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Scenario-based Economic Analysis with Electricity Mix Simulation Model from 2024 to 2045 Based on the Korean 11th Basic Plan for Electricity Supply and Demand

Pilhyeon Ju[a], Ji Eon Kim[a], Jongho Lee[b*], Sungyeol Choi[a,b,c*]
[a] *Department of Nuclear Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu,*
Seoul 08826, Republic of Korea
[b] *Nuclear Research Institute for Future Technology and Policy, Seoul National University, 1 Gwanak-ro, Gwanak-gu,*
Seoul 08826, Republic of Korea
[c] *Institute of Engineering Research, Seoul National University, 1 Gwanak-ro, Gwanak-gu,*
Seoul 08826, Republic of Korea

**Corresponding authors: jhlee6108@snu.ac.kr, choisys7@snu.ac.kr*

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1. Introduction

The Government of the Republic of Korea has made an effort to reduce the carbon emissions in the electricity sector. Research and policies continue to be made to seek an optimized electricity mix enabling harmonization between nuclear and renewable energy. The 11th Basic Plan for Electricity Supply and Demand (11BP), finalized in 2025, is one of the policies which supports this trend related to the future electricity mix. Accordingly, further research about scenario analyses and economic evaluation is required for the electricity mix plan mentioned in the 11BP. As the 11BP involves the gradual increase of renewable energy, it is of significant importance to consider systematic and economic analyses for the future electricity system, such as the intermittency of the renewable energy, the following occurrence of negative load, and the quantitative calculation of required Battery Energy Storage System (BESS) capacity.

This study aims to analyze the Korean future electricity mix from 2024 to 2045 with three scenarios, which have been newly established based on the 11BP. In previous studies, simulation models have been developed: a seasonal-daily averaged simulation model [1] and a seasonal-weekly averaged simulation model [2]. This study newly develops a module which enables an economic evaluation by combining it with the previous seasonal-weekly averaged simulation model. The module proceeds the economic evaluation for the three scenarios, with the sensitivity analysis to see the interactions between the nuclear energy and BESS.

2. Methodologies

The simulation model derives the seasonal electricity supply and demand patterns based on the input values of electricity generation and capacity for each power source. Based on the patterns, the model calculates the required BESS capacity corresponding to the electricity mix in the specific year by deriving the power amount of excess and shortage for each season. As the analysis period is set from 2024 to 2045, this study sets the future electricity mix from 2024 to 2038 based on 11BP and that from 2039 to 2045 according to each scenario.

2.1. Assumptions for simulation model

To simplify the calculation, the power sources applied are as follows: nuclear power, renewable energy (Solar Photovoltaic (PV) and wind only), coal power, Liquefied Natural Gas (LNG) and Carbon-Free Gas Turbine (CFGT). The LNG is applied as a flexible power source to adjust the imbalance of the power between daytime and nighttime. The load-following operation of nuclear power is also applied for the adjustment. The other renewable sources excluding solar PV and wind are classified 'Others' and assumed to be applied the same as LNG during the economic evaluation.

Table I. Electricity Mix for the Years Mentioned in the 11th Electricity Supply and Demand Plan [3]
(calculated/assumed values with purple color).

Year	Nuclear	Solar PV	Wind	Coal	LNG	CFGT	Others	Total	Adjusted
(2023)	180.5	36.5	5.1	184.9	157.7	0.0	23.4	588.0	60.0
2030	204.2	73.2	42.4	110.5	161.0	15.5	35.8	642.6	114.6
2032	215.4	81.1	57.7	102.8	135.5	22.8	49.7	665.1	137.1
2034	233.0	89.1	69.6	97.1	103.8	28.5	60.7	681.7	153.7
2036	236.9	95.8	82.5	83.5	91.1	36.1	67.4	693.3	165.3
2038	248.3	101.4	94.4	70.9	74.3	43.9	71.2	704.5	176.5

(Unit: TWh)

Table II. Capacity Amount in Each Year [3-7] (calculated values with purple color).

Year	Nuclear	Solar PV	Wind	Coal	LNG	CFGT	Others	PSH
2024	26.1	28.2	2.3	40.2	46.3	0.6	3.4	4.7
2030	28.9	55.7	18.3	31.7	59.2	5.7	4.8	5.2
2032	30.3	61.7	24.9	29.7	63.1	10.6	6.7	5.8
2034	32.0	67.8	30.0	28.1	64.7	17.8	8.1	7.9
2036	32.4	72.9	35.5	27.1	65.7	26.0	9.0	9.4
2038	35.2	77.2	40.7	22.2	69.1	40.8	9.6	10.4

(Unit: GW)

The shortage of power during the nighttime is covered by Pumped Storage Hydropower (PSH) and BESS. As the PSH has a fixed amount of capacity, BESS compensates for the remaining power shortage.

