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Cost Assessment of 2030 Electricity Generation Mixes Changing the Nuclear Energy Portion under South Korean Nationally Determined Contribution Target

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1. Introduction

In October 2021, the Korean government announced the National Greenhouse Gas Reduction Goals, so called 'Nationally Determined Contribution (NDC).' The first NDC of Korea, which was established in 2015, aimed at 37% reduction in Greenhouse Gas (GHG) emissions compared to the BAU of 2030. Through revisions, the South Korean NDC has been solidified in its current form of 40% reduction in GHG emissions compared to 2018 by 2030 (hereafter referred to as 3040 NDC plan) [1].

The largest amount of carbon reduction in the 3040 NDC plan takes place in the energy conversion sector, to which a 119.7MtCO2eq reduction is allocated by 2030 from 269.6MtCO2eq in 2018. A controversial problem is how to determine the target proportions of electricity generation produced by major sources in 2030 to meet the reduction goal. In the plan, the Korean government suggests an electricity generation mix in 2030 based on its nuclear phase-out policy which refrains from building additional nuclear power plants (NPPs) and prohibits life extensions of all the NPPs.

In this paper, we compare investment and annual electric power generation costs for three electricity generation mixes to meet the 2030 NDC goal – the government scenario under the nuclear phase-out policy, a scenario with two new NPP constructions of Shin Hanul Units 3 and 4, and a scenario considering the NPP life extension in addition to the two new NPP constructions.

2. Methods and Results

2.1. Scenario selection

For performing cost assessment, three scenarios were determined considering the feasible options of new construction and continuous operation of NPPs. The first scenario assumes a situation in which the electricity generation mix of 2030 follows the 3040 NDC plan. The second scenario postulates that Shin Hanul Units 3 and 4 corresponding to 2.8 GWe of equipment capacity, of which constructions have been suspended, will be operated until 2030. The third scenario assumes that 10 NPPs of which the design life expires by 2030 will be extended with the resumption of construction of Shin Hanul Units 3 and 4. In particular, two detailed scenarios were considered under the conditions of scenario 3. Scenario 3-1 decreases the proportion of renewable energy generation and Scenario 3-2 decreases the proportion of coal-fired generation to reduce the GHG emissions as the proportion of nuclear power generation increment. The capacity of major electric power generation sources by scenarios is shown in the following Table 1. In the case of coal-fired power generation, a method of balancing the capacity factor to meet the required electricity generation amount was adopted while the equipment capacity was fixed.

Table I: Equipment capacity of sources by scenarios

	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2
Nuclear	20.4	23.2	31.7	31.7
LNG	50.1	48.3	42.9	50.1
Solar PV	124.4	110.0	67.3	124.4
Wind	12.5	11.0	6.73	12.5
ESS	410.5	363.0	222.1	410.5
Ammonia	9.3	8.9	8.0	9.3

(Unit: GWe, GWh)

2.2. Simulation method of daily electricity generation by time in 2030

According to the 3040 NDC plan, the annual required electricity generation estimation for 2030 is 612.4 TWh. The simulation was conducted assuming that the daily power demand by time in 2030 will follow the same shape as in 2020. We used the KPX (Korea Power Exchange) 2020 electric power generation data [2] by multiplying the annual total electricity generation ratio of 2020 and 2030 to simulate the electricity generation in 2030.

In the case of nuclear power generation, we applied 82% capacity factor with an annual uniform operation for each scenario. The coal-fired power generation was also assumed as a baseload, uniformly generating energy without fluctuations in annual operation.

Only three power generation sources were considered for renewable energy sources: hydropower, wind, and solar PV (Photovoltaic). In the case of hydropower, a 20% capacity factor with 2 GWe equipment was assumed. Next, the equipment capacities of wind and solar PV were set at a ratio of 1:10 considering the current equipment capacity and were adjusted to meet the target amount of the annual renewable energy generation in each scenario. The capacity factor of wind and solar PV were assumed to be 27.2% and 15%, respectively. After that, we calculated the hourly electricity generation of wind by multiplying the equipment capacity ratio of 2020 and 2030 by the 2020 renewable energy hourly electricity generation data of KPX. In the case of solar PV power generation, the daily power generation data of KPX in 2020 was also used. For solar PV power generation by hour, the simulation was carried out under assumption that the solar PV power generation shape follows the year-averaged regular hourly generation fraction of {0.000, 0.000, 0.000, 0.000, 0.000, 0.000, 0.004, 0.019, 0.049, 0.085, 0.118, 0.139, 0.146, 0.139, 0.120, 0.091, 0.056, 0.025, 0.007, 0.000, 0.000, 0.000, 0.000, 0.000}.

