

Article

Economic Competitiveness Evaluation of the Energy Sources: Comparison between a Financial Model and Levelized Cost of Electricity Analysis

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Abstract: The levelized cost of electricity (LCOE) is used widely to compare the economic competitiveness of the energy mix. This method is easy to understand and simple to apply, which makes it preferable for many energy policymakers. However, the method has several disadvantages from the energy business perspective. First, the LCOE approach does not consider revenue, and a high-interest rate usually correlates with the tariff growth rate. Thus, if a high-interest rate increases the cost, that high rate increases the revenue, which can affect economic competitiveness. Second, the LCOE does not consider different stakeholders. Equity investors and loan investors have different interests depending on different financial indicators, which influence the same energy sources' differential economic attractiveness. This study analyzes and compares the LCOE, Project Internal Rate of Return (Project IRR), Equity Internal Rate of Return (Equity IRR), and Debt Service Coverage Ratio (DSCR) of an illustrative wind, coal, and nuclear power project using Monte-Carlo simulations. The results show that energy sources' economic competitiveness can vary depending on financial indicators. This study will help energy policymakers develop more economically realistic energy portfolios.

Keywords: energy business; energy source; project finance; financial model; levelized cost of electricity; internal rate of return; tariff growth rate; loan period; sensitivity analysis

1. Introduction

The energy mix throughout the world has changed very quickly as renewable energy has emerged [1–3], and energy mix policies must consider many factors, such as economic competitiveness, climate change, public acceptance, safety, and energy security [4]. Thus, in many cases, it is difficult to determine whether one specific energy source necessarily is better than others. Further, when only their economic competitiveness is compared, the results can vary according to the uncertainty of input variables, such as discount and interest rates, overnight capital cost, and capacity factor. For these reasons, many researchers have compared energy's economic competitiveness with probabilistic distribution variables using Monte Carlo simulations [5–7]. Most of these articles have analyzed this economic issue using the levelized cost of electricity (LCOE), which is adopted as a metric to estimate power generation technologies' competitiveness [6–9]. The LCOE is an indicator used widely, in that it can compare different lifecycle energy sources easily [8,10]. LCOE provides us with remarkable information with regard to the cost side in that LCOE itself is a concept of the minimum required tariff to cover the project costs. However, despite its worldwide and traditional use, the LCOE itself is not a perfect approach, particularly from the financial point of view in an actual business [11,12].

LCOE usually is calculated as follows: the total project life-cycle cost divided by the total lifetime energy production [13]. The biggest issue of the LCOE calculation from the energy business is that it

only deals with the costs which naturally exclude the concept of revenue and profit. The basic concept of finance comes from both the cost and the revenue which leads to the final outcome known as net income or profit. As the revenue side is not applied in the LCOE calculation, LCOE naturally does not take into consideration the revenue-related variables such as *TGR* which is corresponding to the *IR* of cost as the value for money. Another issue is that the financial attractiveness can be varied depending on the financial stakeholders. Equity investors pursue their profit from their financial investment and long development. They try to find the optimum equity-debt portfolio to maximize the profit leverage effect. This profit varies according to the *CP*, the ratio between *LP* and *OP*, *IR*, *TGR*, and so on. Whereas, loan investors weight not only the amount of interests but also the payback stability over the long *LP*. This stability also varies according to volatility of *CF* and *TGR*, *CP*, cash flow, the ratio between *LP* and *OP*, dividend arrangement, and so on. For these reasons, LCOE cannot sufficiently explain the various interests of different stakeholders. Thus, if the financial model is used, the various financial indicators can help provide the various values to various different stakeholders. These various financial values can be helpful to establish a realistic and balanced economic energy mix. This paper aims to explain how the economic and financial competitiveness of each energy generation can be varied depending on the various conditions using not only the LCOE calculation but also the financial model approach. This study does not aim to reveal which energy source itself is more competitive or not because it can be varied depending on the assumptions of input variables and project condition. Thus, the various assumptions of this study aim to explain the principles of its variable economic attractiveness. If this study changes the assumptions, the priority results of economic competitiveness can be varied. In order to achieve this objective, this article shows the following contents. First of all, this study briefly introduces the concept of LCOE and financial model in background section. Second, this article explains the various input variables and assumptions in methodology section. Third, the results section analyzes the economic and financial competitiveness depending on various conditions. Then, this article summarizes the findings and suggests insights in discussion section. Last, the conclusion section expresses the value, limitation and future study of this study.

2. Background

2.1. LCOE Approach

The LCOE is a widespread indicator used to compare cost competitiveness and identify the grid parity among different energy generation technologies [14–18]. It presents the per-MWh cost of constructing and operating a generating plant over the assumed project life. The LCOE value usually is calculated as follows: total lifetime cost divided by total lifetime energy production [13]. It also is calculated by dividing the total capital investment's Net Present Value (NPV) by the discounted energy yield, which results in the average cost per energy unit [9,14,19]. If the NPV reaches zero, a break-even situation occurs, which is referred to as grid parity [15,18,20]. Many variable inputs also are considered in the LCOE's calculation, such as *OCC*, *F_OM*, *V_OM*, *CF*, *CRF*, *FC*, and *HR*. The formula below shows the way the LCOE is calculated with various input variables [6]:

$$\text{LCOE (\$/MWh)} = \frac{\text{OCC} \times \text{CRF} + \text{F_OM}}{8760 \times \text{CF}} + \text{FC} \times \text{HR} + \text{V_OM} \quad (1)$$

Typically, the *CRF* is referred to as the ratio of the constant annuity to the present value of receiving that annuity at a given time [21]. The *CRF* equation consists of the *IR* (*i*) and *OP* (*n*). The formula for the *CRF* is expressed below [6]:

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (2)$$

LCOE has become a key indicator which is utilized worldwide to compare the unit cost of each other generation especially thanks to its easiness and simplicity. LCOE is still quite useful in that it shows the economic competitiveness of each energy generation in its simple way. However, despite its

worldwide and traditional utilization, LCOE equation itself is not the perfect approach if it comes to the financial business perspective [12]. First, LCOE evaluates the economic strength based upon only the costs which are different from the general finance concept which should consider both the cost and the revenue side. Even though LCOE provides the minimum required tariff to recover the total costs, LCOE cannot reflect well that the *TGR* offsets the effect of the *IR*. Second, the same *IR* is usually applied for comparing the LCOE of each energy source [12]. However, the *IRs* can vary depending on the cash flow, *LP*, *D_ER* and guarantee agreement. Third, the traditional LCOE usually assumes that the *LP* is same as the lifecycle *OP*. The LCOE calculation measured under the discounting method should consider the real *LP*, though [22]. The LCOE formula in this paper does not take into consideration the real *LP*. In reality, the *LP* of NPP or coal projects is shorter than the whole lifecycle. As a result, such LCOE's simplicity leads to overlooking the actually complicated finance world. In reality, the more the projects are getting complicated, the more realistic input variables are to be used.

2.2. Various Approaches for Better Economic Competitiveness Evaluation

Two kinds of LCOE methods are most popular in energy economics [8]. The US Department of Energy's National Renewable Laboratory defines LOCE using Equation (1), which is called as "annualizing" method [8,22]. This method is simple and easy but assumes that the *LP* is same as the *OP*. On the other hand, the UK defines LCOE as "the discounted lifetime cost of ownership and use of a generation asset, which considers every year's different cost of every variable [23]. This approach is more complicated but can consider the differences between *LP* and *OP*. However, this one has to assume or calculate the discount rate, which sometimes evokes the subjective evaluation issues [24,25]. So, some researchers suggested several alternative metrics such as undiscounted cost of energy approach, discounted cost of energy approach and total cost of energy [8,26]. These tried to improve the weakness of the traditional LCOE approach but are not used much until now [8].

Many researchers mentioned the energy economic issues related to the *TGR* [14,22,27,28]. First, tariff growth variation has an effect on the economic value of grid parity. Both the LCOE and tariff have to be considered simultaneously [14,27,28]. Second, the economic value of electrical energy storage is affected by tariff growth variation. As the volatility of tariff growth increases, the value of electrical energy storage also increases [22]. Third, tariff growth has an influence on increasing the lower NPV of energy business, but the LCOE does not change and keeps the same value, which induces the policymaker or investor to make wrong decision [14]. However, they did not explain the value of *TGR* comparing the *IR* from the financial feasibility perspective.

The *LP* is an important issue to evaluate project feasibility in all investment industries [29–31]. Investors usually prefer the shorter *LP* rather than long one. So, short *LPs* request low-*IRs*, whereas long *LPs* induce high-*IRs*. This means that the reduction of *LP* has an effect on increasing profitability [11]. However, energy industry has not studied this area much even if each energy project has different cash flow structures, and requires different *LPs* and *IRs*.

When the LCOE is calculated, the value of many input variables is uncertain. Input variables such as *OCC*, *CP*, *F_OM*, *V_OM*, and *CF* are difficult to be determined by one value. So, many researchers prefer using probabilistic approach rather than deterministic approach [5–7,9,25]. Particularly, Monte Carlo simulation is preferred to predict and compare the energy competitiveness with uncertain situations [5–7]. This study also uses Monte Carlo simulation to compare the value of LCOE, Project Internal Rate of Return (Project IRR), Equity Internal Rate of Return (Equity IRR), and Debt Service Coverage Ratio (DSCR).

