MATHEMATICAL MODELING OF GENERATION EXPANSION PLANNING PROBLEM IN A PARTIALLY REGULATED MARKET: PRIVATE COMPANY PERSPECTIVE

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Overview

One of the important topics of the system management on energy industry is the generation expansion problem. Generation Expansion Planning (GEP) is an investment planning problem that determines when and how much capacity to add to the existing facilities over a planning horizon. The aim is to satisfy the expected energy demand with the least expected cost. This problem became even more important for the industry due to the changes experienced in energy industry and the introduction of legislations about carbon mitigation. Since most of the energy demand of the world is satisfied using fossil fuel combustion, and this results in climate change that has hazardous potential, it became a pushing requirement that the energy investment planning must include low carbon emissions type of plants, emissions trading mechanisms, carbon mitigation requirements, etc. (Chen et al. 2010).

In this study, we consider a generation expansion planning problem of a private company that aims to maximize its profit while obeying the constraints on capacity, market share, investment portfolio, and carbon emissions. The electricity generating company plans to enter the market that is partially regulated. There is a cap and trade system in operation in the industry, which limits the total carbon emission of the company to a cap value determined by the government. There are nine possible power plant types that the company considers to invest on through a planning horizon. Some of these plants may include a carbon capture and sequestration technology. Depending on the investment types, the total emission of the company will change. The decisions that the company needs to make are the time, type, amount and technological properties of the investments. In this problem, while investment decisions are made, the company also decides on how much to invest on the technology for carbon mitigation for certain investments or what kind of strategies to follow in order to obey carbon restrictions.

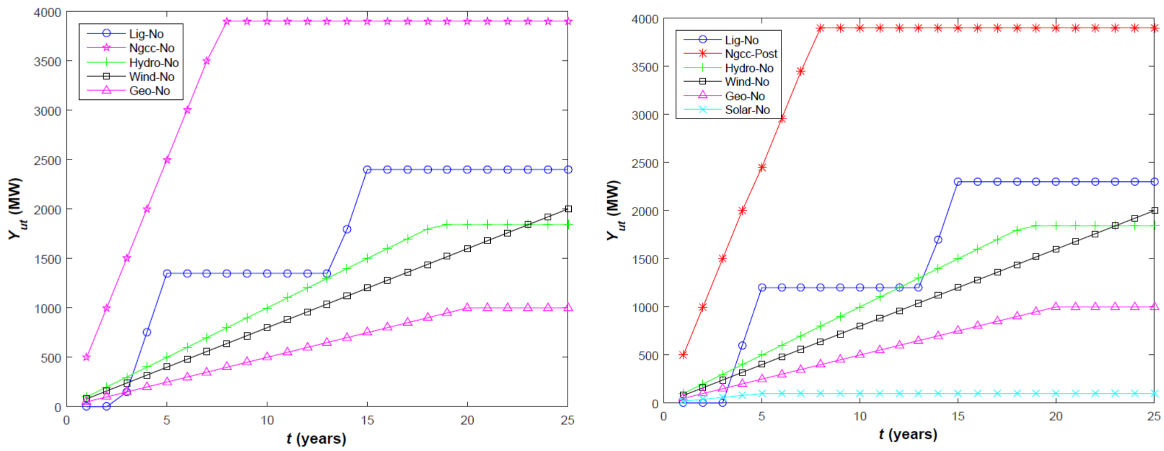
Methodology

We develop a mixed integer linear program for this problem. We implement the model by using data obtained for Turkey's energy industry. We enforce market share conditions such that the percentage of the total investments of the company over the total installed capacity of the country, in which the company is operating, stay between upper and lower bounds. Moreover, in order to distribute the investment risk, the percentage of each type of power plant investments is restricted by some upper bounds. Then, we determine the parameters that affect the optimal investment decisions. Fuel prices, future electricity prices and carbon market prices bear a high degree of uncertainty. We create scenarios to apply sensitivity analysis that allow us to analyze the effects of these parameters on the technology choice and system performance, and provide the results of this analysis. We implemented the mixed-integer program on GAMS 23.7.3, and used Cplex 12.3 as the solver.

