the growth rate (3.5%) was quite low compared to growth in previous years. The annual average growth rate of renewable energy use between 2010 and 2019 was 13.08% in the ROK. Despite the restriction policies, the consumption of nuclear energy increased because the average capacity factors of nuclear plants in the previous two years were poor as a result of frequent problems at the facilities. Hydro energy accounts for less than 1% of total ROK electricity supplies, and its availability and use depend on the weather in the ROK.

Figure 5-3: Comparison of Primary Energy Consumption by Source (2019=100)



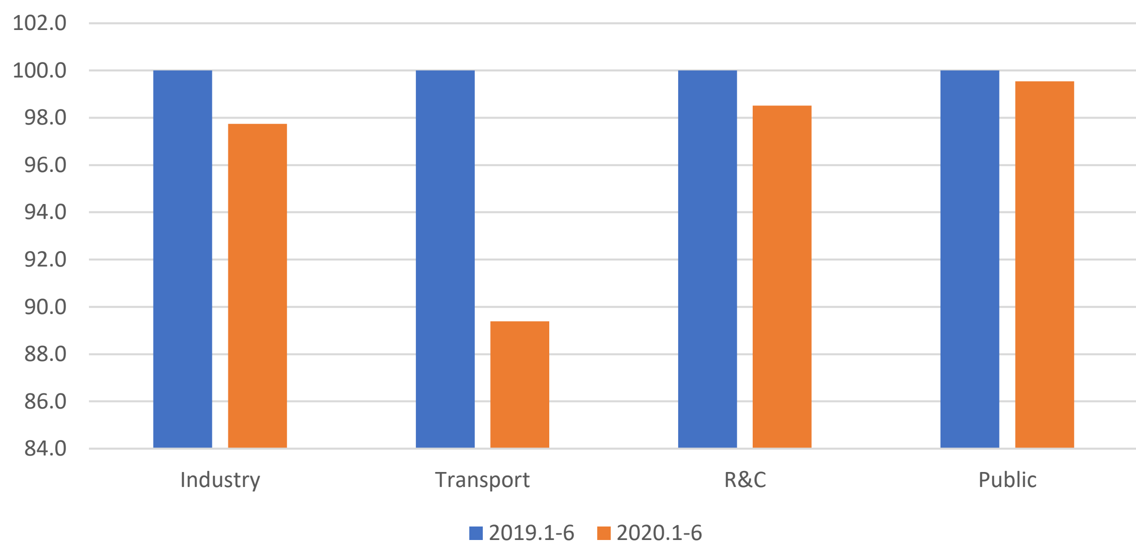
Total ROK final energy consumption declined in the first half of 2020, as did consumption of each type of fuel. Among the fuels, the decrease in the rate of coal consumption was the highest, due to the decline in industrial output, followed by the decline in the use of city gas. Coal as a secondary energy source is usually used only in the industrial sector. The consumption of city gas fell significantly due to in part to sluggish business in the restaurants sector. Although the use of renewable energy sources in primary energy increased in 2020, the consumption of the renewable fuels in final energy demand sectors decreased, though its rate of decrease rate was the lowest among the different energy sources (see Figure 5-4).

Figure 5-4: Comparison of Final Energy Consumption by Source (2019=100)



Energy consumption in all of the demand sectors decreased during the first half of 2020. Among them, the rate of decline for the transport sector was the largest (-10.6%), showing wide gaps relative to declines in other sectors. Energy consumption in the residential & commercial (R&C) and public sectors showed a relatively small declines when comparing with the industry and transport sectors (Figure 5-5).

Figure 5-5: Comparison of Final Energy Consumption by Sector (2019=100)



Although energy consumption declined in nearly all ROK economic sectors in the first half of 2020, electricity use in the residential sector sharply increased by 5.1% for the first half of this year because many people stayed home in order to avoid the pandemic. On the other hand, electricity consumption in the commercial sector decreased by 2.1% in the same period. In the case of city gas, consumption in the commercial sector significantly decreased (by 13.3%) because people reduced their use of restaurants and coffee houses in order to comply with social distancing rules. The consumption of city gas in the residential sector also slightly decreased in the first half of this year when compared with the same period, last year, but has increased by 4% between March and June of 2020, even though the March-to-June period normally sees a decline in energy demand for heating. The increase in city gas use from March to June in the second quarter of 2020 reflects the increased use of city gas for cooking in 2020 due to peoples' increased time at home relative to 2019. In the industry sector, the consumption of petroleum increased by 2.4% in the first half of 2020, despite the decrease in all other forms of energy consumption in the sector. It seems that the petrochemical business, which accounts for 95% of industrial oil demand in the ROK, increased its production to take advantage of low international oil prices. Table 5-2 shows monthly consumption of city gas and electricity in the residential sector for the first half of 2019 and 2020.

Table 5-2: Monthly Consumption of City Gas and Electricity in the Residential Sector

(units: thousand toe)

	City Gas			Electricity		
	2019	2020	Change (%)	2019	2020	Change (%)
Jan	1997	1851	-7.87	537	538	0.22
Feb	1738	1680	-3.50	528	540	2.09
Mar	1321	1363	3.08	460	505	8.89
April	976	1001	2.50	482	510	5.47
May	535	595	10.10	448	479	6.31
June	316	327	3.21	455	495	8.06
Total	6,883	6,816	-0.98	2,911	3,067	5.07

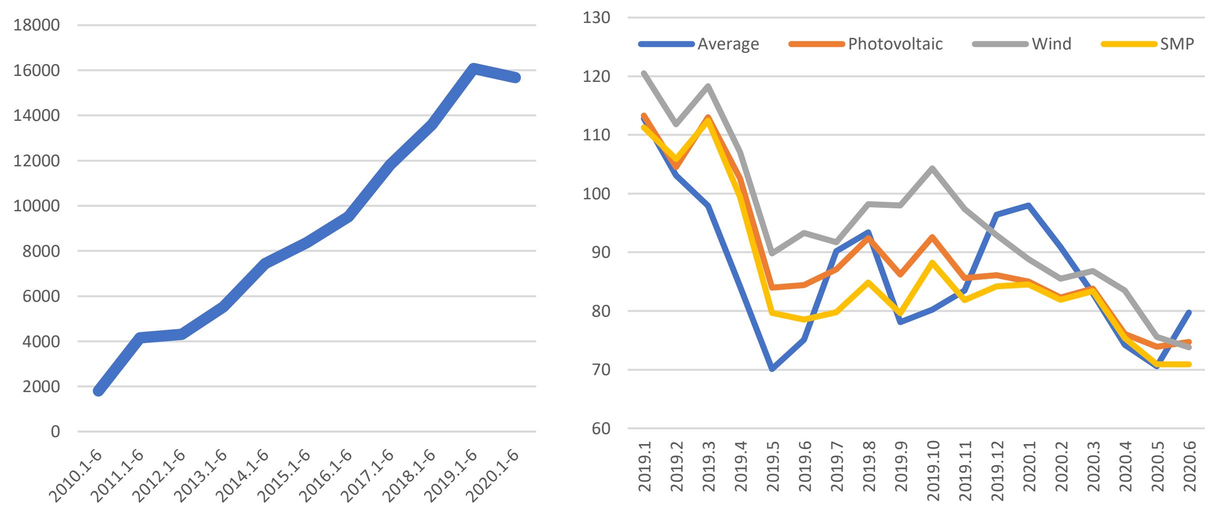
Source: *Monthly Energy Statistics*, Korea Energy Economics Institute (KEEI), September, 2019

During the outbreak of COVID-19 in the ROK, trends in renewable energy demand were notable. In particular, power generation from renewable energy sources in the first half of 2020 declined (-2.5%) for the first time since renewable energy statistics in the ROK power sector were first published (in 2004). This also contrasts with the approximately 10-fold increase in renewable generation over the past 10 years through 2019. Although the generation capacity of renewable energy systems increased in the first half of 2020 year, the state electricity wholesaler (KEPCO) reduced purchases of renewable generation because electricity consumption fell during the spread of the pandemic. The SMPs (System Marginal Prices) for power generation in the power exchange market also fell significantly because international prices for fossil fuels fell, together with the decreasing consumption of electricity. According to the electric power statistics information system in the Korea Power Exchange (KPX), the SMP in the first six months of 2020 declined by 20.5% from the same periods in 2019. With the falling SMPs, the generation price for photovoltaic and wind power generations in the first half of 2020 fell by 20.9% and 22.9%, respectively, from the same period of 2019, while the average price of total power generation decreased by just 8.6% (see Figure 5-6). This implies that the impact of COVID-19 on renewable energy sources was stronger than the impact on fossil energy-fueled power sources in the electricity generation sector in the ROK. Low prices received for renewable power generation would reduce the revenues of renewable generation businesses and will likely slow investment in renewable generation facilities.

The consumption of renewable energy in the industrial sector also declined after COVID-19 arose, but renewable energy consumption in the residential and commercial and public sectors slightly increased, but those sectors together account for just a small portion (about 10%) of total renewable energy demand.

