A study on carbon cap and trade effect to cost of electricity in accordance with the Merit Order of 300-400 MW coal power plants

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Abstract. Electricity is the basis of national development in a country. Power plants in Indonesia produces up to 283.8 TWh and are dominated by coal power plants which increase the amount of the greenhouse gases (GHG). In order to prevent more environmental problems, Indonesia ratified Paris Agreement by publishing the roadmap of Nationally Determined Contribution (NDC) that committed in reducing 29% of GHG emissions in 2030, which 11% of them are from the energy sector contributions. This research focuses on the implementation of the carbon cap and trade (CAT) between coal power plants having 300-400 MW capacity, which can affect their cost of electricity (Rp/kWh). It is well known that cap and trade (CAT) is a method used for reducing the mitigation cost of emission reduction in an effective way. From this research, it is found that the highest rise of incremental cost belongs to the 300 MW power plant in scenario 9 and the increase is from Rp.431.00/kWh to Rp.462.77/kWh, or approximately 7.37%. This research also shows that the most optimal carbon price is in the range of Rp.130,165 to Rp.130,183 because the rank of the 330 MW and 400 MW power plant in merit order changes over in this condition. In the future, this research can be used as a comparison with the higher coal power plant capacity, so that an alternative way is obtained to determine the more optimal merit order.

Keywords: Greenhouse gases, Cap and Trade, Nationally Determined Contribution, Indonesia

Track Name: Human, Social, Economic and Environmental Sustainability

1. Introduction
Under Paris Agreement in 2015, Indonesia was committed in reducing greenhouse gas (GHG) emissions by publishing NDC (Nationally Determined Contribution) and pledged to reduce the emissions by 29% against the business as usual (BAU) baseline on its own effort, which 11% of them are from energy sector, and by 41% against the BAU baseline with international support, so that Indonesia could keep the average global temperature increase under 2 °C above pre-industrial level and limit the temperature growth to 1.5 °C [1]. The Electricity Supply Business Plan (RUPTL) 2019-2028 stated that in 2019 coal power plants produced 83% GHG emissions among all power plants in Indonesia in terms of mixed energy projected [2]. In 2018, based on the usage of primary energy in the
power system of all over Indonesia, coal power plants dominated the system by about 60% [2]. The National Electricity Master Plan (RUKN) 2019-2038 targeted the use of coal in primary energy mix by approximately 55% in 2025 and by approximately 47% in 2038 [3]. In accordance with the Paris Agreement, Indonesia could make a policy about some methods to accelerate GHG emission reduction. Some of those methods are carbon tax and carbon emission trading. Carbon tax is a form of carbon pricing by putting tax on companies emitting carbon dioxide [4]. Carbon emission trading is also a form of carbon pricing where the government sets a carbon cap for all over the country to limit the carbon dioxide produced by companies. Companies emitting carbon dioxide under the cap can sell the allowance to the companies producing carbon dioxide over the cap [4]. Carbon emission trading prices will fluctuate based on supply and demand schemes.

Studies about emission trading in Indonesia are very rare. Ragimun has stated that Indonesia would face some challenges if it implemented carbon trading system, such as the lack of suitable system to calculate emission reduction, the absence of required carbon credit policy, no regulation tying the voluntary system, and the requisite of the big number of participants [5]. Besides, previous research is also taken from other countries. In India Surender Kumar et al. implied that if its government constituted a cap and trade system, it would obtain economic gain with the provision of banks with over a 5 year period of study [6]. Linda Meleo et al. presented Italian aviation case study where direct costs from EU-ETS could only slightly impact companies’ revenues, airfares, and social costs [7]. E. Delarue et al. simulated that the cap and trade policy in EU without renewable energy generation (RES) policy could increase CO2 price and raise the quantity of emissions from the electric power sector unless there were any external factors (such as economic recession) [8].

Compared with previous studies, this paper will detail the initiation of carbon trading in Indonesia’s energy sectors by analysing the changes in cost of electricity because of carbon price variations in cap and trade simulations among 25 coal power plants which produce 300 to 400 MW of electricity in Jamali power system.