2.3. Financial Model

The financial model adopts all possible necessary financial input variables, which make it more suitable for real businesses, as it considers not only the cost but the revenue as well. In addition, the financial model provides various financial indicators, including the Project IRR, Equity IRR, DSCR, and NPV, which explains the various attributes of a project's financial feasibility and economic

competitiveness. IRR is the *IR* that makes an investment's NPV equal to zero. Thus, if the IRR is larger than the *IR*, NPV becomes greater than zero. In this sense, the Project IRR is the *IR* at which the NPV of the project cash flows equals zero, which also is referred to as Return on Investment (ROI). The Project IRR is calculated assuming that no debt is used for it [32], for example, that the annual cash flow for the Project IRR is calculated from the Cash Available for Debt Service (CAFDS), which is the amount of cash a project keeps within one year. This study analyzes Project IRR, as it is a type of yield rate expected from the project investment overall. In this sense, the Project IRR must be higher than *IR*, which is an important criterion for loan investors. Meanwhile, the Equity IRR is calculated by considering principal and interest, and also is referred to as the Return of Equity (ROE). Shareholders give more weight to Equity IRR rather than Project IRR because it is related directly to the shareholders' profit. Generally, Equity IRR is the leveraged version of Project IRR and the former will be lower than the Project IRR only when the cost of debt exceeds the Project IRR, which happens rarely [21]. In addition to the Project IRR and Equity IRR, DSCR is an important financial indicator from loan investors' perspective, because they must confirm that the borrowers can afford the amount of debt every time. This is calculated as the CAFDS divided by the debt service, which includes both the principal and interest. Lenders normally request that project owners maintain between 1.2 and 1.5 the value of DSCR at least [33]. This study analyzes and compares the Project and Equity IRR, and DSCR of each energy source to understand its economic and financial competitiveness depending on equity and loan investors. The energy mix preference can vary depending on these results.

3. Methodology

3.1. LCOE Variables

To compare the economic competitiveness between the LCOE and the financial model, we chose three representative energy sources: coal, wind, and nuclear. Coal and nuclear represent conventional energy while wind does renewable energy. Especially, these energy sources are chosen due to their distinctive characteristics in terms of the financial structure. Renewable energies such as wind, solar and biomass request lower capital cost, shorter *CP* and *LP*, but yields relatively low and voltaic cash flow. In contrast, nuclear energy requires very huge capital cost, long *CP* and *LP*, but yields high and stable cash flow. Coal energy positions between wind and nuclear from the financial structure perspective. These clear differences among three energy sources provide better comparison with the calculated financial results between the LCOE approach and the financial model.

The LCOE normally is calculated according to a basic formula (1) that uses the *OCC*, *F_{OM}* and *V_{OM}*, *CF*, *IR*, and *OP* as the primary input variables. The *FC* and *HR* variables are added to calculate the LCOE of coal and nuclear power, as they also are considerable input variables. The data for input variables in coal, wind, and nuclear plants are gathered from the journal [5] and this journal article used the data sources [34–38]. The data set is based upon the U.S. energy market and gathered from the operating power plants in all 50 states and one district in the U.S. The *OP* is needed to calculate the *CRF* in formula (2) and the *OP* of coal, wind, and nuclear facilities are assumed to be 30, 20, and 60 years, respectively. The *IR* also is included in the LCOE calculation as the discount rate [8]. This paper uses the term 'interest rate' henceforth to prevent any confusion because it also is used in the financial model.

The *IR* has a significant influence on the LCOE, and the rate varies depending on the country and energy source. High-income and upper-middle-income countries normally have lower *IRs* than do low and lower-middle-income countries because there is relatively less market volatility with respect both to economics and politics. Therefore, this study assumes three different *IRs*, i.e., 3%, 7%, and 10%. Normally between 3% and 10% *IRs* are widely in journal papers for comparison. Tran and Smith utilized 3% and 10% *IRs* in their journal paper as they are commonly used [6]. A 3% rate would be used by government-owned utilities with fine bond ratings. The 7% rate would be considered as the rate available to an investor with a low risk of default in a relatively stable market. The 10% rate can be

considered as the investment cost facing substantially higher risks. [9] As a result, 3% rate represents a relatively stable market and less risky project among three rates, while 10% rate represents the most unstable market and risky project under volatile circumstances [9].

3.2. Financial Model Variables

This study develops the financial model to compare its economic competitiveness to the LCOE calculation by performing the financial feasibility analysis of each energy source: coal, wind, and nuclear. It is necessary to use as many and the most appropriate financial input variables as possible to derive more precise financial cash flow in the financial model. Tables 1–3 summarize the input variables used for coal, wind, and nuclear in the LCOE and financial model.

Table 1. Coal Input Variables.

Input Variables	Range	Distribution	Input Arguments	References
OCC (\$/kW)	1584–8071	Log-normal	$\mu = 8.182, \sigma = 0.407$	[5,34,35,38]
F_OM (\$/kW-year)	19.67–30.80	Normal	$\mu = 25.27, \sigma = 2.80$	[5,34,35,38]
V_OM (\$/MWh)	2.2–6.1	Normal	$\mu = 4.15, \sigma = 0.975$	[5,34,35,38]
CF (%)	93.0	Constant	-	[5,34]
IR (%)	3.0, 7.0, 10.0	Uniform	Min. = 3, Max. = 10	[6,9]
OP (years)	30	Constant	-	Assumption
FC (\$/MMBtu)	1.27–2.41	Normal	$\mu = 1.84, \sigma = 0.285$	[5,34,36,37]
HR (Btu/kWh)	8755–12,005	Normal	$\mu = 10,380, \sigma = 812.5$	[5,34–37]
TGR (%)	0.0, 3.0	Uniform	Min. = 0, Max. = 5	Assumption
IF (%)	0.0, 3.0	Uniform	Min. = 0, Max. = 5	Assumption
IT (\$/MWh)	53.71 (48.83 × 110%) 67.94 (61.76 × 110%) 80.20 (72.81 × 110%)	Log-normal	In case of IR 3% In case of IR 7% In case of IR 10%	Based upon LCOE Calculation
LP (years)	30	Constant	-	Assumption
CP (years)	5	Discrete	Min. = 4, Max. = 6	Assumption
D_ER (%)	70.0–80.0	Uniform	Min. = 70, Max. = 80	[39]

#NOTE: Input variables in the highlighted are additionally applied in the financial model.

Table 2. Wind Input Variables.

Input Variables	Range	Distribution	Input Arguments	References
OCC (\$/kW)	1270–2670	Normal	$\mu = 1,970, \sigma = 350$	[5,34,35,38]
F_OM (\$/kW-year)	12.00–60.00	Triangular	Min. = 12, Max. = 60	[5,34,35,38]
V_OM (\$/MWh)	5.86–21.50	Log-normal	$\mu = 2.418, \sigma = 0.325$	[5,34,38]
CF (%)	22.75–50.75	Normal	$\mu = 36.75, \sigma = 7$	[5,34,38]
IR (%)	3.0, 7.0, 10.0	Uniform	Min. = 3, Max. = 10	[6,9]
OP (years)	20	Constant	-	Assumption
TGR (%)	0.0, 3.0	Uniform	Min. = 0, Max. = 5	Assumption
IF (%)	0.0, 3.0	Uniform	Min. = 0, Max. = 5	Assumption
IT (\$/MWh)	70.20 (63.82 × 110%) 88.52 (80.47 × 110%) 103.94 (94.49 × 110%)	Log-normal	In case of IR 3% In case of IR 7% In case of IR 10%	Based upon LCOE Calculation
LP (years)	20	Constant	-	Assumption
CP (years)	1	Discrete	Min. = 0.8, Max. = 1.5	Assumption
D_ER (%)	70.0–80.0	Uniform	Min. = 70, Max. = 80	[39]

#NOTE: Input variables in the highlighted are additionally applied in the financial model.

Table 3. Nuclear Input Variables.

Input Variables	Range	Distribution	Input Arguments	References
OCC (\$/kW)	4146–8691	Log-normal	$\mu = 8.7, \sigma = 0.185$	[5,34,35,38]
F_OM (\$/kW-year)	54.19–121.19	Normal	$\mu = 87.69, \sigma = 16.75$	[5,34,35,38]
V_OM (\$/MWh)	0.42–2.14	Triangular	Min. = 0.42, Max. = 2.14	[5,35,38]
CF (%)	85.0–95.0	Normal	$\mu = 87.5, \sigma = 1.25$	[5,34,38]
IR (%)	3.0, 7.0, 10.0	Uniform	Min. = 3, Max. = 10	[6,9]
OP (years)	60	Constant	-	Assumption
FC (\$/MMBtu)	0.65	Constant	-	[5,34]
HR (Btu/kWh)	10,420–10,480	Normal	$\mu = 10,450$ & $\sigma = 15$	[5,34,36]
TGR (%)	0.0, 3.0	Uniform	Min. = 0, Max. = 5	Assumption
IF (%)	0.0, 3.0	Uniform	Min. = 0, Max. = 5	Assumption
IT (\$/MWh)	52.66 (47.87 $\times$ 110%)	Normal	In case of IR 3%	Based upon LCOE Calculation
	82.84 (75.31 $\times$ 110%)	Log-normal	In case of IR 7%	
	107.97 (98.15 $\times$ 110%)	Log-normal	In case of IR 10%	
LP (years)	60	Constant	-	Assumption
CP (years)	7	Discrete	Min. = 5, Max. = 15	Assumption
D_ER (%)	70.0 - 80.0	Uniform	Min. = 70, Max. = 80	[39]

#NOTE: Input variables in the highlighted are additionally applied in the financial model.

