Preventing Stranded Coal Power Assets by Using Comparative Scenario of Energy Mixture and The SWOT Analysis of Energy Sector in Indonesia

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Abstract
The generation of electricity is somewhat problematic due to the fact that the big contributor in generating electricity is also a big contributor in accelerating global warming and climate change. With the presence of historical demand of electricity in Indonesia, power plant capabilities, operational cost, and assets cost of electricity generation in Indonesia, we can forecast electricity demand in 2030 and 2050. In addition, optimization by using Lingo Program, which includes 13 decision variables consists of PLTA, PLTU, PLTG, PLTGU, PLTP, PLTD, PLTMG, PLTS, PLTB, PLTBM, Independent Power Producer (IPP), Rented Unit, and PLTU CCS, could be done to foresee the possible scenario of electricity generation that was divided into (1) when coal power have no limitation, (2) when capacity of coal reduced and replaced with cleaner energy, and (3) when coal power capacity is reduced and replaced with the installation of CCUS. Thus, the result shows that in order to fulfill the electricity demand with clean energy for 2030 and 2050, the investment needed are, nearly Rp1,372.96 trillion and Rp2,902.32 trillion respectively. To address the characteristic of energy sector in Indonesia, the SWOT analysis is conducted to mitigate risk and take greatest advantage of chances for success.

Keywords
Paris Agreement, sustainable development, energy mixture, SWOT, and Linear Programming.

1. Introduction
Energy has been an interesting topic that is discussed over the years. The development of energy is rapidly increasing as human and nature demand balance source that is efficient yet eco-friendly. One type of energy that is fundamental in every human activity nowadays is electricity. Recent survey done by International Energy Agency stated that almost 87% of human population on earth use electricity daily (Feldman, 2019). Based on the first law of thermodynamics, energy can neither be created nor destroyed but it can change its form (Joule, 1843). To generate electricity, kinetics are applied to turbines and generators in power plant. One type of power plant that has contributed a lot in electricity is coal fired power plant.

Currently, the carbon dioxide (CO_2) level in atmosphere has reach 409.8 ppm (parts per million) which is higher than at any point of 800,000 years ago. This amount of CO_2 has affected the temperature around 2^o-3^oC and sea level around 15-25 meters to increase (Lindsey, 2020). This led to the need of clean energy that is aimed to phased out coal combustion to 0-2% usage only by the end of 2050 to maintain the environment (Blondeel et. al, 2020). However, in 2016, coal fired power plant has contributed around 38.2% of global electricity production. This indicates that even up to now, coal is still needed by global population to generate electricity.

In 2015, United Nation Framework Convention on Climate Change (UNFCCC) has legitimated Paris Agreement to fight against climate change and intensify as well as supports action and investment for a sustainable low carbon future. Based on the official website of UNFCCC, Paris Agreement specifically aims to keep the global temperature rise below 2^{o}C above pre-industrial levels and to pursue effort to limit the temperature increase even further to 1.5^{o}C (UNFCCC, 2018). In 2017, as a way to help countries that commit to do transition from coal to clean energy, Powering Past Coal Alliance (PPCA) was launched in United Kingdom and Canada (Blondeel et. al, 2020).

Carbon Brief (2015) stated that Indonesia was the 4th largest emitter of greenhouse gasses – which most of the sources coming from fossil fuel combustion. In the current situation, Indonesia plans to increase domestic coal powered generator to help closing 'electricity gap' between wealthy and less connected island. With regards to Paris Agreement, Indonesia has pledged to decrease emission by 29 - 41% by 2030 (Dunne, 2019). Indonesia is also the world 5th largest producer of coal, in which 80% of them is exported. According to Greenpeace, coal mining activities in Indonesia affected the environment, one of which is the destruction of tropical coral reef in Borneo (Greenpeace, 2020). Regardless of the environmental effects, nevertheless, Indonesia's electricity was generated by coal for around 58% in 2017, nearly 152TWh (terawatt-hour) (Dunne, 2019). As coal was the backbone of Indonesia's economy and electricity, major changes as a result from external rules that limit the use of coal will have significant impact to coal fired power plant.

This paper first describes the current state of energy sector in Indonesia and gives analysis of coal power and how many coal power plant should be reduced every year to be in track with the current Safety Data Sheet (SDS). An analysis of potential Renewable Energy (RE) was extracted from literature reviews to provide insight of how coal power could potentially be replaced with RE. Next, author clarifies unusual terms used in the analysis and provide data extracted from *PLN Statistik 2019*. Author will later discuss the method used to forecast the electricity demand and determining the objective, constraints, and variable used to be optimized using Linear Programming with Lingo Programming. Finally, the paper ends with the most optimal solution served with the SWOT analysis of energy sector to generate mitigation plans together with a thorough conclusion.