Figure 5-6: Volume and Prices of Renewable Electricity Production

<Power generation from renewable energy, GWh> <SMP and generation prices by source. Won/kWh>



Source: KEEI, 2020.8 Source: Korea Power Exchange

2. Projections of Future Changes in ROK Energy System due to COVID-19

If the COVID-19 pandemic continues until the second half of next year or beyond and Korea's economy suffers a prolonged downturn, ROK energy consumption is expected to decrease further. In particular, energy demand in the transport sector will decline much more if there is a long period of social distancing campaigns. Sluggish industrial activity would also decrease electricity demand, but the demand for electricity and city gas will increase in the household sector as telecommuting can be expected to proliferate even more than in 2020.

Reductions in demand for renewable energy could be intensified if fossil energy prices continue to be low and if generation dispatch policies remain as they are. If electricity demand decreases further due to a continued economic recession, concerns about the flexibility of the ROK power system will grow. As power generation from variable renewable energy (VRE) sources such as solar PV and wind begin to increase on a large scale over the next few years in the ROK, the flexibility issue in the power system will begin to become more important due to the intermittency, variability, and uncertainty of VRE. This issue has already appeared this year in Jeju, the ROK's largest island and a famous tourist destination. Renewable power accounts for 35% of generation on the island, and as electricity consumption on Jeju has decreased due to the sharp decrease of tourist activity caused by the COVID-19 pandemic, the number of VRE curtailments in the island's power system has rapidly increased.

A few VRE curtailments in the ROK occurred several years ago due to the increase of renewable generation capacity, but the curtailment problem has become more serious during 2020 since the coronavirus outbreak. There are ways to secure additional flexibility in the power system, such as transmission links to countries outside the ROK and implementation of energy storage technology (EES), but because the country is in effect an energy island, transmission to other countries is not a possible alternative (at least in the short term), and power storage technologies are still expensive and it is not certain whether they can be safely integrated into the ROK electricity system—a concern resulting from several fires that have already occurred at battery energy storage facilities in the ROK—although global experience with EES technologies is growing rapidly. If the outbreak of COVID-19 continues for a long time and ROK electricity demand decreases further, the VRE curtailment problem is expected to worsen, which could curb investment in renewable energy. This will have a negative impact on the current government's policy to expand renewable energy use.

If the COVID-19 pandemic ends, the prices of oil and other fossil energy are expected to rise significantly in the short term because oil supplies would initially be tightened by the decreased investment in oil production during the period of the pandemic. With the rising price of fossil energy, investment in renewable energy would be expected to be revitalized. As electricity demand increases, the problem of VRE curtailment is expected to be alleviated.

In the mid to long term, fossil energy demand will shrink, as nations worldwide work to reduced GHG emissions, and prices will fall. Low fossil energy prices, however, likely will not significantly frustrate the expansion of renewable energy due to the increasingly serious impacts of climate change, and the increasing deployment of GHG emissions mitigation measures by the international community to address climate change. In addition, the outbreak of the virus reminds people of the importance of the environment, which could help to sway public opinion in favor of pushing ahead with renewable energy expansion policies. However, in the ROK, as well as in other countries, if problems related to VRE curtailment caused by the volatility of renewable energy generation are not resolved by technology development and/or the implementation of policies to strengthen the flexibility of the power system, investment in renewable energy is likely to shrink.

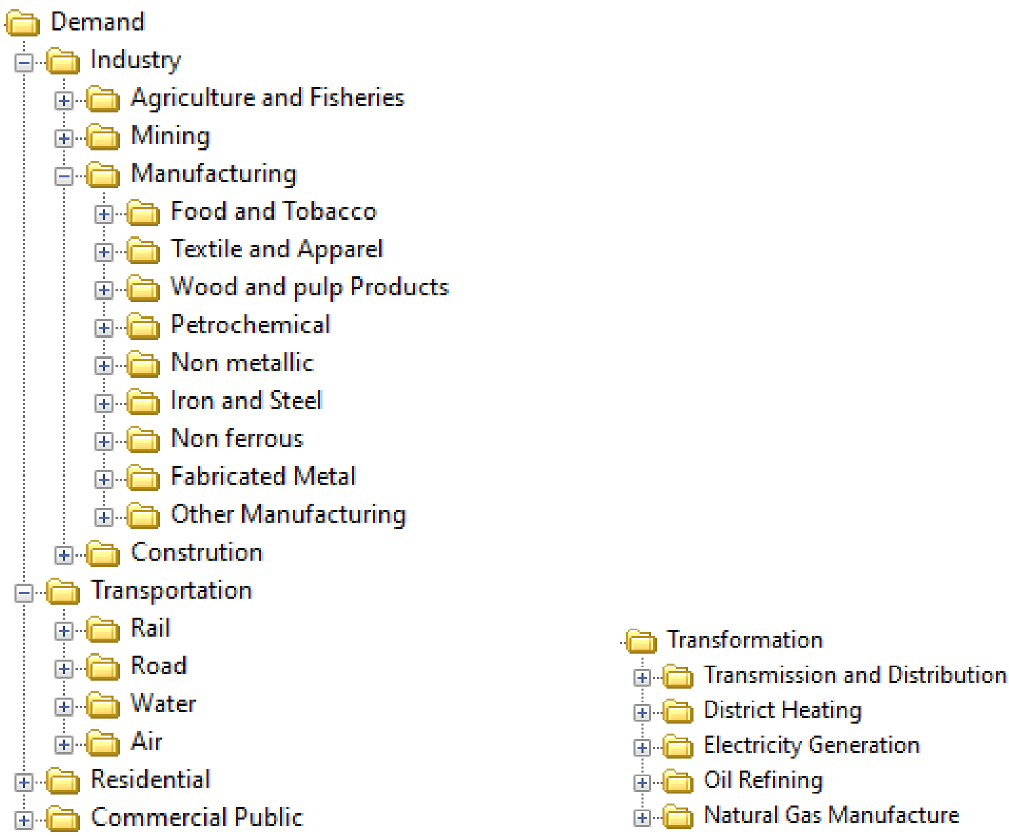
The experience with COVID-19 has changed the modes of operation of some businesses within the ROK economy, just as it has changed the lives of the ROK people. Delivery service businesses have been greatly expanded since the outbreak of COVID-19, but on the other hand, businesses like department stores and restaurants where many people gather have experienced significant declines in sales. Video meetings and conferences where people do not gather have also significantly increased. The changes in business types and living culture brought on by adaptation to COVID-19 isolation measures are likely to continue even after the pandemic ends. The experience of working from home during the outbreak of COVID-19 will influence the further expansion of the flexible working hours policies in many companies even after the coronavirus pandemic has subsided. In the long-term, this will cause electricity demand to decrease in the commercial and building sectors, but to increase in the residential sector. Prospects for city gas demand in the commercial sector post-COVID-19 remains uncertain. The restaurant business will likely shrink as it transitions to expanding food delivery, rather than eat-in dining, which will become a factor in decrease the demand for city gas for cooking. But if people reduce cooking at home and expand food delivery, city gas demand in the commercial sector may increase due to the expansion of “factory cooking”.

In the ROK, energy security concerns have mainly focused on external markets for fuels because the country has historically imported more than 95% of its energy requirements. Traditional policies for energy security have been oil stockpiling, overseas resource development, and diversification of energy import sources, policies that are designed to alleviate external energy risks to the ROK. During the period of the pandemic, however, external energy risks are significantly reduced as oil and oil products are in oversupply and as fossil energy prices in general have fallen sharply. On the other hand, risks related to ROK electricity infrastructures have rapidly emerged as the power capacities of variable renewable electricity sources have increased while electricity demand has declined. This situation force a transformation in the focus of energy security policies in the ROK from traditional measures for management of energy imports supply and price risks to new measures to manage internal risks. As a result, policies such as oil stockpiling, overseas resource development, and diversification of energy imports among supplier countries are expected to be less predominant in the ROK over time, in part due to the COVID-19 experience.

6 ROK LEAP Model Update: Business as Usual Case

The ROK Working Group to the Regional Energy Security project developed an updated LEAP model to explore different energy futures for the ROK. The updated ROK LEAP model includes a representation of energy demand that subdivides final consumption of each of the fuels used in the ROK into demand categories (sectors, subsectors, and in some cases end-uses and devices) within the ROK economy. For each of these demand “branches”, the determinants of energy consumption are at an annual (typically) activity level—such as sectoral GDP, number of households, physical output of a product, or transport activity—together with an energy intensity (use or a particular fuel per unit of activity). For each branch, prospects for future changes in activity and/or energy intensity are explored, and demand for energy is summed for each fuel over the different branches. This approach presents a bottom-up view of energy demand using the coupling between the historical and future determinants of demand for each branch. The ROK LEAP model has a typical sectoral structure similar to that which forms the basis for energy balances in most countries. The model basically divides the demand into four major sectors of the ROK economy--industry, transportation, households, and commerce and public--and estimates final energy consumption in each subdivision and each year based on the energy consumption behavior and demand characteristics of each subdivision. Figure 6-1 presents the structure of the ROK LEAP model, including both the demand-side components and the components of energy supply, namely the Transformation modules that are used to model the conversion of one (or more) fuels into one (or more) other fuels, or to model the movement of a fuel or energy form (such as electricity) from place to place (such as electricity transmission and distribution).

