Cost competitiveness simulation of nuclear power plant considering external cost and tax fairness

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1. Introduction

According to the 8th Basic Plan for Electricity Supply and Demand, the government plans to reduce the capacity of nuclear power generation from 22.5GW in 2017 to 20.4GW in 2030 but to increase the LNG power plant from 37.4GW in 2017 to 47.5 GW in 2030. This energy policy change is largely influenced by controversial safety and cost evaluation gaps between pro-nuclear group and anti-nuclear group.

This study focuses on the uncertainty of levelized cost of energy (LCOE) of the nuclear power plant and LNG generation. Each cost input can be varied according to the professionals' assumption and evaluation. So, this study derives the probabilistic levelized cost range of each energy source using Monte Carlo simulation.

This study investigates the various previous studies and uses the probabilistic distribution of input variables. Especially, this study more focuses on the external cost and tax application of each energy source. So, this study presents a reasonable range of LCOE values for the relative competitiveness assessment of each generation source.

2. Methodology

2.1 Revised LCOE

LCOE indicates the cost of each unit of electricity generated, given all required physical assets. The fundamental definition of LCOE is shown in Eq.(1). [1]

$$LCOE = \frac{\sum_{t=0}^{T} \frac{p_t}{q^t}}{\sum_{t=0}^{T} \frac{E_1(1-d)^{t-1}}{q^t}} \quad \cdots \; Eq.(1)$$

In general, the following simplified LCOE Eq.(2) is used. [2] However, this paper will apply the following Eq. (3) to reflect the external cost.

$$LCOE = \frac{OCC \times CRF + Fixed\,OM}{8760 \times CF} + FC \times HR + Variable\,OM \quad \cdots \; Eq.(2)$$

$$LCOE = \frac{OCC \times CRF \times n}{8760 \times CF \times l} + OM + FC \times HR + External\,Cost \quad \cdots \; Eq.(3)$$

· OCC : Overnight Capital Cost · CRF : Capital Recovery Factor
· $CRF = \frac{d(1+d)^n}{(1+d)^n - 1}$ (d : discount rate, n : loan period)
· Fixed O&M : Fixed Operation and Maintenance costs
· Variable O&M : Variable Operation and Maintenance costs
· FC : Fuel Cost · HR : Heat Rate · CF: Capacity Factor

2.2 Variables

Most research studying the LCOE in Korea usually present the LCOE using point values. Some delicate studies calculated several values assuming several scenarios to the some uncertain variables. This study uses more advanced method defining an uncertainty variable and presenting a range of LCOE values using Monte Carlo simulation.

2.2.1 Discount rate

Even if it is a domestic project, the discount rate may vary depending on the size of the business, the credit-worthiness of the business, and the expected return of investors. In addition, the impact of the discount rate in the nuclear power project, which has a high overnight-capital cost, is larger than that of the LNG project. So, this study applies a discount rate of 3 ~ 10%.

2.2.2 Payback period(n) & operation period(l)

The Payback period(n) used in the CRF should correspond to the operation period in Eq.(2). Almost all previous studies assume that these two periods are the same. However, this assumption is not realistic in most energy projects. Due to these simplified assumptions, there is a tendency that the LCOE of nuclear power projects is highly evaluated. Therefore, this study uses 20 year bonds issued by KHNP and 60 years operation. LNG projects uses the 5-year corporate bonds issued by thermal power companies and 40 years operation periods.

2.2.3 Overnight Capital cost and O&M cost

Overnight cost (OCC) and O & M have lower uncertainties than other variables due to the large number of construction and operation experiences in NPPs and LNG power generation as shown Table 2.

2.2.4 Fuel cost and heat rate

In the case of LNG generation, the effect of fuel prices on LCOE is significant. This study uses the probabilistic distribution price of LNG evaluating the past 10 year price records.

2.2.5 Capacity Factor

Capacity Factor considerably impacts on LCOE. Recently, the utilization rate of NPPs is on the decline due to the more strict regulation. Therefore, this study uses the probabilistic distribution value using the 10 year data provided by KHNP.

