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# Analysis of Nuclear Power Build-up Scenario for Net Zero Carbon in 2050

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## 1. Introduction

In October 2021, the Korean government announced the 2050 Net-Zero Scenarios with the goal of greenhouse gas reduction. The scenarios consist of scenario A and B. Especially, the target amount of greenhouse gas emission is set to be zero in scenario A. The government is willing to achieve the goals by increasing renewable energy usage to account for most of the total power production in the energy sector.

To analyze the economy of the scenario with the drastically expanded renewable energy, this study suggests Nuclear Power Build-up scenarios and compares them with the government's scenario A. In order to apply the property of renewable energy, we developed a new simulation model which can describe the future power supply and demand. The verification of the model was conducted with the government's scenario A.

## 2. Model Development and Verification

In the future power system, the power supply-demand pattern turns out to be asymmetric in day and night. It is mainly due to the high proportion of renewable energy, which operates intermittently. Therefore, the existing methodology for scenario application using yearly Load Duration Curve (LDC) has its limit for planning the future energy mix, as it analyzes 8,760 hours comprehensively.

To consider the characteristics of renewable energy sources in the energy mix, this study developed a simulation model describing daily average power supply and demand for each season. For the verification of the model, we apply the government's scenario A, using the same value of power production for each energy and total sum [1].

Table I: Power Production in Government's Scenario A [1].

| | | | |
|---|---|---|---|
| Nuclear | 76.9 | Carbon-free Gas turbine | 270.0 |
| Renewable | 889.8 | | |
| Fuel Cell | 17.1 | By-product Gas | 3.9 |
| Sum | | 1,257.7 | |

(Unit: TWh)

Regarding the total power demand, the power production pattern of 2017 from Korea Power Exchange [2] is used in this study, since the renewable energy did not influence on the total power demand in earnest until 2017. Here, the Transmission and Distribution Loss (T&D Loss) is not considered in the total power demand so that it is set to be the same value with the total power production. In addition, we assume that the hydrogen is produced only with the excess power in daytime, so the amount of demand for hydrogen production is excluded from the total power demand. The demand for hydrogen production is given in the Basis of Calculation for Net-Zero Scenarios: 235.3 TWh (before considering T&D Loss) [3].

Also, as Chun has analyzed the renewable energy production patterns of 2017 [4], we use the same 2017 patterns in this study. Otherwise, the same assumptions with the Basis of Calculation for 2050 Net-Zero Scenarios are applied: 5% curtailment, power storage with the ratio of 1:3 in Pumped-storage Hydroelectricity (PSH) and Energy Storage System (ESS) on the basis of total shortage at nighttime, and the following conversion loss (20% and 10% for each) [3].

Fig. 1 shows the result of applying the data of scenario A in the model as an example. In Fig. 1 the daily average power supply and demand in spring is shown, with the daytime excess power presented below the horizontal axis. After the 5% curtailment, the excess power is used for the PSH storage, ESS storage for the day-to-night conversion and hydrogen production.

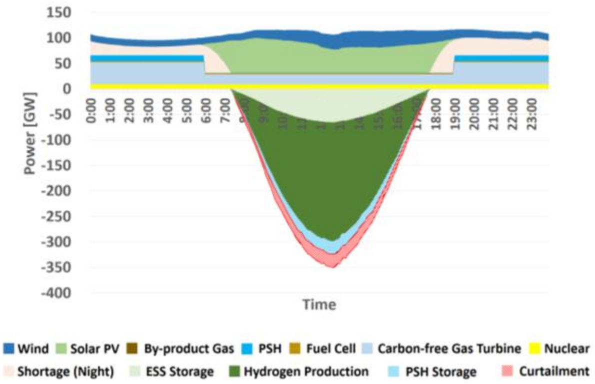


Fig. 1. Application to model with government's scenario A. The model describes the daily average power supply and demand in spring. The excess power in daytime due to the renewable energy is shown below the horizontal axis.

With this model, the daily average power for producing hydrogen in each season can be calculated as Table II. The model is developed well if the amount of hydrogen production derived from the data of Table II is equal to 5.50 million $tH_2$, suggested in the Korean government's scenario [3].