Figure 6-1: Structure of the ROK LEAP model

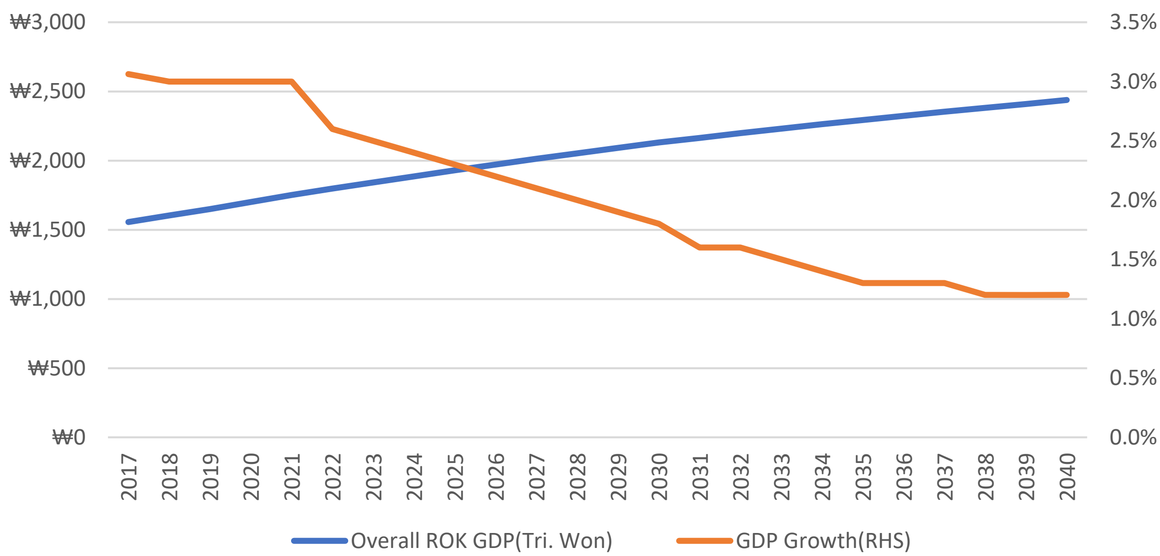


As noted above, final energy consumption for each branch of the model is basically determined by the product of the activity variable and the energy unit (intensity). The level of activity that induces energy demand is described by an economic and social variable that is directly or indirectly related to energy consumption in each sector and is typically linked to economic growth and population growth. The most frequently used variable representing the level of activity in the industrial sector is the added value, which is also used to describe activity in agriculture, forestry and fisheries, mining, construction, and manufacturing. Added value is subdivided based on the shares of particular industries in total GDP. By multiplying the value added by each industry by the energy intensity for each fuel used in that industry, the final energy consumption of an industry (or other branch) by fuel can be estimated. In the current ROK LEAP model, it is assumed that the activity level of each industrial subsector maintains a particular share of GDP corresponding that industry's share of industrial GDP in the base year (2017), which assumes that the current industrial structure will remain the same in the future.

6.1 Assumptions and Inputs for the LEAP model

Assumptions for the future energy outlook are based on the 3rd Basic Energy Plan for 2019. GDP growth is assumed to decline over time, starting at a rate of 3% annually in 2021, declining to 2%/yr by 2028, and falling to 1%/yr by 2040. This future economic growth trend (see Figure 6-2), based on projections from the Korea Development Institute (KDI) may in fact be rather high compared to recent economic growth (particularly when including consideration of the impacts of COVID-19), but this future trend is frequently used as a standard for establishing ROK national policy goals and is thus a reasonable reference rate for our revised LEAP model.

Figure 6-2: Assumed Future Trends in GDP and GDP Growth



Source: KDI, 2017

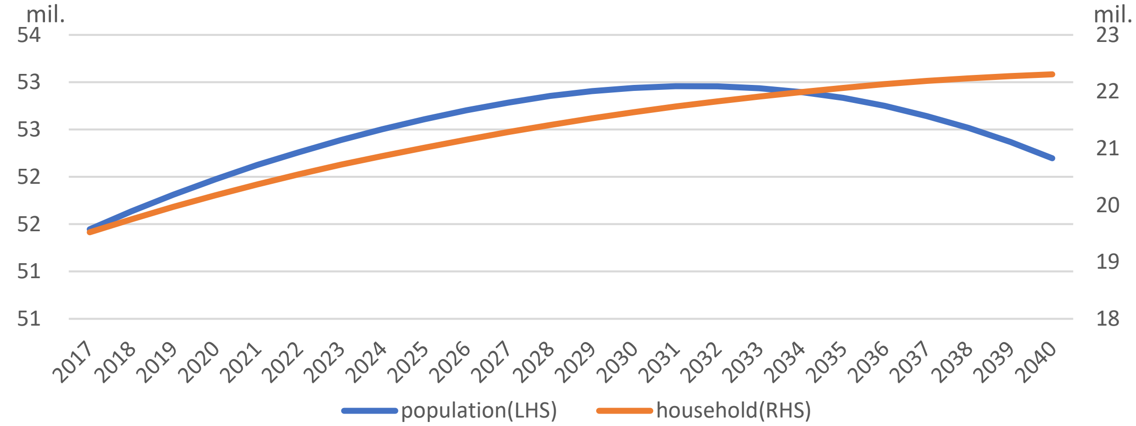
The data series used to model historical demand in the transportation sector in the ROK LEAP model extend from 2010 onwards. This is because the standardization criteria for transportation data changed in 2010, and data in the same categories in previous compilations are not readily comparable to the post-2010 figures. The ideal data to describe transportation activity is often vehicle-km statistics, but in reality historical ROK vehicle-km data are not considered consistent and accurate enough to serve as the basis for future projections. The ton-km data for freight that is currently available for the ROK is likewise not reliable, so converted passenger-km data were used for the passenger transportation subsectors. The Korea Energy Economics Institute is currently conducting research to improve its energy balances and forecast data using realistic vehicle-km rather than passenger-km data. Since the decrease in the population (the ROK’s population is growing very slowly and will peak soon) directly affects passenger-km traveled, projections for passenger-km shows the same outlook in terms of average growth rate from 2017 to 2040 as does the net projected population change. On the other hand, freight ton-km projections show continuous growth because freight activity is assumed to grow at roughly the same rates as economic activity, that is, as overall GDP. Commercial and public sector activities were assumed to grow at the same rate as GDP based on the premise that activity in these sectors will grow in proportion to overall ROK economic activity. Table 6-1 summarizes the key input assumptions related to activity and energy intensity for the updated ROK LEAP model.

Table 6-1: Primary Inputs for the ROK LEAP Model

	unit	**2000**	**2017**	**2030**	**2040**	**AAGR**	
						00-17	**17-40**
GDP	T. Won	820.8	1,556.0	2,130.1	2,438.2	3.8%	2.0%
Population	Million	47.0	51.4	52.9	52.2	0.5%	0.1%
Household	Million	14.5	19.5	21.6	22.3	1.8%	0.1%
Energy efficiency	Toe/GDP (M. Won)	0.235	0.193	0.163	0.142	-1.2%	-1.3%
		2010	**2017**	**2030**	**2040**	**10-17**	**17-40**
Passenger-km	Billion	416.3	496.3	511.6	504.4	2.5%	0.1%
Ton-km	Billion	141.8	182.6	249.2	285.3	3.7%	2.0%

According to the Statistical Office's announcement in 2016, the ROK's population is projected to increase to 52.96 million in 2031 and decrease thereafter. From 2029, the number of deaths is expected to begin to decline. Despite the beginning of this decline in population, the number of households, which can be viewed as the basic unit of energy consumption in the residential sector, continues to increase. This phenomenon reflects ongoing changes in the household composition of the ROK. ROK households were centered on multi-child, and often multi-generational, families in the past, but there has been a gradual increase in the number of single-child families. This is consistent with the decline in the number of births due to fewer marriages and fewer births per woman in the ROK. The ROK government is increasing support intended to help provide incentives for citizens to have larger families, including policy measures such as financial support and educational environment improvement for multi-child households to encourage childbirth. These measures have to date, however, not been enough to increase the fertility rate. The number of households drives energy use in the household sector. Therefore, although population will peak around 2030 and decline thereafter, the number of households will continue to grow as average household size decreases (Figure 6-3).