The financial model uses more varied input variables than does the LCOE calculation while most of them are derived from previous papers and sources as in the LCOE calculation. In fact, the OCC, F_OM and V_OM, CF, IR, OP, FC, and HR also are used in the same way as in the LCOE calculation. On the other hand, D_ER, CP, LP, IT, TGR, and IF are new variables used only in the financial model. These additional variables are used rarely in the traditional LCOE calculation, and thus, they make the financial model's outcome more practical and suitable in the real business environment.

The IR also has a significant influence on the financial results, as it does in the LCOE calculation. As mentioned in the previous section, IR is assumed at 3%, 7%, and 10% respectively to show each influence on the results. In the case of distribution and tornado diagrams, the graph results are shown based upon the 7% rate representatively, which is the in-between value of 3% and 10%. The LP and TGR, which are used exclusively in the financial model, are also used differently depending on each situation. For example, the LP will be used differently to find its effect on the financial model, while TGR and IF will be used to assess revenue's effect. As mentioned previously, these two input variables make the financial model distinctive and more practical. The LP is based primarily upon the OP and can be shortened depending on the given circumstances. The TGR plays a strong role in the revenue side, while the IR does so on the cost side. The financial model's consideration of the tariff is one of its important features. The TGR normally is lower than the IR. Therefore, this paper assumes different TGRs that are lower than IRs to find their large influence on the financial indicators' results. 0% and 3% TGRs are assumed, respectively, to identify its drastic effect on the financial values. This paper equates the IF and TGR because both are typically coupled, although the IF actually is a different concept from the TGR. It is normal for economically stable countries to have lower economic growth rates, including TGR, IF, and IR. This paper also assumes that the IT is proportional to the LCOE's simulated distribution. For instance, the median LCOE values at 7% IR are 61.76\$/MWh for coal, 80.47\$/MWh for wind, and 75.31\$/MWh for nuclear, respectively which will be analyzed in the LCOE calculation. LOCE can be understood as the minimum electricity price or tariff represented in \$/MWh. Since the LCOE is the cost concept, the electricity price or tariff, which is the revenue concept, should be larger than the LCOE to yield profit. In this sense, this paper uses the IT price with each LCOE value with 10% profit margin, so each 110% of LCOE values calculated is used for coal, wind, and nuclear power. For this reason, the price of each energy source starts differently although it does not make sense in open electricity market. However, this study uses this assumption for explaining the effect of LP and TGR depending on the attributes of each energy source. The D_ER is assumed to range from 70 to 80 percent with uniform distribution similar to actual financing projects [39].

3.3. Financial Sensitivity Analysis

Financial sensitivity analysis evaluates financial input variables' effect on the financial indicators' resulting values when other conditions remain constant. To improve financial viability and feasibility, more sensitive input variables are considered in the financial analysis. This analysis helps prioritize and manage the financial factors that affect a project's financial success. Monte Carlo simulation is the tool used most widely and is based on random generation and a probabilistic distribution. Spinney and Watkins proposed using Monte Carlo simulation techniques to analyze energy resource decisions and evaluate each decision's advantages and disadvantages [6,40]. This kind of simulation also is a relatively simple and established technique to account for uncertainty in quantitative models [5]. All financial input variables except for those that are held constant are included in the financial sensitivity analysis.

This study uses the @risk commercial tool that provides the Monte Carlo Simulation, and tornado and spider diagrams [6]. The study uses the tornado diagrams to show each input variable's degree of sensitivity. This is represented with a coefficient value, and the most sensitive variable is located at the top of the Y-axis. A tornado graph from a sensitivity analysis displays a ranking of the input distributions that affect output. Inputs that influence the output's distribution most have the highest bars in the graph. A tornado graph also shows the change in the output statistic's value overall. The financial sensitivity analysis shows which financial feasibility factors to prioritize by determining how much they affect the financial indicators' values. Different investors have different financial concerns that various input variables represent in the financial model. Based on the results of the financial sensitivity analysis, they can determine their priorities of which factor they must consider the most.

4. Results

4.1. Interest Rate Effect

It is simple to compare energy sources' cost competitiveness using the LCOE calculation. The probabilistic distribution graphs in Figure 1 show each LCOE value of coal, wind, and nuclear power at 3%, 7%, and 10% IRs.

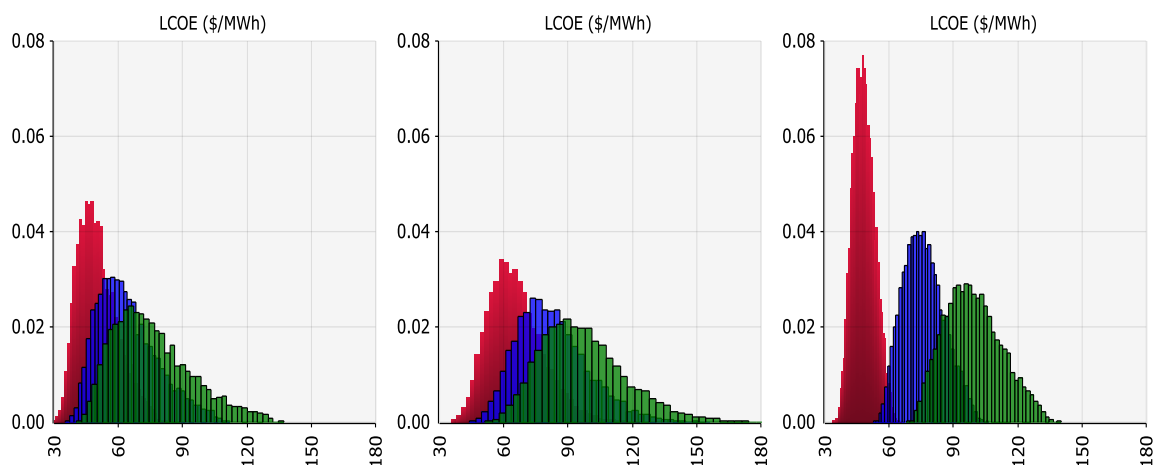


Figure 1. LCOE distributions of Coal (left), Wind (middle), and Nuclear (right) at 3%, 7% and 10% IR.

Red represents the LCOE distributions at the 3% IR, blue represents it at the 7% rate, and green does at the 10% rate. It is clear that the LCOE values with the 3% IR are the smallest, as they are located on the left side in each graph. When the three energy sources are compared, coal appears to be the most competitive in overall, in that the graphs generally are skewed to the left compared to those in the wind and nuclear. In fact, the LCOE value of coal at 7% IR is the lowest, with 61.76\$/MWh median LCOE value. As for 3% IR, coal also has high-cost competitiveness along with nuclear power although

it ranks the 2nd by little gap. This low cost encourages energy project investors to develop independent power plant projects in low and middle-income countries. On the other hand, it is complicated to compare the LOCE between wind and nuclear; the LCOE values of nuclear at the 3% and 7% *IR* are more competitive than those of wind under the same condition. In contrast, with the 10% *IR*, the LCOE median value for wind is slightly smaller than that of nuclear, although the distribution's width is wider in the case of wind. The distribution's width indicates uncertainty, and therefore, it can be concluded that wind is the most volatile energy generation source in this sense. Nuclear power is the most stable source among the three, as its narrow distribution shows. As a result, competitiveness with respect to the LCOE value differs depending on the *IR*. In particular, that of nuclear power increases drastically when the *IR* goes up from 3% to 10%. Table 4 summarizes each energy source's median LCOE values at 3%, 7% and 10% *IR*s.

Table 4. Median LCOE values of Coal, Wind, and Nuclear at 3%, 7% and 10% *IR*.

Rank		3% <i>IR</i>		7% <i>IR</i>		10% <i>IR</i>
1	Nuclear	47.87\$/MWh	Coal	61.76\$/MWh	Coal	72.91\$/MWh
2	Coal	48.83\$/MWh	Nuclear	75.31\$/MWh	Wind	94.49\$/MWh
3	Wind	63.82\$/MWh	Wind	80.47\$/MWh	Nuclear	98.15\$/MWh

Nuclear power is the most competitive energy source at 3% *IR* with its lowest median LCOE value among three technologies. However, nuclear power's LCOE value has increased so much that it becomes the least competitive one with respect to the LCOE at the 10% *IR*. In general, the NPP projects require an enormous *OCC* compared to other power plants. Further, the long *CP* induces even more financial cost, and the *IR* affects high-intensity *OCC* greatly. In this sense, nuclear power's LCOE value at 3% *IR* seems plausible. However, 7% and 10% *IR* affect the huge capital even further, which leads to less competitive LCOE values. It is common for low and lower-middle-income countries to have relatively high *IR*s. It is clearly shown in Figure 1 that relatively bigger gap exists among the colored graphs in the distribution of the nuclear which means a drastic increase of LCOE as *IR* goes up. Under these circumstances, NPP projects cannot be economically competitive without other countries' financial support. This is a weakness of the LCOE calculation attributable to its simplicity.

