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Electricity System Planning under the CO_2 Emission Restriction

Chae Young Lim and Man Ki Lee

Korea Atomic Energy Research Institute
150 Dukjin Yusong
Daejeon, Korea 305-353

Jae Hyung Roh and Eun Hwan Kim

Korea Power Exchange
167 Samsungdong, Kangnam
Seoul, Korea 135-791

Abstract

Objective of this study is to analyze how the restriction of CO2 emission from power generation will affect the national electricity supply system. The role of nuclear power is investigated under the restriction of CO2 emission in Korea. A simplified electricity system was modeled for the analysis. To analyze the impact of CO2 emission restriction, 2 different scenarios were established and compared with the base scenario. The first scenario was 'CO2 emission restriction with new nuclear power installation'. In this scenario, a CO2 emission restriction of 0.11kg-C/kWh was imposed and there was no restriction on the nuclear power construction. While, in the second scenario, 'CO2 emission restriction without new nuclear power installation', the same amount of CO2 restriction was imposed with no consideration of nuclear power installation. It is found out that the current national emission target(0.11kg-C/kWh) in the electricity sector can not be achieved without nuclear and renewable(wind power) options considered

1. Energy and greenhouse gas emission prospects of Korea

Korea's primary energy consumption was estimated at 198.4 million TOE (tons oil equivalent) in 2001 ranking it the 10th largest energy consuming nation in the world. Of the total energy consumed, 97.2% was imported. Oil was the major source of energy at 50.7%, followed by coal (23.0%), nuclear energy (14.1%), LNG (10.5%), hydraulic power (0.5%) and others (1.2%). Of the total energy consumption, about 55.7% was used by industry, 21.5% by the residential and commercial sectors, 20.9% by the transportation sector and 1.92% in others including the public sector.

Rapid economic growth and increase in personal income have led to a sharp growth in the demand for transportation and the number of cars has greatly increased from 127,000 in 1970 to 12,694,000 in 2001, recording a 100-fold growth in thirty years. The number of privately owned cars showed particularly rapid growth. In the passenger transport sector, subway routes continue to expand in line with the growth of national income and the subway and domestic aviation play a greater role as important transportational modes, while maritime shipping is increasingly taking on a bigger role in the freight transport sector.

Rising energy consumption is the major cause of the increase in greenhouse gas emissions which rose 2.6% from 144.3 million tons of carbon (MtC) in 2000 to 148.0 MtC in 2001. The energy sector was a major contributor to this increase at 104.2% while industrial processes, agriculture and waste contributed -3.5%, -3.0% and 2.2%, respectively. The trend of total greenhouse gas emissions between 1990 and 2001 indicates an annual increase of 5.2% with per capita emissions rising by 4.3% per year since 1990, recording 3.13 tons of carbon (tC) in 2001. However, the greenhouse gas intensity indicated the increase seen during the early 1990s began to fall after 1996. In the energy sector, which consists of fuel combustion and fugitive emissions, greenhouse gas emissions increased 5.6% per year from 67.6 MtC in 1990 to 123.5 MtC in 2001. After 1990, emissions from industrial processes recorded a sharp increase of 10.2% per year.

The growing trend of greenhouse gas emissions will continue if the current shift of Korea's industrial structure continue and considerable efforts to reduce emissions are not implemented. Projections indicate that Korea's greenhouse gas emissions17) will rise by 70% above 2000 levels in 2020 (Figure 1). However, the carbon dioxide intensity during the forecast period is expected to gradually decrease due to improvements in demand-side energy efficiency and shift to cleaner fuels. Greenhouse gas emissions from energy, agriculture and waste which accounted for about 90% of the total emissions of greenhouse gases is expected to increase by 2.7% annually from 2000 to 2020. During the same period, emissions from fuel combustion will increase by 2.8% annually and emissions from waste by 2.4%, whereas removals from land-use change and forestry and emissions from agriculture are projected to annually decrease by 1.4% and 1.1% annually, respectively.

