Long Term Energy Plan for Korea using MESSAGE for Energy Optimization

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***Abstract* – Energy policy on electricity demand and supply is a key component of the country's sustainable economic development. Recently, the Korean government has decided to cancel the construction plan of new nuclear power plant in the electricity energy policy and decide not to extend the life extension of the nuclear power plant. In addition, it announced that it would minimize the amount of coal power generation for coal power plants in order to reduce carbon and fine dust emissions. In particular, power shortages due to the phase out policy of nuclear and coal power plants are expected to replace renewable energy and gas power generation in the long term.**

In order to present a more meaningful and realistic alternative to Korea's long-term energy policy, the Model for Energy Supply Strategy Alternatives and their General Environmental impacts (MESSAGE) code was used. In this study, the long-term policy scenario considered for current energy policy evaluation and new energy policy evaluation in South Korea is three scenarios: i) current existing scenarios, ii) response scenarios based on greenhouse gas emissions, and iii) strengthening of renewable and gas portion.

As a result, despite the promotion policies of renewable energy and gas power generation in South Korea, the nuclear and coal power generation still plays an important role due to the limitation of power supply by renewable energy and the economics of gas generation as the main power source. Therefore, it is necessary for the Korean government to establish a more economical and realistic long-term power supply plan in order to maintain sustainable economic growth and security from the phase out policy of nuclear and coal power plants.

Keywords – Energy, Nuclear, Long Term, Mixture, MESSAGE, South Korea

I. INTRODUCTION

A. BACKGROUND

South Korea is located on the Korean peninsula, surrounded by the sea except the north, where it borders North Korea. Due to the relationship with North Korea, political, social, and economical exchanges are virtually impossible. Due to this geopolitical position, energy exchange with other countries by an overland route is fundamentally blocked. The natural resources that can be used as energy sources are only domestic anthracite. However, the amount of reserves is small and the quality is lower than imported coal. Therefore, South Korea imports most of the raw materials that can be used as power generation sources: uranium, bituminous coal, Liquefied Natural Gas (LNG), and oil. In order to stabilize electricity supply and demand, the South Korean government has established a fifteen-year plan which is revised every two years by the Minister of Trade, Industry and Energy [1]. So far, the 7th Basic Plan for Supply and Demand of Electricity has been established. According to the plan, the low carbon power mix for greenhouse gas reduction will be strengthened by construction of 6 more nuclear power plants until 2030 instead of coal power reduction [1][6]. However, with the launch of the new government, the 8th power supply and demand basic plan will be planned differently from the 7th. As the new government's phase out policy of nuclear and coal power plants become reality, the plans for the construction of new nuclear power plants as well as the coal power generation plants will be deferred. On the other hand, new gas plants will be added to make up the electricity shortage and renewable energy generation will be increased to 20% of the total electricity production by 2030 [3][4].

In this study, three scenarios were evaluated. First, the current existing scenario was applied on MESSAGE based on the 7th plan of power supply and demand. Second, the low-carbon power mix policy which is a common direction of the 7th and 8th power supply basic plans was applied. Lastly, it evaluated the renewable energy and gas generation policies to complement the reduction of nuclear and coal power generation [4].

B. ELECTRICITY GENERATION CAPACITY

As shown in the Table 1, the interconnected system in Korea has a total installed capacity of 93216 MW shared 20716 MW by nuclear, 26274 MW by coal, 26742 MW by gas, 3850 MW by oil, and 15634 MW by others. As shown in the Table 2, total power generation in 2014 was 521409 GWh, shared 156407 GWh by nuclear power, 203765 GWh by coal, 111705 GWh by gas, 7759 GWh by oil, and 41773 GWh by others.

