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RESEARCH PAPER

Is sustainability challenging in Indonesia's energy provision? Fuel type vs. externalities in electricity cost analysis

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Abstract. This study aims to reveal the challenging sustainability within Indonesia's energy provision by studying the electricity generating cost (GC) formation, externalities' effect, and current Indonesia's electricity and budget condition. In studying GC formation, two variables thought to have remarkable influence are fuel price (represented by Fuel Cost/FC) and operating time, which indicates the power plant's type (represented by Capacity Factor/CF). The regression results indicate that CF has a greater impact on GC than FC; GC increases as FC increases but decreases as CF increases. FC contributes by 10%-86% of GC, subject to fuel prices and CF. Since coal is the cheapest, $GC_{Coal} < GC_{Gas} < GC_{Diesel}$, but internalizing the externalities triples the GC_{Coal} and doubles the GC_{Diesel}. However, its internalization is challenging as it affects the producers' and consumers' welfare. Sustainable energy provision is challenging due to two factors. First, there is a dilemma between applying sustainability principles and providing energy immediately. The fastest route, which is the lowest price orientation, is preferable, indicated by coal domination in the electricity mix. Second, sustainability is not the priority yet, indicated by the environment programs is outside the top ten priority development programs.

Keywords: Indonesia energy provision; sustainability; fuel cost; capacity factor; externalities; electricity-generating cost

1. Introduction

Sustainability contains the objective of meeting the present's needs without sacrificing the future's needs. Its three core elements are economic growth, social inclusion, and environmental protection. The energy-related sustainability goals are not only on affordable and clean energy, but more comprehensive, covering decent work and economic growth, good health and well-

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being, climate action, life below water, and life on land (The UN, 2020). As energy is the prerequisite of economic activities, its sufficiency is essential for economic growth. The decision to use which type of energy determines the impacts on the environment and the life system. The use of clean energy (NRE) will lead to a healthy environment and sound people. Vice versa, the use of relatively cheaper but dirty energy will lead to a degraded environment. Energy provision is essential as it is the prime mover of the economy, but at the same time, it is also the determiner of the environment's health level. The decision of which energy type to use will determine the environmental-economy balance, but environmental issues are often cast aside against financial returns. Especially in developing countries, it is a sustainability-financial dilemma (Jayanti & Gowda, 2014), as achieving sustainability is relatively pricey. To accomplish all at the same time is very challenging. Environmental health is often neglected to pursue economic growth.

Under sustainability, there is a big dilemma in Indonesia's electricity provision (Asri & Yusgiantoro, 2021b) and in most developing countries. On one side, the government must immediately fulfill the electricity needs (Afful-Dadzie et al., 2017), but on the other side, some impacts (of the preferable option) are too risky to neglect. The dilemma emerges due to financial constraints, where the cheaper fuel would be prioritized without first conducting the overall analysis (Asri & Yusgiantoro, 2020). This study compares the electricity's generating cost of three fuel types: fuel oil (diesel), gas, and coal. It is crucial to understand how the cost is generated since electricity provision (especially in developing countries) usually only considers the lowest cost (Ekholm et al., 2013; Siddayao, 1992). Coal is arguably preferred due to its (cheapest) price (compared to oil and gas). However, by internalizing the environmental cost (External Cost), generating electricity from coal is no longer the cheapest. Knowing the influential factor is believed to provide an equal analysis of electricity generation. This study believes that the challenging sustainability of energy provision in less-developed countries is related to the national priorities since they are under financial constraints. By studying the formation of GC, investigating the effect of externalities, and observing the current electricity and financial situation, this study tries to reveal the challenging sustainability within Indonesia's energy provision.

In an economic analysis of electricity generation, technical parameters to consider are fuel type (Jeong et al., 2008; Locatelli & Mancini, 2010), fuel price (Reddy, 2018), technology (Knoope et al., 2013; Sayyaadi & Sabzaligol, 2010), annual operating time and energy efficiency (Bartnik et al., 2018), also environmental factors (Feretic & Tomsic, 2005; Park et al., 2011). The inclusion of environmental factors could be conducted, for example, by imposing tax instruments (Parry et al., 2014) or carbon price (Teng et al., 2017) while maintaining the effectiveness and competitiveness of electricity prices (Mignone et al., 2012; Newbery, 2011). The inclusion of environmental factors means internalizing the externalities (Di Valdalbero & Kovács, 2004; Ding et al., 2014), which is the cost due to the ecological or social impacts of power plants operation (Feretic & Tomsic, 2005; Rewlay-ngoen et al., 2014). An external cost is internalized as compensation for environmental and social impacts (Rodgers et al., 2019; Sakulniyomporn et al., 2011). Neglecting the environmental aspect would cause a higher overall cost. Ideally, the environmental aspects should be taken into account to show the actual, overall generating cost. The findings of those studies are valuable feed as the basis for this study. In this study, fuel price which represents the fuel type and the technology, and the capacity factor, which represents the annual operating time are considered as two essential variables in electricity cost. Another study believed that forecasting the increase of fuel price, which prices are not kept constant is essential in calculating the electricity cost (Partridge, 2018). Hence, in this study, fuel prices are varied in ten price ranges to represent the price volatility like the actual condition. This study also considers the externalities as an additional cost component, then compares the generating cost with and without it.

Previous studies on electricity costs are usually about sensitivity analysis to see the economics of several power plants (Feretic & Tomsic, 2005; Jeong et al., 2008; Knoope et al., 2013; Locatelli & Mancini, 2010; Park et al., 2011). Some of the observed technical variables are environmental costs, including carbon costs (Locatelli & Mancini, 2010), interest rates (Jeong et al., 2008), and technology (Knoope et al., 2013; Park et al., 2011; Reddy, 2018). The studies compared the generating cost of electricity under the variation of the technical variables. By taking technology as the observed parameter, a study examined the electricity cost of two different power plants that use different fuel types (fuel type used will affect the power plant's technology). For example, is the study comparing the electricity cost between a conventional pressurized water reactor (PWR) nuclear power plant and a hybrid PWR-fossil fuel power plant (gas and coal) (Sayyaadi & Sabzaligol, 2010). The technology could also be applied in a modified generator with CCS (as environmentally friendly power plants) to mitigate climate change (Knoope et al., 2013; Park et al., 2011). Other studies on GC use a mathematical analysis approach, such as functional analysis (calculus of variations dealing with extrema of functionals) and a probabilistic method to predict generation costs that are influenced by several parameters (Bartnik et al., 2018; Feretic & Tomsic, 2005). One of the studies observed the influence of two types of fuel – gas and coal, which is believed to affect the generator's efficiency, which subsequently affects the electricity cost. The price of gas is three times the price of coal). The study also observed the pattern of electricity costs influenced by environmental costs (CO2, SO2, CO, NO), annual operating time, interest rate, and internal electrical load value (Bartnik et al., 2018). Another study estimated a discounted generating cost, which is a cost affected by interest rate and fuel price change during the lifetime of the power plant, by using the probabilistic method with the Monte Carlo simulation (Feretic & Tomsic, 2005).

However, among those studies, no study observes which variable or parameter, among the observed technical parameters, has the most significant influence on the cost of electricity generation. Moreover, the previous studies considering the effect of externalities have not yet observed the impact of environmental costs on the increase in GC observed at various operating times. Therefore, this study seeks to fill the gap left by previous studies by finding the component that has the most influence on the cost of electricity generation through the disclosure of how GC is formed. In observing the effect of environmental costs, this study reveals how externalities affect the increase in GC of the three fuel types at different operating times. This study also offers significance, especially for Indonesia and other developing countries facing similar situations, through the analysis of electricity mix and state budget, which might reveal why sustainability is challenging in Indonesia's electricity provision. Therefore, the results obtained by this study are expected to be the input for policymakers in establishing sustainability in energy provision through electricity generation.

Electricity cost is site-specific and influenced by a country's specific circumstances (Krishnan & Gupta, 2018; Larsson et al., 2014; Palacios & Saavedra , 2017). The cost of production could also be affected by the internal situation (Sequeira & Santos, 2018). In Indonesia, the electrification ratio is 93.5% (2017) and still relies on fossil energy to pursue 100% electrification. Through National Energy Policy (Government Regulation 79/2014), New and Renewable Energy (NRE) is targeted to fill 23% of the electricity energy mix in 2025. However, until 2017, NRE only met 13% of the electricity mix (MEMR, 2012; PT PLN, 2018). NRE was not well developed due to the vast investment and the advanced technology (Ghimire & Kim, 2018; Gómez-navarro & Ribó-pérez, 2018; Kennedy, 2018). In this case, Indonesia has less capability (Dutu, 2016; Martosaputro & Murti, 2014) to develop NRE. Fossil is preferred (more suitable) for a quick electricity development, for it has established infrastructures. However, while NRE is more expensive in initial cost, fossil fuel's fuel cost remains to exist during the lifetime of power plant operation (Asri & Yusgiantoro, 2020).

This study explains how electricity cost is generated and compare it with and without considering the overall impact. Firstly, it describes how GC is formed and which component has the most significant influence on the GC. Then, this study shows how internalizing the externalities affect the resulting GC. Secondly, why sustainability is challenging by investigating the electricity mix and reviewing budget allocation under priorities. The environmental impact analysis aims to initiate the awareness of sustainability and end fossil domination. Achieving sustainability is challenging if Indonesia cannot escape from the low-price orientation.

2. Research methods

This study analyzed GC formation with variations on fuel type, fuel price, and the power plant's capacity factor. Fuel cost is an essential component since it takes 48%-70% of GC (Partridge, 2018). The fuel type is also crucial since it affects the power plant's operating time and, eventually, the GC. The environmental effect on GC was also analyzed. The observation was conducted only on fossil fuels due to their domination in the electricity mix and how challenging it is to switch to the more sustainable NRE (New and Renewable Energy Sources). Data and numbers may change over time, but GC's calculation remains the same. Thus, this study focused on obtaining the general pattern in GC formation and how the elements interacted rather than presenting exact calculation results. Adjustments and assumptions were also inevitable, for the real counts are more complicated due to many factors (transmission and distribution cost, government policies, political decision, etc.) involved. The real GC is also only known by the electricity producer. Data were taken from literature and previous studies with some adjustments and assumptions. Table 1 shows the cost components.

Table 1. Components of electricity generation costs

Components of Cost	Value
Investment cost per net-output	1,200 US$/kW
IDC	1.24
CF	Varied by 10% - 80%
CV	In a separate table (Table 2)
FP	In a separate table (Table 3)
The efficiency of a power plant	47%
O&M cost	0.9 cents/kWh
The lifetime of a power plant	30 years
Interest rate	10%

Table 2. Caloric Value of the three fuels

Fuel	Caloric Value	Unit
Coal	4,200	kcal/kg
Gas	252,000	kcal/mmbtu
Diesel	9,370	kcal/liter

Table 3. Fuel price variation of the three fuels

Fuel Price (FP_n)*	Fuel Type		
	Coal (US$/ton)	Gas (US$/mmbtu)	Diesel (US$/liter)
FP_0	40.00	5.00	0.30
FP_1	44.80	5.60	0.34
FP_2	50.18	6.27	0.38
FP_3	56.20	7.02	0.42
FP_4	62.94	7.87	0.47
FP_5	70.49	8.81	0.53
FP_6	78.95	9.87	0.59
FP_7	88.43	11.05	0.66
FP_8	99.04	12.38	0.74
FP_9	110.92	13.87	0.83
FP_{10}	124.23	15.53	0.93

Table 4. Compensation rates of the three power plants

Power plant	Compensation rates (Eurocents/kWh)	Convert to US$ (1 Euro ≈ 1.17 US$)
Coal	8.4	9.8280
Gas	2.0	2.3400
Diesel	6.75	7.8975

This study used a descriptive method with some supporting methods: data processing (to calculate, among others, GC, the proportion of FC to GC, and externalities), regression, and trendline analysis. The methods were conducted to show the formation of GC and its pattern under the variation of fuel cost and capacity factor. Trendline equations were used to observe the pattern or trend of GC under the variation of FC and CF and to compare the impacts of FC and CF, individually, on GC. The trendline approach was used, as the FC variable on the graphs is non-numeric data. On the other hand, regression analysis was the supporting method to examine the simultaneous impacts of both FC and CF on GC. The regression analysis is taken from GCs, which was selected one from each FC (FC1-8) and CF (10%-80%). The regression and the trendline analyses were the supporting methods to compare the impacts of FC and CF on GC, simultaneously and individually. The equations were obtained using the 'trendline' and 'data analysis' features provided by Excel. However, as the sample was small, which seems to be less than the ideal (since its purpose is to observe rather than to forecast), the equations obtained may not be suitable to predict precisely the value of GC. The study also used the descriptive approach to analyze the impacts of externalities on GC and to observe the proportion of fuel type in the current and target Indonesia electricity mix.