Wind and solar PV are rigid sources influenced by the weather. Therefore, Energy Storage Systems (ESS) are required to cope with the intermittency of renewable energy sources by storing surplus energy in a high generation time and releasing it in the evening when the electricity generation is insufficient. In this study, the ESS capacity was assumed to be three times the wind and solar PV power generation equipment capacity. The energy conversion efficiency factor was set to be 0.85 and the charge/discharge capacity ratio of 0.8 was applied.

Lastly, LNG, ammonia, pumped-storage generation, and other power sources were assumed that the remaining loads except nuclear, coal, and renewable energy are generated by these non-rigid power generation sources to satisfy the proportion of annual electricity generation.

2.3. Calculation Criteria

In each scenario, the investment cost and annual electricity generation cost were calculated based on the investment cost and the LCOE (Levelized Cost of Energy) data with a 7% interest rate case presented by IEA (International Energy Agency) [3].

There are some power generation sources that Korean data did not exist in the IEA data. In that case, the following criteria were applied. First, the US data of nuclear continuous operation was used for investment cost, and the LCOE data of Korea's new construction was used for electricity generation cost. The investment cost of ESS equipment was assumed to be 0.4 trillion won per GWh, and only depreciation cost was applied under the assumption of a 10-year lifespan and an 7% interest rate. In the case of ammonia power generation, which is currently an unimplemented technology, 3 trillion won per GWe and 200 won per kWh were assumed under consideration of the investment cost of CCUS LNG power generation. For other power generation costs, the average value of pumped-storage LCOE in Australia and fuel cell LCOE in France, 126.4 won per kWh, was applied.

For the simulation of Scenario 3-2, which evaluated the amount of GHG emission reduction by decreasing additional coal-fired power generation equipment, we used the life cycle CO_2 equivalent emission coefficient for each source provided by IPCC (Intergovernmental Panel on Climate Change) [4].

2.4. Results

The annual electricity generation proportion for each power source is calculated through the sum of daily electricity generation obtained by simulation. Fig. 1 shows the average daily hourly electricity generation in 2030. In scenario 1, the average surplus electricity generation amount during the daytime is up to 33.8 GWe since the proportion of solar PV is high. The maximum surplus electricity generation decreases to 28.4 GWe in scenario 2 and 13.4 GWe in scenario 3-1 as the proportion of nuclear power generation increases and the proportion of renewable energy decreases. In scenario 3-2, the daytime surplus electricity generation is maintained the same as in scenario 1. Compared to scenario 1, only nuclear power and coal-fired power generation at the bottom of the graph are exchanged. Annual nuclear power generation proportion, which accounted for 23.9% (146.5 TWh) of total power generation in scenario 1, is increased to 27.2% (166.7 TWh) in scenario 2 and 37.1% (227.3 TWh) in scenario 3. The total annual electricity generation by major power generation sources is shown in Table 2.

Based on the values presented in Table 1 and Table 2, investment cost and annual electricity generation cost in 2030 are calculated. Table 3 shows additional equipment investment costs, and Table 4 shows annual electricity generation costs for each scenario. As a result of the cost assessment of scenarios 1, 2, and 3-1, both equipment investment cost and annual electricity generation cost tend to be reduced when the proportion of renewable energy is decreased as the proportion of nuclear energy is increased. In the case of scenario 3-2, compared to scenario 1, equipment investment cost rather increases while annual electricity generation cost decreases.

Table II: Annual electricity generation by sources

	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2
Nuclear	146.5	166.7	227.3	227.3
Coal	133.2	133.2	133.2	52.4
LNG	119.3	119.3	119.3	119.3
Hydropower	3.5	3.5	3.5	3.5
Solar PV	152.4	135.8	85.0	152.4
Wind	29.3	26.0	16.0	29.3
Ammonia	22.1	22.1	22.1	22.1
Etc.	6.0	6.0	6.0	6.0

(unit: TWh)