TABLE 1. SIZE AND SHARE OF INSTALLED CAPACITY (UNIT: MW)

Year	Nuclear	Coal	Gas	Oil	Other	Sum
'05	17716	17965	16447	4710	5420	62258
	28.5%	28.9%	26.4%	7.6%	8.7%	100%
'14	20716	26274	26742	3850	15634	93216
	22.2%	28.2%	28.7%	4.1%	16.8%	100%

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TABLE 2. AMOUNT AND SHARE OF GENERATION BY TYPE (UNIT: GWH)

Year	Nuclear	Coal	Gas	Oil	Other	Sum
'05	146779	134892	57962	16385	8352	364370
	40.3%	37%	15.9%	4.5%	2.3%	100%
'14	156407	203765	111705	7759	41773	521409
	30%	39.1%	21.4%	1.5%	8%	100%

* Other: Renewable Energy, Pumped-storage, and RCS (Regional Cogeneration System)

C. ELECTRICITY DEMAND TARGET OUTLOOK

Recently economic growth rates and utility rates are one of the major factors considered in demand forecast. Forecast has been based on a scientific modelling and the experts in power demand. The main premise for predicting electricity demand are based on the assumption of target demand by reflecting economic growth, electricity rates, population growth rate, and weather forecast.

Economic growth reflected the growth forecast of South Korea as shown in the Table 3. Electricity rates have reflected recent trends in electricity rates and cost factors. The population reflects the National Statistical Office's future population estimates and the population will continue to increase by 30 years as shown in the Table 4. The temperature reflected the Meteorological Administration's long-term climate change scenarios on the Korean Peninsula.

As shown in the Table 5, Power consumption is expected to grow at an annual average of 2.1% over the next 15 years from 2015 to 2029, eventually electricity demand target will reach to 656883 GWh in 2029. The maximum installed electricity will be reached at 111929 MW in 2029 with an annual average growth rate of 2.2% over 15 years (from 2015 to 2029).

TABLE 3. GDP GROWTH RATE OVERLOOK

Year	'14	'15	'20	'27	'29	Average
6th Plan	4.3	4.5	3.5	2.7	2.4	3.48
7th Plan	3.1	3.5	3.3	2.5	2.3	3.06

TABLE 4. POPULATION OVERLOOK (UNIT: 1000 PERSONS)

Year	'11	'15	'20	'27	'29
7th Plan	49779	50617	51435	52094	52154

TABLE 5. ELECTRICITY DEMAND TARGET OUTLOOK

Year	6th Plan [1]		7th Plan [1]	
	Power Consumption (GWh)	Maximum Power (MW)	Power Consumption (GWh)	Maximum Power (MW)
'15	516156	82677	489595	82478
'16	532694	84576	509754	84612
'17	548241	88218	532622	88206
'18	564256	91509	555280	91795
'19	578623	93683	574506	94840
'20	590565	95316	588352	97261
'21	597064	97510	600063	99792
'22	602049	99363	609822	101849
'23	605724	100807	617956	103694
'24	611734	102839	625095	105200
'25	624,950	105056	631653	106644
'26	640133	108037	637953	107974
'27	655305	110886	644021	109284
'28			650159	110605
'29			656883	111929
Plan*	2.2	2.4	2.1	2.2

*Annual average increase rate

II. METHODOLOGY

A. MESSAGE GENERAL DESCRIPTION

MESSAGE stands for Model for Energy Supply Strategy Alternatives and their General Environmental Impacts. MESSAGE software is used to set up models of energy systems (i.e. energy supplies and utilization) in order to find their optimum expansion path in the medium to long-term period. It was originally developed at the International Institute for Applied Systems Analysis (IIASA). The IAEA acquired the latest version of MESSAGE, and several enhancements have been made to it, most importantly the addition of a user-interface to facilitate its application. In its general formulation, MESSAGE allows building of dynamic linear programming (LP) models with a mixed integer option. The formulation and evaluation of the optimum capacity addition strategy of alternative technologies based on restrictions or constraints / bounds on new investment limits, fuel availability and trade, environment emissions regulations and market penetration rates for new technologies were made possible by MESSAGE by optimization of an objective function, which is defined as the total discounted energy system costs encompassing investment costs, fix, and variable operation and maintenance cost, cost induced by constraints and any additional penalty costs defined for limits, bounds, and constraints on relations.