Greenhouse gas emissions from fossil fuel combustion is projected to increase by 3.8% annually from 2000 to 2010. After 2010, however, the average annual growth rate of emissions from fossil fuel combustion is projected to decrease to 1.8% until 2020. Greenhouse gas emissions from the energy sector are estimated to rise by 74% above 2000 level by 2020. In the long-run, however, greenhouse gas intensity (GHG/energy) is projected to decline by 5% from 2000 to 2010 (Figure 1).

The proportion of greenhouse gas emissions generated by the industrial sector to the total greenhouse gas emissions from energy use is projected to decrease to 31% in 2020 from a 35% in 2000 as a consequence of a slowdown of energy-intensive industries, reduction of the share of bituminous coal in energy consumption and gradual decline in the growth rate of energy consumption. The transportation sector is projected to record the highest growth rate of greenhouse gas emissions among the energy sector due to the relatively high increase in the energy demand and limited substitution possibility among energy sources. The proportion of emissions from the transportation sector to energy use is estimated to increase to 23% in 2020.

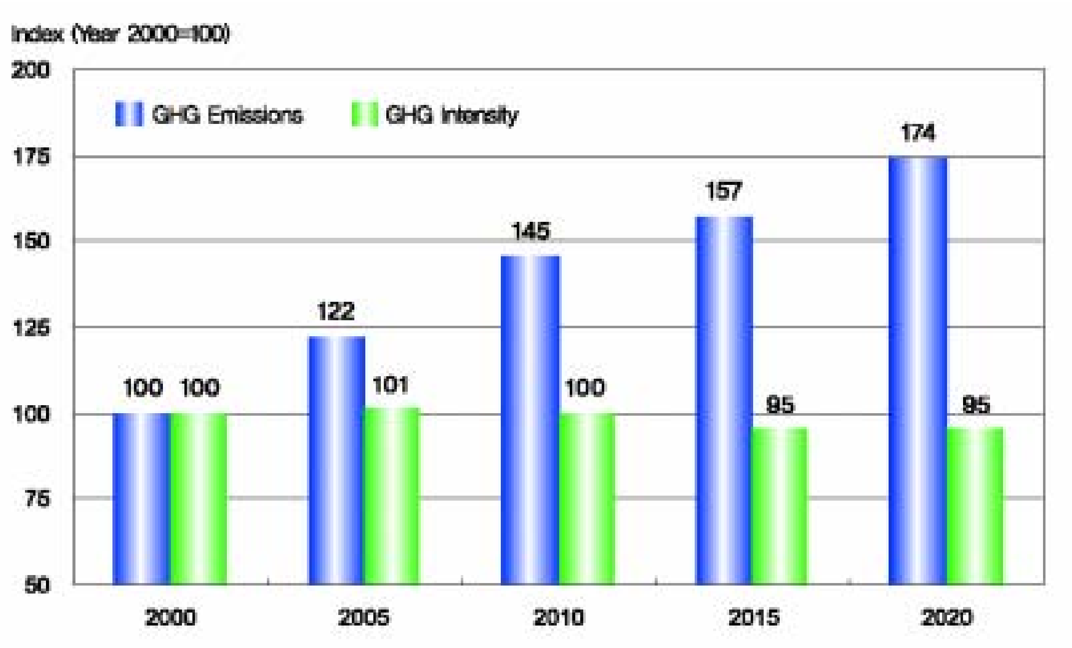


Figure 1. Projected Trend of GHG Emissions and the intensity (2000~2020)

Although the growth rates of the population and number of households may be slowing down, greenhouse gas emissions from the residential sector is projected to increase largely due to the expansion of the total floor area as a consequence of the increasing income level. However, the proportion of greenhouse gas emissions from the residential sector is projected to decrease from 12% of total emissions from energy use in 2000 to 9% in 2020. The advanced industrialization and rise in income have accelerated the consumption of electricity compared to other energy sources. As a result, emissions in the energy transformation sector, which accounted for 29% in 2000, are projected to account for 34% in 2020.