With respect to wind power, the relatively higher LCOE value is attributable primarily to its low *CF*. Renewable energy sources inevitably have a relatively less attractive *CF* compared to conventional power sources, including coal and nuclear. This is the weakest point in renewable energy at present that limits the locations that provide it. Combined with the low *CF*, high *V_{OM}* is one of the reasons that they have a high LCOE value. It gets worse if the *IR* goes up from 3% to 10%. As a result, *IR* plays an important role in calculating the LCOE value. The higher the *IR* is, the worse the LCOE value becomes depending on each energy sources' own characteristics.

The *IR* has a strong effect on the financial outcome, not only in the LCOE calculation but also in the financial model. The financial model explains *IR*'s influence better than the LCOE approach does. For example, interest accrues during both the *CP* and *LP*, and the former one is frequently prolonged. The *LP* often is equated with the *OP*. Table 5 shows the comparison of the total interests both during the *CP* and *LP* per each energy source's *OCC*.

Table 5. Interests incurred during *CP* and *LP* for Coal, Wind, and Nuclear.

Category	IR	Coal	Wind	Nuclear
(a) Interests during <i>CP</i>	3%	\$148,972,648	-	\$608,699,932
	7%	\$358,902,236	-	\$1,499,114,109
	10%	\$525,160,182	-	\$2,230,836,458
(b) Interests during <i>LP</i>	3%	\$1,349,353,799	\$54,263,910	\$8,157,248,404
	7%	\$3,843,264,845	\$139,926,502	\$25,196,153,620
	10%	\$6,206,961,123	\$212,632,737	\$41,572,681,388
(c) Total Interests (a) + (b)	3%	\$1,498,326,447	\$54,263,910	\$8,765,948,336
	7%	\$4,202,167,081	\$139,926,502	\$26,695,267,729
	10%	\$6,732,121,305	\$212,632,737	\$43,803,517,846
(d) OCC	-	\$3,030,000,000	\$197,000,000	\$8,121,400,000
(e) Total Interests per OCC (c) / (d)	3%	49.45%	27.55%	107.94%
	7%	138.69%	71.03%	328.70%
	10%	222.18%	107.94%	539.36%

Because wind facility construction requires 1-year, no interest is incurred and the interest accrued during the *LP* also is relatively small with its small OCC compared to other energy sources. On the other hand, the *IR* has serious effects on NPP projects' cost especially as it increases to 10%, largely because of their high OCC and long *CP*. This result is quite similar to that in the LCOE calculation. However, in the real energy business, most countries that construct NPP plants have a budget with an approximately 5% rate. This interest can be reduced by shortening the *LP*, which will be addressed in the next section.

4.2. Loan Period Effect

The traditional LCOE calculation does not distinguish the *LP* from the *OP* [21]. However, in reality, some projects with reasonable cash flow can afford to pay back the debt earlier than the estimated *OP*. Because the debt amount is proportional to the *IR* and *LP*, it is much better to repay the loan as soon as possible if the project cash flow can afford it. From this perspective, the minimum DSCR (MDSCR) is used to assess the worst time to repay with respect to cash flow. The MDSCR always must be larger than 1.0×; otherwise, the project cannot afford the debt at that time. On the other hand, the Average DSCR (ADSCR) calculates the project owners' ability to repay the loan overall. The project developer or borrower must maintain a minimum degree of DSCR to show that they have no financial problems during the *LP*. Project financing usually requires a 1.2×~1.5× ADSCR depending on the project and the situation's characteristics. As mentioned previously, this paper assumes that the *IT* price of coal, wind, and nuclear power starts at 110% of the LCOE of each energy source. Thus, the *IT* price is different from the value of the real energy market.

ADSCR values for each energy source during the original *LP* are at least over 1.2×, which indicates that it is possible for them to shorten the *LP*. For instance, in case of the 7% *IR*, the coal has the highest ADSCR value, 1.551×, followed by wind with 1.457× and nuclear power with 1.240×. Among various factors which affect the amount of debt service, the *LP* can be adjusted by distinguishing it from the *OP*. ADSCR values also can be optimized with such shortened *LP* by meeting the minimum ADSCR criterion. The shortest possible *LP* is shown in Table 6 with adjusted ADSCR values which still remain above 1.2×. Adjusted ADSCR values are 1.220× for coal with 17 years, 1.203× for wind with 14 years, and 1.201× for nuclear power with 45 years. ADSCR and MDSCR have no differences in value as no *TGR* is applied. Nuclear power's *LP* is shortened the most, in that its ability to repay the debt originally was originally divided by the *OP*, which is the longest among the three sources. In other words, nuclear power's decent cash flow affords the earlier repayment of the debt service. In addition, Figure 2 shows that nuclear power's distribution has the narrowest range, which indicates that it has the lowest possible volatility. This implies that nuclear power is likely to shorten *LP* the most with satisfying the minimum ADSCR. In Figure 2, red graphs mean ADSCR values during the adjusted *LP*

while blue ones mean during *OP*. The delimiter is fixed at 1.2 ADSCR which means that the percentage on the right side is the possibility of ADSCR over 1.2 $\times$. For example, the likelihood of having over 1.2 $\times$ ADSCR value during the shortest possible *LP* for wind is 57.5%. Since the ADSCR value becomes lower close to 1.2 $\times$ during the adjusted *LP*, the probability over 1.2 $\times$ naturally gets lower accordingly.

Table 6. ADSCR values of Coal, Wind, and Nuclear during original and adjusted *LP*s.

<i>LP</i>	<i>IR</i>	Indicator	Coal	Wind	Nuclear
<i>LP</i> as Same as <i>OP</i>	3%	ADSCR	1.718 $\times$	1.490 $\times$	1.409 $\times$
- Coal: 30 years	7%	ADSCR	1.551 $\times$	1.457 $\times$	1.240 $\times$
- Wind: 20years	10%	ADSCR	1.454 $\times$	1.439 $\times$	1.142 $\times$
- Nuclear: 60 years	3%	ADSCR	1.206 $\times$	1.258 $\times$	1.207 $\times$
Shortest possible (Adjusted) <i>LP</i>	7%	<i>LP</i>	18 years	16 years	42 years
		ADSCR	1.220 $\times$	1.203 $\times$	1.201 $\times$
		<i>LP</i>	17 years	14 years	45 years
		ADSCR	1.207 $\times$	1.201 $\times$	1.142 $\times$
	10%	<i>LP</i>	16 years	13 years	60 years
		ADSCR			

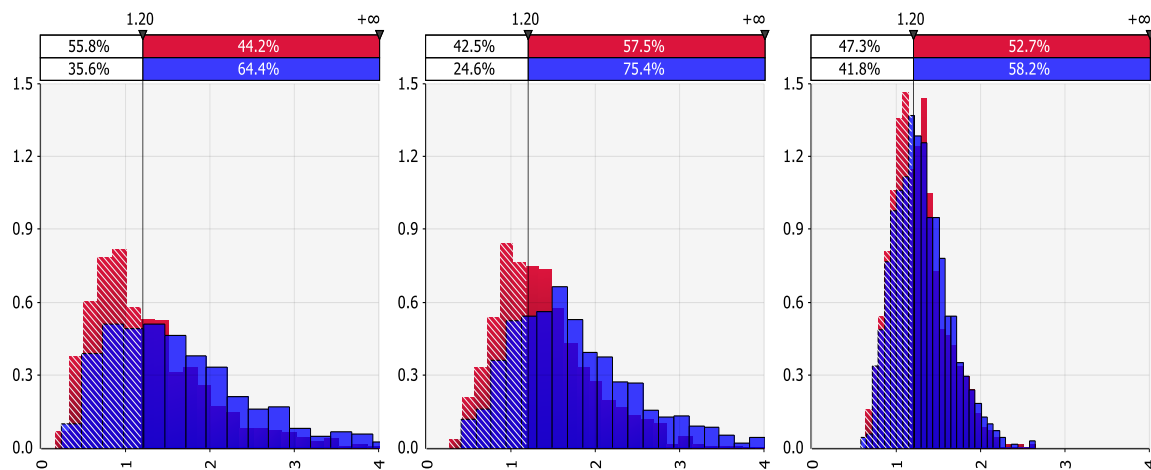


Figure 2. ADSCR distributions of Coal, Wind, and Nuclear during original and adjusted *LP*s at 7% *IR*.

The reduced *LP*s of each energy source has an influence on the value of the Equity IRR. Shortening the *LP* naturally reduces the amount of the debt service, which includes the interest and principal. To validate the extent to which it affects each energy source, Figure 3 shows the variations in Equity IRR between the original and shortened *LP*s.

For instance, the Equity IRR values during the original *LP* for each energy source are 12.58% for coal, 15.62% for wind, and 4.25% for nuclear at 7% *IR*. Relatively a large gap exists among energy sources because Equity IRR involves both the debt and interest concepts. Wind power has the highest Equity IRR value for all *IR* cases, in that its debt service is the smallest because of its small OCC and short *OP*. In contrast, nuclear generation, with its huge OCC and long *OP*, has the lowest value. As the *LP* gets shorter different from the *OP*, each Equity IRR changes, respectively.