CF indicates the operating time of a power plant and the power plant load type. In this study, CF value is varied at 80%, 70%, 60%, 50%, 40%, 30%, 20%, and 10%. Fuel type is tightly related to power plant load type. In Indonesia, coal is the main energy source for electricity, followed by gas and fuel oil (diesel). Thus, this study observed these three fuels with Caloric Value or CV (British Petroleum, 2017; MEMR, 2017), as shown in Table 2.

Fuel price was varied by predicting the increase of price by 12% (Eq. 1) in ten data sets (Table 3). The prices are not the current prices to possibly pick the lowest and the highest prices in the ten data sets following price volatility on the British Petroleum Statistics and MEMR websites. These prices were assumed to have included transportation costs and applicable taxes in Indonesia covering value-added tax, income tax, and vehicle fuel tax (tax imposed on fuel utilization for vehicles). The analysis focused more on observing the relationship between the dependent and independent variables, not on the calculation results.

$$FP_n = FP_{n-1} + (FP_n \times 12\%) \quad (1)$$

The external (environmental aspect) impact on GC was observed by internalizing the compensation rates (Chatzimouratidis & Pilavachi, 2008; NEA-OECD, 2003), as shown in Table 4.

Since the real GC is known only to the electricity producers, the GC obtained here was not the real GC. It also differs from the applicable electricity tariffs since the latter has contained political decisions. Thus, the calculation of GC here was only the approach to understand how GC is generated and what factors influence it.

3. Results and discussion

This study conducted sensitivity analysis to observe the impacts of fuel price and the utilization of power plants (as a peak-, medium-, or base-load bearer). This study conducts sensitivity analyses to observe the impacts of externality (as an external factor), fuel price, and the utilization of power plants (as a peak-, medium-, and base-load bearer) on GC. The number may change over time, but the method remains the same. This study tries to obtain the pattern and relationship among variables based on the independent variables' impact on the dependent variable. The observed variables, the variables thought to have remarkable influence, are fuel price (represented by Fuel Cost or FC) and a power plant's operating time, which indicates the type of a power plant (represented by Capacity Factor or CF). Besides, FC covers up to 70% of GC, while CF indicates how long a particular type of power plant is operating, and eventually, determines the value of GC.

3.1. Electricity load character

The role of CF is crucial in electricity planning, especially in recognizing the electricity load. The three categories of load are base-load, medium-load, and peak-load. Base-load is a load when the electricity consumption is moderate, while peak load is a load when electricity consumption is highest. In a day, the combination of the three loads forms the electricity load character, following the electricity usage of each consumer (Figure 1). The pattern in Figure 1 shows that electricity demand varies depending on people's activities and the type of activities in a day. For example, 'Residential' (Figure 1, bottom left) demands a low electricity load in the morning, which steadily increases over time (towards the evening). On the contrary, 'Public Lighting' (Figure 1, bottom right) only requires electricity in the morning and the night. Thus, it requires a comprehensive planning to avoid loss either on the producer or consumer sides. Failure to recognize these patterns means a loss on the producer side if the electricity generated is greater than its demand or a loss on the consumer side if the electricity supplied is less than its demand or blackout. Consumers' loss also includes economic activities since all of their activities are powered by electricity (Fahrioglu, 2016).

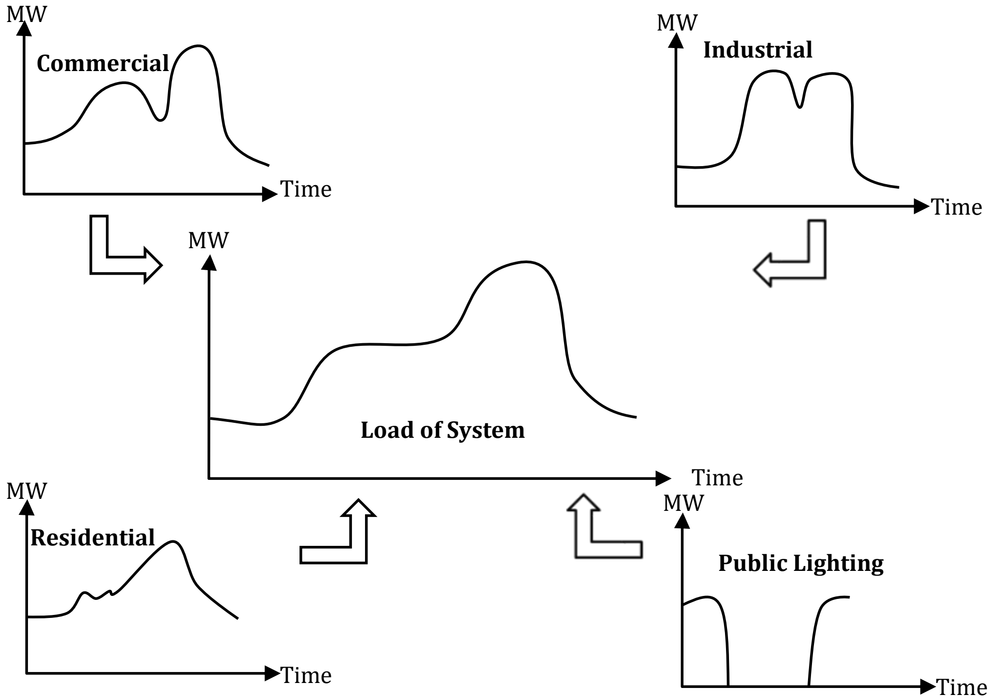

Figure 1. The curves of load pattern (electricity consumption characteristic) of each customer group and load curve system in Indonesia (Kadaffi, 2011)

Table 5. Type of power plants according to the load

Load	Average operation (hr/yr)	CF (%)	Power Plant (pp)
Base	5,000	> 57%	Steam coal pp, geothermal pp
Medium	> 2,000 to < 5,000	> 23% to < 57%	Combined cycle pp, gas pp
Peak	< 2,000	< 23%	Fuel oil pp, pump storage

As the electricity consumption pattern varies (Andersen et al., 2017), the power plants utilized to bear the load are different. The power plant bearing a base-load operates for long hours, while the power plant bearing a peak load operates for a short time, following the load duration (electricity consumption). According to its role in bearing the load or fulfilling the electricity needs, the power plant is classified into three categories: base-load power plant, medium-load power plant, and peak-load power plant (Table 5) (Rahman, 2012b; Wikarsa, 2010).

Following the load duration, the base-load power plant's main characteristics are that it takes a long time (several days) to start up, has a long operating time, and cannot flexibly follow the load changes. Thus, cheap fuel is more preferred for the base-load power plant. On the contrary, peak load occurs only two to four hours. Thus, peak load requires a flexible power plant that can quickly supply the additional electricity needed when the load increases. Peak load requires fuel that can react immediately to generate electricity (Wikarsa, 2010). This situation shows how fuel type plays a crucial role in electricity generation. It will also affect the fuel price and GC eventually.

$$Capacity\ Factor\ (CF) = \frac{\sum Gross\ production\ \ per\ year\ (kWh)}{\sum Installed\ capacity\ (kW)\ \times\ 8{,}760\ jam} \times 100\% \tag{2}$$

Where *Gross production* is generated energy (kWh) by generator before used for own-use: auxiliary equipment, central lighting, etc. or electricity energy production as measured at the terminal generator; and *Installed Capacity* is the capacity of a power plant (kW) as written on the nameplate of a generator or prime mover (pick the smaller one) (PT PLN, 2015)

Capacity Factor (CF) of a power plant is the ratio between maximum electric power generated and the real power generated (the load covered). CF is the percentage of rated capacity and installed capacity (Eq. 2) (PT PLN, 2015). If the CF value is close to 1, a power plant bears a peak load, for it works in almost the entire load, and vice versa. Thus, a peak load power plant has a low CF value (PT PLN, 2015; Rahman, 2012b).

Therefore, this study investigated how fuel type, operating time, and the electricity generated (represented by CF) affect the GC. Sensitivity analysis was conducted to determine which one of those variables delivers a more significant effect on GC.

3.2. The analysis of fuel cost (FC) and capacity factor (CF) in GC formation

Three components of cost in GC calculation are Total Investment Cost (TIC), Fuel Cost (FC), and Operational & Maintenance Cost (OMC). TIC consists of EPC (Engineering, Procurements, and Construction) cost plus financial cost known as IDC (interest during construction). FC consists of fuel price and is influenced by the efficiency (Heat-Rate of the power plant) and the fuel's caloric value. OMC consists of O&M costs including fixed costs and variable costs, such as wages, machine lubricants, maintenance, etc. GC or total cost per KWh is the sum of the three, calculated using equation 3 to 9 (Harun, 2011; Rahman, 2012a; Yusgiantoro, 2000).

$$TICC = \frac{ATIC}{8760\ x\ CF} \tag{3}$$

$$ATIC = TIC\ x\ CRF \tag{4}$$

$$CRF\ = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{5}$$

$$TIC = BIC\ x\ IDC\ x\ \frac{1}{(1 - own\ use)} \tag{6}$$

$$BIC = \frac{Power\ Plant\ investment\ cost}{Power\ Plant\ Capacity} \tag{7}$$

$$FCC = HR\ x\ FP \tag{8}$$

$$\mathrm{HR} = \frac{kwh}{\eta} \tag{9}$$

Where *ATIC* is Annualized TIC (US \$/kW); *TIC* is Total Investment Cost (US \$/kW); *CRF* is Capital Recovery Factor; *BIC* is Base Investment Cost (US \$/kW); *IDC* is interest during construction, which is 1.24; *n* is economic lifetime of the power plant (year); *own use* is assumed 5 %; *HR* is Heat rate (kcal/kWh); η is efficiency; and *FP* is Fuel Price.

To check the pattern of GC under the variation of CF at each FC (Figure 2 to 11) and the pattern of GC under the variation of FC at each CF (Figure 12 to 19), the study observed the trend line of GC by using the 'Trendline' feature provided by Excel. The equations obtained may not explicitly represent the individual impact of FC and CF on GC, but they can be used to compare the contribution of each FC and CF in forming GC.