The underlying principle of a model, built using the MESSAGE, is optimization of an objective function under a set of constraints that define the feasible region containing all possible solutions of the problem [9]. The value of the objective function helps to choose the solution considered best according to the criteria specified. In general categorization, models built using MESSAGE belong to the class of LP models with the option of mixed integer programming as they may contain some integer variables [9].

The main objective of developing the MESSAGE software, however, was to facilitate the building of an energy system model. An energy model is designed to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations and market penetration rates for new technologies. Environmental aspects can be analyzed by accounting; and if necessary limiting, the amounts of pollutants emitted by various technologies at various steps in energy supplies. This helps to evaluate the impact of environmental regulations on energy system development.

As shown in the Fig. 1, MESAGE is designed to develop an optimized model of an energy mix by optimization of the generated matrix. It is also used to present energy supply strategy alternatives, environmental impact models and to set up energy system models to find the optimal path. It provides an optimized predictive model numerically or graphically with finding the optimal route by inputting economic and social data

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that will affect power supply and demand. As mentioned at the introduction, three virtual scenario models for predicting future power supply and demand were predicted and simulated with MESSAGE.

As shown in the Fig. 2, an energy system is composed of many elements such as oil extraction facilities, imports, exports of energy forms. These elements form energy chains where primary energy is extracted from resources or imported in the form of oil, gas, coal, water, solar, wind. Secondary energy is obtained from these primary forms through conversion (typically a power plant producing electricity) or through a process (typically a refinery producing different types of fuels). The secondary energy forms are typically diesel, kerosene, gas, electricity, coal. Final energy is the energy delivered to the final user. It is obtained from secondary energy through the activities of transmission, transport and distribution [9].

A current existing scenario was simulated by MESSAGE according to forecasts of power supply from 2014 to 2031 without regulation of nuclear power and coal power generation. In the current existing scenario, the current plant data is entered in MESSAGE as it is, and the new plant planned by 2030 is also entered in MESSAGE. The second scenario was simulated to strengthen the low-carbon power mix. Carbon taxes imposed on carbon emissions under the Paris Climate Convention were applied to coal and oil power plants and over 30 years old coal power plants have been deleted to stop generation without extending their lifetime.

In the third scenario, nuclear power and coal plants that reached the end of their life time were shut down without life extension and nuclear and coal power plants were not added, according to the government 's policy to phase out nuclear power and coal power plants. Also, renewable energy was introduced up to 20% in 2030[3].