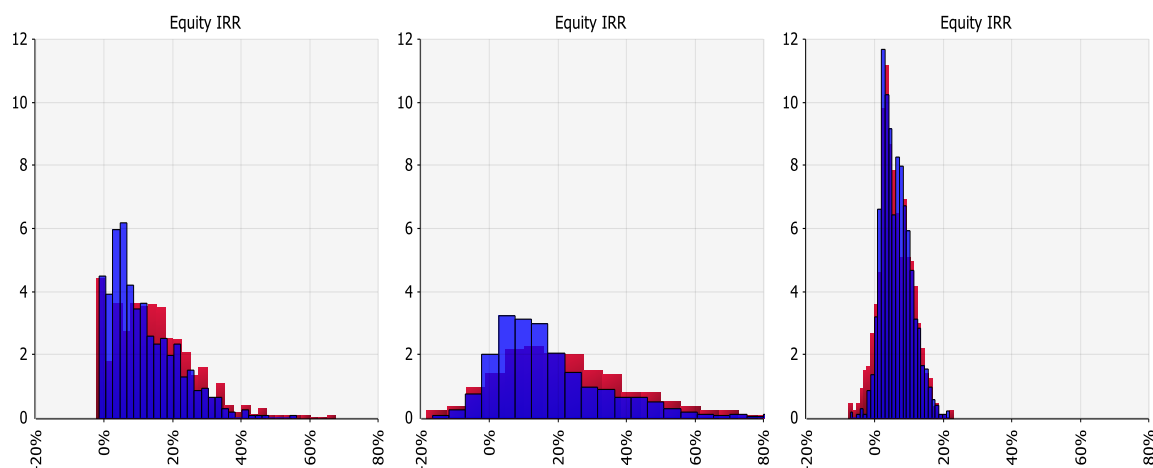


Figure 3. Equity IRR distributions of Coal, Wind, and Nuclear for original and adjusted LPs at 7% IR.

The LPs are shortened the most with satisfying the minimum ADSCR, 1.2 $\times$. With respect to the distribution shown in Figure 3, the blue graphs show that Equity IRRs with the OP, while the red graphs indicate Equity IRRs with the shortest possible LP. The graphs show that nuclear power has the narrowest distribution, while wind has the widest. Because the range is related strongly to uncertainty, nuclear power has the lowest possible uncertainty with respect to Equity IRR. Thus, regardless of these relatively low values, it has the lowest uncertainty. In contrast, wind generation has enormous potential volatility, even though its values are somewhat high. Further, the adjusted values are 11.11% Equity IRR with 17 years of LP for coal, 12.81% with 14 years for wind, and 5.82% with 45 years for nuclear. Nuclear power's Equity IRR has increased, while that of coal and wind has decreased. This result means that Equity IRRs for coal and wind are better when the LP is the same as the OP. With the shortened LP, the annual payment of debt service increases compared to that of the OP. This is natural so that the debt is repaid quickly by paying more annual debt service, as the project can afford to do so by satisfying the minimum ADSCR, 1.2 $\times$. In case of coal and wind, repaying the debt service during the whole OP ironically becomes more profitable with respect to Equity IRR. This is mainly because they have relatively short OPs that last only up to around half of nuclear power and the annual operation profit per OCC also is relatively high. As a result, the optimal LP to yield the most profitable Equity IRR is 27 years for coal, which is a decrease of only 3 years from the OP and 20 years for wind, which remains the same as the OP.

With respect to the Project IRR, energy sources in most cases have at least the same or higher IR than each assumed IR. Normally, CP has an enormous influence on Project IRR values. For example, NPPs, with the longest CP (7 years) induce more interest and yield a late operation revenue after the construction competition. Even the IF is applied to the OCC during the CP which leads to a drastic increase in cost. This is why nuclear power has the lowest Project IRR value among three generations. From this perspective, if three energy sources had the same CP with 1 year, for instance, coal would be the first, with the highest Project IRR, as it has the highest operating profit per OCC. In reality, wind power has the best Project IRR, in that it requires only 1 year CP, while coal requires 5 years. Because the Project IRR itself does not consider the debt concept, it does not change in value even if the LP is shortened. Therefore, the LP effect occurs with the Equity IRR. Table 7 summarizes the IRR values for different LPs at each 3%, 7%, and 10% IRs.

Table 7. IRR values of Coal, Wind, and Nuclear for original, adjusted, and optimal *LP*.

Equity IRR	IR	Indicator	Coal	Wind	Nuclear
<i>LP</i> as Same as <i>OP</i> - Coal: 30 years - Wind: 20years - Nuclear: 60 years	3%	Equity IRR	11.21%	11.73%	4.41%
		Project IRR	5.17%	4.98%	3.43%
	7%	Equity IRR	12.58%	15.62%	4.25%
		Project IRR	8.62%	9.06%	6.69%
	10%	Equity IRR	12.94%	18.24%	3.49%
		Project IRR	11.11%	12.16%	8.87%
Shortest possible (Adjusted) <i>LP</i>	3%	Equity IRR	8.25%	9.10%	4.21%
		Project IRR	5.17%	4.98%	3.43%
		<i>LP</i>	18 years	16 years	42 years
	7%	Equity IRR	11.11%	12.81%	5.82%
		Project IRR	8.62%	9.06%	6.69%
		<i>LP</i>	17 years	14 years	45 years
Optimal <i>LP</i>	10%	Equity IRR	12.85%	16.01%	3.49%
		Project IRR	11.11%	12.16%	8.87%
		<i>LP</i>	16 years	13 years	60 years
	3%	Equity IRR	11.21%	11.73%	4.58%
		Project IRR	5.17%	4.98%	3.43%
		<i>LP</i>	30 years	20 years	54 years
Optimal <i>LP</i>	7%	Equity IRR	12.78%	15.62%	5.82%
		Project IRR	8.62%	9.06%	6.69%
		<i>LP</i>	27 years	20 years	45 years
	10%	Equity IRR	13.80%	18.65%	3.49%
		Project IRR	11.11%	12.16%	8.87%
		<i>LP</i>	24 years	18 years	60 years

With respect to the Project IRR, energy sources in most cases have at least the same or higher *IR* than each assumed *IR*. Normally, *CP* has an enormous influence on Project IRR values. For example, NPPs, with the longest *CP* (7 years) induce more interest and yield a late operation revenue after the construction competition. Even the *IF* is applied to the *OCC* during the *CP* which leads to a drastic increase in cost. This is why nuclear power has the lowest Project IRR value among three generations. From this perspective, if three energy sources had the same *CP* with 1 year, for instance, coal would be the first, with the highest Project IRR, as it has the highest operating profit per *OCC*. In reality, wind power has the best Project IRR, in that it requires only 1 year *CP*, while coal requires 5 years. Because the Project IRR itself does not consider the debt concept, it does not change in value even if the *LP* is shortened. Therefore, the *LP* effect occurs with the Equity IRR. Table 7 summarizes the IRR values for different *LP*s at each 3%, 7%, and 10% *IR*s.

The actual *LP* can have an enormous effect on the Equity IRRs, and the optimal *LP* is that most suitable to achieve the most profitable Equity IRR. Even though the optimal *LP*s are longer than the shortest possible periods for coal and wind power in this paper, shortening the *LP* itself has a huge advantage in the real world, in that it also can decrease loan investors' investment risk. Thus, loan investors can require more attractive *IR* if the *LP* is reduced. In this sense, the *IR* naturally goes down with the shortened *LP*s. As a result, the optimal *LP* would be the same as the shortest possible period in a real world by satisfying the minimum criterion, $1.2 \times \text{ADSCR}$.

4.3. Tariff Growth Rate Effect

The *TGR* usually has an effect on the revenue side. The revenue itself will increase drastically under the circumstances with longer *OP*. From this perspective, nuclear generation, with a 60 year *OP*, can take advantage of the *TGR* effect. However, the rate usually accompanies the *IF* and the operation cost increase annually with the *IF*. Therefore, the *TGR* effect when operating profit is calculated as

operation revenue minus operation cost, becomes offset. Nevertheless, considering the tariff concept itself is very useful and necessary in project finance. The assumptions in the previous section is based upon a 0% *TGR*, which means that the *TGR* effect is not considered. This section compares a 0% and 3% constant *TGR* with each energy source's optimal *LP*. This can clearly show the way the *TGR* influences the financial model's financial results.

In Figures 4 and 5, the red graphs indicate that the *TGR* is not considered while the blue graphs consider a 3% rate. It is shown that both Equity and Project IRR values increased as *TGR* is applied. The *TGR* is adapted to the tariff every year which leads to an enormous increase of revenue during the whole lifetime. This makes the improved IRR values with a decent cash flow. As a result, the consideration of *TGR* improves financial feasibility. The *TGR* effect also covers the weakness of the LCOE calculation. As mentioned in Section 4.1, the LCOE value is highly dependent on the *IR*. The financial feasibility gets worse if the *IR* increases especially under the circumstances with the enormous *OCC* and a long *CP*. This negative change in LCOE value can be mitigated by the *TGR* effect. *IR* is closely related to the *TGR* in that both of the rates move coupled. In other words, high *IR* market also provides a high *TGR*. Thus, the annual increase of the revenue with the *TGR* reduces the *IR* effect. This is one of the strong points for the financial model to consider the revenue.