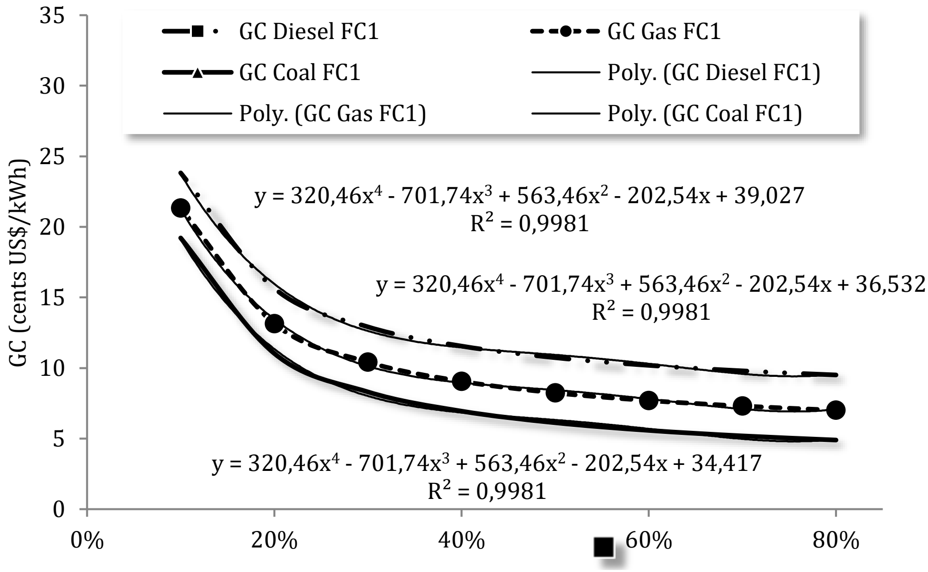

Figure 2. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 1 and trendline equations in FC 1

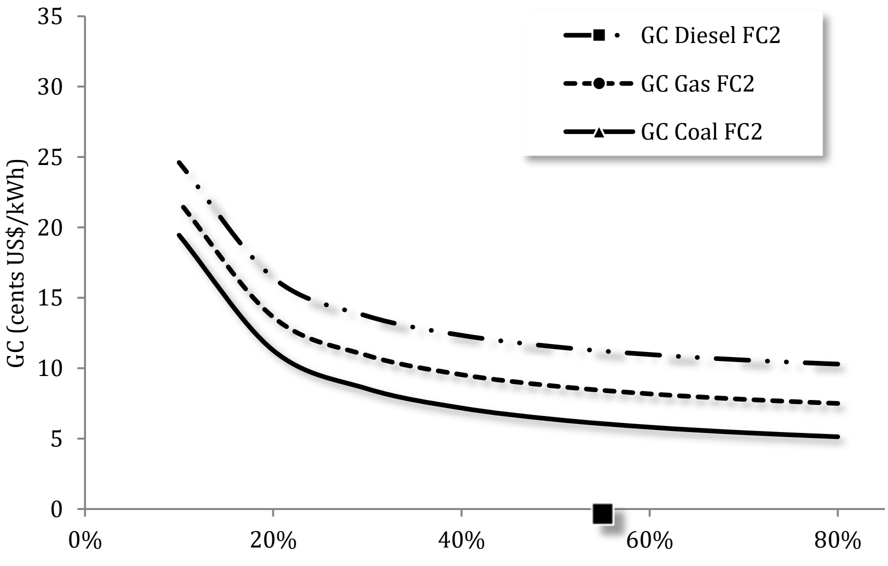

Figure 3. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 2

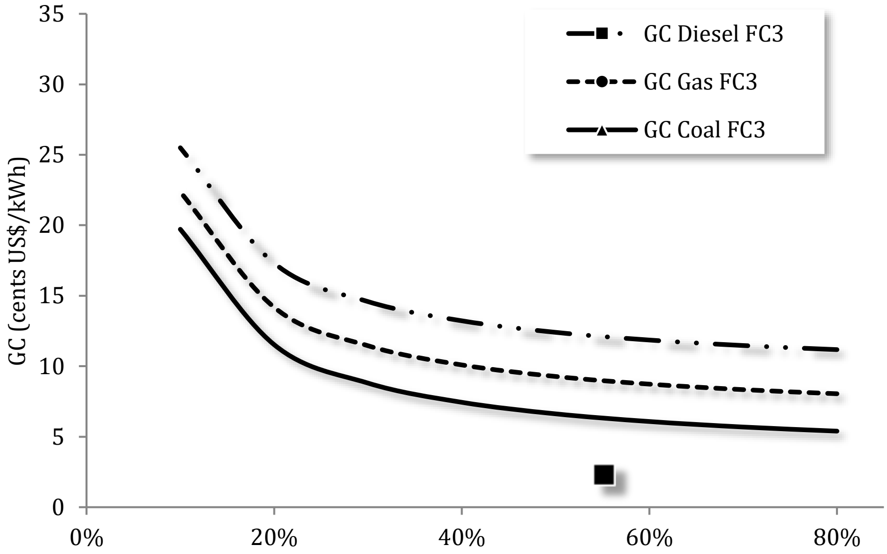

Figure 4. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 3

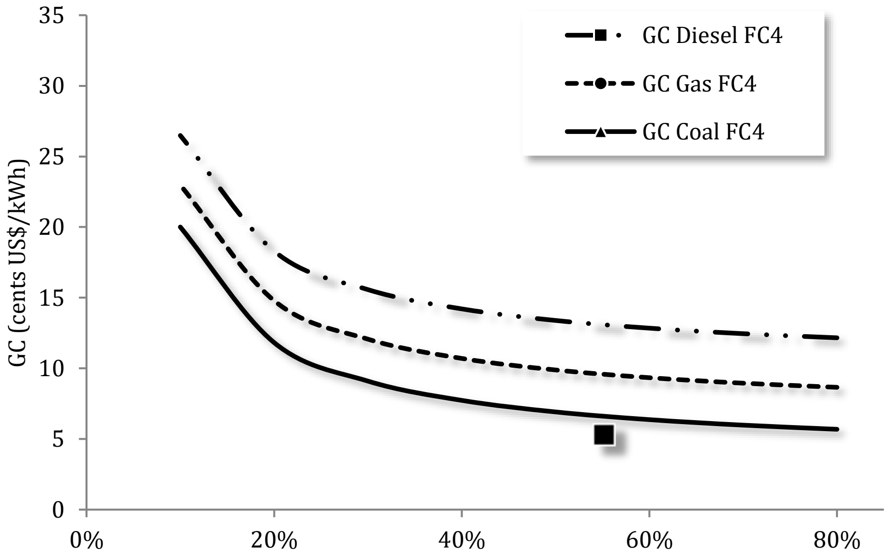

Figure 5. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 4

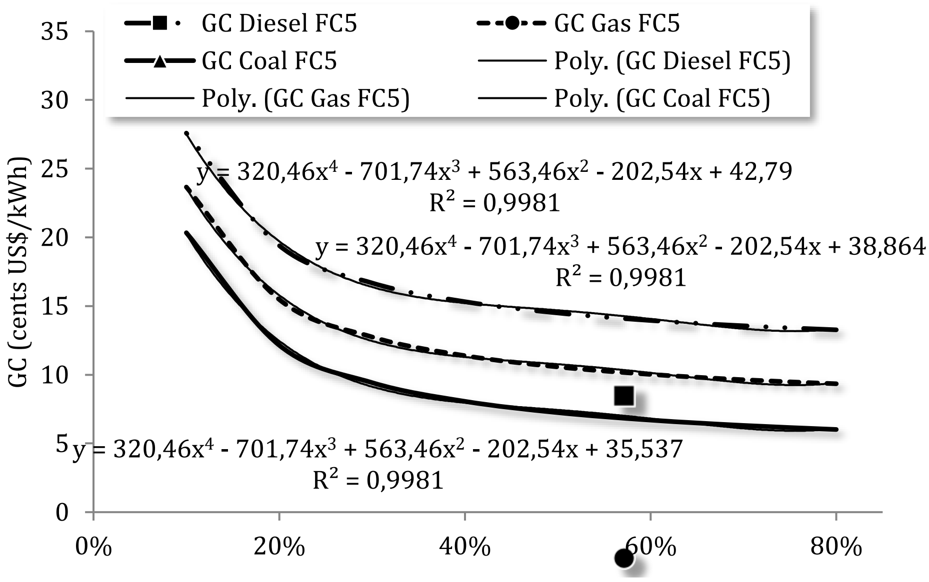

Figure 6. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 5 and trendline equations in FC 5