The total demand is set to follow the total power generation amount from 11BP (2024-2038), and is set to have values interpolated for the years not mentioned in 11BP [3]. The values for the years from 2039 and 2048 were set to be extrapolated from the value of 2038. The electricity mix from 2024 to 2038 based on the 11BP is summarized in Table I. Here, as the power excess and shortage differs in each season, some amount of the demand ('Adjusted' in Table I) is distributed unevenly across the seasons.

The capacity amounts for each power source are also based on the capacity plans from 11BP [3], but has been cross-checked with other data such as Statistics of Electric Power in Korea in 2023 and 2024 [4-5] and Power Generation Facility Status from Electric Power Statistics Information System (EPSIS) in 2023 and 2024 [6-7]. The capacity amounts of each power source from the data are summarized in Table II.

The capacity factors for nuclear power and coal power are calculated internally from the power generation amount and capacity, but are set to be constant values for solar PV (15.0%) and wind (26.5%); the values of which are from the report of International Energy Agency (IEA) [8] cited in this study for the economic evaluation. The capacity factor of CFGT is set to be the same values with that of LNG in each year, and the capacity factor of Others is set to be 85%.

2.2. Selection of scenarios

This study establishes the three scenarios as shown in Table III. Scenario 1 is a reference scenario, in which the generation share of the nuclear power is set to be 35.2% (calculated from 11BP electricity mix in 2038 [3]) from 2038 to 2045. The generation share of renewable energy also increases gradually from 27.8% in 2038 to 35.0% in 2045. Scenario 2 assumes the suspension of additional construction of nuclear power plants, leading to a decrease in the generation share of nuclear power from 35.2% in 2038 to 31.5% in 2045. The decreased amount of power generation is assumed to shift to renewable energy, leading to its generation share increasing to 38.9% in 2045. Scenario 3, conversely, adjusts the generation share of the renewable energy to 30.0% in 2045, and the decreased amount of power generation is assumed to shift to nuclear power, leading to its generation share increasing to 40.3% in 2045.

The same capacity factors for each power source in each year are applied in all scenarios, and the capacity amounts are adjusted in accordance with the generation share for each power source. In all scenarios, the coal power is assumed to decrease linearly from 2039 to 2045, while LNG and CFGT remain the same from 2039 to 2045.

Table III. Summary of Scenarios Applied in This Study.

Scenario	Description	
	Nuclear in 2045	Renewable in 2045
Scenario 1 (Reference)	*"Fixed Nuclear Share (2039-2045, 35.2%)"*	
	35.2%	35.0%
Scenario 2	*"Suspension of Adding Nuclear Power Plant"*	
	31.3%	38.9%
Scenario 3	*"Renewable Share of 30.0% in 2045"*	
	40.3%	30.0%

For the sensitivity analysis, the additional nuclear power plants of 2.8 GW and 5.6 GW are assumed to be constructed in 2040 for Scenario 1, while the rest of the conditions remains the same. Here, the excess power additionally generated is assumed to be curtailed (i.e., not utilized) within the electricity system. This aims to see how the required BESS capacity changes by the decrease of power shortage during the nighttime as the nuclear power generation increases.

2.3. Unit cost for economic evaluation

This study utilizes the data for unit costs of each power sources from the IEA report, applying the exchange rate of 1,101 KRW/USD mentioned in the report [8]. The data for the Republic of Korea was selected for most of the power sources, while the values of the median or with similar scale compared to the values from the Republic of Korea are selected for some power sources when they do not have the data for the Republic of Korea. The unit Capital Expenditure (CAPEX), unit Operating Expenditure (OPEX) and unit Decommissioning cost (D) are summarized in Table IV; the overnight cost is applied in CAPEX [8]. The OPEX of CFGT was selected to be the same with that of LNG, but the fuel cost was adjusted as the CFGT utilizes hydrogen as its fuel. The D was assumed to be a constant ratio of CAPEX for each power source (15% for the nuclear power and 5% for the others), as applied in the same manner in the IEA report [8].

Table IV. Unit CAPEX, OPEX and D
for Each Power Source [8].

Power Source	CAPEX	OPEX	D
Nuclear (New)	3.038	30.575	0.356
Nuclear (LTO*)	0.648	24.497	
Solar PV	1.413	14.214	0.068
Wind (Onshore)	2.257	31.070	0.109
Wind (Offshore)	4.009	49.655	0.194
Coal	1.454	69.022	0.063
LNG	1.352	91.361	0.061
CFGT	1.352	152.007	0.061
Others	1.352	91.361	0.061
PSH	1.021	3.754	0.049
BESS [/GWh]	0.426	20.952	0.021

(Unit: trillion KRW/GWe for CAPEX and D,
KRW/kWh/yr for OPEX)
(LTO*: Long-Term Operation)

This study proceeds the economic evaluation with real values – not considering the effect of inflation – calculating the total investment cost and annual generation cost. For the total investment cost, the linear expense schedule for the new capacity is applied as in the IEA report considering the construction period for each power source [8]. The timing of new capacity installation is set considering the lifespan (N) of each power source [8]. The construction period and the lifespan are summarized in Table V.