Figure 6-3: Projections for Population and the Number of Households in the ROK

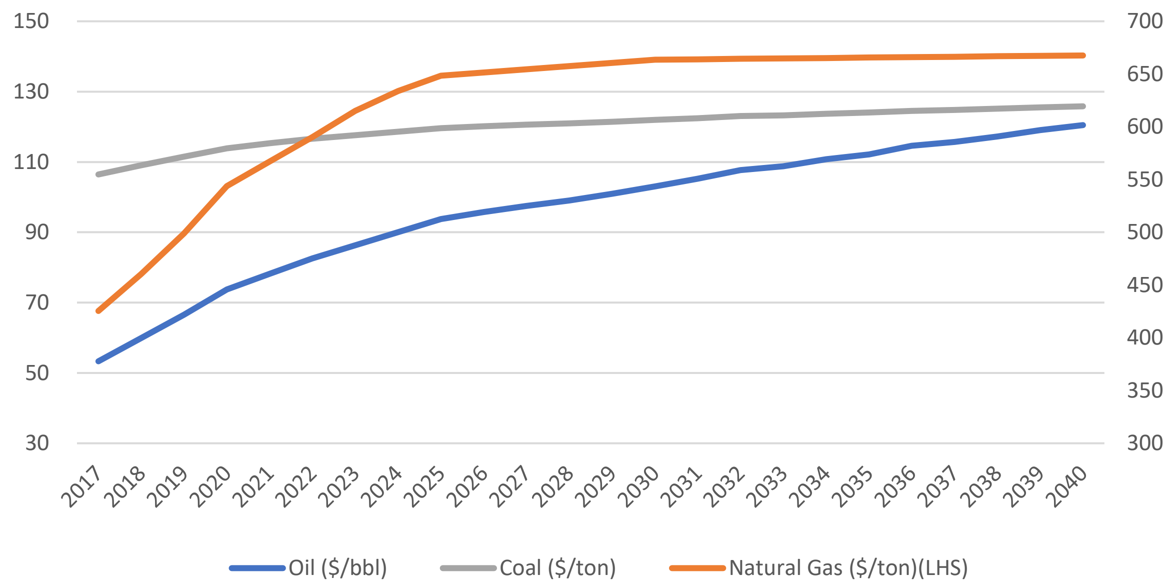


Source: Long-term Population Outlook, kostat 2016

The 3rd Energy Master Plan assumes the future price trends for the different primary energy forms will be as shown in Figure 6-4, below. The average growth rate of international oil prices published by international organizations such as IHS Marikit, the IEA (International Energy Agency), and EIA (the US Department of Energy's Energy Information Administration) were used. In practice there can be a lot of controversy over the future price of natural gas. Although the price of gas at Henry Hub (HH) in the United States, one marker of international gas prices, remains relatively low due to production from US shale deposits, it is assumed that the price of natural gas will rise to some extent in the future. This outlook is in line with the prospects suggested by other international organizations. Although the price of natural gas plummeted after the start of the COVID-19 pandemic, it was assumed that there would be no difference in the long-term trend of gas prices as a result of the pandemic, and the basic assumption of the 3rd Energy Master Plan was used in the LEAP model for the sake of consistency.[15]

[15] *The 3rd Energy Master Plan Working Group Report,* dated 2018.11.

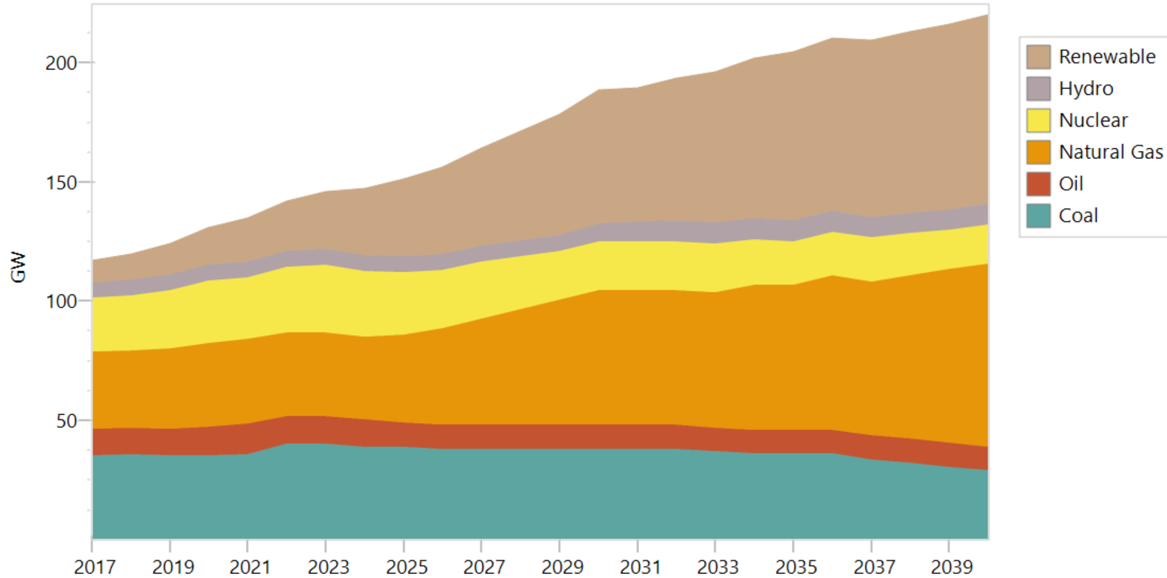
Figure 6-4: Resource Price Outlook



Source: the 3rd Energy Master Plan

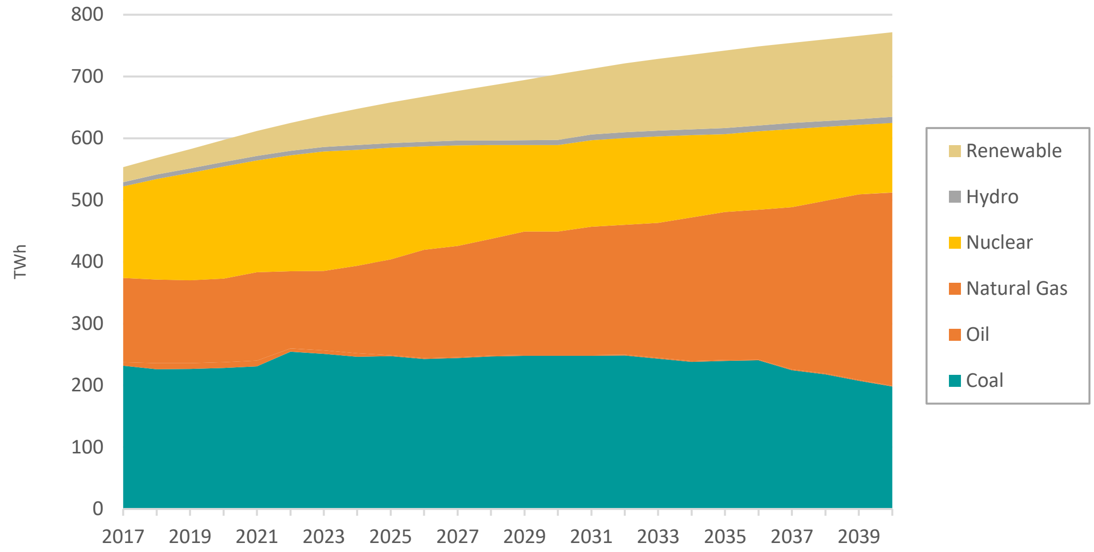
The 3rd Energy Master Plan puts transformation of energy sources, particularly in electricity generation, at the center of plans for the ROK energy transition. The demand for system flexibility that increases as more electricity is supplied from of renewable energy resources is provided through gas-fired generation. Coal-fired capacity will increase by 2022 due to the completion of existing under-construction plants, but will decrease thereafter. Nuclear generation capacity will increase until 2023, but thereafter will continue to decrease assuming no new nuclear power will be introduced. Natural gas-fired generation fills the gap between demand and the reduction in supply caused by the reduction in nuclear and coal generation, showing a massive increase starting from 2025, as shown in Figure 6-5.

Figure 6-5: BAU Scenario Exogenous Capacity Additions (GW)



The mix of generation in the power sector is the key element in the transition policy. Electricity demand will increase by 1.5% per annum during the forecast period, reaching more than 700 TWh in 2040. In the Business as Usual (BAU) case of the 3rd Energy Master Plan, and also reflected in the BAU case of the RES ROK LEAP model shown here, electricity use is expected to increase in all sectors, but the demand for electricity in transportation is expected to increase the fastest, at an annual average of 7.1%, due to the rapid introduction of electric vehicles into ROK fleets. The industrial sector accounts for 54% of the total electricity demand increase during the forecast period, contributing to the overall electricity demand increase. As the roles of natural gas and new and renewable energy increase in the power generation sector, the peak of total energy consumption occurs in the mid-2030s, and the share of renewable energy surpasses nuclear power within 30 years, as shown in Figure 6-6.