2. Literature Review

2.1 Current State of Energy Sector in Indonesia

Indonesia has been struggling to reach the target. In 2017, the amount renewable contributes only 8% with 92% covered by fossil fuels. In the end of 2017, the same trend in power sector, where 12% is coming from renewable energy and the remaining 88% still covered by fossil fuels for generating electricity in Indonesia (IESR, Igniting a Rapid Deployment of Renewable Energy in Indonesia: Lessons Learned from Three Countries, 2018*). Figure 1* below represent electricity production in Indonesia from 2009 to 2017, followed by chart in *Figure 2*.

Year	Coal	Diesel	Gas	Hydropower	Other renewables	Total Renewables	Total Generation (GWh)
2009	39.00%	25.00%	25.00%	8.00%	3.00%	11.00%	156797.20
2010	38.00%	22.00%	25.00%	12.00%	3.00%	15.00%	169786.22
2011	44.06%	22.95%	21.00%	6.80%	5.20%	12.00%	183420.93
2012	50.27%	14.97%	23.41%	6.39%	4.96%	11.35%	200317.56
2013	51.58%	12.54%	23.56%	7.73%	4.58%	12.31%	216188.53
2014	52.87%	11.81%	24.07%	6.70%	4.55%	11.25%	228554.90
2015	56.06%	8.58%	24.89%	5.93%	4.54%	10.47%	233981.98
2016	54.70%	6.96%	25.88%	7.88%	4.58%	12.46%	248610.52
2017	57.22%	5.81%	24.82%	7.06%	5.09%	12.15%	254487.66

Figure 1. Percentage of Electricity Supplier Contribution Each Year From 2009 To 2017 (IESR, 2018)

From *Figure 1* and *Figure 2*, it can be seen that the use of coal in Indonesia keep increases. In 2017, coal contribute around 57.22%, nearly 100TWh, of total electricity production that year, followed by gas with 24.82%, nearly 63TWh, total renewable with 12.15%, hydropower with 7.06%, diesel with 5.81%, and other renewable by 5.09% contribution – in total of 254,487.66 GWh produced.

With this energy distribution, the United Nation Statistic Division (UNSD) grouped Indonesia as top 10 countries with the largest carbon emission together with developed countries, such as Germany, Japan, China, United State, and Russia in 2015 (Kusumawardani & Dewi, 2020). Based on Enerdata (2018), in 2017, Indonesia has emitted 484 Million tons of carbon dioxide equivalent (MtCO2e) with 27% from transportation, 6% from housing and gardening, 31% from industry, and 36% from electricity generation and other burning process as shown in *Figure 2* below.

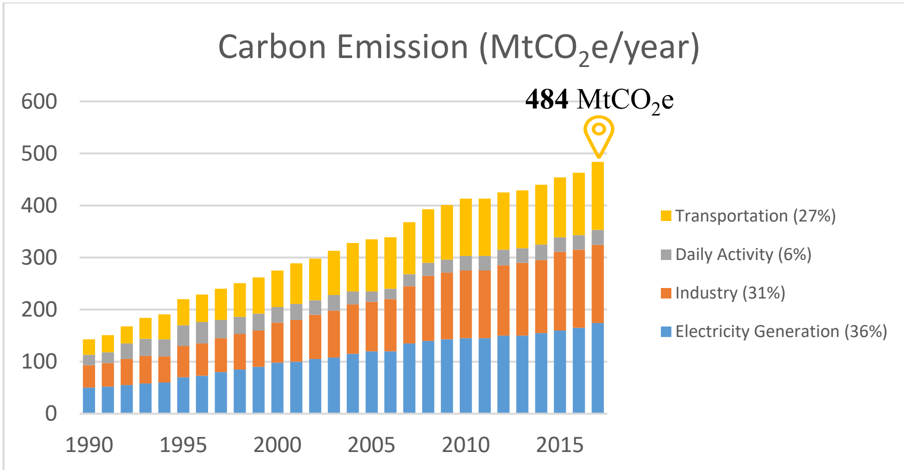

Figure 2. Carbon Emission in Indonesia From 1990 To 2017 (Enerdata, 2018)

On the other hand, from 2012 to 2017, the trend of carbon emission increased around 18 percent. If carbon emission has the same increasing rate for longer time, 2,000 out of 17,000 islands in Indonesia is expected to be drowned due to global warming (Lean & Smyth, 2010). As a way to prevent that from happening, with regards to Paris Agreement, Indonesia has pledged to decrease emission by 29 - 41% by 2030 (Dunne, 2019). This will lead to high demand in developing sustainable low carbon energy in the future.

2.2 Coal Power Operational Trend

Based on statistic, coal reserves in Indonesia remains around 24,910,001,380 tons, in which placed on 11th global rank as a country with most coal remains, sharing for around 2.19% of total coal in the world. With current production rate, around 400-500 million tons of coal produced per year, the total coal reserves could last for around 243 years.