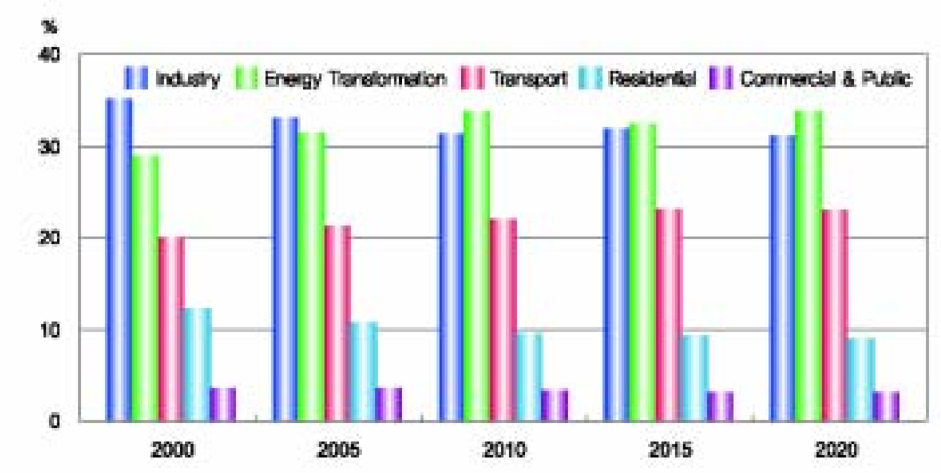


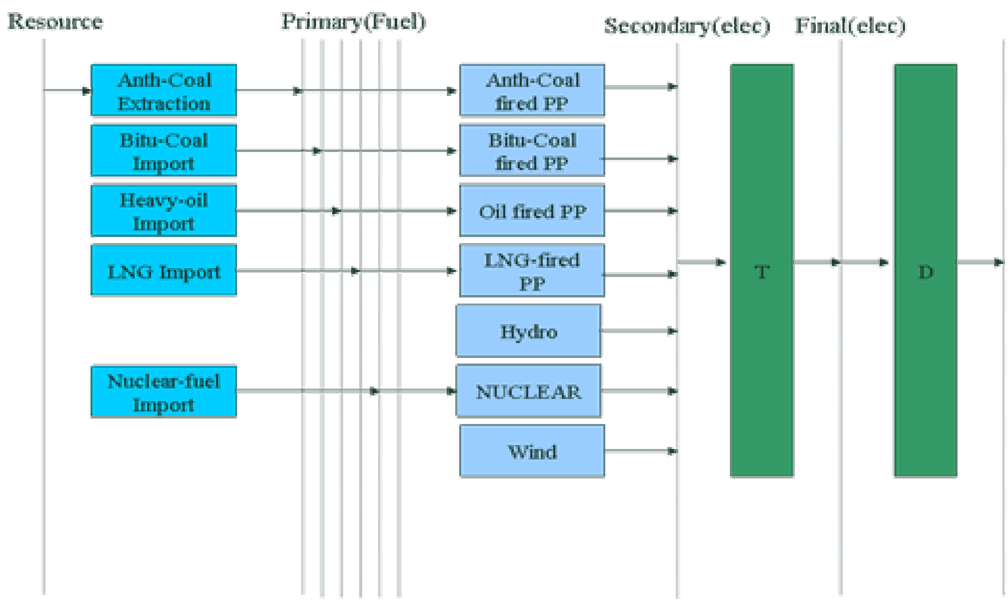
Figure 2. Projected Proportion of GHG Emissions by Energy Sector

2. General Assumption

We used the same input data that was used in ‘the 1st national basic electricity demand and supply plan’ performed in 2001. For that reason, we set up the base year as 2001. The planning period was up to 2015 in the national plan, but we extend the planning period up to 2030 for analyzing the longer term effect. The annual period was adopted for 2002-2015 and the 5-year period was adopted for 2015-2030 for the operational convenience.