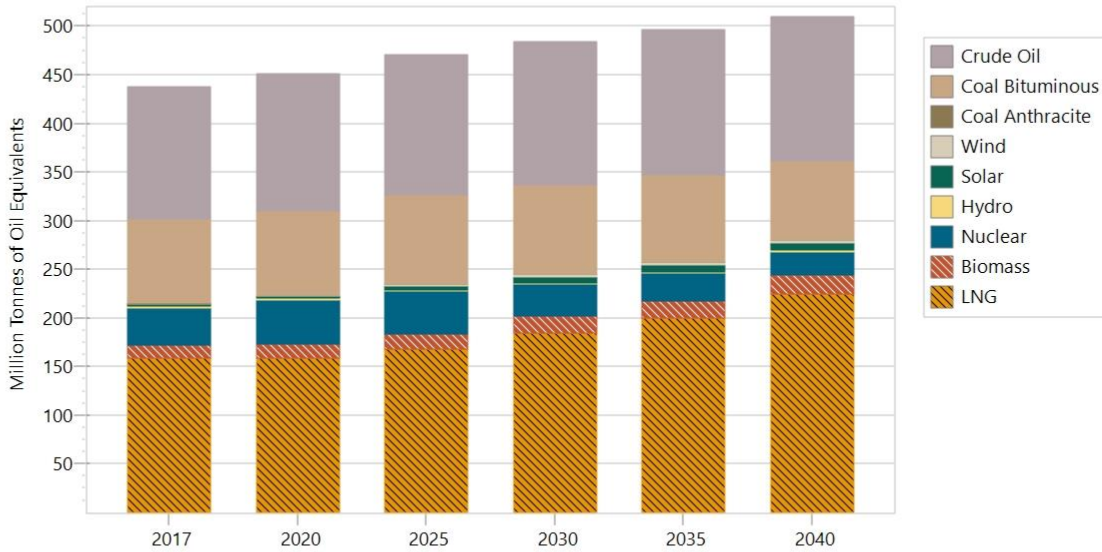
Figure 6-6: BAU Generation Mix



6.2 Results of BAU Calculation

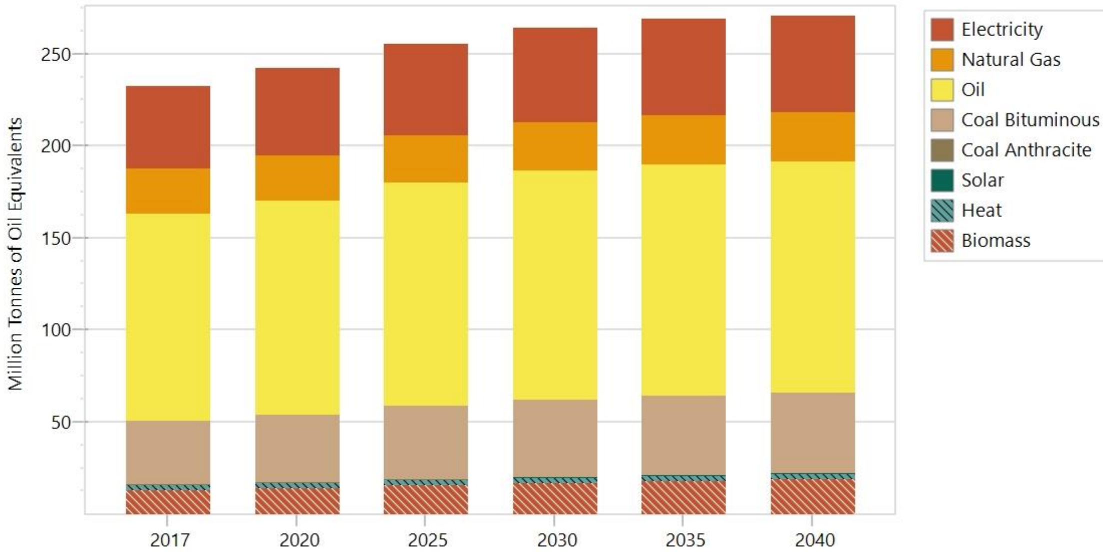
The LEAP model, which has the characteristics of a bottom-up model, calculates and sums primary energy demand and the final energy demand based on basic assumptions for energy demand and supply such as those described above. The calculated primary energy demand in the BAU for the ROK model is shown in Figure 6-7. The demand for fossil fuels such as crude oil, coal, and LNG, continues to rise, driven mostly by the economic growth rate, and the fraction of primary energy demand provided by fossil fuels does not change significantly by 2040. However, the most striking thing about the future pattern of fuels use is the increase in LNG imports, along with the fact that fossil fuel sources continue to account for most energy demand in the future. This is due to the rise in the amount of natural gas required by energy conversion processes, particularly electricity generation. The increased use of natural gas in energy conversion is due to the decrease in the use of nuclear power. Although solar and wind power generation increase through the projection period, they do not fully replace the gap in generation caused by the decline in nuclear power. In other words, the BAU scenario represents an increase in power generation through natural gas. In addition, as renewable energy use increases, the use of natural gas generation increases to ensure the power system's stability.

Figure 6-7: Primary Energy Demand, BAU



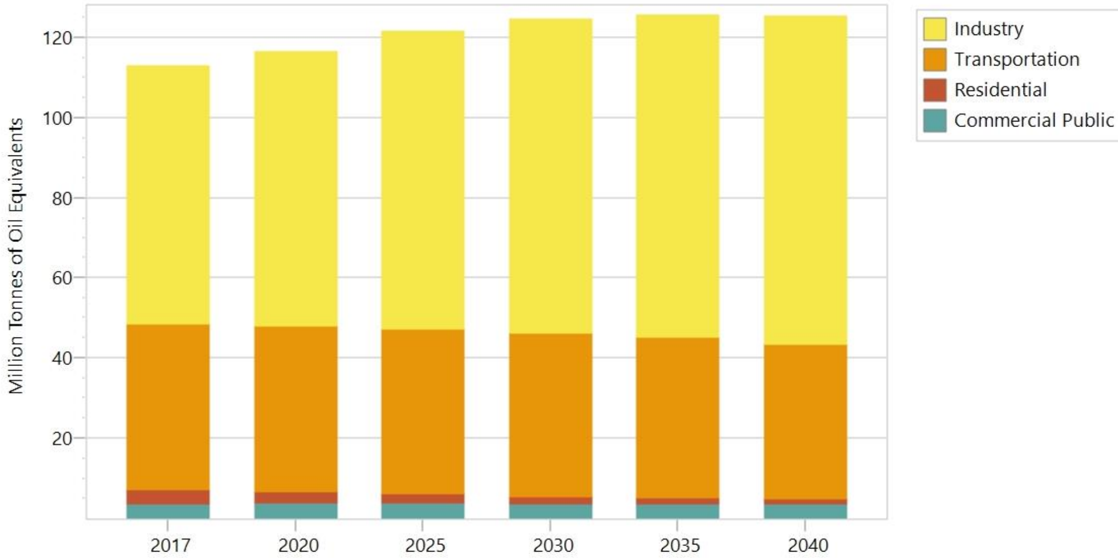
In final energy demand, electricity consumption increases, but the amount of natural gas does not increase significantly (see Figure 6-8). This further evidence that the increase in the fraction primary energy accounted for by natural gas is consumed not in the final demand sectors, but in energy transformation (electricity generation). In final energy in the BAU case, not only does electricity demand increase, but oil and coal demand increase as well, and by greater percentages than the increase in electricity use. Energy transitions away from fossil fuels are being promoted worldwide, and the ROK is also pursuing a policy to reduce the share of carbon-bearing fuels through its own energy transition. Nevertheless, it is unlikely that the share of fossil fuels in final energy consumption will be easily reduced. In particular, oil demand is increasing, which appears to be mainly consumed in industrial applications in the ROK—mainly the petrochemicals sector—although much of this demand is for oil products used as feedstocks for plastics and other materials, and not directly as fuels.

Figure 6-8: Final Energy Demand, BAU Case



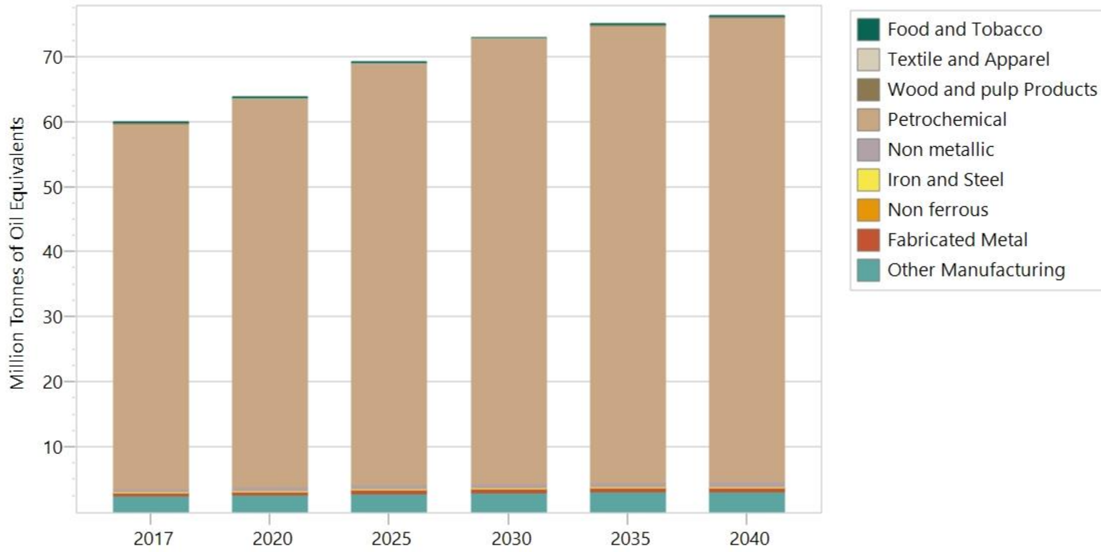
In the ROK, the growth of the industrial sector leads to an overall increase in energy demand. The industrial sector accounts for more than half of the total energy demand not only for oil (see Figure 6-9) but also for electricity. In other words, more than half of the ROK's energy demand is from the industrial sector. In most advanced countries, electricity demand for the industrial, buildings (commercial and services) and residential sectors are similar. Within its large manufacturing industry, however, the ROK includes an unusual concentration of energy-intensive primary industries. Therefore, the economic growth of the ROK, assuming, as is the case in the BAU scenario, that the current industrial structure is maintained, inevitably increases energy demand. The ROK's major export commodities—chemical products, steel, and non-ferrous metals—have the largest shares in the global export market, along with semiconductors.