Coal fired power generation has dropped 3% in 2019 after three years of growth and a record of over 10,000 TWh demand of electricity in 2018 (IEA, 2020). Even though there are drop rate in the number of coal fired power plants in the United State and Europe, China and most part of Asia still set it as a backbone with 36% amount electricity demand covered. This happens because of the availability of the current technology. In a particular case, those country which consist of many separated island (archipelago) – for example Indonesia – will still need the power from coal to support the distribution of electricity to isolated island. The President of Indonesia, Joko Widodo, has pledged to decrease the coal usage after successfully distribute electricity from main islands to small islands. He stated that Indonesia will decrease emission by 29 - 41% which is around 0.69 billion tonnes by 2030 (Dunne, 2019).

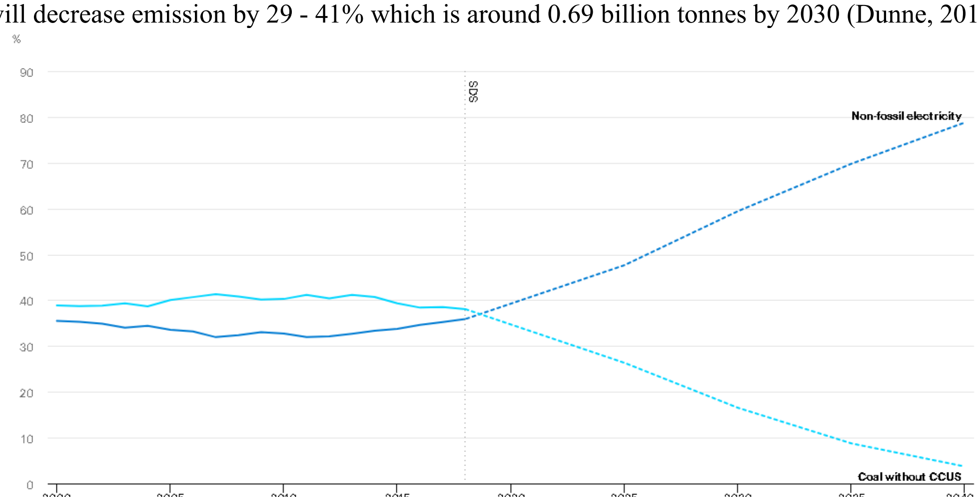

Figure 3. The Scenario of Electricity Generator In The Sustainable Development Scenario (IEA, 2020)

However, the International Energy Agency (IEA) also projected the number of coal-fired power plant, as shown in *Figure 3*, that by the end of 2040, the number of coal-fired power plant without Carbon Capture, Utilization, and Storage (CCUS) should be less than 4%. Therefore, it is suggested that coal fired power generation that have not installed CCUS yet should be decreased by 5.3%, to either start installing CCUS or to be closed, each year to save the environment, nearly 49 unit of coal power plants (IEA, 2020).

2.3 Renewable Energy Potential

In 2019, the total potential of Renewable Energy reaches 442GW of potential capacity installed (Erdiwansyah, et al., 2020). Meanwhile, the capacity installed for RE is only 9.32 GW or nearly 2% from the total potential capacity of RE. *Table 1* below represent the potential and utilized RE in Indonesia in 2019.

Table 1. Potential, Installed, And Installed To Potential Ratio Percentage of RE in Indonesia

Type of RE	Potential Capacity (GW)	Installed Capacity (GW)	Installed to potential ratio percentage (%)
Marine Energy (Tidal)	17.9	0	0
Geothermal	28.5	1.949	6.84
Bioenergy (Biomass, Biofuel, etc.)	32.6	1.858	5.70
Wind Power	60.6	0.147	0.24
Hydro Power	75.0	5.417	7.22
Solar Power	207.8	0.135	0.06

From all type of potential renewable energy in Indonesia, the one that seems to have better development is hydro power with installed to potential ratio rate of 7.22% with 5.4 GW of capacity installed. On the other hand, other type of RE seems to be not well developed with total capacity installed under 2 GW. Each RE type can still be optimized by increasing the capacity installed to the fullest potential. With regards of Government Regulation No. 79 of 2014 on National Energy Policy, the target for RE shares for 2025 and 2050 are at least 23% and 31% respectively.

2.4 Capacity Factor

Every energy sources has capacity factors, which defined as percentage in which actual outputs is divided by the potential outputs of a certain power generators. Actual outputs is how many electricity a certain unit of power plant could made in reality over certain periods of time, while potential outputs is the expected amount of electricity that can be produced theoretically in full capacity (works properly every time without disruption or shortage in fueling the power plant).