We did not consider the unit size of the power plant. We assumed 8% of discount rate in the study and performed the sensitivity test for 6% of discount rate and 1% of annual coal price escalation. Anthracite coal is considered as the only domestic energy resource and, for the simplicity, all fuels except anthracite coal were assumed to be imported from abroad as the final product form.

Existing plant was aggregated by resources; Anthracite coal fired power plant, Bituminous coal fired power plant, Heavy oil power plant, LNG fired power plant, nuclear power and Hydro power. New types of power plants expected to be commercialized during the planning horizon such as new bituminous coal 800 MW, Korean Advanced Power reactor(APR1400) and wind power were also considered in the analysis. Figure 3 shows the reference energy system diagram of the study.



Fgure 3. Reference energy system of the study

The electricity sector was only analyzed in this study. As an input data for the electricity demand, the projection of 'the 1st national basic electricity demand and supply plan' was used for 2002-2015, and after that period, we assumed that the electricity demand would grow as 1.5% per annum.

We separated a year into 5 seasons and each season has 2 different types of day and each day has divided into 3 parts of different load. We assumed the annual load pattern would not be changed during planning period. Figure 3 shows the load curve for the study

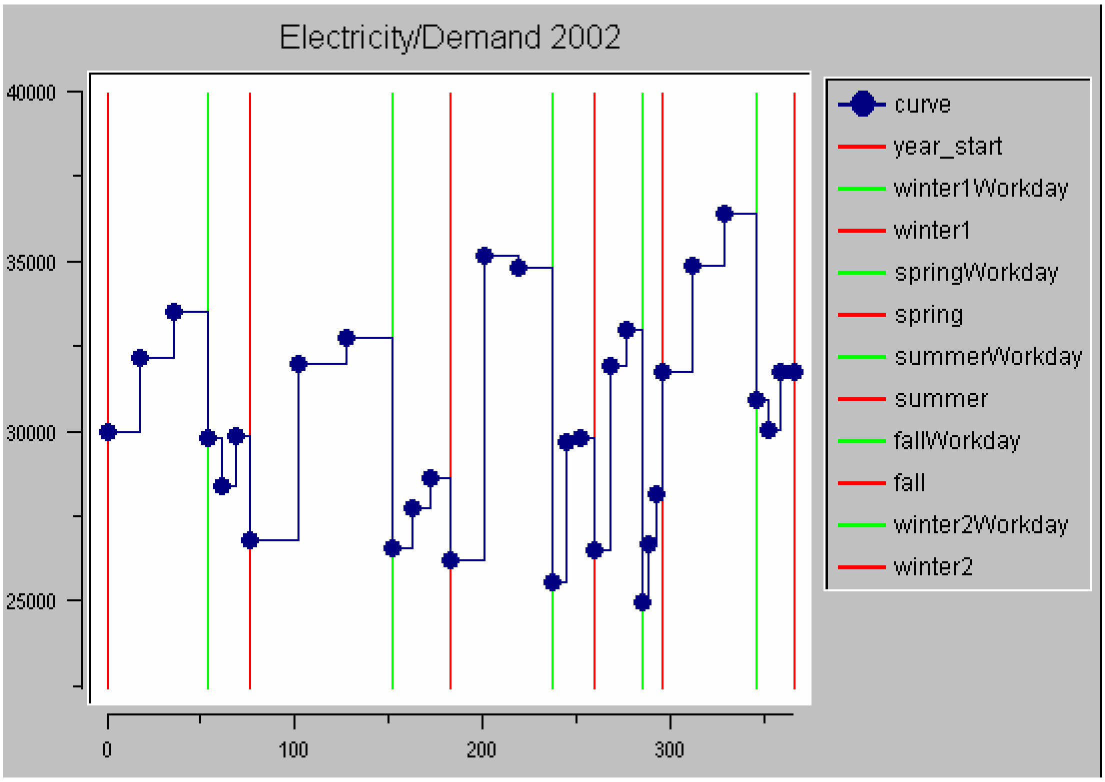


Figure 4. Load curve for the study

3. Scenarios

In the base scenario, the 8% of discount rate was adopted and the price of fossil fuel will be maintained at a constant level. Sensitivity tests of the base scenario were performed with respect to discount rate of 6% and to coal price of 1% annual escalation.