Figure 6-9: Final Oil Demand by Sector, BAU Case



The ROK's top export category by far in terms of value is semiconductors. Semiconductors account for 17.3% of all ROK exports. ROK has been the world's number one semiconductor exporter since 2005. The second-largest export category is automobiles. In fact, petrochemical products and automobiles historically alternately occupy second and third places in the list of ROK exports by value, varying by year. As such, petrochemicals represents a high proportion of ROK industry, and the petrochemical industry has global competitiveness, so the industry is expected to grow in the future. Therefore, industrial oil consumption appears likely to increase in line with ROK economic growth, as shown in Figure 6-10

Figure 6-10: Final Oil Demand for Industry Sectors, BAU Case



The dominance of the petrochemical sector in oil demand, and the continuing growth of petrochemicals output in the ROK, naturally means that the amount of crude oil imported into the ROK does not decrease (see Figure 6-11). As imports of fossil fuels continue to increase, developing policies to reduce greenhouse gas emissions from oil use is one of the government's great interests. For reference, Table 6-2 summarizes the sources of historical and energy data used in this report.

Figure 6-11: Energy Imports, BAU Case

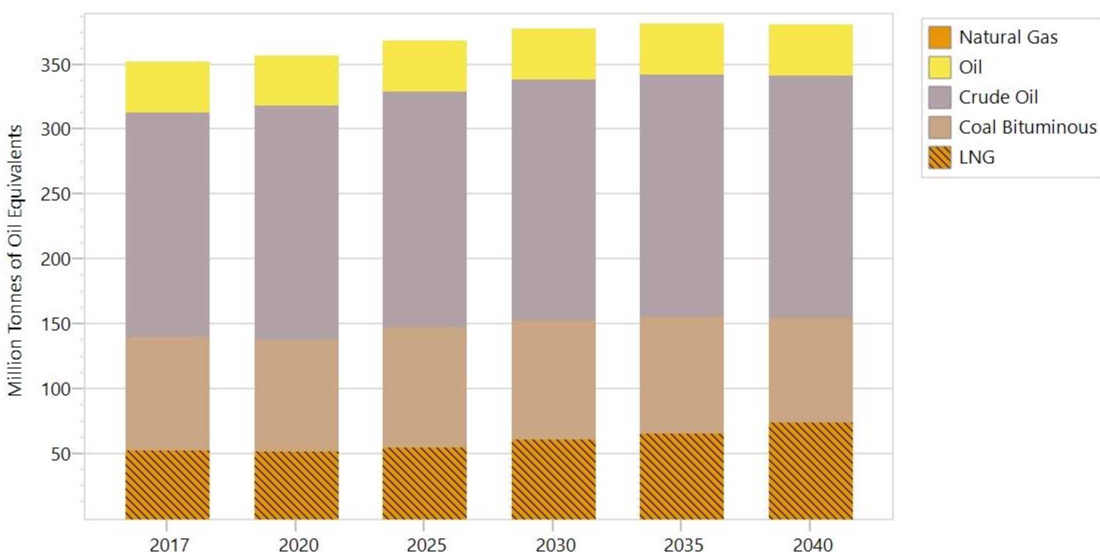


Table 6-2: Sources of Data for the ROK LEAP Model

Sector	Sources
Residential	Energy: Energy Consumption Survey (KEEI), Household Energy Standing Survey (KEEI) Activities: Population Census (kostat)
Industrial	Energy: Energy Consumption Survey (KEEI), Yearbook of Energy Statistics (KEEI) Activities: Economic Statistics System(http://ecos.bok.or.kr)
Commercial	Energy: Energy Consumption Survey (KEEI), Household Energy Standing Survey (KEEI) Activities: Sectoral floor space information from Wholesale & Retail Survey and Service Industry Survey
Transportation	Energy: Energy Consumption Survey (KEEI), Household Energy Standing Survey (KEEI) Activities: Statistical Yearbook of MOLIT (http://stat.molit.go.kr)
Transformation	Household Energy Standing Survey (KEEI), Korea Electric Power Corporation (http://www.kepco.co.kr/), Korea Gas Corporation (http://www.kogas.or.kr), Korea Coal Corporation (http://www.kocoal.or.kr), Korea District Heating Corporation (http://www.kdhc.co.kr/)
Socioeconomic	Statistics Korea(http://kostat.go.kr), Bank of Korea (http://www.bok.or.kr), Korea Development Institute(http://www.kdi.re.kr)

7 REPORT ON DEVELOPMENT OF POLICY CASES IN THE ROK LEAP MODEL

7.1 CONSIDERATIONS FOR ROK ENERGY POLICY

The LEAP model for the ROK can be used to prepare variants of the BAU future case to analyze the energy sector implications of various policy scenarios. First, one of the essential energy policies under the current ROK administration relates to the halt in building new nuclear power plants and a change in policy so as to no longer consider plant life extension. As described above, the nuclear power outlook has shown the most dramatic change in the ROK's electricity supply and demand forecast between the Moon Jae-in administration and the previous government. As the 3rd Energy Master Plan halts the development of previously-planned nuclear power plants, with the exception of those currently under construction, resulting in a rapid decrease in the fraction of generation from nuclear power. Construction of Shin-Kori #5 and #6, which are currently under construction, will continue, but plans for about 8.8 GW of additional reactors, including Shin Hanul #3 and #4, have been canceled. A further reduction in the proportion of nuclear will appears as the extension of the operating life of 30 years for some units will be prohibited. In the case of Wolseong #1, the life extension was originally permitted, so the plant has been retrofitted, but with the introduction of the energy policy regime of the current administration, operation of the unit has been stopped before the completion of its extended life span. Taken together, the nuclear policy changes make a 14.2 GW difference in ROK nuclear power capacities in 2040, relative to a trajectory in which more new plans are built and life extension is approved for older units. We therefore prepared alternative nuclear scenarios based on assumptions that the nuclear policies of the Moon administration might be reversed if the political regime changes. However, more anti-nuclear energy policies that place even greater emphasis on reducing nuclear power use may emerge if more progressive governments are elected. Issues related to nuclear power plant accidents and the disposal of spent nuclear fuel could be an additional driving force for the further reduction of nuclear power use in the ROK. It was the nuclear power plant accident in Fukushima, Japan in 2011 that aroused awareness of nuclear power risks among the people of the ROK. Post-Fukushima, analysis of the cost of potential nuclear accidents in the ROK and discussions regarding the reduction in ROK use of nuclear power continued. In addition, the problem of disposal of spent nuclear fuel generated a strong civil complaint. Heavy water nuclear power plants that generate large amounts of spent nuclear fuel (Wolseong #1 to #4), have a current operating life span ending in 2029, but the saturation rate of spent fuel storage at these plants has already increased to 92.8% of capacity since the installation of a proposed additional spent fuel storage facility was not approved. The saturation rate of spent fuel storage at Kori #4 has increased to 98%. As a result of this trend, the reduction of the utilization rate of nuclear power, in part to make the capacity of the existing spent fuel storage facilities last longer, has been included in the current energy policy, and modeled as a part of the BAU case.

Second, the key to the energy transition in the ROK is the expansion of renewable energy. The ROK government's commitment to the supply of renewable energy is unyielding. Through the Renewable Energy 3020 Plan, it announced a plan to supply 20% of power generation with renewable energy by 2030. Renewable additions were to continue after 2030: the 3rd Energy Master Plan states that renewable energy will be responsible for 30-35% of power generation in 2040. The 9th Basic Plan for long-term electricity supply and demand is being prepared based on the 3rd Energy Master Plan. Although growth in the supply of renewable energy is progressing, the ROK has an issue related to the stability of operation of its grid system. Unlike Europe, which shares its power grid with neighboring countries and has high system strength, the ROK maintains an independent power grid system. In May and October 2020, the ramping down of nuclear power plants was underway. As renewable energy supply has increased, it has also reduced the use of nuclear power, which supplies baseload power to the ROK grid. It is worth noting that the current supply of renewable energy in the ROK is less than 5%. In addition, due to the topography of the ROK—70% of the country is mountainous—large-scale solar power is often installed in mountain areas, which requires to cutting the trees on solar sites. After a typhoon during the summer of 2020, a landslide occurred in the mountain area where a solar power plant was installed, and public opinion has suggested that the solar power installation is the cause of the landslide. Given these issues, it was assumed that the current rate of renewable energy supply growth could be somewhat reduced from planned levels.

Third, renewed interest in regional cooperation for power grid interconnections has emerged recently. The 8th Basic Plan for long-term electricity supply and demand includes consideration of power grid interconnections with China, Russia and Japan. The ROK is expected to start importing electricity from Weihei, China to Incheon, ROK, through a 2.4 GW underwater grid intertie in 2025. Cooperation with Russia may not be easy at the moment due to the high uncertainty that a transmission line passing through the DPRK, can be developed, but interconnections with China appear to have better prospects, as China's Global Energy Interconnection Development and Cooperation Organization (GEIDCO) signed a cooperation agreement with SGCC and KEPCO in 2017.