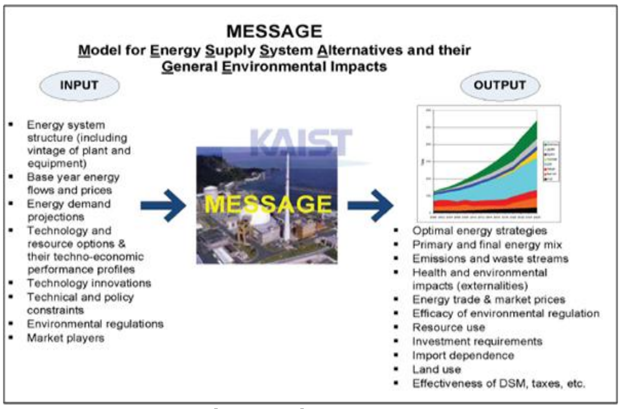

Fig. 1.Typical input and output using MESSAGE

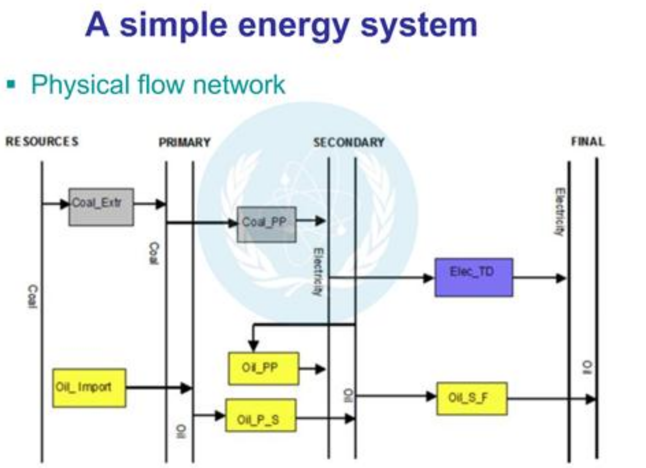

Fig. 2. Simple energy system of MESSAGE

B. BACKGROUND FACTORS FOR MESSAGE MODELING

1) GDP GROWTH & ELECTRICITY DEMAND GROWTH

The recent decline in electricity demand is due to the shift away from developed countries in the manufacturing sector, the increase in electricity rates, the expansion of self-generated power such as roof-type solar cells, and efforts to improve energy efficiency. According to the power unit analysis, which reflects the relationship between domestic economic growth and electricity demand, the downward trend of power consumption has recently increased compared to the past. Electricity demand growth was 1.8% in 2013 when GDP growth was 3%, electricity demand growth was only 0.6%, when GDP growth was 3.3% in 2014 as shown in the Table 6.

It is due to the government's strong energy saving policy. As mentioned earlier in the Electricity Demand Goal Forecast, electricity demand is estimated considering economic growth, electricity rates, population growth, weather forecasts, and etc. Thus, the annual average growth rate of 2.2% predicted by the 7th Plan is reliable data.

TABLE 6. POWER DEMAND & GDP

Year	Power Demand Growth (%)	GDP Growth (%)
2002	7.4	8
2003	2.9	5.4
2004	4.9	6.3
2005	3.9	6.5
2006	5.2	4.9
2007	5.5	5.7
2008	2.8	4.5
2009	0.7	2.4
2010	6.5	10.1
2011	3.7	4.8
2012	2.3	2.5
2013	1.8	3
2014	0.6	3.3

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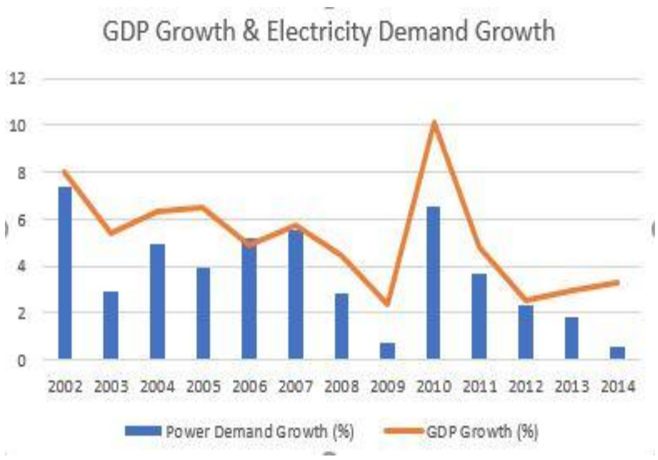

Fig. 3. GDP growth & electricity demand growth

2) FUEL COST & PLANT FACTOR

According to the Korea Power Exchange, the plant factor of each power generation fuel is shown in the Table 8. The reason for the low plant factor of gas power plants is that Korea Electric Power Corporation (KEPCO) purchases power with lower cost. As shown in the Table 7, the fuel cost of the nuclear power plant was 5.09 won per 1kWh, followed by coal 46.35 won and gas 145.54 won. Electricity production prioritizes a power plant with a low fuel cost, so the gas power plants don't operate by priority unless power is particularly not enough.

TABLE 7. FUEL COST (UNIT: $/KWH)

Year	2012	2013	2014	2015
Nuclear	0.0037908	0.0041327	0.0046315	0.0043174
Coal	0.0555462	0.0507583	0.0421747	0.0413481
Gas	0.1326704	0.1346825	0.1324295	0.1036775
Oil	0.2346312	0.2017441	0.1926206	0.1535239

TABLE 8. PLANT FACTOR (UNIT: %)

Hydro	Nuclear	Coal	Oil	Gas	Solar	Wind
36.83	85.24	87.62	26.66	38.68	14.33	15.96

3) POWER COST

In electrical power generation, the distinct ways of generating electricity incur significantly different costs. The cost is typically given per kilowatt-hour. It includes the initial capital, discount rate, as well as the costs of continuous operation, fuel, and maintenance. As shown in the Table 9, it shows the power cost per generation source.