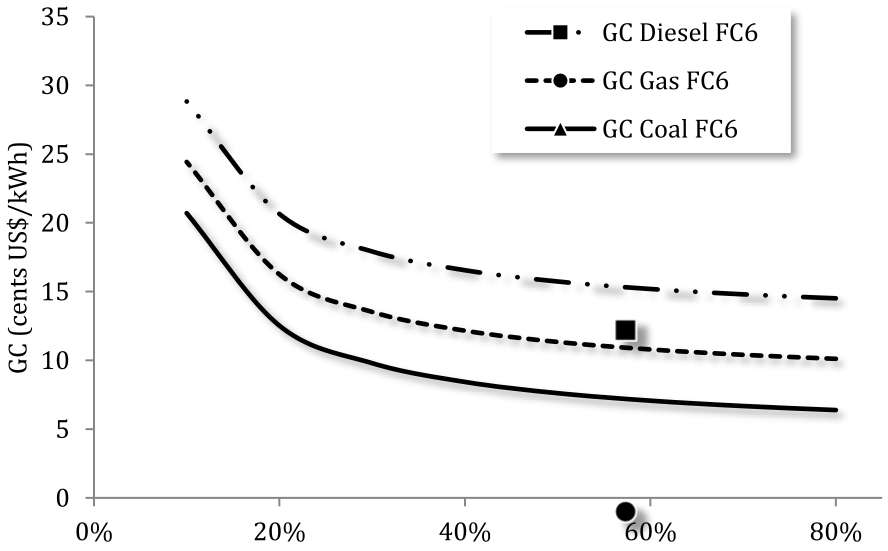

Figure 7. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 6

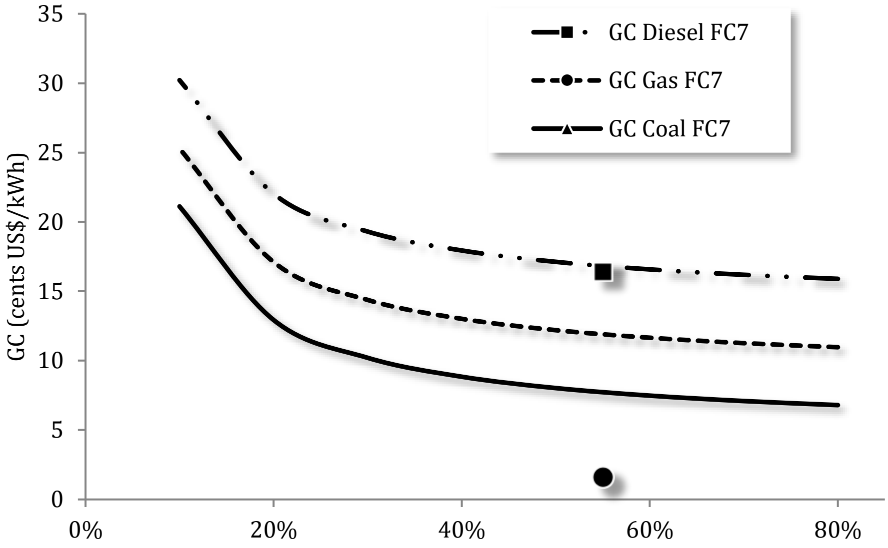

Figure 8. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 7

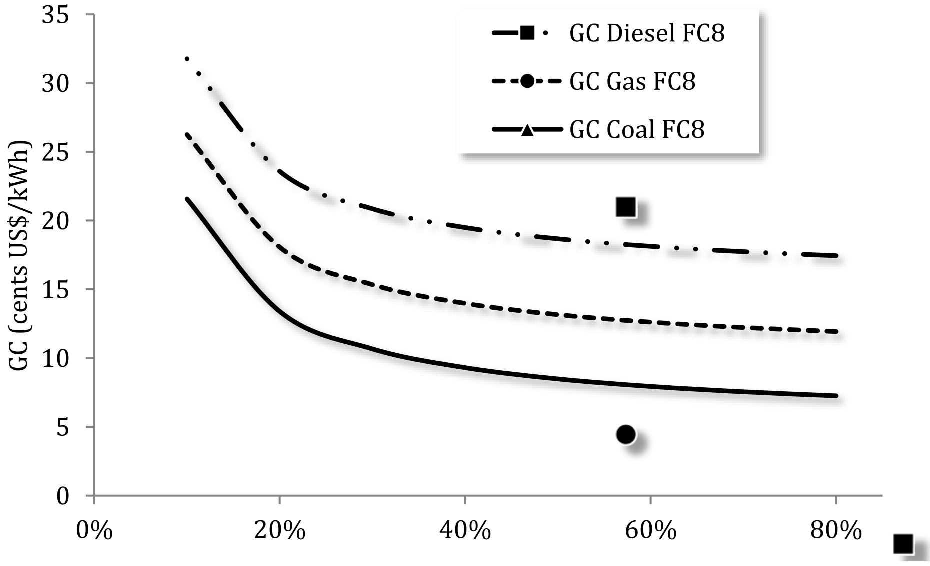

Figure 9. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 8

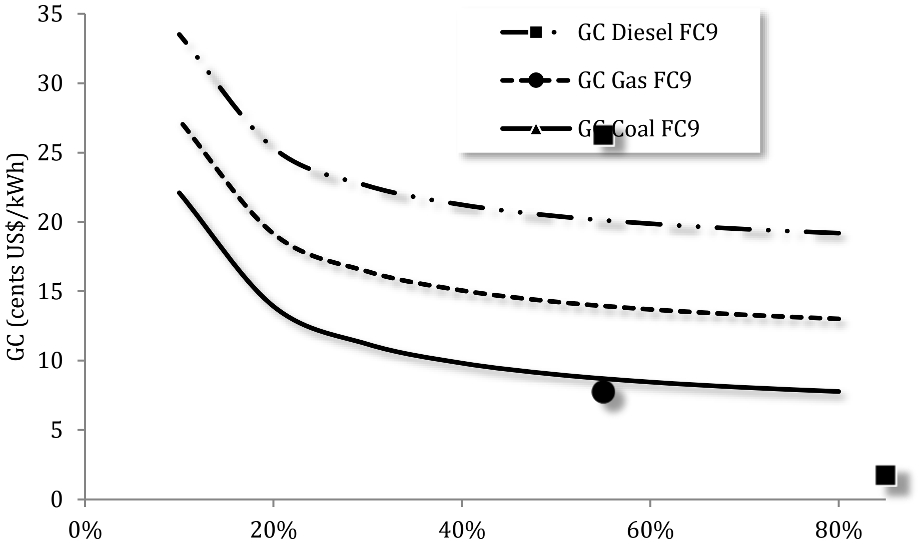

Figure 10. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 9

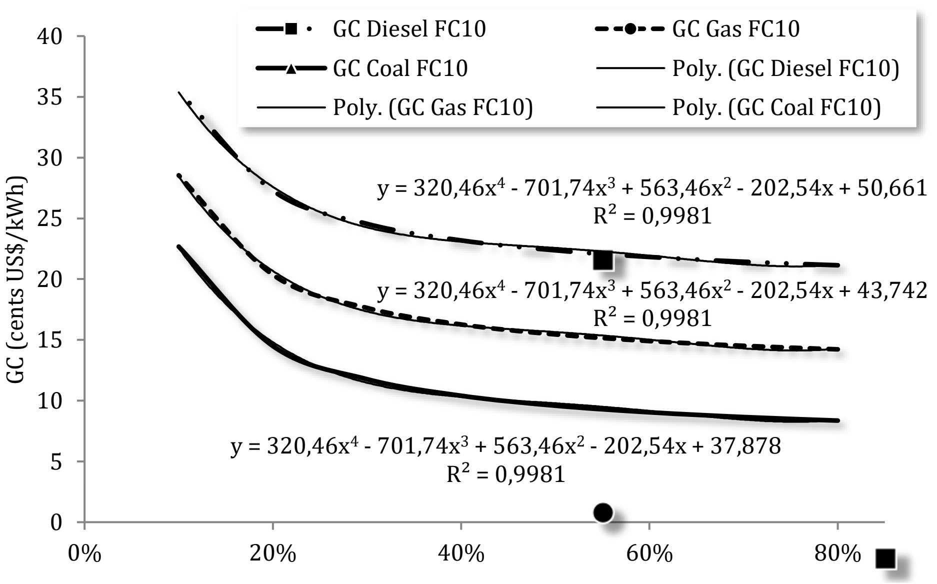

Figure 11. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various CF (10% to 80%) at FC series 10 and trendline equations

GC for the three fuel types (GC_{Coal}, GC_{Gas}, GC_{Diesel}) with various CF are shown in Figure 2 to 11. Since FC is the observed cost component, variation was only conducted to CF to observe its effect on GC. The other two components, TIC and OMC, were made constant. Since diesel is the most expensive fuel, $GC_{Diesel} > GC_{Gas} > GC_{Coal}$. GC decreases gradually as CF increases. At the early stage (10% to 20% CF), GC decreases sharply then decreases moderately until CF 60%. Then at CF> 60%, the decrease is not as significant as the earlier stages. At low CFs (10% to 20%), the GCs of the three fuels are relatively closer than at high CFs. It indicates that the decrease of GC (as CF increases) is more remarkable as the fuel price is cheaper (Figure 2 to 11). Further observation of GC with various FCs is shown in Figure 12 to 19.

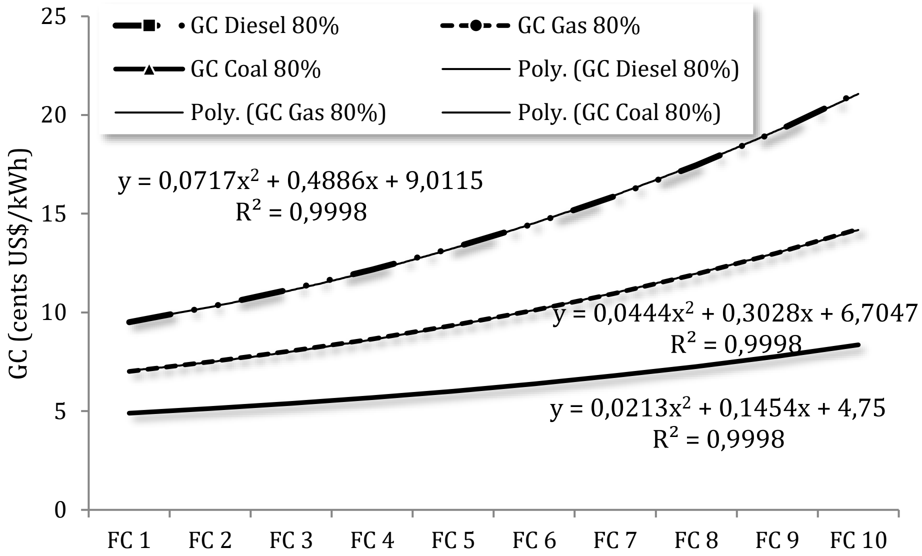

Figure 12. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 80% and trendline equations

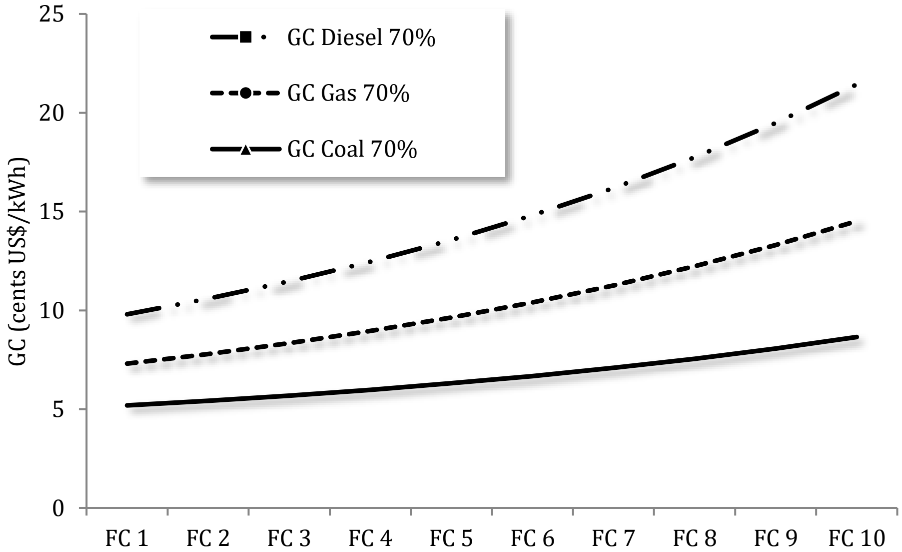

Figure 13. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 70%

Figure 12 to 19 show that the pattern of GC and FC is in line and positive. GC increases as FC increases (on the same graph, from left to right). Besides, as FC increases, the distance among the three graphs widens, and the gap of GC of the three fuels broadens. On the contrary, as CF decreases, GC increases (all graphs in Figure 20 with the same fuel type, from top to bottom). Further observation analyzes the composition (the proportion) of FC in GC (Figure 20).

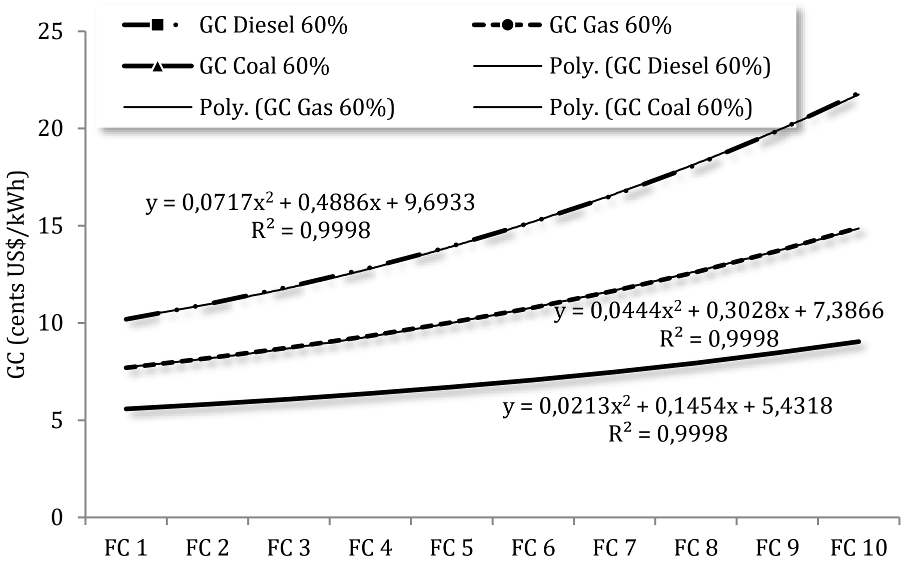

Figure 14. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 60% and trendline equations