To analyze the impact of CO_2 emission restriction, 2 different scenarios were established and compared with the base scenario. The first scenario was 'CO2 emission restriction with new nuclear power installation'. In this scenario, a CO_2 emission restriction of 0.11kg-C/kWh was imposed and there was no restriction on the nuclear power construction. While, in the second scenario, 'CO2 emission restriction without new nuclear power installation', the same amount of CO_2 restriction was imposed with no consideration of nuclear power installation.

4. Results & discussion

4.1 Base scenario

In the base case, new nuclear power plant is not introduced at all(Figure 5). This extreme result may come from the characteristics of the linear programming technique, which tends to choose the cheapest option as a solution.

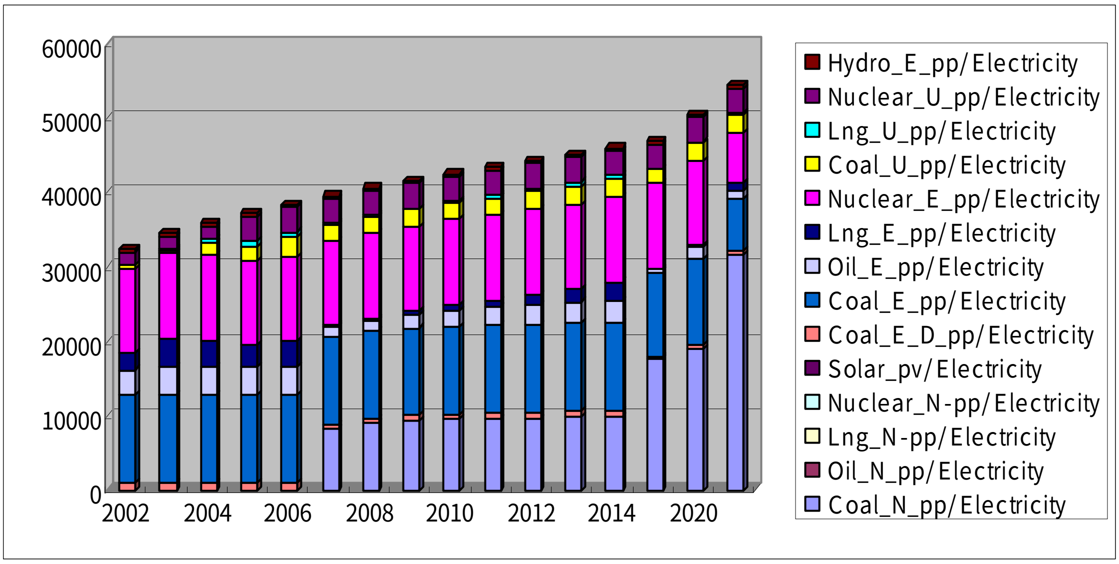


Figure 5. Electricity supply in the base case

The difference of economics between coal and nuclear is marginal in Korea. Therefore, it seems that slight change of input data may produce a solution quite different from the base case solution.

On this observation, we carried out sensitivity analysis with respect to some major inputs such as discount rate and coal price. The result of those sensitivity analyses are shown in Figure 6 & 7. The results indicate that new nuclear power plant replace new coal power plant substantially.