For example, a unit of power plant has a capacity of 600 megawatts (MW), when the unit is working 10 hours straight without break, then the unit could produce 6,000 Megawatts hours (MWh). That is the potential outputs of a certain unit as it is working perfectly. In real situation, approximately the generated electricity is only 5,400 MWh. Hence, the capacity factors for this example would be $\frac{5{,}400\ MWh}{6{,}000\ MWh} = 0.90 \cong 90\%$

High capacity factors is good since it has higher efficiency. The example of high capacity factors of unit in power plant is coming from geothermal power plant since the heat from the earth is working continuously without rest, which leads to a very high capacity factors. There are several reasons that might reduce the capacity factors of a certain unit in power plant, which includes maintenance, equipment failures, and less real time demand which make full capacity of electricity generation become not economical (the excess electricity cannot be stored). When geothermal compared with renewables such as wind power and solar power, it has another reason why it has lower capacity factors. It has very different value as the fuel to generate electricity is very depending on the nature (wind power need wind that is not always available every time, solar power need sunrays that sometimes is blocked by the cloud or during nighttime), leading to a low capacity factors in the mentioned renewable energy sources.

Here is the comparison of average capacity factors from different kind of energy sources in the Indonesia based on *PLN Statistik Indonesia 2019* that is presented in *Figure 4* below:

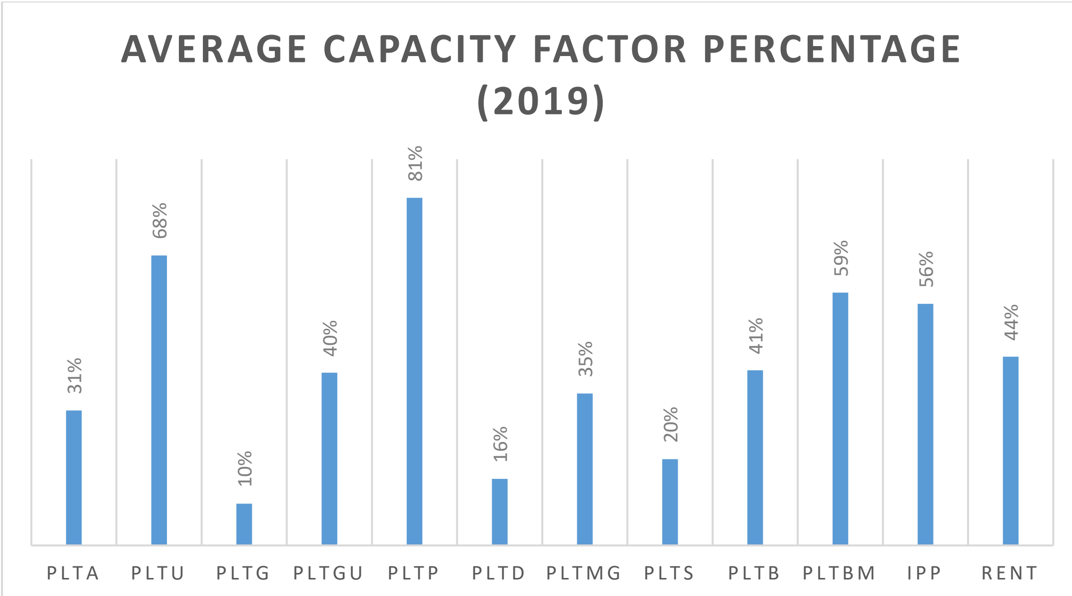

Figure 4. Average Capacity Factor Calculated from PLN Statistik Indonesia 2019

3. Methods

This study conducts the analysis of potential energy mix in Indonesia by measuring technology capabilities and constraints that are complemented with the process of analyzing strengths, weaknesses, opportunities, and threats of energy sector in Indonesia. The goal is that energy mix scenario will still be able to fulfill electricity demand in Indonesia as the amount of RE mix is increased and reliance to coal is decreased. With the supporting data collected by *Badan Pusat Statistik* (BPS), the authors are able to collect the data of electricity demand from 1995 to 2019. On the other hand, the annual report uploaded by *Perusahaan Listrik Negara* (PLN) in 2019, namely *PLN Statistik 2019*, the authors are able to collect the data of current power source capability, cost, and constraints. Hence, the authors decided to have 3 main methods to analyze the data. The specific year chosen to be analyzed will be 2030 and 2050.

- Forecasting : to predict the electricity demand in 2030 and 2050;
- Lingo Programming : to optimize the variables defined with several constraints;
- SWOT Matrix : to identify the current strength, weakness, opportunity, and threat.

4. Data Analysis

4.1 Selecting Suitable Forecasting Method

There are 3 forecasting methods that is being compared to find the best method with less error that is compatible with the demand trend. Those method include Simple Moving Average (3), Weighted Moving Average (3 with weight of 0.05, 0.05, and 0.9 sequentially), and Exponential Smoothing (α=0.4). Here is the result of each method with its error that is presented in *Table 2* below.