2.2.6 External costs

There is a great deal of disagreement about the external costs of NPPs. In this study, the range of uncertainty is based on the minimum and maximum values of external costs presented in various studies. This study mainly uses the data provided by the report "Study on Optimum Power Mix Considering Economic and Social Costs of Nuclear Power Generation" published by the Korea Institute of Energy Economics.[3] The most controversial uncertain variable is estimating the external cost of nuclear power. Therefore, the estimation of external cost proposed in various fields is considered like Table 1. And the utilization rate of NPPs is based on data of KPX for the past 10 years.

Table 1. External cost of nuclear power plant (Won/Kwh)

	A	B	C	D	E	F	G	H	I	J
Value	7.5	24	4	2.9	63.7	1.8	5.75	16.5	18.1	28.1

** The costs of nuclear accident accidents are estimated by the accident cost of Fukushima nuclear plant, Considering the total population density, applied the same level of 86 trillion won as Japan.* [3~8]

LCOE of natural gas is most affected by fuel cost and capacity factor. Therefore, this study uses the energy unit cost and LNG generation utilization statistics of the last 10 years provided by KPX. In accordance with the 'Petroleum and Petroleum Alternative Fuel Business Act', implemented on April 1 2019, the import tax and individual consumption tax rate are updated.

Table 2. Nuclear and Natural Gas uncertain variable

	Nuclear	Natural Gas
Discount rate (%)	● Distribution [Nominal] ● Input argument [Mean(μ)= 5.5 S.d(σ)=0.6]	
OCC (Won/KW)	● Distribution [Nominal] ● Input argument [Mean(μ)= 2,378,000 S.d(σ)=237,800]	● Distribution [Nominal] ● Input argument [Mean(μ)= 904,000 S.d(σ)=90,400]
O&M cost (Won/KWh)	● Distribution [Nominal] ● Input argument [Mean(μ)= 15.65 S.d(σ)=1.57]	● Distribution [Nominal] ● Input argument [Mean(μ)= 3.86 S.d(σ)=0.4]
Fuel cost (Won/Gcal)	● Distribution [Uniform] ● Input argument [min.1232, max.2384]	● Distribution [Uniform] ● Input argument [min.20,558 max.89,105]
Heat rate (kcal/kWh)	● Distribution [Nominal] ● Input argument [Mean(μ)= 2,365 S.d(σ)=236]	● Distribution [Nominal] ● Input argument [Mean(μ)= 1,540 S.d(σ)=154]
Capacity Factor (%)	● Distribution [Uniform] ● Input argument [min.75.5, max.94.2]	● Distribution [Uniform] ● Input argument [min.34.4, max.64.7]
External Costs (Won/KWh)	● Distribution [Uniform] ● Input argument [min.1.8, max.63.7	● Distribution [Uniform] ● Input argument [min.5.66, max.17.47]

4. Results and Conclusion

Figure 1 shows the results of Monte Carlo simulation of NPP and LNG plant. The LCOE of nuclear power generation was expected to be 27.6 ~ 110.5 won, and the mean value was 66.1 won and the standard deviation was 18.3. On the other hand, LCOE of natural gas power generation has a relatively wide range of normal distribution of 24.4 ~ 212.5 won, showing a mean value of 107.7 won and standard deviation of 33.7.

Although there is overlapping of LCOE values, the probability of natural gas LCOE to be lower than the mean LCOE(66.1 won) of nuclear power generation, is only around 11.9%. This is significant for evaluating the competitiveness of these two power generation sources.

However, this study assumes that the natural gas price and utilization rate are within the range of the past 10 years, and there is a limitation that reflects the trend of the downward gas price due to the development of the shale-gas technology.

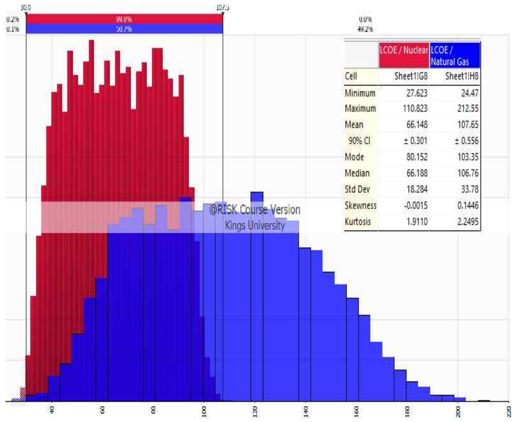

Figure 1. LCOE simulation of NPP and LNG plant

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