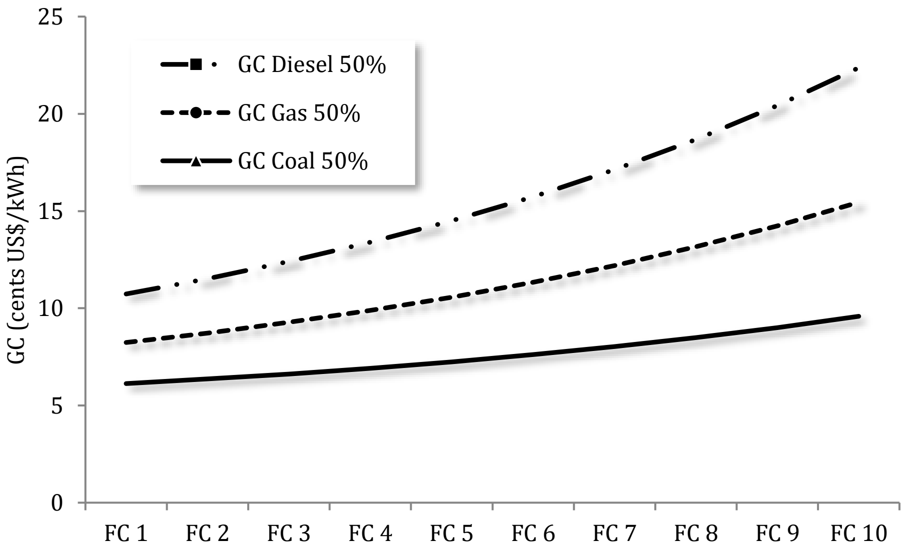

Figure 15. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 50%

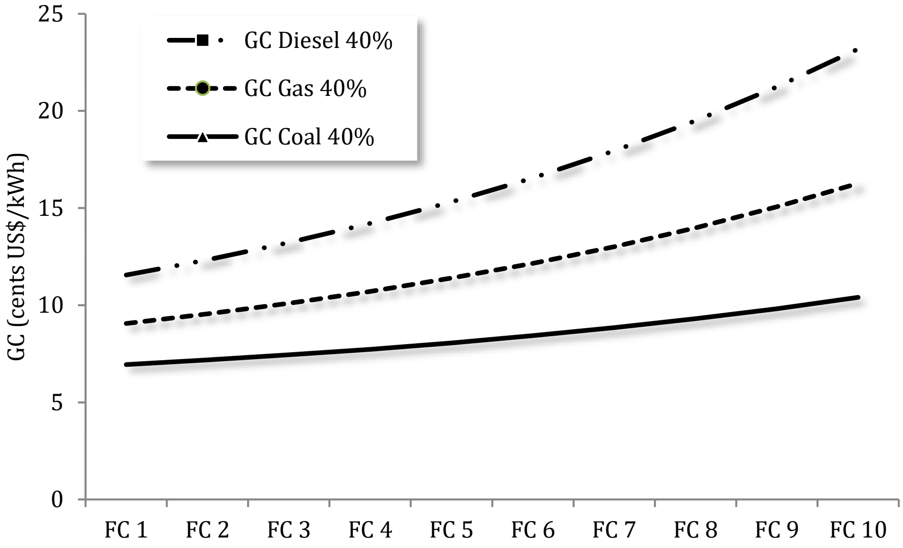

Figure 16. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 40%

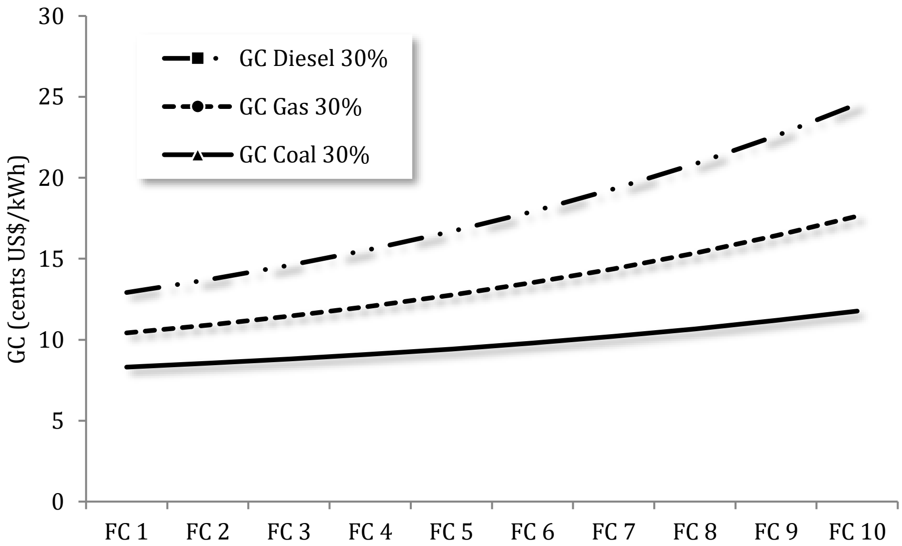

Figure 17. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 30%

Figure 20 shows that the percentage of FC in GC varies from 10% to 86%, depending on FC and CF's values. The higher the FC, the higher the percentage is, and vice versa. The higher the CF (or, the longer a power plant is operated), the higher the percentage is. The percentage of FC to GC of a base-load power plant is the highest since its operating time is the longest. According to the fuel type, the FC percentage in a diesel power plant (pp) is higher than that of coal and gas pp, for diesel price is the highest. It can be concluded that the relationship of FC percentage to GC is positive. The percentage increases as the fuel price and operating time of the power plant increases.

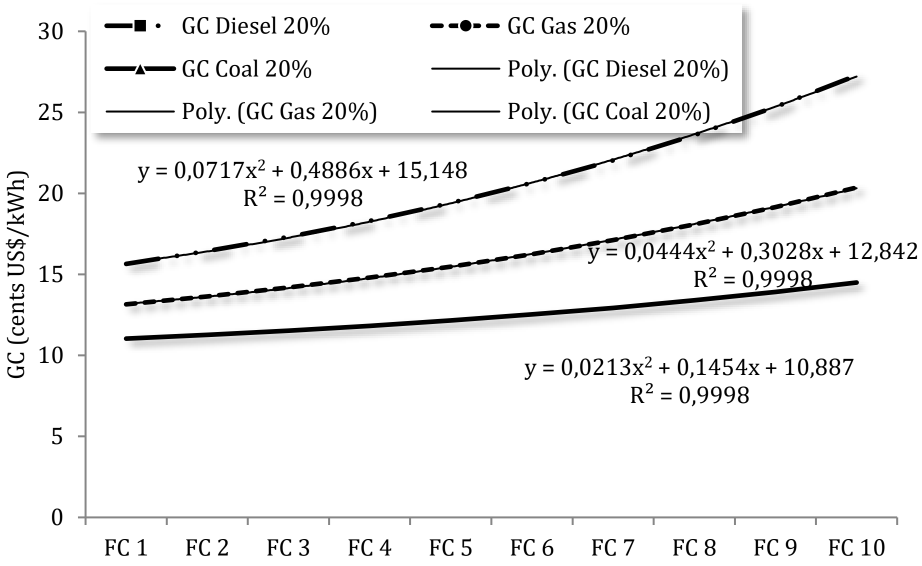

Figure 18. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 20% and trendline equations

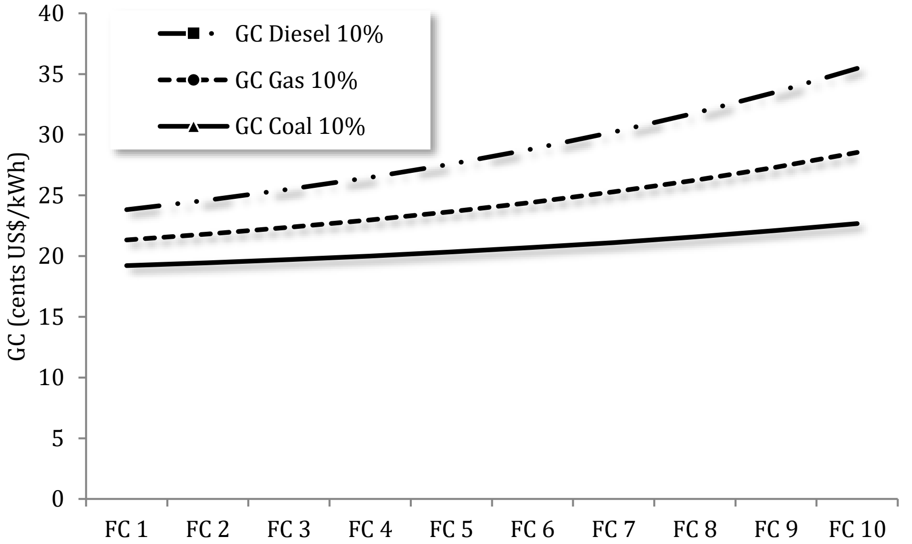

Figure 19. GC_{Diesel}, GC_{Gas}, GC_{Coal} with various FC (1 to 10) at CF series 10% and trendline equations

Table 6 provides trendline equations to compare the contribution of FC and CF, individually, in constructing GC. The observation is conducted by comparing the trendline equation of FC and CF (x) vs. GC (y) resulted by using the 'Trendline' feature in Excel (Table 6). The observation is only conducted on three CF series ($CF_{80\%}$, $CF_{60\%}$, and $CF_{20\%}$) and three FC series (FC_1, FC_5 and FC_{10}). The selected CF series represents the CF from each power plant type (Table 5), while FC represents the prices at extreme points (the lowest, the middle, and the highest price). Equations No. 1-3 (taken from Figure 2) present the contribution of CF (x) on GC (y), while No. 4-6 (taken from Figure 3) shows the contribution of FC (x) in forming GC (y). This indicates that CF's contribution is more significant than FC's, which is the fourth-order (x^4) for CF and the second-order (x^2) for FC equation. The other finding is in one series, coefficients of x are the same. The equations are only different at the constants, where the higher the FC, the higher the constant is (Table 6, No. 1-3), and the higher the CF, the lower the constant is (Table 6, No. 4-6). The same value of x coefficients is due to the variation conducted only to FC and CF (to observe their impact on GC), while the other variables are kept constant. Thus, the equations obtained have the same x coefficients. However, at CF variation, the x coefficients are different in different fuel types because the variables varied are fuel price. Thus, the utilization of different fuel types obtains different x coefficient.

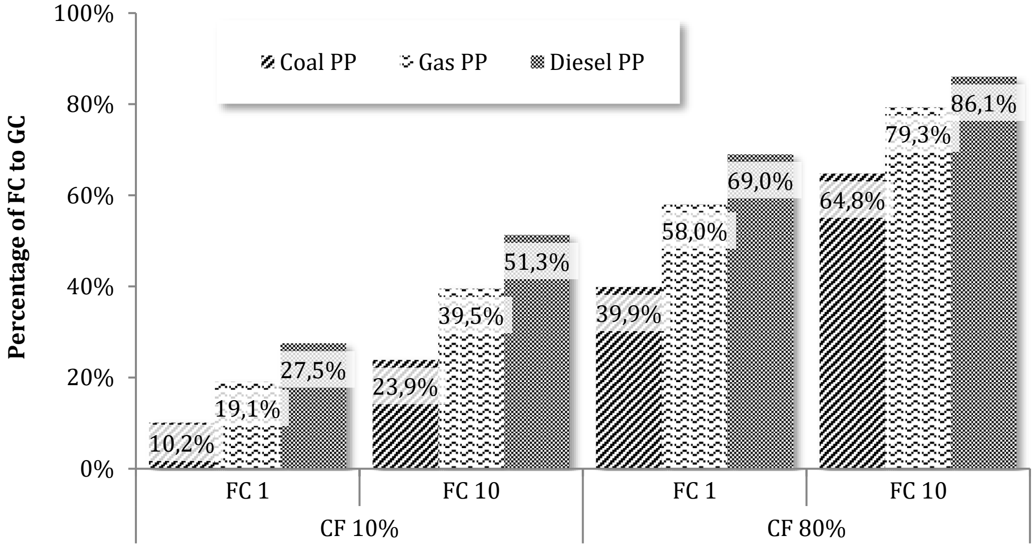

Figure 4. Percentage of FC to GC at lowest and highest FC and CF values

Table 6. The impact level of FC and CF on GC (the equations are from the selected graphs in Figure 2 and Figure 3), presented by the trendline equations