Table V. Construction Period and Lifespan
for Each Power Source [8].

Power Source	Construction Period	Lifespan
Nuclear (New)	7	40 (PWR*) 30 (PHWR**)
Nuclear (LTO)	2	20
Solar PV	1	25
Wind	1	25
Coal	4	40
LNG	3	30
CFGT	3	30
Others	3	30
PSH	5	80
BESS	1	10

(Unit: yr)
(PWR*: Pressurized Water Reactor)
(**PHWR: Pressurized Heavy Water Reactor)

For the annual generation cost, CAPEX and D are annualized by utilizing the Capital Recovery Factor (CRF, Equation 1). Here, the discount rate (i) of 7% is applied as in the IEA report [8].

$$\mathrm{CRF} = \frac{i(1+i)^N}{(1+i)^N - 1} \qquad (1)$$

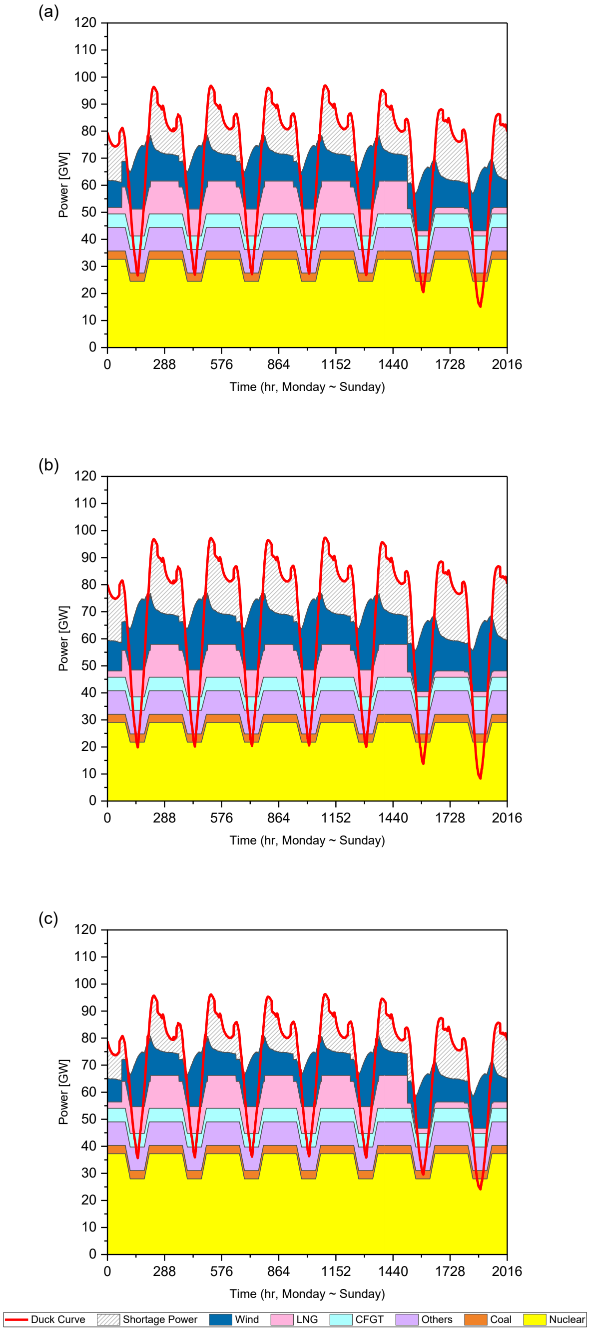

Fig. 1. Calculation results of electricity mix simulation model for 2045 spring season in each scenario: (a) Scenario 1, (b) Scenario 2 and (c) Scenario 3.

3. Results and Discussion

3.1. Electricity mix simulation

Fig. 1 shows the results of calculation from the simulation model for each scenario. The electricity mix of each scenario in each year is applied to the model by setting the representative weeks for each season, thus calculating the required BESS capacity to cover the power shortage in the year. The calculation results for the BESS capacity is summarized in Fig. 2. More BESS capacity is required in Scenario 2 compared to Scenario

1 as the generation share of renewable energy is higher in Scenario 2. In Scenario 3 with high generation share of the nuclear power, the electricity system can cover the nighttime power shortage requiring less BESS capacity.