Table 2. Error Comparison From 3 Different Forecast Method (Electricity Demand)

Method	CFE	MAD	MSE	MAPE	Tracking
MA(3)	363,494.51	17,309.26	350,519,101.27	12.34	21.00
WMA(3)	210,378.49	10,018.02	125,584,785.08	7.11	21.00
ES(0.4)	431,833.76	20,563.51	493,963,193.84	14.57	21.00

Based on the error analysis presented above, it can be seen that WMA(3) has lesser error compared to MA(3) and ES(0.4). The moving average use period of 3 since we do not want to neglect much fluctuation. Hence, the value of 3 period would be somewhat ideal. On the other hand, the suggested alpha for ES is between 0.1 to 0.3 (Jacobs & Chase, 2013), but we choose 0.4 instead because we want the data of demand contribute more to the value of forecast compared to only between 0.1 to 0.3. Hence, the forecast method that is selected is Weighted Moving Average. However, the tracking signal is equal to 21. This means that the forecast will always be an 'under forecast', which means the real demand will always be higher than the calculated forecast. To encounter this, the authors decided to figure out what are the average increase of demand that can be calculated from the historical data available. The calculation shows that there is average of 9,000 GWh increase each year. It has decided to add the value of WMA(3) with 9,000 GWh for every forecast value, resulting in more accurate forecasting. The result is presented in *Table 3* below.

Table 3. Error Comparison of Adjusted WMA(3) (Electricity Demand)

Method	**CFE**	**MAD**	**MSE**	**MAPE**	**Tracking**
MA(3)	363,494.51	17,309.26	350,519,101.27	12.34	21.00
WMA(3)	21,378.49	3,936.08	26,260,362.51	2.97	5.43
ES(0.4)	431,833.76	20,563.51	493,963,193.84	14.57	21.00

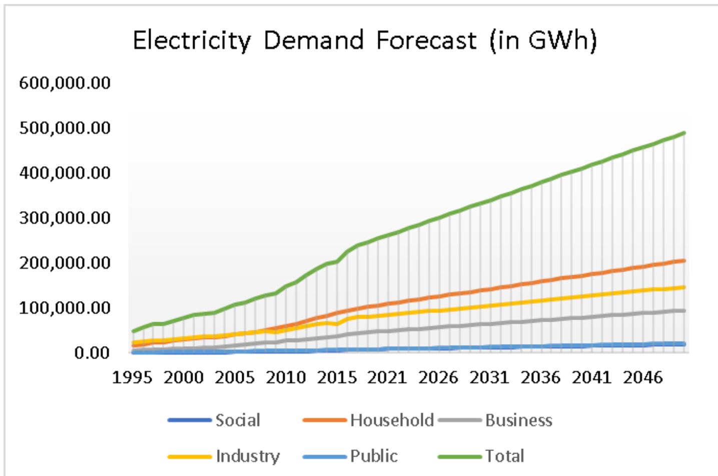

Figure 5. Electricity Demand Forecast (in GWh)

Based on the forecast conducted using WMA(3), the author found out that in 2030 and 2050, the electricity demand will be around 333,409 GWh and 489,930 GWh respectively.

4.2 Data Extracted from *PLN Statistik 2019*

Here are several data extracted from *PLN Statistik 2019*, including number of unit installed, capacity installed, average capacity per unit, electricity generated in 2019, expected electricity generated in 2019, capacity factor, average electricity generated per unit in 2019, total operation cost in 2019, and total assets cost in 2019.

Table 4. Number of Unit Installed 2019

UNIT INSTALLED 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
243	133	68	73	18	5,196
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
154	96	5	1	354	382

Table 5. Capacity Installed 2019

CAPACITY INSTALLED (MW) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
3,583.98	20,750.50	3,188.90	10,708.76	579.50	3,692.38
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
1,336.93	14.65	0.47	0.50	17,135.96	1,840.16

Table 6. Average Capacity per Unit Installed 2019

AVERAGE CAPACITY PER UNIT (MW/UNIT) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
14.75	156.02	46.90	146.70	32.19	0.71
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
8.68	0.15	0.09	0.50	48.41	4.82

Table 7. Electricity Generated 2019

ELECTRICITY GENERATED (GWh) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
9,877.06	122,826.04	2,723.05	37,757.83	4,110.30	5,014.43
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
4,143.79	25.81	1.68	2.58	84,518.74	7,086.09

Table 8. Expected Electricity Generated 2019

EXPECTED ELECTRICITY GENERATED (GWh) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
31,395.66	181,774.38	27,934.76	93,808.74	5,076.42	32,345.25
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
11,711.51	128.33	4.12	4.38	150,111.01	16,119.80

Table 9. Capacity Factor 2019

CAPACITY FACTOR 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
31%	68%	10%	40%	81%	16%
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
35%	20%	41%	59%	56%	44%

Table 10. Average Electricity Generated per Unit 2019

AVERAGE ELECTRICITY GENERATED PER UNIT (GWh/UNIT) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
40.65	923.50	40.04	517.23	228.35	0.97
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
26.91	0.27	0.34	2.58	238.75	18.55

Table 11. Operation Cost 2019

OPERATION COST (Million IDR) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
3,733,532.17	73,588,295.53	18,316,690.97	46,919,171.99	4,096,028.34	1,905,859.31
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
23,299,801.14	44,019.82	11,851.98	25,216.98	0.00	3,617,375.77