No	Series	Diesel	Gas	Coal
1	FC_1	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 39.027$ $R^2 = 0.9981$ (y = GC; x = CF)	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 36.532$ $R^2 = 0.9981$ (y = GC; x = CF)	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 34.417$ $R^2 = 0.9981$ (y = GC; x = CF)
2	FC_5	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 42.79$ $R^2 = 0.9981$ (y = GC; x = CF)	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 38.864$ $R^2 = 0.9981$ (y = GC; x = CF)	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 35.537$ $R^2 = 0.9981$ (y = GC; x = CF)
3	FC_{10}	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 50.661$ $R^2 = 0.9981$ (y = GC; x = CF)	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 43.742$ $R^2 = 0.9981$ (y = GC; x = CF)	$y = 320.46x^4 - 701.74x^3 + 563.46x^2 - 202.54x + 37.878$ $R^2 = 0.9981$ (y = GC; x = CF)
4	$CF_{80\%}$	$y = 0.0717x^2 + 0.4886x + 9.0115$ $R^2 = 0.9998$ (y = GC; x = FC)	$y = 0.0444x^2 + 0.3028x + 6.7047$ $R^2 = 0.9998$ (y = GC; x = FC)	$y = 0.0213x^2 + 0.1454x + 4.75$ $R^2 = 0.9998$ (y = GC; x = FC)
5	$CF_{60\%}$	$y = 0.0717x^2 + 0.4886x + 9.6933$ $R^2 = 0.9998$ (y = GC; x = FC)	$y = 0.0444x^2 + 0.3028x + 7.3866$ $R^2 = 0.9998$ (y = GC; x = FC)	$y = 0.0213x^2 + 0.1454x + 5.4318$ $R^2 = 0.9998$ (y = GC; x = FC)
6	$CF_{20\%}$	$y = 0.0717x^2 + 0.4886x + 15.148$ $R^2 = 0.9998$ (y = GC; x = FC)	$y = 0.0444x^2 + 0.3028x + 12.842$ $R^2 = 0.9998$ (y = GC; x = FC)	$y = 0.0213x^2 + 0.1454x + 10.887$ $R^2 = 0.9998$ (y = GC; x = FC)

Table 7. Simple multi variables regression of GC with various FC and CF

Output	Diesel	Gas	Coal
Multiple R	0.89256268	0.86078497	0.94096364
Adjusted R^2	0.71533540	0.63733108	0.83957760
FC (x_1)	1.0161688	1.7438637	4.58425595
CF (x_2)	-95.661458	-101.99605	-95.661458
Intercept	-21.325182	-25.320483	-21.325182
Equation	$y = 1.02x_1 - 95.66x_2 - 21.33$	$y = 1.74x_1 - 101.99x_2 – 25.32$	$y = 4.58x_1 - 95.66x_2 - 21.33$
	GC = 1.02FC - 95.66CF - 21.33	GC = 1.74FC - 101.99CF - 25.32	GC = 4.58FC - 95.66CF - 21.33

The simultaneous impact of both variables, FC and CF, on GC is observed by a simple multivariate regression (Table 7), using the 'Data Analysis' feature in Excel. The *P-value* and *Significance F* of the three show that the impact of FC and CF, individually (*p-value*) and simultaneously (*significance F*), are statistically significant since the values are lower than $\alpha_{0.05}$ (Appendix). Furthermore, this finding indicates that CF has a greater impact on GC than FC on GC, shown by the coefficients (in absolute value) of x_2 is larger than the coefficients of x_1. However, please note that these equations may not be suitable for generating or predicting (precisely) GC values, as the data points are too few. Besides, the analysis intended only to compare the simultaneous impacts of both variables (FC and CF) on GC instead of generating a formula to forecast GC. The findings from regression analysis confirm and support the previous observation with trendline, where the relationship of FC and GC is positive while the relationship of CF and GC is negative.

To sum up, the results show that CF (represents operating time) affects GC more significantly than FC. The relationship between CF and GC are contrary, where GC increases as CF decreases. This means that the longer the power plant operates, the lower the GC (note that GC is a per kWh cost, not the total cost). Vice versa, the relationship of FC and GC is positive, where GC increases as FC increases. These findings indicate that lower fuel price and longer operating time leads to a cheaper GC. In the actual condition, the findings indicate the existence of a reinforcing cycle formed by fuel price, operating time, and GC, where the cheapest fuel leads to the cheapest GC, the reason why coal is the most preferable. A coal power plant bears a base-load and operates for the most prolonged period. Coal meets all the requirements supporting a budget deficiency condition, where the lowest cost is prioritized. This shows how challenging it is to prioritize cleaner fuels for the plants like gas or NRE and achieve sustainability in energy provision.

3.3. The analysis of externalities on GC formation

3.3.1 What externalities are and how its internalization is tough for developing countries

The externality is a cost or a profit that is not included in the market price, for it is not accounted for in demand and supply price. Externalities arise when a party's economic activities impact (negatively or positively) the welfare of other parties beyond the activities (Di Valdalbero & Kovács, 2004; NEA-OECD, 2001). Since they are beyond the processes, the externalities are often neglected. It is the impact without a compensation flow. Externality causes a different perception of cost from an individual or private's viewpoint versus social's (society's). The externality leads to distortion, where price and quantity might be optimal individually or privately, but not optimal socially. The externality (external cost) is not included in the product's price determination, though it delivers a noticeable impact on the environment and society. Internalization of the externalities is essential to provide the real price information (Di Valdalbero & Kovács, 2004; Yusgiantoro, 2000).

There are positive externalities and negative externalities. The externality is positive if the impacts deliver benefits (positive impacts) and vice versa if the externality is negative. Corporate Social Responsibility (CSR) is a positive externality, while wastewater and power plants' emissions are negative externalities. Negative externalities lead to more considerable impacts, such as disruption to livelihoods due to decreased crop yields and marine catches, decreased building age due to acid rains, and decreased life expectancy due to emission-related diseases (heart attacks, respiratory diseases, etc.). The impacts do not stop at the environment but continue on the living systems relying on the environment (Rewlay-ngoen et al., 2014; Rodgers et al., 2019; Sakulniyomporn et al., 2011; Yusgiantoro, 2000).

In emerging economies, internalizing the externalities is challenging as it affects producers' and consumers' welfare or surplus (Krishnan C & Gupta, 2018; Palacios M. & Saavedra P., 2017) due to the increase in the product's price. Thus, internalizing the externalities is unfavorable, especially by consumers in developing countries who are unable to pay more. A previous study of externalities' effect on electricity cost finds that GCs from a wind turbine and a coal-fired power plant is 7.32 and 5.54 cents US$/kWh, respectively. However, by internalizing the externalities represented by the external cost and carbon tax, the GC becomes 10.196 cents US$/kWh or an increase of 84% (Asri & Yusgiantoro, 2020). Under the lowest price orientation, it is very challenging to achieve sustainability in energy provision. For a less developed country, there is a dilemma of sustainability and financial. The measures towards a healthy environment (sustainability) tend to be overlooked in favor of financial performance (Jayanti & Gowda, 2014).

3.3.2 How Externalities influence GC

In energy provision or electricity generation planning, the externality is not taken into account, but the operation of powerplants impacts the environment and social life. On the other hand, NRE is a perfect choice in electricity provision for sustainability. However, due to financial constraints and immediate electricity provisions, the government tends to choose those with a lower initial cost, though the annual cost and environmental cost will be higher.

The observations in Figure 2 and Figure 3 show that diesel GCs are the most expensive, but the GCs (as shown in Figure 2 and Figure 3) have not internalized has not internalized the environmental factor yet. The externality cost of a power plant varies depending on the damage it causes. The externality cost of coal, gas, and oil fuel power plants is 0.06-72.42, 0.003-13.22, and 0.03-39.93 cents US$/kWh, respectively (Sundqvist, 2004). Another study finds that coal and gas's externality costs are 6.4 and 2.1 Eurocents/kWh, respectively (Feretic & Tomsic, 2005). By using data in Table 4, the GCs after internalizing the externalities change considerably (Figure 5). GC of coal is no longer the cheapest and is replaced by gas. Diesel still has the highest GC, but only slightly higher than that of coal. It shows that the GC of coal experiences the highest increase. This pattern occurs in all three operating times, which are CF 80% (base-load), CF 60% (medium-load), and CF 20% (peak-load). After internalizing external cost, GC in CF 80% of diesel is almost doubled (from 9.5 to 17.4 cents US$/kWh), while GC of coal is tripled (from 4.9 to 14.7 cents US$/kWh). GC of gas experiences the least increase or only about 34% from 7.0 to 9.4 cents US$/kWh. At CF 60%, GC of diesel and coal increase 1.77 and 2.75 times, respectively, while GC of gas 1.29 times. At the shortest operating time or CF 20%, GC of diesel increases 1.5 times, coal 1.9 times, while gas only 1.1 times or about 18%.

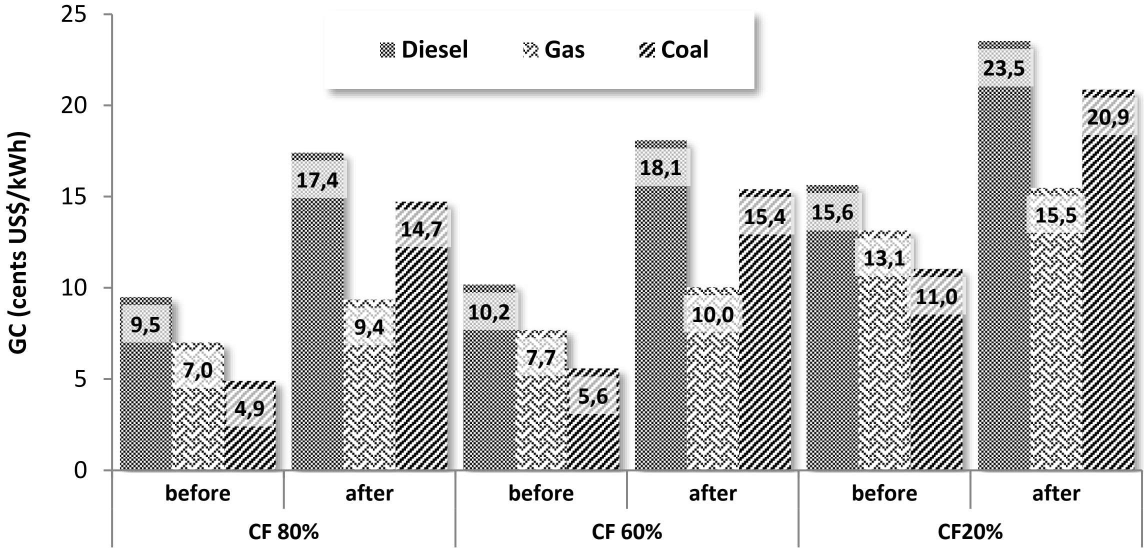

Figure 5. GC at various FCs and CFs after internalizing the externality cost

As CF is increases, the increase in cost due to externalities also increases. The smaller the CF, or the shorter the operating time, the smaller the GC's increase due to the externalities. In other words, the externality's influence is weakened as the operating time of the power plant decreases. This is in line with the practice, where the shorter the operating time, the less the waste generated by the power plant, which means the smaller the impact is. The magnitude of externalities follows the operating time of the power plant.

The study has successfully proven that the externality cost has a significant impact on GC. In practice, the externalities' internalization could be used to repair or prevent the damages. The preventive measure means to prevent the pollutants or wastes from damaging the environment, while a repair measure means to restore the damage. However, since the price is still the primary consideration among the three fossil fuels, the utilization of NRE in electricity provision will continue to be challenging. This study has successfully proven that the environmental aspect has significantly influenced the cost of electricity provision. Therefore, taking into account the externalities is crucial in electricity generation planning. However, achieving sustainability would be challenging if Indonesia cannot escape from the low-price orientation, but of course by noting that there are financial constraints.

3.4. The challenging sustainability in Indonesia energy provision

Externalities are inevitable, but its internalization means cost. Since it is not taken into account by the producers or the consumers, the people living around will bear the cost. For the producers, the decision to internalize the externalities is also influenced by the consumers since it will affect the consumer's welfare or the consumer surplus (Krishnan C & Gupta, 2018; Palacios M. & Saavedra P., 2017). If the consumers are concerned about environmental issues and can afford to pay more, internalizing the externalities is not an issue. Alternatively, the government can also partly bear the cost through, for example, subsidy or other incentives. However, what if it occurs in developing countries, where most people cannot afford to pay more? How challenging it is to conduct. Taking into account the externalities means spending more money. In the production chain, the internalization of externalities is indicated by the more uncompetitive products. Once the externalities are internalized into the cost formation, it increases the cost, and someone must bear it (Ding et al., 2014; Yusgiantoro, 2000).