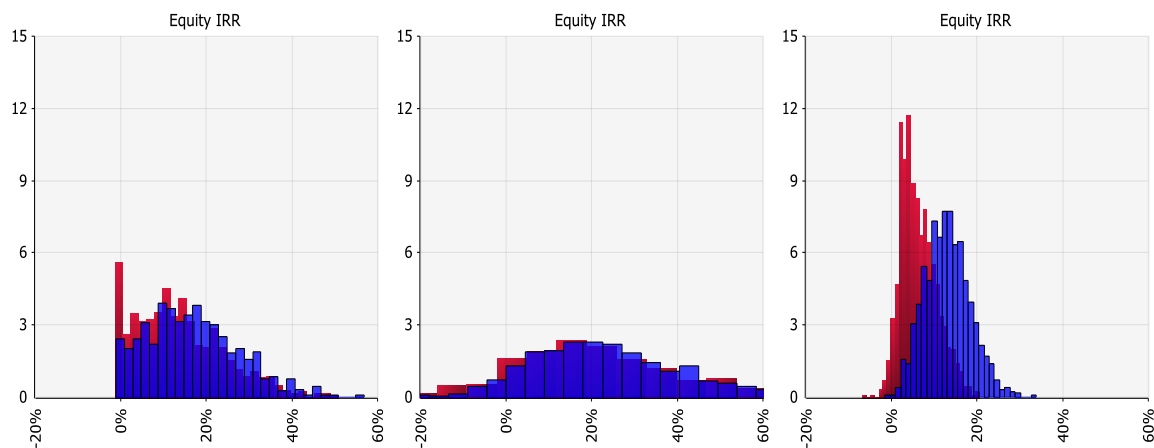


Figure 4. Equity IRR distributions of Coal, Wind, and Nuclear under 0% and 3% *TGR*.

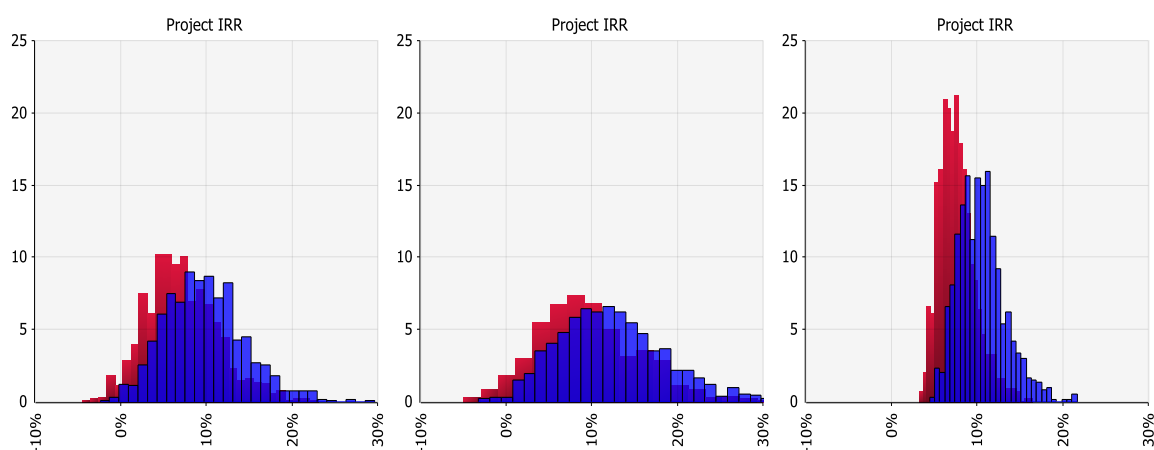


Figure 5. Project IRR distributions of Coal, Wind, and Nuclear with 0% and 3% *TGR*.

In addition, increasing the *TGR* affects both the Project and Equity IRR, while the *LP* effect influences only the Equity IRR. When comparing the influence on each power source, Project IRR increases quite proportionally for three sources. Equity IRR differs somewhat because it involves debt service. An increased *TGR* increases the revenue side, which leads ultimately to the rapid debt

repayment. In this way, the Equity IRR can improve greatly if the *TGR* is considered. Increased IRRs improve the project's cash flow and even the DSCR values with respect to Equity IRR. Table 8 summarizes the *TGR* effect with regard to the IRR and DSCR values. The data are based upon each optimal *LP* in Table 7 for each IRs.

Table 8. IRR and DSCR values of Coal, Wind, and Nuclear with 0% and 3% *TGR*.

<i>TGR</i>	<i>IR</i>	Indicator	Coal	Wind	Nuclear
Not consider (0%)	3%	Equity IRR	11.21%	11.73%	4.58%
		Project IRR	5.17%	4.98%	3.43%
		ADSCR	1.718×	1.490×	1.353×
	7%	Equity IRR	12.78%	15.62%	5.82%
		Project IRR	8.62%	9.06%	6.69%
		ADSCR	1.498×	1.457×	1.201×
	10%	Equity IRR	13.80%	18.65%	3.49%
		Project IRR	11.11%	12.16%	8.87%
		ADSCR	1.386×	1.386×	1.142×
3%	3%	Equity IRR	17.80%	20.05%	11.42%
		Project IRR	8.33%	8.13%	6.53%
		ADSCR	2.979×	2.062×	3.703×
		MDSCR	1.878×	1.535×	1.525×
	7%	Equity IRR	20.60%	25.11%	14.22%
		Project IRR	11.88%	12.34%	9.89%
		ADSCR	2.474×	2.017×	2.799×
		MDSCR	1.641×	1.501×	1.358×
	10%	Equity IRR	22.35%	28.47%	15.35%
		Project IRR	14.44%	15.53%	12.14%
		ADSCR	2.180×	1.858×	3.520×
		MDSCR	1.520×	1.428×	1.295×

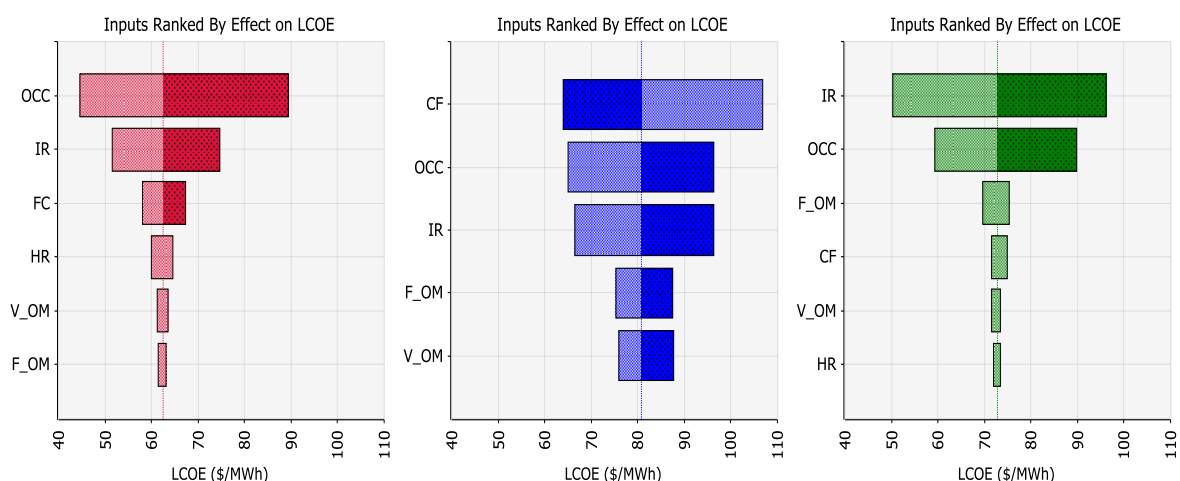
As *TGR* is applied, ADSCR is no longer the same as MDSCR. Overall, DSCR values are improved and it is quite remarkable in case of nuclear power. This is mainly due to its long *OP* which lasts up to 60 years. The *TGR* has an effect during the whole *OP* which yields a constant increase in the revenue. Thus, the improved revenue or net income naturally leads to better DSCR values with decent CAFDS. Moreover, these enhanced DSCR values can shorten the *LP* again, as was the case with the *LP* effect, which eventually yields better Equity IRR values. Similarly, considering the *TGR* offers a more attractive and profitable yield rate for all energy sources, particularly for those that operate for a long while with high debt service, such as nuclear power.

4.4. Financial Sensitivity Effect

A financial feasibility analysis evaluates the financial results based on input variables. It treats various input variables according to their distribution and shows the way they react sensitively to the financial results. The input variables for sensitivity effect in the LCOE calculation are *OCC*, *F_{OM}* and *V_{OM}*, and *CF*. *HR* and *FC* also are added for coal and nuclear generation. Constant variables are not included in the sensitivity analysis. This study assumes that the *CF* is a constant 93% in coal, and *FC* is a constant 0.65\$/MMBtu in nuclear. The *CF* in coal and *FC* in nuclear are quite stable, so that their sensitivity to the LCOE value is relatively quite low. The tornado diagrams in this section are shown with the 7% *IR* with the uniform distribution of minimum 3% and maximum 10%. The full analysis with each 3%, 7%, and 10% *IR* are provided in Table 9 in the Discussion section. As for variables in the LCOE, the financial sensitivity analysis yields relatively simple tornado diagrams as the LCOE calculation formula itself is simple and includes fewer input variables. The tornado diagrams in Figure 6 represent the degree of sensitivity of the coal, wind, and nuclear input variables on each LCOE values.

Table 9. Summary of the results of the LCOE approach and financial model analysis.