Table II: Daily Average Power for Hydrogen in Each Season from Simulation Model (Government's Scenario A).

| | Spring | Summer | Fall | Winter |
|---|---|---|---|---|
| Power for Hydrogen | 1,464.0 | 909.6 | 385.9 | -106.9 |

(Unit: GWh)

The weighted sum of daily average power for hydrogen to the annual value is calculated as 243.9 TWh. Applying the T&D Loss and given 43 kWh/kg$H_2$ [3] leads to the annual hydrogen production of 5.47 million t$H_2$. This result has 0.493% relative error with the government's reference of 5.50 million t$H_2$. Therefore, we can say that the simulation model describes well the government's scenario A.

## 3. Economic Evaluation for Scenarios

### *3.1 2050 Nuclear Power Build-up Scenarios*

This study suggests three Nuclear Power Build-up scenarios, which have increased amount of nuclear power production. We can refer to each scenario as scenario 2, 3 and 4, with the government's scenario A as scenario 1. Scenario 2 adds the assumptions of constructing Shin Hanul Unit 3 and 4, applying Long-term Operation (LTO) and reconstructing new 1,000 MW unit for all expired Nuclear Power Plants (NPP) until 2050, including Kori 1 and Wolsong 1 unit. The extended period is set to be 20 years for LTO. Scenario 3 supplements the construction of eight 1,400 MW units, which were originally designated as Chunji and Dajin units. In case of scenario 4, we additionally assume to substitute half of the coal-fired power plant capacity with Small Modular Reactors (SMR). Table III summarizes all assumptions of Nuclear Power Build-up scenarios with government's scenario.

Table III: Assumptions and Nuclear Capacity in All Scenarios.

| | Addition | Capacity |
|---|---|---|
| Scenario 1 | N/A (Net-Zero Scenario A) | 11.4 |
| Scenario 2 | Shin Hanul #3,4 + LTO | 35.2 |
| Scenario 3 | Chunji + Dajin (#1~8) | 46.4 |
| Scenario 4 | SMR for Coal Power (1/2) | 65.8 |

(Unit: GW)

This study set up the unified condition of producing 5.50 million t$H_2$ for all scenarios. As there are changes of nuclear power production in scenario 2, 3 and 4, we adjusted the amounts of total solar energy production so that the yearly hydrogen production by the excess power (except the power for curtailment, PSH and ESS) would be equal to 5.50 million t$H_2$.

The carbon-free energy, which includes carbon-free gas turbine and fuel cell, is changed to occupy 20% of the total power production. Also, unlike the scenario 1 in which the power production of PSH and ESS was calculated with 1:3 ratio on the basis of total excess power except 5% curtailment, we apply the constant capacity of PSH in the Nuclear Power Build-up scenarios, letting ESS cover the rest of the excess power.

Table IV shows the power production of each energy source for all scenarios. The capacity can also be calculated by applying the capacity factor to the power production. Both capacity and capacity factor applied in this study for each energy source are presented in Table V. For nuclear energy, the capacity factor of 77% from the Basis of Calculation for Net-Zero Scenarios [3] is applied for scenario 1, and 85% for the other scenarios. The capacity factors for solar and wind energy (15.3% and 25.9%) are calculated from the 2030 power production and capacity data of 9$^{th}$ Basic Plan on Electricity Demand and Supply [5]. In case of fuel cell, we apply 50% for scenario 1, but 25% for the others in which the fuel cell is assumed to be used only at nighttime. Also, 30% of the capacity factor is applied for both carbon-free gas turbine and by-product gas. PSH is assumed to be operated with 80% of the 8-hour capacity, so the daily capacity factor can be calculated as 26.7%. For ESS, 70% daily capacity factor is applied, and 25% for hydrogen production as it is assumed that half of the capacity only in the night is used.