To sum up, accounting for externalities is the first step to implement sustainability principles. However, the real issues are who will bear it, and are the people able to pay it? In emerging economies where a low-cost orientation is a priority, internalizing the externalities is challenging, so does achieving sustainability. In Indonesia, the challenging situation could be indicated by two things. The first is by coal domination in the electricity sector, and the second is by budget allocation, which does not prioritize environmental health yet.

3.4.1 Energy provision as the economy's prime mover: Indonesia electricity mix

The electricity energy mix portrays the condition of Indonesia's electricity. Until 2017, fossil energy sources still dominate the electricity energy mix (Figure 6). In 2015, the Indonesia energy mix was dominated by oil (43%), while the rest were coal (34%), gas (19%), and NRE (4%) (MEMR, 2015). However, the electricity energy mix was dominated by coal. Though oil has successfully been reduced from 15% to 6%, coal utilization increased from 51% in 2012 to 58% in 2017. On the other hand, gas persisted at 23%, and NRE was slightly up at 2% to be 13% in 2017 (Figure 6, inner and middle circle). Coal is targeted to cover 54.4% of the electricity energy mix in 2025, while the rest will be met by gas and NRE at 22.3% and 23%, respectively, and oil will be reduced further to 0.4% (Figure 6, outer circle). According to Government Regulation No. 79 of 2014 on National Energy Policy, this target sets the 2025 national energy mix at 30% for coal, 25% for oil, 22% for gas, and 23% for NRE. Fossil, especially coal domination in the electricity mix, shows that fuel cost is still the primary consideration in electricity provision, implying that Indonesia is still stuck in the low-price orientation.

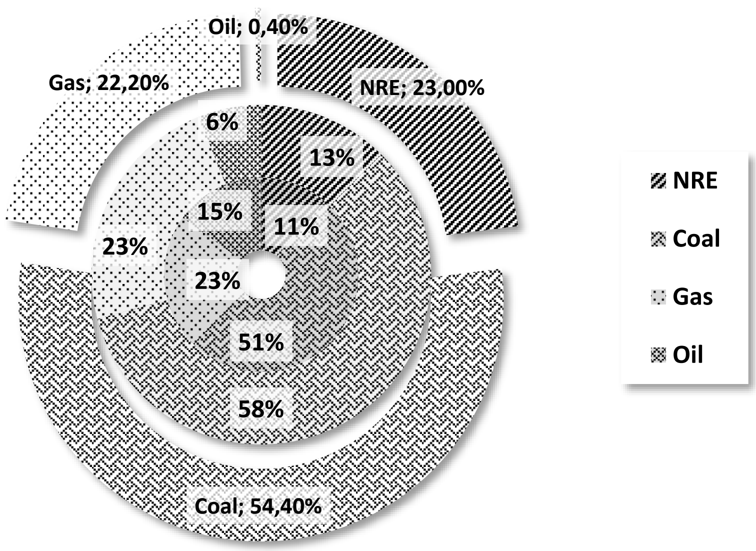

Figure 6. Energy Mix in electricity (inner to outer) in 2012, 2017, and (target) 2025 (MEMR, 2012; PT PLN, 2018)

Energy (including electricity) is the prime mover of the economy (Asri & Yusgiantoro, 2021a). A previous study finds that the timing of electricity provision is crucial for economic performance, as the shortfall in power plant development leads to a 1.5% decline in GDP. Under financial constraints, developing countries provide electricity from the power plant type suited to their current financial capabilities regardless of the later impacts. The decision should be taken immediately, as waiting time in providing electricity (to be able to buy cleaner but costly power plant) means the decline in the economic performance (Afful-Dadzie et al., 2017). The situation seems to portray the situation in Indonesia, where coal dominates the electricity mix. As coal is the easiest and the cheapest, it enables the immediate energy provision to support economic activities and maintain its performance. It is a big dilemma, but the government should start thinking about the solution, for example, by encouraging clean technology research and development in the energy sector. Innovations would boost more affordable technology for more environmentally friendly energy use, such as coal liquefaction.

3.4.2 National priorities in less-developed countries

Developing countries are still struggling with fulfilling people's well-being, food, alleviate malnutrition, etc., which are considered basic needs. However, at the same time, they are also forced to maintain a healthy and clean environment for sustainability. While the former issues are more immediate and urgent to fulfill, the latter will tend to be low prioritized as they are under financial constraints. Thus, they face a big dilemma of fulfilling basic needs or achieving sustainability. As basic needs are more urgent than sustainability, they prioritize it and postpone the other one (Siddayao, 1992).

This phenomenon also seems to occur in Indonesia, which can be seen from the budget allocation. In 2019, the ten ministries/institutions with the largest budget (largest to smallest) were the Ministry of Public Works and Public Housing, Ministry of Defense, Indonesian National Police, Ministry of Religious Affairs, Ministry of Social Affairs, Ministry of Health, Ministry of Transportation, Ministry of Research, Technology, and Higher Education, Ministry of Education and Culture, and Ministry of Finance (MF, 2019). The Ministry of Environment and Forestry is not included in the top ten ministries/institutes receiving the largest budget. This indicates that the environment is currently not considered as a priority. Besides, based on the function, the top five allocations for central government spending are public services, economy, social protection, education, and public order and security. The rests are defense, health, housing and public facilities, environmental protection, religion, and tourism (MF, 2019). The environmental function ranks ninth in the list of development focuses and priorities. It shows how the environment for sustainability is not a top priority. However, further analysis to prove that developing countries face such a dilemma is required.

The observation on the electricity mix and budget allocation reveals that national priorities still need to be met by less-developed countries, where the sustainable energy provision is not included under the priorities. Thus, the difficulty in achieving sustainable energy provision in developing countries is due to the situation that all priorities (the essential needs) have not been fulfilled yet. Before the state can fulfill the basic needs (well-being, eradicate malnutrition) for all its people, the matters beyond the basic needs would receive relatively low priority (Siddayao, 1992), including the implementation of sustainability principles in energy provision (Ekholm et al., 2013). Besides, to maintain economic performance, developing countries are more likely to provide energy (electricity) as immediately as possible, regardless of its impacts. In other words, a developing country tends to choose power plants following their financial to maintain economic performance, rather than waiting until their money is sufficient to utilize cleaner but more costly power plants, at the expense of economic performance (Afful-Dadzie et al., 2017). Further analysis is required to investigate and prove the argument, which is beyond this study's scope. However, this study's investigations have sufficiently proven that Indonesia's sustainable energy provision is challenging due to the fulfillment of basic needs, which have not been fully resolved, and the demand for maintaining economic performance.

The internalization of externalities, which indicates the implementation of sustainability principles, is challenging to implement as it reduces the consumers' surplus. As the consumer unable to pay more, they will favor the cheaper products. The government also faces a limited budget, which hinders them from allocating subsidies to cover the externalities.

4. Conclusion

This study has successfully revealed that a sustainable Indonesia energy provision is challenging. This study divides the discussion into three main parts. The first part describes how GC is generated and which component has the most significant influence (the greatest contribution) on the resulting GC. The second part shows how internalizing the externalities affect (significantly) the resulting GC. The third part seeks the reason behind challenging sustainability by investigating Indonesia's current electricity mix and budget priorities.

In the investigation of GC formation, two main variables thought to have considerable influence are fuel price (represented by Fuel Cost or FC) and the operating time, which indicates the type of a power plant (represented by Capacity Factor or CF). FC covers until 70% of GC, while CF determines how long a particular power plant operates, which eventually determines GC. The analysis of CF indicates that GC decreases gradually as CF increases. Since diesel is the most expensive fuel, the GC of diesel is larger than the GC of Gas and the GC of Coal or $GC_{Diesel} > GC_{Gas} > GC_{Coal}$. The decrease of GC (as CF increases) is greater as the fuel price lower. The analysis of FC reveals that the pattern of GC and FC is in line and positive. The percentage of FC to GC varies from 10% to 86%, depending on the value of FC and CF. The trendline analysis shows that CF's impact is greater than FC's, shown by the equation of the former is in the fourth-order (x^4) while the latter is in the second-order (x^2). The observation of the simultaneous impact of both variables, FC and CF, on GC by using simple multivariate regression shows that CF (Capacity Factor) has a greater impact on GC than FC (Fuel Cost) on GC, shown by the coefficients (in absolute value) of x_2 (CF) are larger than the coefficients of x_1 (FC). The considerable contribution of fuel price (as the indication of the fuel type used) on GC is an indication of why the low-price orientation often conducts in emerging economies, i.e., to make it possible to provide electricity immediately to maintain economic performance.

Externalities are not considered in the transaction between producer and consumer, but the impacts on societies or parties beyond the transactions are real. Internalizing the externality changes the order of GC into $GC_{Gas} < GC_{Coal} < GC_{Diesel}$ (GC of Gas is lower than GC of Coal and GC of Coal is lower than GC of Diesel). GC of coal experiences the highest increase. In CF 80%, GC of diesel after internalizing the external cost is almost doubled (1.8 times), while GC of coal is tripled. This proves that the externality cost significantly impacts the GC. As the indication of sustainability principles' implementation, externalities are tough to conduct in developing countries. This mainly due to its internalization causes the surplus (welfare) reduction.

At least two factors indicate that sustainable energy provision in Indonesia is challenging. The first factor is the domination of coal (as the dominant fuel for power plants) in the Indonesia electricity mix, which is more than half in supplying electricity in Indonesia. New and Renewable Energy (NRE), the sustainable energy source, only contributes less than 20%. The second factor is that environmental programs as an indicator of sustainability principles' implementation are not the current development priorities. The development prioritizes more the provision of public facilities, the economy, and people's well-being. The logic for the challenging energy provision is the dilemma between providing a sustainable energy provision or fulfilling the basic needs and maintaining economic performance.

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References

Afful-Dadzie, A., Afful-Dadzie, E., Awudu, I., & Banuro, J. K. (2017). Power generation capacity planning under budget constraint in developing countries. *Applied Energy*, *188*, 71–82. https://doi.org/10.1016/j.apenergy.2016.11.090

Andersen, F. M., Baldini, M., Hansen, L. G., & Jensen, C. L. (2017). Households' hourly electricity consumption and peak demand in Denmark. *Applied Energy*, *208*(September), 607–619. https://doi.org/10.1016/j.apenergy.2017.09.094

Asri, N. D., & Yusgiantoro, P. (2020). The energy provision dilemma of coal versus wind from the economic, environmental, and social perspective within the energy security framework. *Defense Journal*, *6*(3), 310–327. https://doi.org/http://dx.doi.org/10.33172/jp.v6i3.1049

Asri, N. D., & Yusgiantoro, P. (2021a). A Revisit of the Energy-Economy-Environment Nexus with Multi-regression. *International Journal on Advanced Science, Engineering and Information Technology*.

Asri, N. D., & Yusgiantoro, P. (2021b). Investigating a hampered NRE utilization in Kaltim's energy system: Is there an energy policy with a syndrome of the energy-abundant area? *International Journal of Renewable Energy Development*, *10*(4), 653–666. https://doi.org/https://doi.org/10.14710/ijred.2021.37135

Bartnik, R., Hnydiuk-stefan, A., & Buryn, Z. (2018). Analysis of the impact of technical and economic parameters on the specific cost of electricity production. *Energy*, *147*, 965–979. https://doi.org/10.1016/j.energy.2018.01.014

British Petroleum. (2017). *BP statistical review of world energy 2017* (Issue June).