Table 12. Assets Cost 2019

ASSETS COST(Million IDR) 2019					
PLTA	PLTU	PLTG	PLTGU	PLTP	PLTD
94,755,614.70	348,623,842.47	63,819,984.02	185,282,411.09	17,390,129.30	1,886,459.66
PLTMG	PLTS	PLTB	PLTBM	IPP	Rent
23,062,633.63	580,201.39	37,249.07	28,819.40	0.00	0.00

Table 13. Operation Cost per Unit 2019

AVERAGE OPERATION COST PER UNIT(Million IDR) 2019	PLTA	PLTMG
	15,364.33	151,297.41
	PLTU	PLTS
	553,295.46	458.54
	PLTG	PLTB
	269,363.10	2,370.40
	PLTGU	PLTBM
	642,728.38	25,216.98
	PLTP	IPP
	227,557.13	0.00
	PLTD	Rent
	366.79	9,469.57
	PLTU CCS	1,383,238.64

Table 14. Assets Cost per Unit 2019

AVERAGE ASSETS COST PER UNIT(Million IDR) 2019	PLTA	PLTMG
	389,940.80	149,757.36
	PLTU	PLTS
	2,621,231.90	6,043.76
	PLTG	PLTB
	938,529.18	7,449.81
	PLTGU	PLTBM
	2,538,115.22	28,819.40
	PLTP	IPP
	966,118.29	0.00
	PLTD	Rent
	363.06	0.00
	PLTU CCS	6,553,079.75

4.3 Scenarios

There will be several scenarios regarding to the number of coal fired power plant as it is the main concern in the research. As the world demands for cleaner energy, we will see which scenarios is feasible and has the least cost without neglecting the significant changes in total cost. The scenarios for both 2030 and 2050 include:

1. When the number of Coal Fired Power Plant USC is not limited (only focusing on fulfilling electricity demand).
2. When the number of Coal Fired Power Plant USC reduced respectively and replaced with cleaner energy development.
3. When the number of Coal Fired Power Plant USC reduced respectively as it is replaced with CCUS.

4.4 Variables

Table 15. Variables Assigned

Type of Energy Source	Assigned Variable
Hydro (PLTA)	X_1
Coal (PLTU)	X_2
Gas (PLTG)	X_3
Gas & Steam (PLTGU)	X_4
Geothermal (PLTP)	X_5
Diesel (PLTD)	X_6
Gas (PLTMG)	X_7
Solar PV (PLTS)	X_8
Wind (PLTB)	X_9
Biomass (PLTBM)	X_{10}
IPP	X_{11}
Rented Unit (Rent)	X_{12}
Coal CCS (PLTU)	X_{13}

4.5 Linear Programming

Table 16. Linear Programming

Minimize	$\boldsymbol{Z = \sum_{i=1}^{13} O_i X_i + \sum_{i=1}^{13} A_i (X_i - U_i)}$	
Subject to	For 2030	For 2050
For all scenario	$\sum_{i=1}^{13} AE_i X_i \geq 333{,}409.09\ GWh$	$\boldsymbol{\sum_{i=1}^{13} AE_i X_i \geq 489{,}930.83\ GWh}$
For all scenario	$U_i \leq X_i$	
For all scenario	$\boldsymbol{0.32\left(\sum_{i=1}^{10} AE_i X_i + \sum_{i=12}^{13} AE_i X_i\right) \geq AE_{11} X_{11}}$	
For all scenario	$\boldsymbol{0.026149\left(\sum_{i=1}^{11} AE_i X_i + AE_{13} X_{13}\right) \geq AE_{12} X_{12}}$	
For scenario 2	$0.23\left(\sum_{i=1}^{13} AE_i X_i\right) \leq \sum AE_{RE} X_{RE}$	$\boldsymbol{0.31\left(\sum_{i=1}^{13} AE_i X_i\right) \leq \sum AE_{RE} X_{RE}}$
For scenario 2 & 3	$\boldsymbol{32.19X_5 \leq 14.75X_1 + 0.15X_8 + 0.09X_9 + 0.50X_{10}}$	
For scenario 2 & 3	$14.75X_1 \leq 0.15X_8 + 0.09X_9 + 0.50X_{10}$	
For scenario 2 & 3	$0.15X_8 - 0.09X_9 \leq 0.50X_{10}$	
For scenario 2 & 3	$X_2 = 127$ $X_6 \leq 6338$ $X_8 \geq 42650$ $X_9 \geq 20000$ $X_9 \leq 40000$ $X_{10} \leq 6000$ $X_{13} \geq 6\ (scenario\ 3\ only)$	$X_2 = 0$ $X_1 \geq 678$ $X_6 \leq 8590$ $X_8 \geq 85000$ $X_9 \geq 40000$ $X_{10} \leq 9000$ $X_{13} \geq 133\ (scenario\ 3\ only)$

Where X_i represents number of unit for power plant variable i, O_i represents Operation Cost per unit of variable i, A_i represents Assets Cost per unit of variable i, U_i represents current number of unit installed for variable i, AE_i represents the average electricity generated per unit of variable i, $_{RE}$ represents variable i = 1, 5, 8, 9,10 or the one which is categorized as Renewable Energy. All of the constraints above are coming from the forecasted data of electricity demand in both 2030 and 2050, *PLN Statistik 2019, Pasal 33 UUD 1945*, Government Regulation No. 79 of 2014 on National Energy Policy, RUPTL 2018 – 2027, and official website of *Kementerian ESDM*.