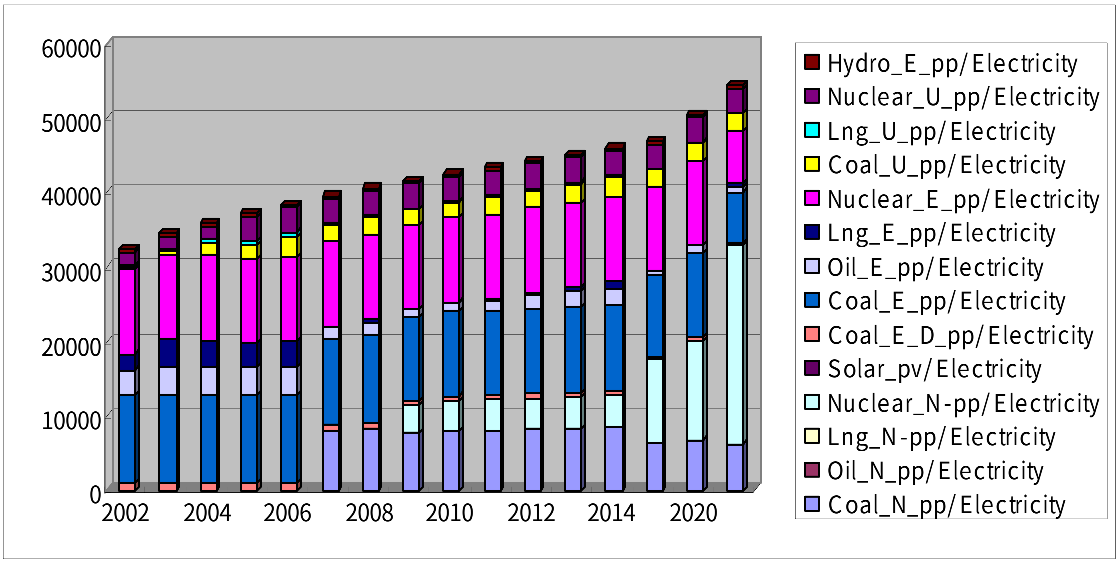


Figure 6. Electricity supply in the base case with 6% discount rate

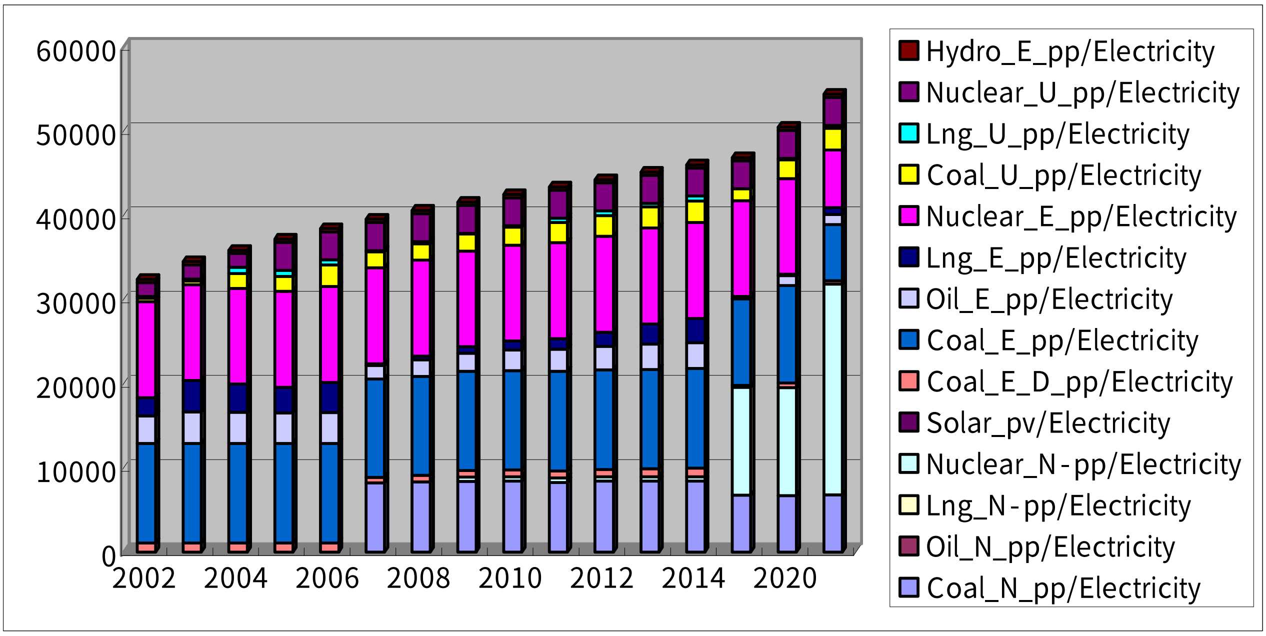


Figure 7. Electricity supply in the base case with 1% coal price escalation per annum

4.2 CO2 emission restriction scenario

In the case of imposing CO2 emission restriction in the model, the coal power plants are replaced with nuclear option(Figure 8). However, the wind power is not selected