TABLE 9. POWER COST (UNIT: $/KWH)

Year	2011	2012	2013	2014	2015
Nuclear	0.03393	0.03690	0.03700	0.04977	0.05349
Coal	0.05822	0.06186	0.05577	0.05926	0.06057
Gas	0.12347	0.15701	0.15245	0.14646	0.10783
Oil	0.19585	0.23634	0.20988	0.20089	0.12786
Hydro	0.14643	0.19975	0.12761	0.15605	0.11327
Renewable	0.09851	0.12708	0.13846	0.11803	0.09248

III. RESULTS

A. CASE 1: CURRENT EXISTING SCENARIO

This scenario considers the current existing energy policy. In the Fig 4, South Korea has an energy sector that makes coal, gas, and nuclear power generation as major source of power generation.

During the MEESAGE modeling, all investment and operation cost of the future years will be discounted to the first model year 2014 using the discount rate 6%. For this project, the basic model for estimating future electricity demand was adopted from Gross Domestic Product (GDP). However, the correlation between GDP growth rate and electricity demand is not similar in South Korea. The growth rate in this study was assumed by the annual average growth rate of 2.2% as mentioned in the Introduction C.

This scenario will be regarded as the current existing scenario and it includes the current existing energy sources and planned energy sources [6]. South Korea comprises seven types of power plants: the coal power plant, oil power plant, gas (LNG) power plant, hydropower plant, nuclear power plant, solar power plant and wind power plant.

The total installed capacity for the current existing scenario was 111929 MW. Coal power plants accounted for 35% (39099 MW) of total power generation by 2030, nuclear power plants accounted for 27% (30827 MW), and gas power plants accounted for 20% (23019 MW). Other hydropower and renewable power plants accounted for 17% (18985 MW) as shown in the Table 11. Fuel purchase prices vary from time to time, however nuclear power is typically inexpensive relative to coal, and gas (LNG) [4]. Therefore, fuel price competitiveness is the highest for nuclear power and lowest for gas. However, the construction cost of recently constructed nuclear power plants have risen sharply due to safety enhancements. As a result, coal power plants are considered to be more competitive power generation sources than other plants in the current existing scenario and account for the highest percentage. On the other hand, gas power plants accounted for about 20% of power generation due to expensive fuel.

As a result of calculation, the optimum mixture for long term plan of the case 1 is shown in the Table 10 and the total cost of electricity generation by fuel type for the case 1 is shown in the Table 11.