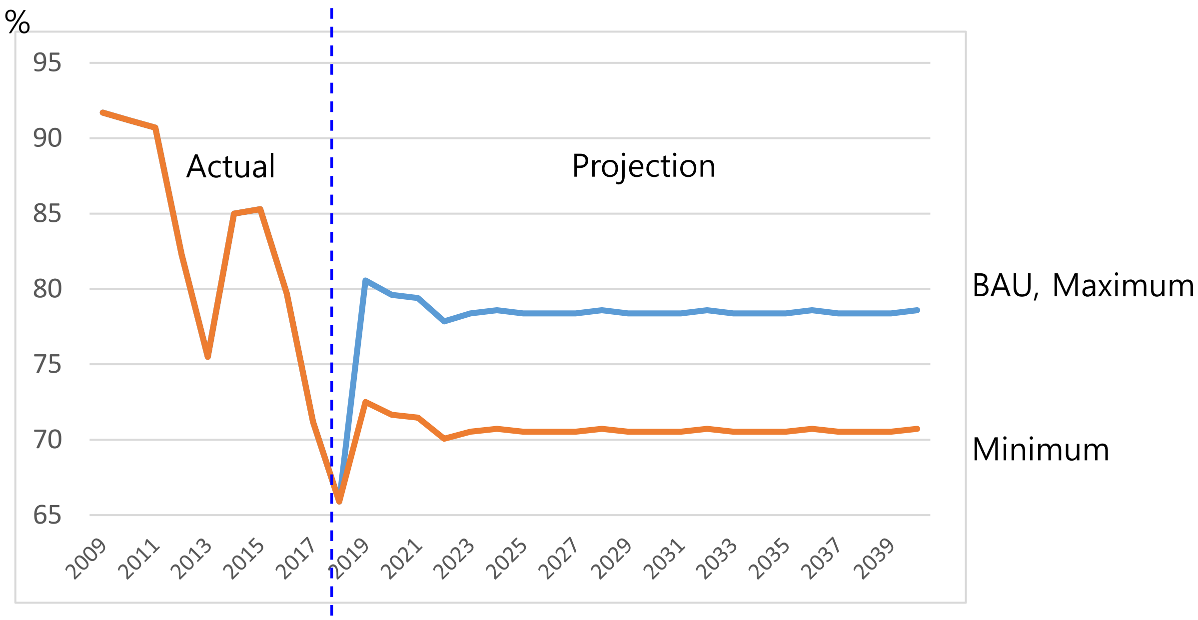
7.2 BUILDING ROK ENERGY POLICY SCENARIOS

The ROK Working Group has prepared five scenarios that differ from the BAU case, each focused on different paths for the development and management of electricity generation in the ROK. The Nuclear Max S1 scenario uses a mild nuclear phase-out assumption in which all currently- planned nuclear power plants would be installed, and existing facilities would have their operating periods extended by ten years. As a result of these modifications, as of 2040, the nuclear capacity difference from BAU would be16.2 GW. The expanded supply of electricity arising from the easing of nuclear power reduction policies causes a reduction in natural gas use for generation, as gas-fired power is responsible for marginal power generation in the ROK system. Renewable energy assumptions in this scenario follow those in the BAU case. Regional cooperation was considered to be absent in the Nuclear Max S1 scenario, as in the BAU.

The Nuclear Max S2 scenario adds slowing the growth rate of renewable energy deployment to the assumptions in the S1 scenario. The rate of renewable energy supply in the BAU case is not the same as the target value of the 3rd Energy Master Plan, with renewables accounting for 15% of electricity output in 2030 and 18% in 2040, which are somewhat lower than in the 3rd Energy Master Plan. Under the Nuclear Max S2 scenario, however, in addition to changes with nuclear power use, the application of conservative assumptions reduces the share of renewable electricity generation to about 9% in 2030 and about 10% in 2040. It is assumed that nuclear power and renewable energy partially substitute for each other. As renewable energy shows less growth than planned in the Nuclear Max S2 case, it is necessary to consider supplying electricity through other power sources. Since the increase in coal power generation is inconsistent with policy trends related to mitigation of greenhouse gas emissions, it is assumed that the share of natural gas increases as renewable generation falls.

The Nuclear Min scenario reflects the more progressive regime's nuclear reduction energy policy. In practical terms it is difficult to reduce the capacity of nuclear power plants below what it is today (2020). Therefore, although the capacity of the nuclear power plants follows the BAU scenario, we assume for the Nuclear Min case that the utilization rate of nuclear plants will be reduced by an additional 10% to minimize nuclear power generation. In fact, since the Korean nuclear power utilization rate in 2018 and 2019 was already around 70%, the nuclear power utilization rate in this scenario is not an unrealistic number. Instead, it can be viewed as a scenario that more closely matches the current government policy. Renewable energy assumptions in the Nuclear Min case follow those in the BAU. Regional cooperation was considered to be absent as in the BAU. Figure 7-1, below, shows the capacity factor used in the BAU and nuclear power scenarios.

Figure 7-1: Capacity Factor Assumptions for Nuclear Generation by Scenario



Like the Nuclear Max and Min cases, the ROK regional cooperation scenarios are based on the BAU scenario. RegCo S1 followed the BAU for nuclear and renewable energy policies. For regional cooperation, RegCo S1 applies imports of electricity from China according to the 8th Basic Plan for Long-term Electricity Supply and Demand and KEPCO's plan. Identification of the power generation source that is replaced by electricity imported through regional cooperation is the key in the regional cooperation scenarios. In RegCo S1, nuclear, coal and renewables are assumed to run as base load plants. As a result, the electricity imported through regional interconnections lowers the use of generation fueled with natural gas, which is the source of marginal power generation in the BAU case.

RegCo S2 assumes that electricity imports from China would replace renewable energy use instead of natural gas-fired generation. As a result, in this case, nuclear power generation follows BAU trends, but renewable energy has a new generation pattern. RegCo S2 is thus a scenario in which renewable generation capacity grows more slowly than expected, and electricity imports would replace the power that would have been generated from renewable sources. Therefore, the amount of natural gas used for generation does not change in the RegCo S2 case relative to the BAU case. Table 7-1shows a summary of the nuclear, renewable, and regional cooperation elements of each of the five policy scenarios considered.

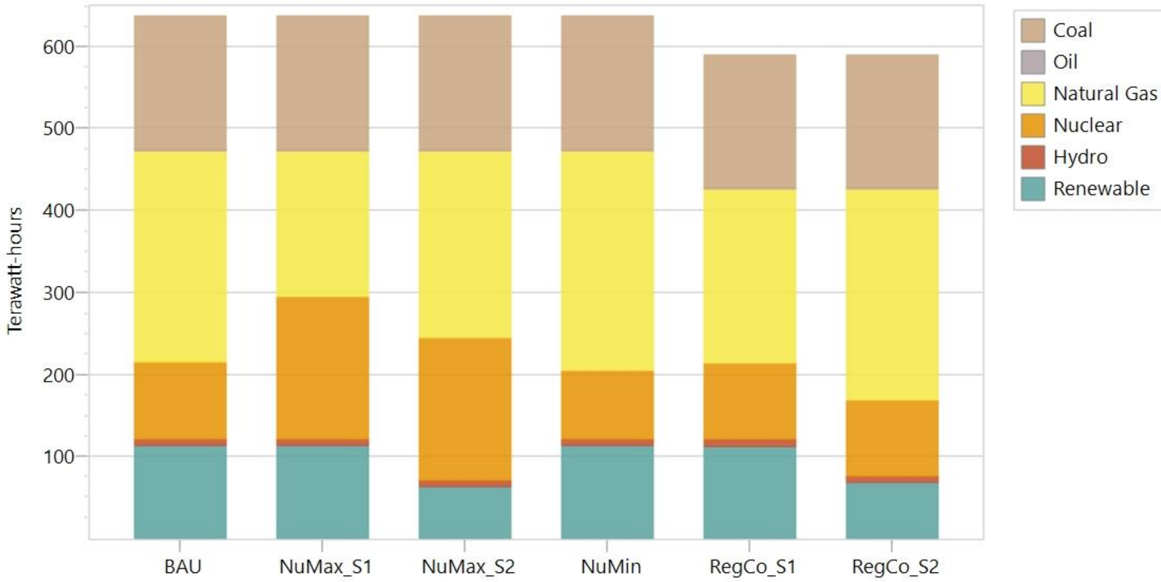
Table 7-1: Scenarios Scheme

Scenarios	Acronym	Nuclear Phase-out	Renewable Growth	Regional Cooperation
BAU	BAU	BAU	BAU	None
Nuclear Max S1	NuMax S1	Mild	BAU	None
Nuclear Max S2	NuMax S2	Mild	Mild	None
Nuclear Min	NuMin	BAU with less capacity factor	BAU	None
Regional Cooperation S1	RegCo S1	BAU	BAU	China
Regional Cooperation S2	RegCo S2	BAU	Replaced by import	China

7.3 ANALYSIS OF ROK ENERGY POLICY SCENARIOS

The following figure shows domestic ROK electricity generation under each scenario in 2040. The amount of power generation in 2040 reflects the basic premise of each scenario. In 2040 (see Figure 7-2), nuclear generation in the BAU case is 112.9 TWh, but increases to 210.7 TWh in the NuMax S1 Case. NuMax S2's nuclear power generation is the same as in NuMax S1. As renewable energy supply has decreased in NuMax S2, however, the amount of renewable energy generation in 2040 under NuMax S2 is only 55% of the total in 2040 in the BAU case. The renewable generation reduction in the NuMax S2 case in 2040 is replaced by generation fueled with natural gas, which is responsible for following peak load in the ROK system. In NuMin, the amount of nuclear power generation was reduced by about 10%. Since the proportion of nuclear power is not large in 2040, this policy change has a relatively small effect in BAU results. On the other hand, the regional cooperation scenarios include a 5.6 GW import line from China and assume that it will be used at a 100% rate. Under these assumptions, the ROK would import 47 TWh of electricity from China each year. The imported electricity will take the place of 6.1% of the total electricity demand.