Table IV: Power Production in Each Scenario.

| Scenario | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Nuclear | 76.9 | 262.1 | 345.5 | 489.9 |
| Solar PV | 799.9 | 686.4 | 593.0 | 431.3 |
| Wind | 171.0 | 171.0 | 171.0 | 171.0 |
| Fuel Cell | 17.1 | 50.7 | 50.7 | 50.7 |
| Gas Turbine | 270.0 | 152.1 | 152.1 | 152.1 |
| By-product Gas | 3.9 | 3.0 | 3.0 | 3.0 |
| PSH | 65.4 | 30.4 | 30.4 | 30.4 |
| ESS [GWh] | 588.9 | 559.9 | 383.8 | 79.3 |
| Hydrogen | 243.9 | 245.1 | 245.1 | 245.1 |

(Unit: TWh)

Table V: Capacity and Capacity Factor in Each Scenario.

| Scenario | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Nuclear | 11.4 (77.0%) | 35.2 (85.0%) | 46.4 (85.0%) | 65.8 (85.0%) |
| Solar PV | 597.2 (15.3%) | 512.4 (15.3%) | 442.7 (15.3%) | 322.0 (15.3%) |
| Wind | 75.4 (25.9%) | 75.4 (25.9%) | 75.4 (25.9%) | 75.4 (25.9%) |
| Fuel Cell | 3.9 (50.0%) | 23.1 (25.0%) | 23.1 (25.0%) | 23.1 (25.0%) |
| Gas Turbine | 102.7 (30.0%) | 57.9 (30.0%) | 57.9 (30.0%) | 57.9 (30.0%) |
| By-product Gas | 1.5 (30.0%) | 1.2 (30.0%) | 1.2 (30.0%) | 1.2 (30.0%) |
| PSH | 28.0 (26.7%) | 13.0 (26.7%) | 13.0 (26.7%) | 13.0 (26.7%) |
| ESS [GWh] | 841.3 (70.0%) | 799.9 (70.0%) | 548.3 (70.0%) | 113.3 (70.0%) |
| Hydrogen | 111.4 (25.0%) | 111.9 (25.0%) | 111.9 (25.0%) | 111.9 (25.0%) |

(Unit: GW)

### *3.2 Application of Scenarios to the Model*

The simulation results with the data of power production in each scenario are shown in Fig. 2. In this paper, only the results for spring are presented for simplicity. The increase of nuclear energy as a base load leads to the decrease of the shortage in night time, due to the reduction in solar energy production. Considering the fact that 5.50 million tons of hydrogen are being produced simultaneously in all scenarios, the daily power demand and hydrogen production can be made up with less amount of solar PV and ESS in the Nuclear Power Build-up scenarios.

### *3.3 Economic Evaluation*

For the economic evaluation, the investment costs and annual costs of each scenario are calculated in this study. We use the data from the report of IEA and OECD/NEA as the unit prices for investment cost and Levelized Cost of Electricity (LCOE) of each energy [6]. Basically, Korean data of 7% interest rate with the exchange rate of 1,101 KRW/USD are chosen, but the world values are used in the absence of Korean data. Especially, the investment costs are calculated for 25 years: the period from 2025 to 2050. Since the unit prices applied in this study are based on the 2020 data from the above-mentioned report, both the investment costs and annual costs are calculated as the Present Value (PV) of 2020. The unit prices are listed in Table VI. Here, the LCOE of ESS are respectively derived for each scenario as we apply the investment cost of Korean market for ESS (0.4 trillion won/GWh) rather than that from the report. The calculated LCOE are as follows: 261.9 won/kWh, 282.4 won/kWh, 291.5 won/kWh and 481.1 won/kWh for scenario 1, 2, 3 and 4.