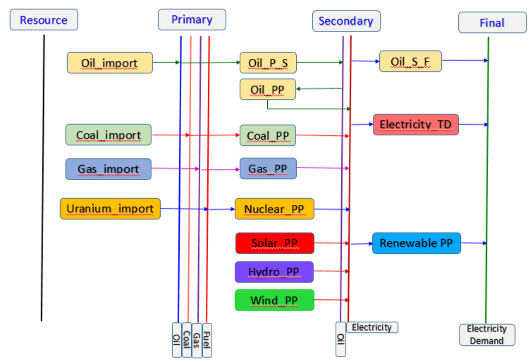

Fig. 4. Energy flow of South Korea for a current existing scenario

TABLE 10. ENERGY SHARE OF THE CURRENT SCENARIO

Years	2015-2017		2018-2021	
Fuel	MW	Share	MW	Share
Gas	4153	4.71%	8491	8.51%
Nuclear	30206	34.24%	32202	32.27%
Coal	37378	42.38%	40516	40.60%
Oil	3480	3.95%	5207	5.22%
Solar	4051	4.59%	3847	3.85%
Wind	2770	3.14%	2953	2.96%
Hydro	6168	6.99%	6575	6.59%
Total	88206	100%	99792	100%
Years	2022-2025		2026-2031	
Fuel	MW	Share	MW	Share
Gas	15219	14.27%	23019	20.57%
Nuclear	31793	29.81%	30827	27.54%
Coal	40323	37.81%	39099	34.93%
Oil	5638	5.29%	5729	5.12%
Solar	4263	4.00%	4134	3.69%
Wind	2916	2.73%	2827	2.53%
Hydro	6492	6.09%	6295	5.62%
Total	106644	100%	111929	100%

TABLE 11. GENERATION COST FOR THE CASE 1(UNIT: ONE MILLION $)

Year	2017	2021	2025	2030
Gas	7775	7775	1393	2107
Nuclear	13720	14627	14441	14002
Coal	19226	20840	20740	20111
Oil	3778	5653	6121	6220
Renewable	5356	5340	5638	5466
Total	49856	54236	60878	66879

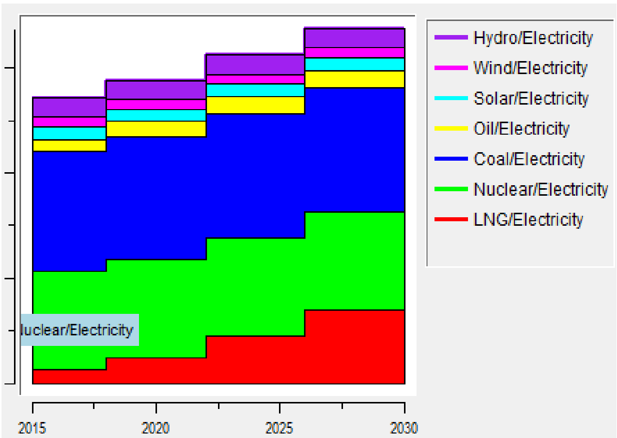

Fig. 5. MESSAGE result of the current existing scenario

B. CASE 2: STRENGTHENING THE LOW CARBON POWER MIX

The energy flow for this scenario is almost the same as the energy flow of the current existing scenario, however in this case the focus is the coal and oil power plants, as shown in the Fig. 6.

Under the scenario of strengthening the low-carbon power mix, the carbon tax was imposed on coal and oil power plants. As shown in the Table 13, the total installed capacity was 111929 MW. Coal power plants accounted for 30% (33836 MW) of total power generation by 2030, nuclear power plants accounted for 28% (31470 MW), gas power plants accounted for 30% (32431 MW), and other power plants accounted for 13% (14192 MW). Despite the high fuel price competitiveness and low investment cost of coal power plants, the amount of power generation was reduced due to the carbon tax, and the power generation of gas power plants absorbed the reduced power generation of coal and oil power plants as shown in the Table 12. As shown in the table 13, the amount of generation cost can be calculated by the power cost and the rate of power generation as follows.