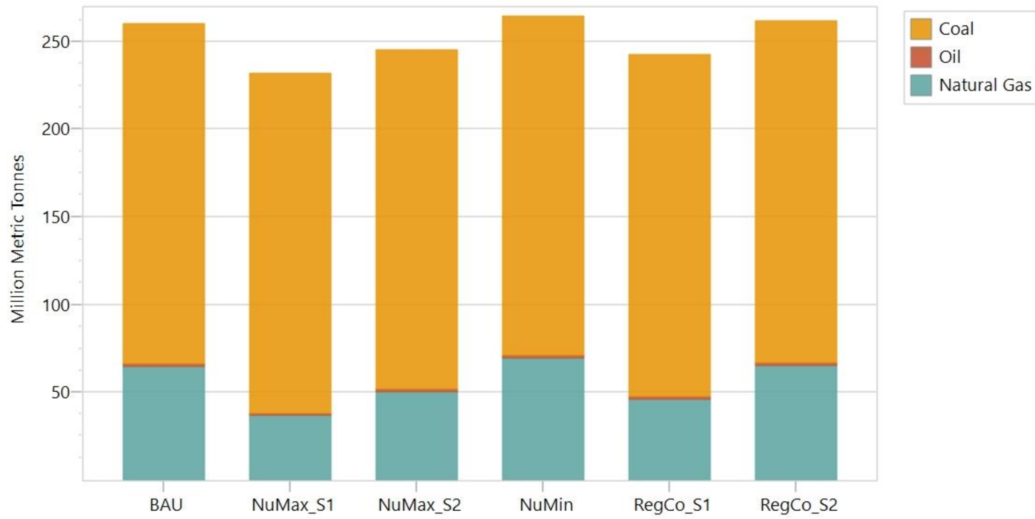
Figure 7-2: Generation by Scenario, 2040



One of the most significant advantages of the LEAP model is that it can easily be used as an analysis tool for greenhouse gas emissions. The ROK has declared that it will reduce greenhouse gas emissions by 34.1 million tons by 2030 in the transformation sector (mostly via reductions in emissions from electricity generation) in its Intended Nationally Determined Contributions (INDC) filed with the UNFCCC (United Nations Framework Convention on Climate Change). The ROK's industrial sector produces the second-highest share of the ROK's greenhouse gas emissions, after energy transformation GHG sources. The industrial sector is still responsible for more than half of the nation's greenhouse gas emissions, but the transformation sector also emits about 30% of annual greenhouse gases in ROK. In the ROK LEAP model, under BAU conditions transformation sector greenhouse gas emissions are expected to be than 270 million tons of carbon dioxide equivalent (CO_2e) by 2030 due to continued economic growth. The 270 million tons figure may be different in 2030, as different ROK government documents—for example submissions to the UNFCCC estimating the impact of NDCs—provide different estimates of 2030 BAU GHG emissions from energy transformation. It is possible, however, to focus LEAP model results on the numerical change between scenarios. Greenhouse gas emissions in 2020 will be identical (by definition) in all scenarios, as policy changes between the scenarios do not, for the most part, start before 2021. Greenhouse gas emissions in 2030 by scenario shown in Figure 7-3 show relatively large differences between scenarios. The biggest reduction in emissions relative to BAU levels is shown in the NuMax S1 case, which reduces greenhouse gas emissions by 28 million tons. The second most significant greenhouse gas reductions are from the RegCo S1scenario. This case shows a reduction of 17 million tons CO_2e by 2030, relative to BAU conditions in the electricity sector, which is nearly half of the 34.1 million tons proposed by the ROK as its reduction target for 2030. This corresponds to the amount of greenhouse gas emissions that can be reduced with annual electricity imports of 47

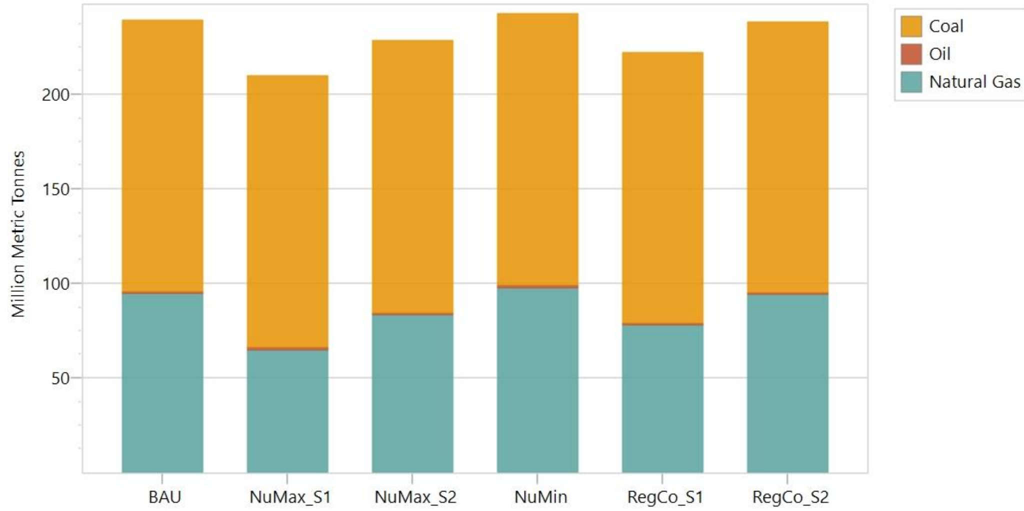
TWh. In other words, if the electricity imported from abroad is carbon-free, the domestic policy burden for carbon emissions reduction can be greatly reduced.

Figure 7-3: Electricity Sector GHG Emissions in 2030 under Six Scenarios



By 2040 overall greenhouse gas emissions in the ROK decrease in all scenarios. Compared to 2030, the results presented in Figure 7-4 show a reduction of 20 million tons due to the reduced share of coal-fired power. Looking more closely, one can see that the total amount of emissions from coal-fired power have decreased, but emissions from natural gas-fired generation have increased. The most significant difference in greenhouse gas emissions results by scenario when compared with BAU is still found in NuMax S1, which shows emissions of about 30.6 million tons less than in the BAU case. It is expected that NuMin would have the highest greenhouse gas emissions since in this case nuclear generation has been replaced by natural gas. In fact, 2040 emissions in the NuMin case are 3.6 million tons CO_2e higher than in the BAU case. While NuMax scenarios lead to lower 2040 emissions than in the BAU case, RegCo S1 presents an interesting result. It appears that a significant amount of greenhouse gas reduction is possible because RegCo S1 is assumed to replace domestic natural gas power generation with imported electricity. It should be noted that the primary assumption here is that imported power is carbon-free. As noted above, in the NuMin scenario, where nuclear power use is minimized, greenhouse gas emissions in 2040 are particularly high. The reduction of the safety risks associated with nuclear power, which is a goal of the scenario, leads to increased greenhouse gas emissions, presenting a difficult policy trade-off that the government must resolve.

Figure 7-4: Electricity Sector GHG Emissions in 2040 by Scenario



8 CONCLUSIONS

The ROK's energy policy stands at a crossroads. Korea is facing a policy issues associated with its planned energy transition. A shift from an emphasis on economic growth, which has been at the center of energy policy formulation in the ROK thus far, to an energy policy that considers the environment and safety, is gradually appearing. The current administration (as of 2020) is trying to reduce the ROK's use of nuclear power, which has played an important role in energy security policy over the last several decades, and to build an energy mix in the future, focusing on renewable energy that does not generate carbon emissions. Recently, as the problem of fine dust has emerged, voices have been raised about the need to phase out coal-fired power plants, which are the major source of fine dust in the power generation sector.

In this process, a conflict between an ideology of reducing nuclear and coal generation with the reality of the current status of the ROK's energy sector arises, as do considerations of the impact of potentially higher energy prices on what is already slowing economic growth. The expansion of renewable energy promoted by the government may not occur as expected due to problems such as civil complaints about siting new and renewable energy facilities. Even if the supply of renewable energy is expanded, there remains a problem to be solved: the operation of a stable power system as the use of intermittent generation resources rapidly increases.

Although the energy transition is being carried out to convert the ROK to a low-carbon economy, in some ways the transition may actually exacerbate the problem of greenhouse gas emissions. Expanding nuclear power has long been a significant tool favored by ROK policymakers to reduce greenhouse gas emissions in Korea. Generation powered by renewable energy also does not emit GHGs. Even if renewable energy use increases, however, the nuclear reactor decommissioning policy that is part of the current energy transition plan may increase total domestic greenhouse gas emissions. That is because the use of power generation sources that emit greenhouse gases such as natural gas will need to increase due to the low capacity factors that are associated with intermittent sources of renewable energy such as wind and solar.

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