Table VI: Investment Cost and LCOE for Each Energy [6].

| | Investment Cost | LCOE |
|---|---|---|
| Nuclear(New-built) | 3.0 | 58.7 |
| Nuclear(LTO) | 0.6 | 33.5 |
| Solar PV | 1.4 | 107.2 |
| Wind(Onshore) | 2.3 | 124.8 |
| Wind(Offshore) | 4.0 | 177.2 |
| Fuel Cell | 2.7 | 213.3 |
| Carbon-free Gas Turbine | 1.4 | 182.2 |
| By-product Gas | 1.4 | 121.6 |
| PSH | 3.6 | 89.3 |
| ESS [trillion won/GWh] | 0.4 | - |
| Hydrogen Production | 0.8 | - |

(Unit: trillion won/GW, won/kWh)

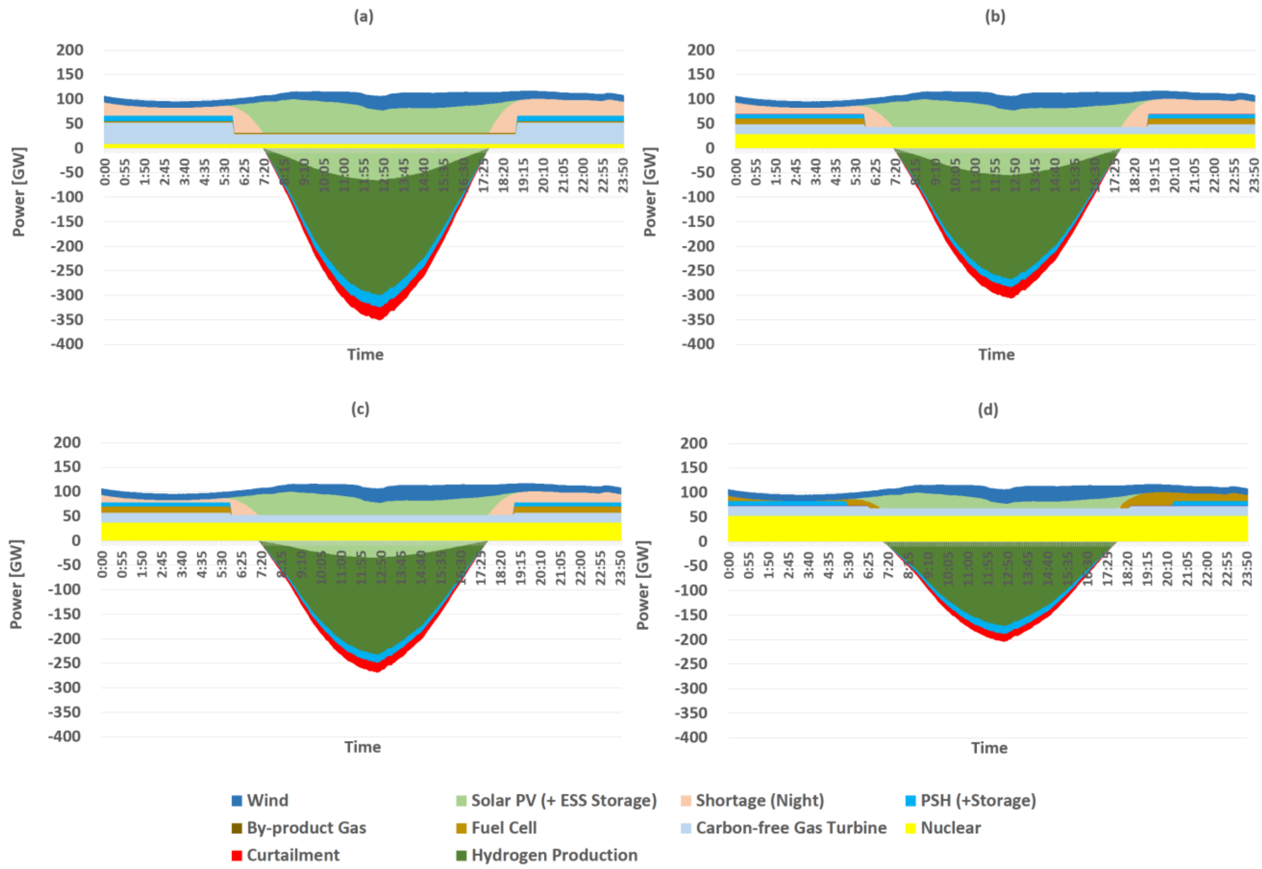


Fig. 2. Results of model application for all scenarios. Presented are the daily average aspects of power supply and demand for spring season regarding (a) scenario 1, (b) scenario 2, (c) scenario 3 and (d) scenario 4.