in the given CO2 emission restriction. It is because the carbon credit is not enough to compensate for its high cost of electricity production.

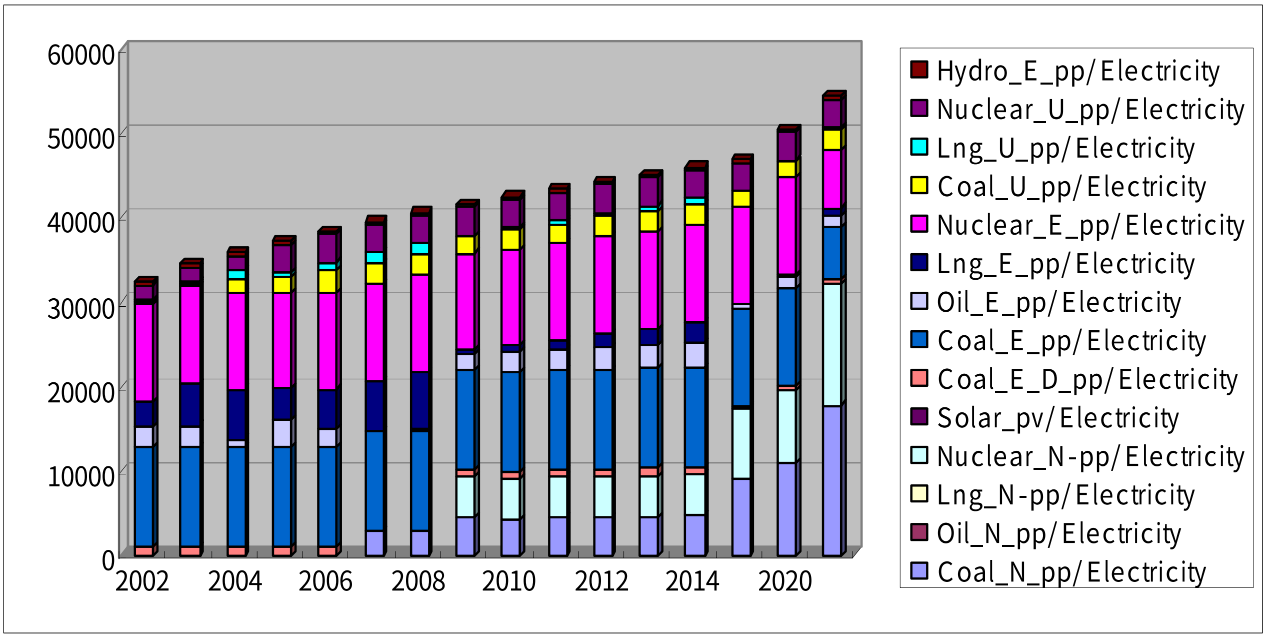


Figure 8. Electricity supply in the CO2 limit with new nuclear installation scenario

If, for some reason, the nuclear power should not be built any more, LNG power and wind power will play an important role in meeting the carbon emission restriction(Figure 9).