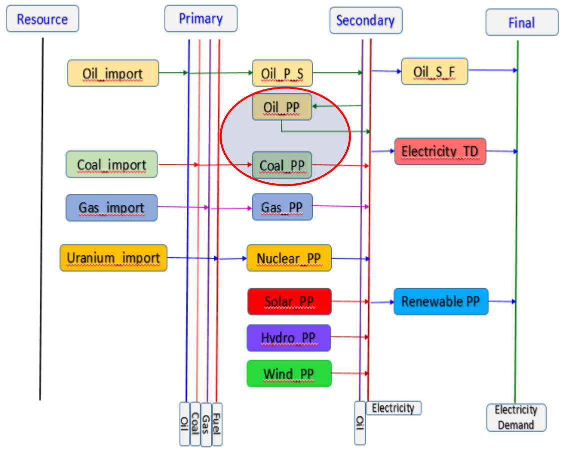

Fig. 6. Energy flow of South Korea for the scenario 2

TABLE 12. ENERGY SHARE OF THE STRENGTHENING THE LOW CARBON

Years	2015-2017		2018-2021	
Fuel	MW	Share	MW	Share
Gas	11347	12.86%	17453	17.49%
Nuclear	30835	34.96%	32874	32.94%
Coal	32765	37.15%	35330	35.40%
Oil	0	0.00%	0	0.00%
Solar	4135	4.69%	4408	4.42%
Wind	2828	3.21%	3015	3.02%
Hydro	6296	7.14%	6712	6.73%
Total	88206	100%	99792	100%
Years	2022-2025		2026-2031	
Fuel	MW	Share	MW	Share
Gas	25337	23.76%	32431	28.97%
Nuclear	32455	30.43%	31470	28.12%
Coal	34896	32.72%	33836	30.23%
Oil	0	0.00%	660	0.59%
Solar	4352	4.08%	4220	3.77%
Wind	2977	2.79%	2886	2.58%
Hydro	6627	6.21%	6426	5.74%
Total	106644	100%	111929	100%

TABLE 13. GENERATION COST FOR THE CASE 2(UNIT: ONE MILLION $)

Year	2017	2021	2025	2030
Gas	10390	15982	23200	29697
Nuclear	14006	14932	14742	14294
Coal	16853	18172	17949	17404
Oil	0	0	0	716
Renewable	5468	5829	4970	5565
Total	46718	54916	60863	67677

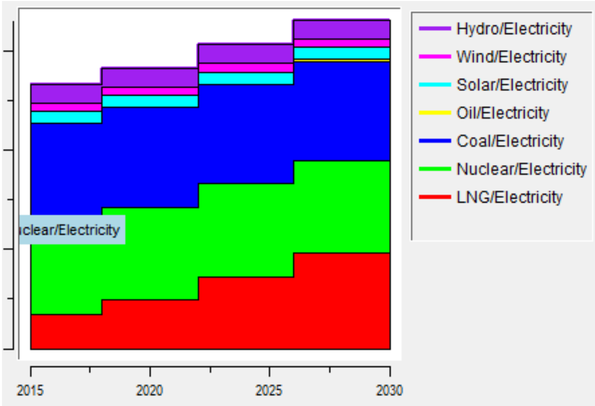

Fig. 7. MESSAGE result of the strengthening the low carbon power mix

C. CASE 3: EXPANSION OF RENEWABLE ENERGY

In this scenario, renewable energy generation was expanded up to 20% according to the policy of renewable energy expansion by 2030 [4]. The construction of new coal power plants and new nuclear power plants is not considered. Instead, renewable power plants and gas power plants are added as shown in the Fig 8. As a result, the total installed capacity was 111929 MW. Coal power plants accounted for 22% (24638 MW) of total power generation by 2030, 22% (25176 MW) for nuclear power generation, 26% (29469 MW) for gas power generation, 20% (22827 MW) for renewable power generation, and 9% (9920 MW) for other power plants as shown in the Table 14. Despite in no addition of new nuclear power plants and new coal power plants, coal power plants maintained a significant amount of power generation due to fuel and construction costs competitiveness. Nuclear power plants also maintained high power generation without additional construction due to fuel cost competitiveness. As a result of the increase in new gas power plants in accordance with the government's new energy policy, Case 3 showed the most ideal and optimized energy mix. As shown in the table 15, the amount of generation cost can be calculated by the power cost and power generation as follow. The amount of electricity increased by 11% (7221 million dollars) compared to the case 1 and increased to 10% (6423 million dollars) compared to the case 2. The main reason is the increase in gas power plants and renewable power plants which have higher power generation cost.