The changes in the investment costs for each energy are shown in Table VII. The maximum increase for the nuclear energy followed by the expansion of nuclear capacity is 67.2 trillion won, while the maximum reduction for the solar PV and ESS is 386.5 trillion and 473.2 trillion won, respectively. Regarding the annual costs of Table VIII, the increment in nuclear energy (22.8 trillion won) is much less than the decrease in solar PV and ESS (39.5 trillion and 165.8 trillion won). These results are attributed to the reduction in the requirement of solar PV and ESS, caused by the satisfaction of nighttime shortage from the nuclear energy.

Table VII: Calculation Result of Investment Cost.

| Scenario | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Nuclear | 0.0 | 28.5 | 42.7 | 67.2 |
| Solar PV | 838.6 | 719.6 | 621.7 | 452.1 |
| Wind | 262.0 | 262.0 | 262.0 | 262.0 |
| Fuel Cell | 17.1 | 101.1 | 101.1 | 101.1 |
| Gas Turbine | 115.8 | 65.2 | 65.2 | 65.2 |
| By-product Gas | 1.7 | 1.3 | 1.3 | 1.3 |
| PSH | 31.9 | 14.8 | 14.8 | 14.8 |
| ESS | 546.8 | 519.9 | 356.4 | 73.6 |
| Hydrogen | 85.8 | 86.2 | 86.2 | 86.2 |
| Sum | 1,899.6 | 1,798.7 | 1,551.4 | 1,123.7 |

(Unit: trillion won)

Table VIII: Calculation Result of Annual Cost.

| Scenario | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Nuclear | 4.5 | 13.9 | 18.8 | 27.3 |
| Solar PV | 85.7 | 73.6 | 63.6 | 46.2 |
| Wind | 27.6 | 27.6 | 27.6 | 27.6 |
| Fuel Cell | 3.6 | 10.8 | 10.8 | 10.8 |
| Gas Turbine | 49.2 | 27.7 | 27.7 | 27.7 |
| By-product Gas | 0.5 | 0.4 | 0.4 | 0.4 |
| PSH | 5.8 | 2.7 | 2.7 | 2.7 |
| ESS | 220.3 | 225.9 | 159.8 | 54.5 |
| Sum | 397.3 | 382.5 | 311.3 | 197.2 |

(Unit: trillion won)

The generation cost can be calculated through dividing the total annual cost by the amounts of power production. Here, the power of PSH, ESS and hydrogen production is excluded from the total power production as they are already included in the renewable power production. Table IX shows the result for calculating generation costs, compared with the reference value of Korean average generation cost in 2021 which is represented in Monthly Report on Major Electric Power Statics [7]. The government's scenario A (scenario 1) shows about 3.085 times increase, whereas the scenario 4 of the expanded nuclear energy stands for only about 1.579 times increase.

Table IX: Comparison of Generation Cost.

| Scenario | (2021) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Generation Cost | 96.2 (100.0%) | 296.8 (308.5%) | 288.7 (300.1%) | 236.7 (246.1%) | 151.9 (157.9%) |

(Unit: won/kWh)

## 4. Conclusion

This study targeted to analyze and compare the government's 2050 Net-Zero scenario with Nuclear Power Build-up scenarios, by using the new model simulating daily average power supply and demand for each season. It is verified that the model accords well with the government's scenario A, showing only 0.493% of relative error in hydrogen production. Regarding the economic evaluation, it is shown that increasing nuclear energy from 76.9 TWh (scenario 1) to 489.9 TWh (scenario 4) cuts back over 700 trillion won for investment cost and 200 trillion won for annual cost. Also, the generation cost is expected to have less rate of increase (with the difference of 150.6%p) due to the increased amount of nuclear energy.

However, this study performed the rough calculation for 2050 Scenarios with simple assumptions. More detailed analyses such as supply reliability and seasonal characteristics were not considered in the calculations. Therefore, further study with the advanced assumptions and calculations is needed for more elaborate simulation.

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