Approach	Indicator	Conditions	Coal	Wind	Nuclear
LCOE Approach	LCOE (\$/MWh)	(a) $IR = 3\%$	(2) 48.83	(3) 63.82	(1) 47.87
		(b) $IR = 7\%$	(1) 61.76	(3) 80.47	(2) 75.31
		(c) $IR = 10\%$	(1) 72.91	(2) 94.49	(3) 98.15
		(d) $= (c-a) / (c)$	(3) 33.03%	(2) 32.46%	(1) 51.23%
Financial Model	Equity IRR	Financial Sensitivity Tables 1–3 (excluding highlighted)	(1) OCC (2) IR (3) FC	(1) CF (2) OCC (3) IR	(1) IR (2) OCC (3) F_OM
		$IR = 3\%$	(e) Original LP (f) Optimal LP (g) $= (f-e)/(f)$	(2) 11.21% (2) 11.21% (2) 0%	(1) 11.73% (1) 11.73% (2) 0%
		$IR = 7\%$	(h) Original LP (i) Optimal LP (j) $= (i-h)/(i)$	(2) 12.58% (2) 12.78% (2) 1.56%	(1) 15.62% (1) 15.62% (3) 0%
		$IR = 10\%$	(k) Original LP (l) Optimal LP (m) $= (l-k)/(l)$	(2) 12.94% (2) 13.80% (1) 6.23%	(1) 18.24% (1) 18.65% (2) 2.14%
	Project IRR	Financial Sensitivity Tables 1–3 (including highlighted)	(1) OCC (2) IT (3) IR	(1) IT (2) CF (3) OCC	(1) TGR (2) OCC (3) IT
		$IR = 3\%$	(n) $TGR = 0\%$ (o) $TGR = 3\%$ (p) $= (o-n)/(o)$	(2) 5.17% (1) 8.33% (3) 37.94%	(2) 4.98% (2) 8.13% (2) 38.75%
		$IR = 7\%$	(q) $TGR = 0\%$ (r) $TGR = 3\%$ (s) $= (r-q)/(r)$	(2) 8.62% (2) 11.88% (2) 27.44%	(1) 9.06% (1) 12.34% (3) 26.58%
		$IR = 10\%$	(t) $TGR = 0\%$ (u) $TGR = 3\%$ (v) $= (u-t)/(u)$	(2) 11.11% (2) 14.44% (2) 23.06%	(1) 12.16% (2) 15.53% (3) 21.70%
		Financial Sensitivity Tables 1–3 (including highlighted)	(1) IT (2) OCC (3) TGR	(1) IT (2) CF (3) OCC	(1) TGR (2) CP (3) IT
		$IR = 3\%$	(n) $TGR = 0\%$ (o) $TGR = 3\%$ (p) $= (o-n)/(o)$	(2) 5.17% (1) 8.33% (3) 37.94%	(2) 4.98% (2) 8.13% (2) 38.75%
		$IR = 7\%$	(q) $TGR = 0\%$ (r) $TGR = 3\%$ (s) $= (r-q)/(r)$	(2) 8.62% (2) 11.88% (2) 27.44%	(1) 9.06% (1) 12.34% (3) 26.58%
		$IR = 10\%$	(t) $TGR = 0\%$ (u) $TGR = 3\%$ (v) $= (u-t)/(u)$	(2) 11.11% (2) 14.44% (2) 23.06%	(1) 12.16% (2) 15.53% (3) 21.70%

**Figure 6.** LCOE tornado diagrams of Coal, Wind, and Nuclear.

From the left, the red diagrams refer to coal, the blue to the wind, and the green to nuclear. The diagrams show that the ranking of each power generation source differs depending on its distinctive characteristics. OCC is one of the most critical input factors for all energy sources. It is the most

sensitive input variable for coal and rank 2nd for wind and nuclear power because its ratio is relatively high. On the other hand, *CF* is the most sensitive input variable for wind generation, followed by *OCC*. In fact, the climate and natural conditions affect renewable energy sources, including wind power, quite strongly. Therefore, their *CF* is significantly lower than that of conventional power sources and their volatility increases naturally. The *CF* has an even greater influence than does the *OCC* in wind power. On the other hand, it is not such a sensitive input variable for nuclear because its *CF* is quite stable and high and is assumed constant even in coal power. Nuclear power's *IR* becomes the most sensitive input variable, also followed by *OCC*. This is quite reasonable, in that *IR* plays an important role in the projects with high *OCC* and long *OP* which is closely related to the cost side. In this sense, *IR* ranks 1st in nuclear, 2nd in coal, and 3rd in wind source in order by *OCC* and *OP*. Also high *OCC* usually is one of the critical factors in NPP projects. Because these are quite complicated projects that involve various kinds of new technologies, they always have a huge amount and high proportion of *OCC* compared to other projects. In this sense, *F_OM* costs also compose a relatively high proportion of the cost of nuclear power, as nuclear generation technology itself is first-of-its-kind engineering that requires periodic maintenance. Therefore, except for *IR* which is decided by the owner's side, to manage the *OCC* and *F_OM* cost within a limited budget is a very important task for NPP projects. With respect to coal power, the *OCC* remains the most sensitive input variable and *IR*'s sensitivity also is high.

To determine any differences between the LCOE calculation and the financial model approach with respect to each input variable's degree of sensitivity, the financial sensitivity analysis is based largely upon the same situation as the LCOE calculation. The tornado diagrams for the financial model are shown at *TGR* 3% with a uniform distribution of minimum 0% and maximum 5%. Full analysis with 0% and 3% *TGR* are provided in Table 9 in the 5. Discussion section and *IR* remains the same as utilized in the financial sensitivity for LCOE. The *IT*, *CP*, and *D_ER* are added in the financial model. This paper uses Equity IRR and Project IRR as financial indicators, which are the most representative, as they show the project's projected total yield rates during the total lifetime from the perspective of equity investors and project developers, respectively. The financial model's consideration of various financial indicators, such as Equity and Project IRR, is one of its strongest points. Further, it considers various stakeholders related to the project, while the LCOE calculation considers only the project developer.

In this sense, the Project IRR can be compared directly to the LCOE, as both consider the project developers' perspectives. The degree of sensitivity of input variables in Equity IRR is relevant particularly to equity investors. Therefore, the differences between the degree of sensitivity in Project IRR and Equity IRR eventually indicate the way different input variables should be considered depending on the stakeholders. The tornado diagrams in Figures 7 and 8 show each degree of sensitivity in the Equity and Project IRR of coal, wind, and nuclear power.

From the left, the red diagrams indicate coal, the blue wind, and the green nuclear, as in the LCOE calculation. Because the financial model considers more input variables, more ranked variables exist than in the LCOE calculation, and their degree of sensitivity differs considerably based upon their distinctive characteristics. First, for the Equity IRR, the tariff-related input variables which are exclusively utilized in the financial model generally rank high. For instance, *IT* has strong sensitivity in all sources; ranks 1st in wind, 2nd in coal, and 3rd in nuclear power. This means that the electricity price should be regarded very important in terms of revenue. *OCC* still has a huge influence on all three sources. Especially, *OCC* becomes the 1st sensitivity input variable, in that operating profit per *OCC* is the highest in coal power. As for *TGR*, it becomes the most sensitive input variable for nuclear power. As nuclear has the longest *OP* which leads to the yield of revenue for a long time, *TGR* plays a very important role in this sense. The *IT* and *TGR*'s high sensitivities indicate that considering the input variables with respect to the revenue side is very important. As a result, this demonstrates that the financial model, which considers not only the cost but also revenue, is more practical in the real business world. Other than *TGR* and *IT*, the remaining input variables have similar degrees of

sensitivity, as in the LCOE calculation. The *IR* still ranks high especially for nuclear source and the *CP* relatively ranks higher in nuclear, because the 7-year *CP* affects the NPPs to a greater degree.

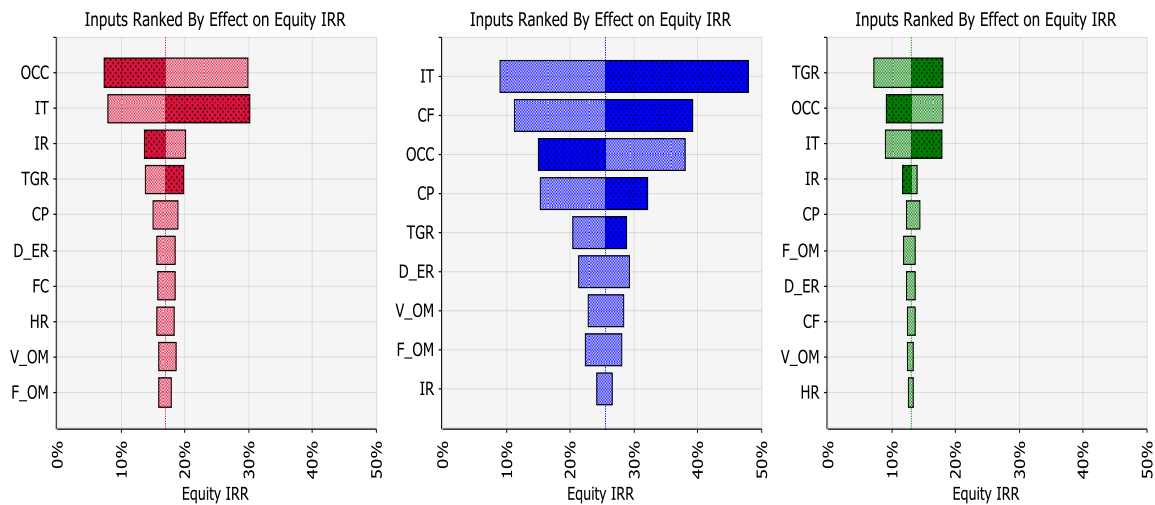


Figure 7. Equity IRR tornado diagrams of Coal, Wind, and Nuclear.