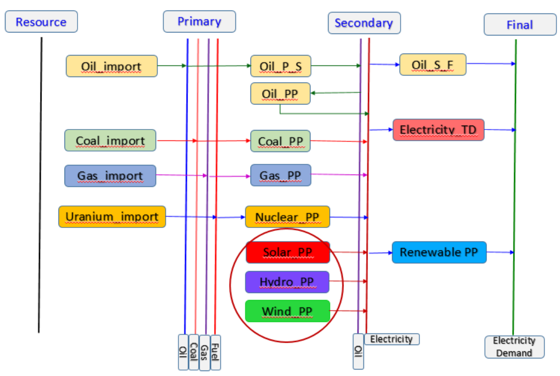

Fig. 8. Energy Flow of South Korea for the scenario 3

TABLE 14. ENERGY SHARE OF THE EXPANSION OF RENEWABLE ENERGY

Years	2015-2017		2018-2021	
Fuel	MW	Share	MW	Share
Gas	24482	27.76%	29139	29.20%
Nuclear	24668	27.97%	26299	26.35%
Coal	24142	27.37%	25738	25.79%
Oil	4585	5.20%	4888	4.90%
Hydro	5037	5.71%	5370	5.38%
Renewable	5292	6.00%	8359	8.38%
Total	88206	100%	99792	100%
Years	2022-2025		2026-2031	
Fuel	MW	Share	MW	Share
Gas	31204	29.26%	29469	26.33%
Nuclear	25964	24.35%	25176	22.49%
Coal	25410	23.83%	24638	22.01%
Oil	4825	4.52%	4679	4.18%
Hydro	5302	4.97%	5141	4.59%
Renewable	13939	13.07%	22827	20.39%
Total	106644	100%	111929	100%

TABLE 15. GENERATION COST FOR THE CASE 3(UNIT: ONE MILLION $)

Year	2017	2021	2025	2030
Gas	22418	26682	28573	26984
Nuclear	11205	11945	11793	11435
Coal	12417	13238	13070	12673
Oil	4977	5306	5239	5080
Renewable	4156	6564	10946	17927
Total	55175	63738	69623	74100

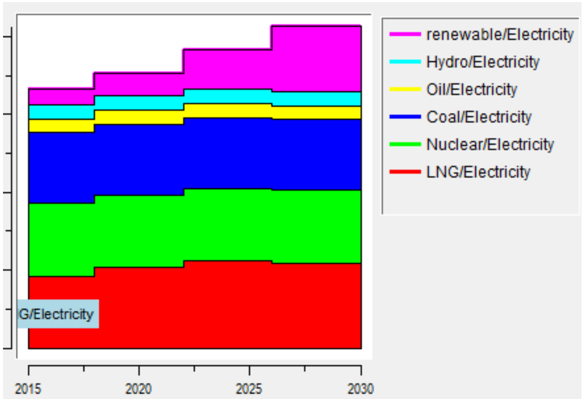

Fig. 9. MESSAGE result of the expansion of renewable energy

Ⅳ. CONCLUSION

The South Korean government has decided to cease construction of new nuclear and coal power plants in its long term energy policy. Instead, it plans to replace the shortage of power due to the reduction of power generation by renewable energy and gas power generation in the long term. Moreover, it plans shutting down nuclear power plants that have reached their end of lifetime [3][4]. The government also proposed a policy of expanding renewable energy by 20% by 2030 [4].

However, there are many difficulties in expanding ratio of renewable energy and gas power plants. Renewable energy sources such as solar and wind power, which are recommended by the government, are limited by geographical conditions and the generation efficiency is less than about 20%. In addition, operation time is limited by climate conditions and life time is shorter than other plants. Therefore, in order to replace nuclear power and coal power, it highly requires not only the time but also the technical development to improve efficiency and life

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time etc. Moreover, gas plant also has a lot of disadvantages such as high generation costs, requirement for large volume of fuel handling, and energy security etc. In particular, South Korea, which has no gas resources, must import a huge amount of LNG from foreign countries.

Therefore, nuclear and coal power generation is still an important energy source in Korean economic environment. It is necessary to establish gradually a stable and safe energy policy by mixing various power generation sources such as gas and renewable energy as well as nuclear power and coal power rate. Thus, it is strongly required to establish a sophisticated and realistic energy roadmap that can contribute to the development of Korea's industrial economy in the long term phase.

Ⅴ. ACKNOWLEDGEMENT

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