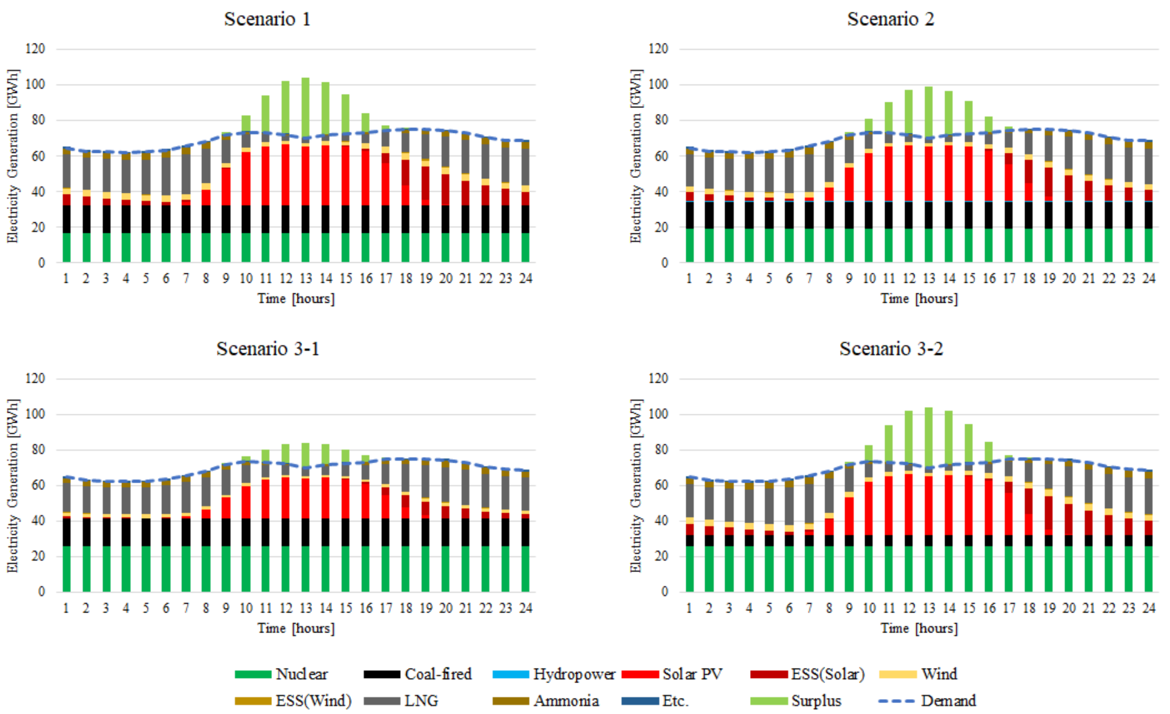

Fig. 1. Average daily hourly electricity generation in 2030 by scenario

Table III: Additional equipment investment cost

	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2
Nuclear	0.0	8.5	12.4	12.4
Solar PV	148.7	128.5	68.7	148.7
Wind	44.1	32.3	18.2	44.1
ESS	164.2	145.2	88.8	164.2
Ammonia	27.8	26.8	24.1	27.8
Total	377.8	341.4	212.3	390.2

(unit: trillion won)

Table IV: Annual electricity generation cost

	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2
Nuclear	8.6	9.8	13.3	13.3
Coal	13.1	13.1	13.1	5.2
LNG	12.7	12.7	12.7	12.7
Solar PV	16.2	14.4	9.0	16.2
Wind	4.6	4.1	2.5	4.6
ESS	21.9	18.4	11.8	21.9
Ammonia	4.4	4.4	4.4	4.4
Etc.	0.8	0.8	0.8	0.8
Total	82.2	78.6	67.7	79.0

(unit: trillion won)

Instead of less competitiveness in terms of cost, scenario 3-2 shows an advantage for carbon emission reduction. The reduction in coal-fired power generation leads to an additional reduction in carbon emissions compared to other scenarios. The amount of carbon equivalent GHG emission is calculated to be 111.9 $MtCO_2eq$ (Metric tons of CO_2 equivalent) in scenario 3-2, which is a considerably reduced value compared to 177.2 $MtCO_2eq$ in scenario 1 and 174.8 $MtCO_2eq$ in scenario 3-1.

3. Conclusions

In this study, we performed a cost assessment for three scenarios depending on the capacity of nuclear power generation equipment. The assessment result shows that the resumption of construction of Shin Hanul Units 3 and 4 and continuous operation of the NPPs have advantages in both terms of cost and carbon emission reduction in the process of implementing the Korean NDC target.

REFERENCES

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