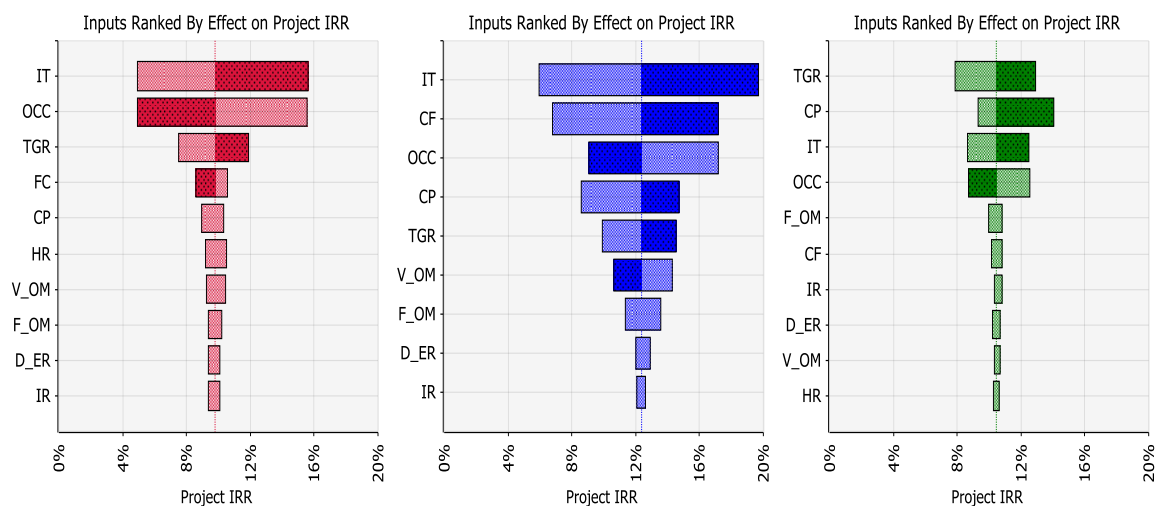


Figure 8. Project IRR tornado diagrams of Coal, Wind, and Nuclear.

Second, Project IRR shows some notable changes compared to Equity IRR. The *IT* becomes the 1st sensitive input variable for coal, while it is 2nd in the Equity IRR. This largely is because Project IRR does not consider any debt and interest. *OCC* becomes more sensitive with interest, but as the Project IRR is unrelated to interest, it becomes the 2nd with respect to sensitivity. For nuclear, the *CP* becomes a highly sensitive variable. This also is related to Project IRR's features. As the *CP* increases, the annual *OCC* divided by the *CP* increases with the *IF*. Even the revenue comes late, as the operation should begin after the completion of the *CP*. As a result, a long *CP* invariably has a strong influence on Project IRR, and ranks high in nuclear. The *IR* and *D_ER*'s degree of sensitivity also becomes relatively less important in Project IRR. Thus, *IR* and *D_ER* are quite important in the Equity IRR, which considers the debt service. As for wind power, most of the important input variables rank the same in the financial sensitivity analysis of the Equity IRR and Project IRR. It is mainly because it has the shortest *OP* with small *OCC*.

What the tornado diagrams in Figures 6–8 show are that nuclear power has the shortest length of bars compared to the other two sources, in which wind has the highest. This is attributable primarily to its distinctive features. Because there is high uncertainty in wind power, as the distribution graphs also

show, each input variable has a relatively huge range. This is a weak point of wind power. Although it has competitive value, its uncertainty and high risk can be less attractive to the stakeholders. In contrast, despite its relatively small values, nuclear power's strong point is that it is less volatile and carries a small risk. Therefore, not only the indicators' financial results but also the power source's uncertainty and volatility should be considered together.

5. Discussion

This study shows various illustrative examples to reveal how the evaluation of the economic competitiveness for energy mix can be varied using the financial model and LCOE approach. Table 9 shows a summary of the results. First, the *IR* is a very sensitive variable to calculate the LCOE. Depending on the *IR* in the energy business market, renewable energy can be more economically competitive than non-renewable energy as shown (c) in Table 9. However, most country's *IR* is around 5%. Thus, conventional energy sources such as coal and nuclear can be still more economically complete than renewable energy in most cases. Second, if the *IT* price can be proportional to LCOE by government support, wind energy is more competitive than coal and nuclear shown (e), (h), and (k) in Table 9. Wind energy power plant has a shorter *CP* and lower costs compared to other coal and nuclear plants, which means that wind energy plant can deliver the required funding with relatively little financial costs. This enables the wind energy to yield high Equity IRR and Project IRR. Third, *LP* is not equal with the *OP* in most energy projects. Thus, if the *LP* is shortened given that DSCR meets the minimum specific criteria, Equity IRR can be increased in most cases shown (f), (i), and (l) in Table 9. The nuclear energy has a long *OP* and relatively stable operation income compared to renewable energy. Thus, the effect of adjusted *LP* in nuclear energy is higher than others. Fourth, *TGR* in revenue is similar to the *IR* in cost from the time value for money perspective. *IR* is usually correlated with *TGR*. Thus, the negative effect of high *IR* in LCOE can be offset by high *TGR* in Project IRR as shown in (d), (p), (s), and (v) in Table 9. Last, sensitive variables can be varied depending on the intrinsic attributes of the energy plants and utilized financial indicators. If the stakeholders are equity investors or government officers, the sensitivity variables of the LCOE and Equity IRR must be more important, whereas if the stakeholders are loan investors, the sensitivity variables of Project IRR can be more emphasized. For these reasons, energy preference from the economic perspective which eventually affects the decision of the energy mix cannot be explained by only LCOE method. If the energy policymaker considers these various indicators, the energy mix plan would be more efficient and effective.

6. Conclusions

LCOE method is a useful way to compare the lifecycle cost considering energy production, which enables many policymakers to refer this value for their energy mix. However, this way is sometimes not complete to reflect realistic business issues. Thus, this study shows what kinds of factors should be considered more important in order to evaluate better the economic and financial competitiveness for energy mix. First, the *LP* is usually different from *OP*. This *LP* can be shortened depending on the amount and stability of cash flow. This shortened *LP* can reduce the total amount of interest and eventually improve the Equity IRR. It is not applied the same to all energy sources because some energy plants have low cash flow and high revenue volatility. Thus, the reduction of *LP* is different depending on the energy plants. Second, *TGR* should be considered in real business. The energy market in high *IR* usually accompanies the high *TGR*. High *IR* has a negative effect on project cost. Similarly, high *TGR* means positive in terms of project revenue. This effect is varied depending on the *CP* and *OP*. Last, sensitive variables are varied depending on the financial indicators. Each stakeholder has different interests in different financial indicators in the energy economy and business. So, most important variables can be varied depending on the financial indicators. Thus, the stakeholders should try to improve the variables depending on their interesting financial indicators.

Even though the contributions above mentioned, this study has several limitations. First, this study assumed that the *IT* price in the financial model is equal to 110% of LCOE. This assumption is not realistic. Regardless of the LCOE of each energy source, the tariff price is almost the same in open electricity market. Governments support the subsidiary or incentive to specific energy to promote this energy being more popular. At this moment, this incentive or subsidiary has an effect on reducing the gaps among the LCOEs of different energy sources. However, it does not mean that the *IT* price increases as much as the profit. Second, the probabilistic distribution of input variables can be varied depending the country and project. Even though this study used the well known previous study produced based on the US energy market [5], the results can be varied to some degrees depending on the referred data. Third, the comparative cost analysis between the renewables and none-renewables can be more complete with the life-cycle cost such as emissions costs due to trading schemes or carbon taxes. Last, the effect of *LP* and *D_ER* might depend on the expected opportunity costs of investments according to Modigliani-Miller theorem [41,42]. This study just showed the principles and illustrative explanations depending on the different analysis methods and energy sources. In the future, the parametric variables including external cost can be applied to show these principles more quantitatively and to suggest the optimization value for a better energy mix.

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Nomenclature

<i>OCC</i>	Overnight Capital Cost (\$/kWh)
<i>F_OM</i>	Fixed O&M cost (\$/kW-year)
<i>V_OM</i>	Variable O&M cost (\$/MWh)
<i>CF</i>	Capacity Factor (%)
<i>IR</i>	Interest Rate (%)
<i>OP</i>	Operation Period (years)
<i>FC</i>	Fuel Cost (\$/MMBtu)
<i>HR</i>	Heat Rate (Btu/kWh)
<i>TGR</i>	Tariff Growth Rate (%)
<i>IF</i>	Inflation Rate (%)
<i>IT</i>	Initial Tariff (\$/MWh)
<i>LP</i>	Loan Period (years)
<i>CP</i>	Construction Period (years)
<i>D_ER</i>	Debt to Equity Ratio (%)
<i>CRF</i>	Capital Recovery Factor (%)

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