5. Results and Discussion

From the calculation conducted via Lingo app Ver. 18, it is found that the scenario with the least cost that are also able to reduce the amount of carbon emission is from both Scenario 2 of 2030 and Scenario 2 of 2050. *Figure 6* below represents the significant level of investment depending on what scenario of energy mixture would take. The calculation of total carbon emission per year based on capacity installed is based on study conducted by the International Energy Agency (2020) that 27 GW capacity of Coal Power would nearly emit 200 Million Ton of CO_2 Equivalent ($MtCO_2e$). With the current plant to deactivate 1 GW of coal power capacity by 2030, scenario 2 would have the least cost and will reduce the carbon emission rate by 15.82%, nearly 27.57 $MtCO_2e$, of current carbon emission rate per year. On the other hand, the plan to deactivate 24 GW of Coal Power by 2045 makes the scenario 2 of 2050 has nearly 0 carbon emission as coal power is utterly deactivated, whilst the electricity generation will be supported by geothermal power with the capacity of 28.3 GW, nearly 99.3% of total potential of geothermal power in Indonesia. The total cost needed, including operational cost and asset cost for building new power plant, for both 2030 and 2050 will be Rp1,372.96 trillion and Rp2,902.32 trillion respectively. In addition, the SWOT Matrix analysis as shown in *Table 17* is conducted with additional readings conducted by the author with the discussion in both conference and webinar attended.