Results

We analyze the optimal investment strategies using a base scenario, and then, by changing one parameter at a time, we analyze the effect of each parameter on the optimal decision. For base scenario, we assume that the interest rate is fixed over time to 5%. The electricity price for thermal power plants is fixed to its initial value throughout the planning horizon. We assume that the feed-in tariff of electricity generated from renewable energy resources last for 10 years; and after 10 years, the price becomes equal to the regular price of electricity generated from other resources, which is compatible with the current law. The fuel prices are also fixed to the initial year throughout the planning horizon. The carbon price is fixed to $30. For the base scenario, investing on geothermal power fully every year until its maximum potential is reached is optimal. The model also invests in wind power plants fully every year starting from the first year until year 25. The reason for stopping to invest in wind after 25 years is to ensure that the portfolio balance constraints are satisfied. The same characteristic exists in hydro power plant investment decisions: the optimal strategy is to invest fully on hydro starting from the first year until year 18, invest at the maximum possible value in year 19 such that the portolio balance constraints are satisfied. The most profitable option based on the investment cost and capacity factor is investing in natural gas thermal power plants.

Carbon price is the most uncertain parameter used in the model. Therefore, we want to analyze its effect on the optimal decisions. As seen from Figure 1 (a), when the carbon price is low, (i.e., $10 and $20), investing in natural gas power plants with no CCS technology added is optimal; however, as the carbon price increases, investing in natural gas power plants with postcombustion CCS technology plants enters the optimal solution. While, for carbon prices between \$10 and \$80 lignite power plants with no CCS technology investments are optimal (see Figure 1 (b)), over \$90 of carbon price, lignite power plants with postcombustion CCS technology enters the optimal solution, and for \$100 of carbon price, lignite power plants with no CCS leaves the optimal solution. If the carbon price becomes \$100, which is unlikely according to today's carbon markets, the optimal investments occur either for renewable energy sources or CCS technology added thermal power plants. For hydroelectric, wind and geothermal power plants, the optimal investment decisions are not significantly sensitive to the carbon price. When the carbon price is low, \$10 and \$20, there is no solar energy investment. As the carbon price gets higher, solar energy investments enter the optimal solution.



(a) Carbon price =\$20 (b) Carbon price =\$50

Figure 1. Cumulative investment decisions for different carbon prices.

Another uncertainty exists in the electricity prices. In order to anlyze its effect on optimal decisions, we create different scenarios. According to the results, investing on hard coal power plants is optimal only if the electricity price increases in the future. For all scenarios investing on natural gas power plant is optimal and at its maximum possible value. As the electricity price increases, these prices become close to the subsidized electricity prices given to renewable energy resources. This results in lower investments to renewable energy sources. When the electricity prices decrease, all types of investments also decrease, except investments to wind and hdroelectric power plants. Solar energy investments enter the optimal solution only when the subsidized electricity prices generated from solar energy continues longer than the subsidy given to other renewable energy sources.

The portfolio balance constraints affect the optimal decisions significantly. When there is no portfolio balance constraint, the model invests fully on natural gas power plants starting from the first year as natural gas power plants are the most profitable investment options. Investing on hydro is profitable only if it is realized in first three years. Similar situation occurs for wind for five years, and for geothermal for 12 years. When the portfolio balance constraint are enforced, the investment amounts for wind, hydro and geothermal power plants increase. As these constraints becomes restrictive, the optimal investment mixture includes different types of investments such as lignite, which is the most restrictive scenario. The annual interest rate is another parameter that affects the optimal investment decisions significantly. As the interest rate increases, the net present value of the gains obtained from generating and selling electricity decreases. When the interest rate is at its lowest value (3%), the optimal decision includes investment to solar energy. However, for other scenarios solar energy investment is not in the optimal mixture because the gains obtained from solar energy do not compansate its high installation cost and low capacity factor. Moreover, as the interest rate increases, the total invesment throughout the planning horizon decreases as the net present value of the gains decrease.

Conclusions

The results show that the model is suitable to be used for determining the investment strategy of the company over a planning horizon. Also the results obtained for the sensitivity analysis are consistent with the expected outcomes, showing that the model can be used for determining alternative strategies under a set of alternative assumptions with respect to uncertain parameters.

References

Chen, Q., C. Kang, Q. Xia, J. Zhong. 2010. Power generation expansion planning model towards low-carbon economy and its application in China. IEEE Transactions on Power Systems 25(2) 1117-1125.