Total system cost is varying dependent on the established scenarios(Table 1). Table 1 shows that restriction of CO2 emission will increase the total system cost substantially. That impact can be greatly alleviated in the presence of nuclear power option.

It is found out that the current national emission target(0.11kg-C/kWh) in the electricity sector can not be achieved without nuclear and renewable(wind power) options considered.

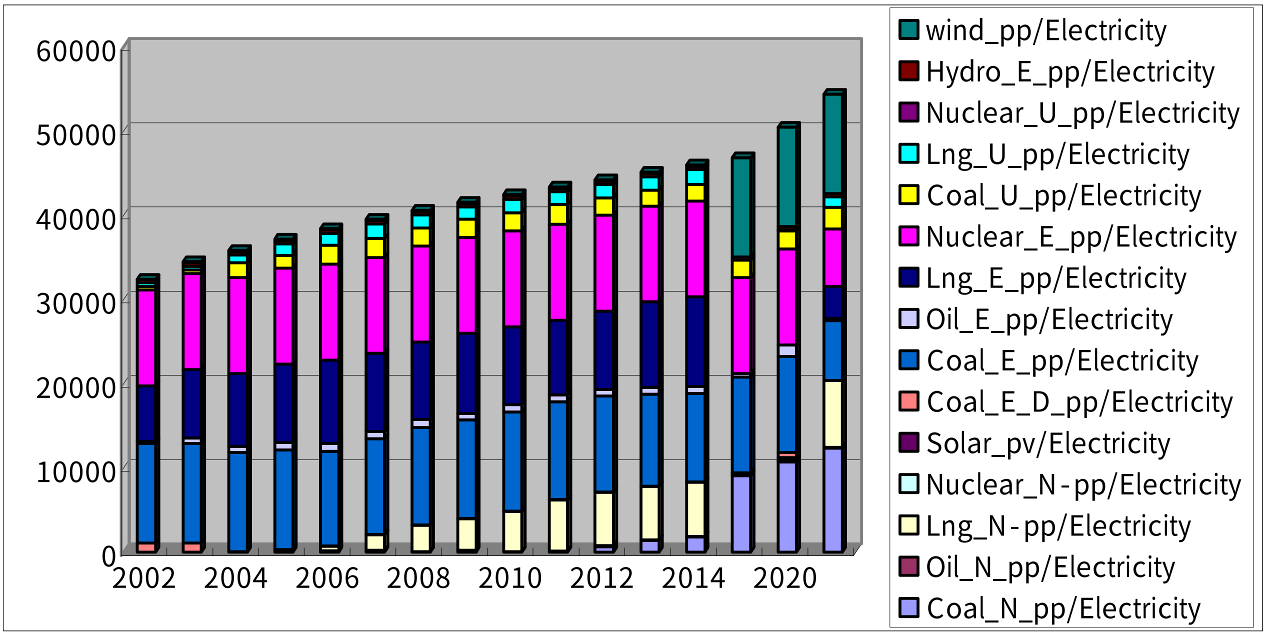


Figure 9 Electricity supply in the CO2 limit without new nuclear installation scenario

Table 1. Total system cost of scenarios

Scenario	Objective value
Base	97,913,148.7
CO2 limit with nuclear installation	99,846,852.2
CO2 limit without nuclear installation	120,486,128.9

5. Conclusion

Carbon emission restriction has a great influence on the national electricity supply system. This study shows that the degree of impact is totally dependent on the availability of nuclear and renewable energy option. Nuclear option appears to be preferable to renewable option in meeting the restriction of CO2 emissions. If nuclear option is available, all the renewable options are faded away. This study also indicates that there are no solutions to meet the current restriction level of CO2 emission, if both nuclear and renewable options are not available as an alternative in the Korean electricity supply system. This results place a special emphasis on the importance of the role of nuclear power under a carbon emission regulation in Korea.

References

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