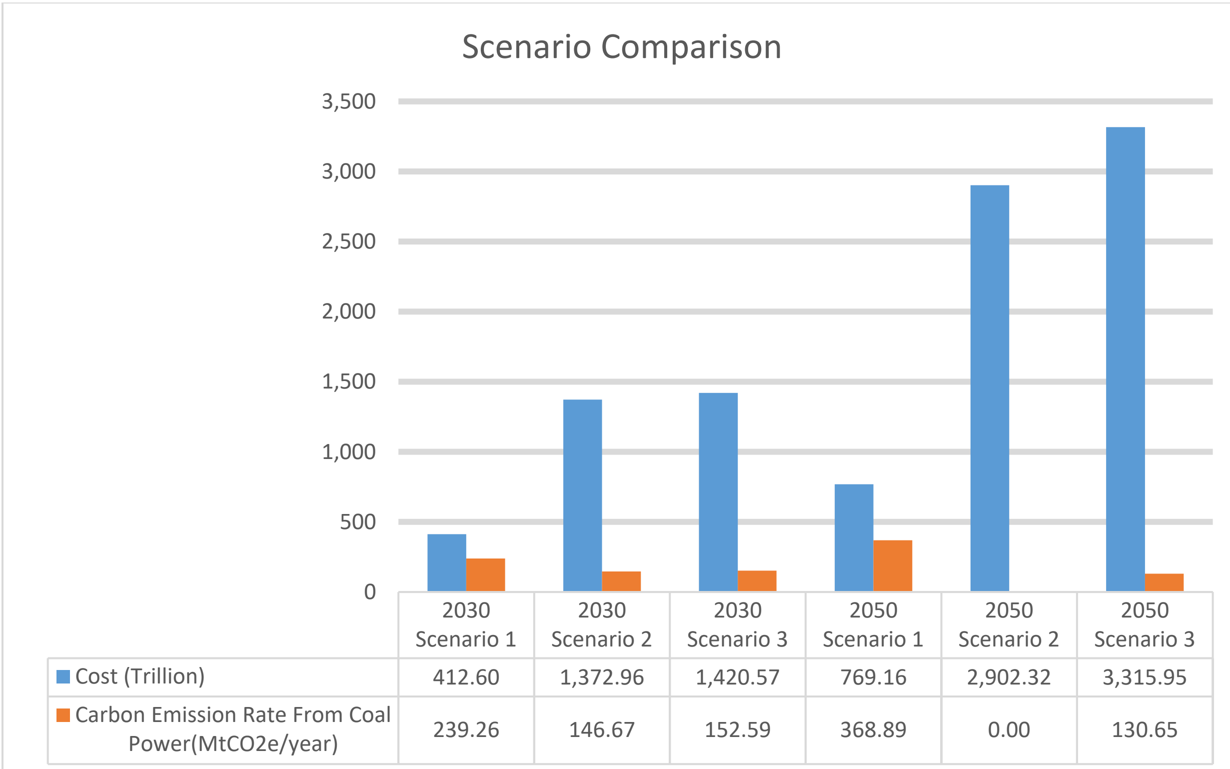

Figure 6. Scenario Comparison Chart

6. Conclusion

In sustainable development scenario (Paris Agreement), the target is to limit the temperature increase to 2°C from pre-industrial era, or even further to 1.5°C. Thus, any action or scenario that allows decarbonization would be prioritized to fight the climate change. Indonesia has a big potential of Renewable Energy power, which is supported with its strategic location that is located in both equator and ring of fire, making Indonesia become one of the country with biggest potential in geothermal power and solar power. However, according to *PLN Statistik Indonesia 2019*, Indonesia still have high reliance on coal because of its reliability and cost efficiency for supporting electricity generation sector in Indonesia. In fact, based on statistic, coal reserve in Indonesia could last for around 243 years with the current consumption rate of 400-500 million ton per year (Worldometer, 2016). Regardless, the awareness to global environmental issue, such as climate change, should be increased. Even if it costs more to provide sufficient electricity to the demand, it is better rather than keep accumulating damage to the environment. Thus, preventing stranded coal power asset by advancing the development of cleaner energy is advised as calculated above.

That being said, for both 2030 and 2050, scenario 2 is the optimized scenario with expected investment around Rp1,372.96 trillion and Rp2,902.32 trillion respectively. With the chosen scenario, the electricity demand in respective year will be fulfilled with cleaner energy, leading to lesser amount of carbon emitted to the atmosphere per year. However, for 2050, even though scenario 2 will cost lesser than scenario 3, this option is still debatable depends on the priority that might occur later. In scenario 2 of 2050, the old coal power are replaced with Renewable Energy. Study found that renewable energy will cost extra space compared to coal power. Thus, if Indonesia is lack of space in 2050, then installing CCUS as explained in scenario 3 of 2050 would be preferable. With a great amount of attention and investment from the government, the development of technology in both cleaner energy and CCUS will led to a better efficiency and more competitive market price.

Table 17. The SWOT Matrix Analysis

	Strengths	**Weaknesses**
	1. Balanced source of potential energy sources; 2. Highly populated country;	1. High reliance to coal power; 2. Archipelago;
Opportunities	**S-O strategies:**	**W-O strategies:**
1. Tidal power plant as new type of RE; 2. Introducing pump hydro as electricity storing technology; 3. Electric Vehicle (EV); 4. RE tariff become more competitive to coal; 5. Development of coal derived product; 6. Moving the nation's capital city from Jakarta to Borneo;	1. Construct a dedicated team to focus in RE development in Indonesia; 2. Learn from other countries that has specialty of a certain source (like Brazil with its hydro power capacity of 114 GW); 3. EV will have more time to dominate car population in Indonesia. Hence, we have more time to prepare cleaner energy for it; 4. Start planning ahead in balancing energy mix; 5. Construct the infrastructure as soon as possible with opening job opportunity to people under unemployment;	1. Reorganize RUEN with lesser coal fired power plant projects to avoid it to become stranded assets later; 2. Add more variety and capacity of RE including tidal power for hard-to-reach island and pump hydro to store the electricity; 3. Thoroughly plan the development of coal derived product as a way to help region with high reliance on coal production economically; 4. Planning the transition from coal power to cleaner energy as soon as it could before EV totally dominate car population in Indonesia so that less emission from power plant will take place;
Threats	**S-T strategies:**	**W-T strategies:**
1. Domination of IPP; 2. Economic depreciation; 3. Electricity needed for new capital city in Borneo;	1. Strengthen PLN in dominating electricity sector by increasing its security through governmental regulation and increasing its working quality; 2. Open more job opportunities to RE installation projects in vulnerable places (East Borneo and other coal producing region) and set the new capital city to be a pioneer of green city; 3. Utilizing unused coal mining sector as a place to either install solar power or planting palm tree for biofuel;	1. Reduce the reliance to coal piece by piece and start opening work opportunities in re project to avoid economic depreciation; 2. Arrange IPP to help distributing electricity to the remote island instead of making business in highly populated islands; 3. Preventing the explosiveness of new coal fired power plant projects to support development of infrastructure of the new capital city of Indonesia;

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Jeanne Svensky Ligte is the Head of Smart Production and Supply Chain Lab and Industrial Engineering Lecturer at Sampoerna University. Ligte holds a Bachelor of Engineering in Industrial Engineering from the University of Hasanuddin. She got her Master of Engineering in Logistics and Supply Chain Management from Universitat Autònoma de Barcelona and Riga Technical University, with specialization in Logistics System Engineering and Implementation from Technische Hochschule Wildau. She is a Certified Supply Chain Association and The Fresh Connection Game Academic Instructor. Her research interests including sustainable supply chain and interdisciplinary research related to Goal 12 of UN SDGs. Ligte recently got admitted in pursuing her PhD degree under Marie-Skłodowska Curie Actions Fellowship for European Union's Horizon 2020 "SAPIENS Network" Project, a collaborative research with Lodz University of Technology in Poland.