Chatzimouratidis, A. I., & Pilavachi, P. A. (2008). Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process. *Energy Policy*, *36*(x), 1074–1089. https://doi.org/10.1016/j.enpol.2007.11.028

Di Valdalbero, R., & Kovács, T. G. (2004). Energy the real cost. *IEE Power Engineer*, 23–25. www.iee.org/powermagazine

Ding, H., He, M., & Deng, C. (2014). Lifecycle approach to assessing environmental friendly product project with internalizing environmental externality. *Journal of Cleaner Production*, *66*(April 1995), 128–138. https://doi.org/10.1016/j.jclepro.2013.10.018

Dutu, R. (2016). Challenges and policies in Indonesia's energy sector. *Energy Policy*, *98*, 513–519. https://doi.org/10.1016/j.enpol.2016.09.009

Ekholm, T., Ghoddusi, H., Krey, V., & Riahi, K. (2013). The effect of financial constraints on energy-climate scenarios. *Energy Policy*, *59*, 562–572. https://doi.org/10.1016/j.enpol.2013.04.001

Fahrioglu, M. (2016). Effect of demand management on regulated and deregulated electricity sectors. *Energy Policy*, *90*, 115–120. https://doi.org/10.1016/j.enpol.2015.12.018

Feretic, D., & Tomsic, Z. (2005). Probabilistic analysis of electrical energy costs comparing: production costs for gas, coal and nuclear power plants. *Energy Policy*, *33*, 5–13. https://doi.org/10.1016/S0301-4215(03)00184-8

Ghimire, L. P., & Kim, Y. (2018). An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renewable Energy*, *129*, 446–456. https://doi.org/10.1016/j.renene.2018.06.011

Gómez-navarro, T., & Ribó-pérez, D. (2018). Assessing the obstacles to the participation of renewable energy sources in the electricity market of Colombia. *Renewable and Sustainable Energy Reviews*, *90*(March), 131–141. https://doi.org/10.1016/j.rser.2018.03.015

Harun, N. (2011). *Teaching Material: Design of Electricity Generation*.

Jayanti, R. K., & Gowda, M. V. R. (2014). Sustainability dilemmas in emerging economies. *IIMB Management Review*, *26*(2), 130–142. https://doi.org/10.1016/j.iimb.2014.03.004

Jeong, S., Kim, K., Park, J., Lim, D., & Lee, S. (2008). Economic comparison between coal-fired and liquefied natural gas combined cycle power plants considering carbon tax: Korean case. *Energy*, *33*, 1320–1330. https://doi.org/10.1016/j.energy.2008.02.014

Kadaffi, M. (2011). *Teaching Material: The Characteristics of Electricity Load* (No. 14).

Kennedy, S. F. (2018). Indonesia's energy transition and its contradictions: Emerging geographies of energy and finance. *Energy Research & Social Science*, *41*(June 2017), 230–237. https://doi.org/10.1016/j.erss.2018.04.023

Knoope, M. M. J., Meerman, J. C., Ramírez, A., & Faaij, A. P. C. (2013). Future technological and economic performance of IGCC and FT production facilities with and without CO2 capture: Combining component based learning curve and bottom-up analysis. *International Journal of Greenhouse Gas Control*, *16*, 287–310. https://doi.org/10.1016/j.ijggc.2013.01.002

Krishnan C, M., & Gupta, S. (2018). Political pricing of electricity – Can it go with universal service provision? *Energy Policy*, *116*(June 2017), 373–381. https://doi.org/10.1016/j.enpol.2018.02.009

Laporan Tahunan Greenpeace Asia Tenggara 2012. (n.d.).

Larsson, S., Fantazzini, D., Davidsson, S., Kullander, S., & Höök, M. (2014). Reviewing electricity production cost assessments. *Renewable and Sustainable Energy Reviews*, *30*, 170–183. https://doi.org/10.1016/j.rser.2013.09.028

Locatelli, G., & Mancini, M. (2010). Small-medium sized nuclear coal and gas power plant: A probabilistic analysis of their financial performances and influence of CO2 cost. *Energy Policy*, *38*(10), 6360–6374. https://doi.org/10.1016/j.enpol.2010.06.027

Martosaputro, S., & Murti, N. (2014). Blowing the wind energy in Indonesia. *Energy Procedia*, *47*, 273–282. https://doi.org/10.1016/j.egypro.2014.01.225

MEMR. (2012). *General Plan of Electricity Draft 2012-2031*.

MEMR. (2015). *Kebijakan dan Strategi Pengembangan EBTKE untuk Memenuhi Target Kebijakan Energi Nasional*. The Ministry of Energy and Mineral Resources.

MEMR. (2017). *Handbook of Energy & Economic Statistics of Indonesia 2017*.

Mignone, B. K., Alfstad, T., Bergman, A., Dubin, K., Duke, R., Friley, P., Martinez, A., Mowers, M., Palmer, K., Paul, A., Showalter, S., Steinberg, D., Woerman, M., & Wood, F. (2012). Cost-effectiveness and economic incidence of a clean energy standard. *Economics of Energy and Environmental Policy*, *1*(3), 59–86. https://doi.org/10.5547/2160-5890.1.3.5

NEA-OECD. (2003). Nuclear Electricity Generation: What Are the External Costs? In N. E. A. of OECD (Ed.), *Nuclear Energy* (NEA 4372). OECD Publications.

NEA-OECD. (2001). Externalities and Energy Policy: The Life Cycle Analysis Approach. In Nuclear Energy Agency of OECD (Ed.), *Workshop Proceedings* (Issue November, pp. 195–234). OECD Publications. http://www.nea.fr/ndd/reports/2002/nea3676-externalities.pdf

Newbery, D. (2011). *Reforming competitive electricity markets to meet environmental targets* (No. 1126; 1154, Issue August). www.eprg.group.cam.ac.uk

Palacios M., S., & Saavedra P., E. (2017). Alternative policies for the liberalization of retail electricity markets in Chile. *Utilities Policy*, *49*, 72–92. https://doi.org/10.1016/j.jup.2017.06.009

Park, K., Shin, D., & Yoon, E. S. (2011). The cost of energy analysis and energy planning for emerging, fossil fuel power plants based on the climate change scenarios. *Energy*, *36*(5), 3606–3612. https://doi.org/10.1016/j.energy.2011.03.080

Parry, I., Heine, D., Li, S., & Lis, E. (2014). How should different countries tax fuels to correct environmental externalities? *Economics of Energy & Environmental Policy*, *3*(2), 1–17. https://doi.org/10.5547/2160-5890.3.2.ipar

Partridge, I. (2018). Cost comparisons for wind and thermal power generation. *Energy Policy*, *112*(September 2017), 272–279. https://doi.org/10.1016/j.enpol.2017.10.006

PT PLN. (2015). *PLN Statistics 2015*.

PT PLN. (2018). *The Power Supply Business Plan of PT. PLN 2018-2027*.

Rahman, F. (2012a). *Teaching Material: The Economic Analysis of Power Plant*.

Rahman, F. (2012b). *Teaching Material: The Technology of Electric Power Generation*.

Reddy, B. S. (2018). Economic dynamics and technology diffusion in indian power sector. *Energy Policy*, *120*(April), 425–435. https://doi.org/10.1016/j.enpol.2018.05.044

Rewlay-ngoen, C., Papong, S., & Sampattagul, S. (2014). The NPP and social asset impacts of acidification from coal-fired power plant in Thailand. *Energy Procedia*, *52*, 234–241. https://doi.org/10.1016/j.egypro.2014.07.074

Rodgers, M., Coit, D., Felder, F., & Carlton, A. (2019). Assessing the effects of power grid expansion on human health externalities. *Socio-Economic Planning Sciences*, *66*(July 2018), 92–104. https://doi.org/10.1016/j.seps.2018.07.011

Sakulniyomporn, S., Kubaha, K., & Chullabodhi, C. (2011). External costs of fossil electricity generation: Health-based assessment in Thailand. *Renewable and Sustainable Energy Reviews*, *15*(8), 3470–3479. https://doi.org/10.1016/j.rser.2011.05.004

Sayyaadi, H., & Sabzaligol, T. (2010). Comprehensive exergetic and economic comparison of PWR and hybrid fossil fuel-PWR power plants. *Energy*, *35*(7), 2953–2964. https://doi.org/10.1016/j.energy.2010.03.030

Sequeira, T. N., & Santos, M. S. (2018). Does country-risk influence electricity production worldwide? *Journal of Policy Modeling*, *40*(4), 730–746. https://doi.org/10.1016/j.jpolmod.2018.01.013

Siddayao, C. M. (1992). Energy investments and environmental implications: Key policy issues in developing countries. *Energy Policy*, *20*(3), 223–232. https://doi.org/10.1016/0301-4215(92)90080-L

Sundqvist, T. (2004). What causes the disparity of electricity externality estimates? *Energy Policy*, *32*(15), 1753–1766. https://doi.org/10.1016/S0301-4215(03)00165-4

Teng, F., Jotzo, F., & Wang, X. (2017). Interactions between market reform and a carbon price in China's power sector. *Economics of Energy and Environmental Policy*, *6*(2), 39–53. https://doi.org/10.5547/2160-5890.6.1.ften

The UN. (2020). *The Sustainable Development Agenda*. https://www.un.org/sustainabledevelopment/development-agenda/

Wikarsa, M. T. (2010). *Studi analisis program percepatan 10.000 MW tahap I pada operasi sistem tenaga listrik Jawa Bali*. Universitas Indonesia.

Yusgiantoro, P. (2000). *Ekonomi Energi: Teori dan Praktik* (1st ed.). Pustaka LP3ES.

Appendixes

Followings are the GC (Generating Cost) data (rounded by two decimal places) selected from the calculation as the sample (data points) for the multiple regression analysis and its regression output (with decimal rounding). For uniformity, FC is in US$/barrel oil equivalent (BOE).

Table A1. The selected GC of Coal for multi-regression analysis

GC_{COal}	FC_{COal}	CF_{COal}
7.26	23.16	0.8
7.09	20.68	0.7
7.07	18.46	0.6
7.24	16.48	0.5
7.73	14.72	0.4
8.80	13.14	0.3
11.27	11.73	0.2
19.22	10.47	0.1

Regression results for Coal by using 'Data Analysis' feature in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.94096364
R Square	0.88541257
Adjusted R Square	0.83957760
Standard Error	1.67872278
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	108.877138	54.4385691	19.3174026	0.0044447
Residual	5	14.0905509	2.81811019		
Total	7	122.967689			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-21.325182	10.28199	-2.07403	0.092763	-47.7559	5.105506
FC	4.58425595	1.274122	3.59797	0.015576	1.30902	7.85949
CF	-95.661458	23.08439	-4.14399	0.008962	-155.002	-36.3211

Table A2. The selected GC of Gas for multi-regression analysis

GC_{Gas}	FC_{Gas}	CF_{Gas}
11.93	68.93	0.8
11.26	61.55	0.7
10.79	54.95	0.6
10.57	49.06	0.5
10.70	43.80	0.4
8.80	39.11	0.3
13.64	34.92	0.2
21.33	31.18	0.1

Regression results for Gas by using 'Data Analysis' feature in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.86078497
R Square	0.74095077
Adjusted R Square	0.63733108
Standard Error	2.32725226
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	77.4575886	38.7287943	7.15067527	0.03415512
Residual	5	27.0805154	5.41610307		
Total	7	104.538104			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-25.320483	14.25416	-1.77636	0.135831	-61.9616	11.32099
FC	1.7438637	0.593435	2.93859	0.032309	0.21839	3.269336
CF	-101.99605	32.00242	-3.18713	0.024343	-184.261	-19.73119

Table A3. The selected GC of Diesel for multi-regression analysis

GC_{Diesel}	FC_{Diesel}	CF_{Diesel}
17.45	114.50	0.8
16.19	102.23	0.7
15.19	91.28	0.6
14.49	81.50	0.5
14.21	72.77	0.4
14.59	64.97	0.3
16.43	58.01	0.2
23.83	51.79	0.1

Regression results for Diesel by using 'Data Analysis' feature in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.89256268
R Square	0.79666815
Adjusted R Square	0.71533540
Standard Error	1.67872278
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	55.2077447	27.6038724	9.79517142	0.0186429
Residual	5	14.0905509	2.81811019		
Total	7	69.2982957			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-21.325182	10.28199	-2.07403	0.092763	-47.7559	5.105506
FC_{Diesel}	1.0161688	0.257692	3.94334	0.010923	0.35375	1.678588
CF_{Diesel}	-95.661458	23.08439	-4.14398	0.008962	-155.001	-36.32114