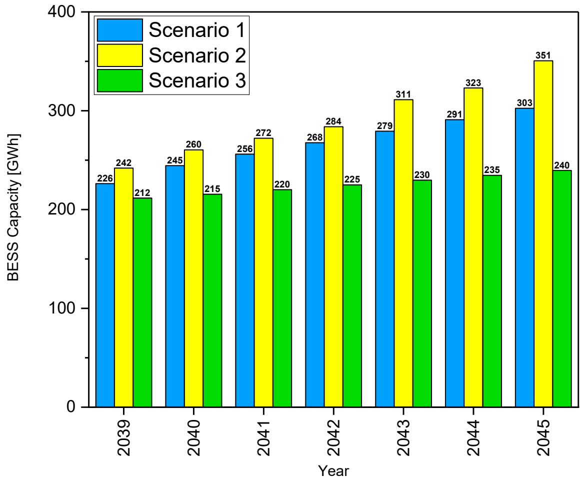

Fig. 2. Required BESS capacity calculated from the simulation model for each scenario.

3.2. Economic evaluation

The left side of Fig. 3 shows the total investment costs from 2024 to 2045 in each scenario. Scenario 2 with its high generation share of renewable energy requires more investment cost of about 659 trillion KRW than Scenario 1 (about 621 trillion KRW). Scenario 3, on the other hand, requires less investment cost of about 572 trillion KRW with less installation of BESS capacity, despite the increased nuclear power plant capacity.

The annual generation costs in 2045 for each scenario are summarized in the right side of Fig. 3. A similar trend with the total investment costs is shown in the annual generation costs as well; Scenario 2 has the highest cost of 145.6 KRW/kWh, while Scenario 3 has the lowest cost of 131.6 KRW/kWh. This demonstrates that the deployment of BESS led by the renewable energy clearly affects the overall electricity system.

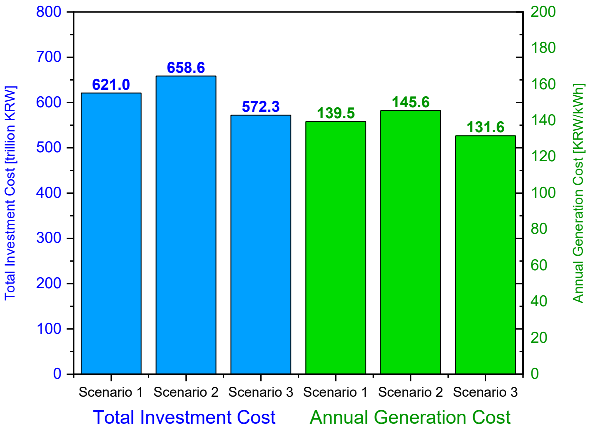

Fig. 3. Total investment cost (Left) and annual generation cost (Right) for each scenario.

3.3. Sensitivity analysis

The increase of the nuclear power plant capacity and the following increase of the total power generation, with the curtailment of excess power in daytime, lead to a decrease in the power shortage during the nighttime and lead to a decrease of required BESS capacity. Fig. 4 shows the change in the total investment cost and annual generation cost in accordance with the addition of nuclear power plant in 2040. The increased nuclear power plant capacity decreases the total investment cost from 10 to 15 trillion KRW, and decreases the annual generation cost up to 4.3 KRW/kWh. This implies that increasing the number of nuclear power plants may lower the cost of the electricity system by reducing the required BESS capacity, even if the excess power during daytime is curtailed.

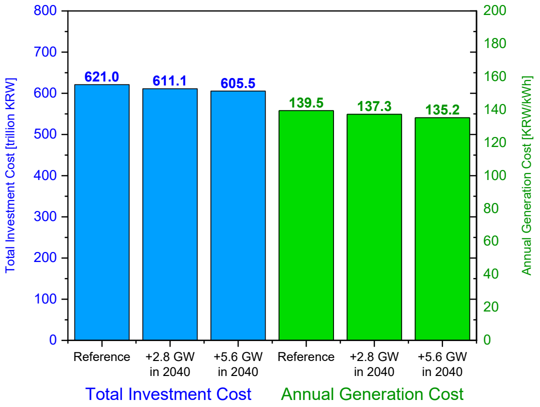

Fig. 4. Change of total investment cost (Left) and annual generation cost (Right) from sensitivity analysis.

4. Conclusions

This study has developed a module for the economic evaluation which is combined with the previous seasonal-weekly averaged simulation model, and has analyzed the three scenarios of Korean electricity mix from 2024 to 2045 established with the basis of the 11BP data. The results showed that Scenario 2 with a higher ratio of renewable energy required a higher total investment cost and annual generation cost, while Scenario 3 with a higher ratio of nuclear power required less cost compared to the reference Scenario 1. Also, the addition of nuclear power plants with the excess power curtailed turned out to reduce the cost of the overall electricity system under identical conditions.

Future works will involve the conversion loss of PSH and BESS, and the power demand for hydrogen production based on the excess power, improving the scenario and economic analysis more delicate.

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