This paper is organized as follows, section 2 presents briefly about Jamali (Java Madura Bali Island) power system, cost of electricity, merit or der and cap & trade mechanism. Section 3 shows the methodology used for estimating cost of electricity variations based on the cap and trade scheme. Section 4 provides analysis and results of this research. Section 5 is the summary of this paper.

2. Study Literature

2.1. Jamali (Java Madura Bali Island) Power System
Jamali power system contains electric power generation, transmission, and distribution systems that are interconnected over Java, Madura, and Bali Island. It is the biggest power system built in Indonesia. Many types of power plants supply electricity into the power system, but the coal power plants dominate the system.

2.2. Cost of electricity
Based on the regulation of Ministry of Energy and Mineral Resources, electric power purchase consists of 2 main components named component A and C. Component A is the investment cost of power plant capacity which is depreciated for 20 years or more, meanwhile component C is the fuel cost of primary energy used in the power generation [2]. Calculating the primary energy needed on a thermal power plant can be done using heat rate value, as shown in equation (1) and (2). So, component C has a relationship to the heat rate of a power plant.

2.3. Merit Order
Merit order is a ranking system of all available power plants from the lowest value of marginal generation cost to the highest value of it. Because marginal generation cost relates to heat rate value [8], merit order also has a relationship to the fuel cost of a power plant (component C).
2.4. Cap and Trade Mechanism

In general, carbon cap is a carbon emission value which is set by the government to be followed by all entities which produce emissions. The gap between the emissions produced and the cap could be traded by those entities. If an entity emits more carbon dioxide than the cap, it has a carbon dioxide deficit and must buy carbon allowances to fulfil its deficit from the one which has a carbon dioxide surplus. The carbon price goes based on carbon supply and demand. Cap and trade mechanism concerns about allowance allocation and pricing. Allowance allocation could be done by grandfathering or benchmarking schemes. On the other hand, its pricing could be made by an auction system [9].

3. Methodology

This section explains sequences of the methodology used in this research. At first, describing quantitative methods is done by literary reviews from some references, such as articles/journals, books and policies that are still applicable. The next sequence is about classifying data needed which will be processed with numerical computation based on scenarios used in this research.

Technical data used in this research are power plant capacities, primary energy types used by power plants, carbon dioxide equivalent emitted by power plants that generate 300 MW to 400 MW electricity in Jamali power system. Cap and trade implementation in several countries will also be used as descriptive data of this research. In this research, the cap will be varied into 3 values and the fluctuation of carbon prices are going to be simulated also into 3 values. So, there will be 9 scenarios where each cap value will be simulated with every value of determined carbon price.

After collecting all data, numerical computation is done by putting GHG emission components, which is carbon dioxide in this case, into the cost of electricity of power plants. The calculation focuses on the coal power plants that produce 300 MW to 400 MW electricity for Jamali power system. Adding carbon cost directly to cost of electricity could affect the merit order of Jamali power system.

3.1. Jamali Power Generation System

Reference [10] provides data of 25 units of 300 MW to 400 MW coal power plants in 2019. Based on their capacity, the data are classified to 300 MW, 315 MW, 330 MW and 400 MW coal power plants as shown in Table 1.

| Capacity (MW) | Gross Power Generated (MWh) | Nett Power Generated (MWh) |
|---------------|----------------------------|---------------------------|
| 300           | 7,428,025.83                | 7,026,816.80              |
| 315           | 14,900,110.29               | 14,127,474.42             |
| 330           | 7,013,188.80                | 6,503,017.61              |
| 350           | 12,067,305.53               | 11,429,056.58             |
| 400           | 17,551,572.56               | 16,421,882.29             |

Source: Data processed from the Directorate General of Electricity ESDM [10]

Heat rate tests are done by each coal power plants to measure the heat energy input of the fuel used for generating 1 kWh electricity. Table 2 shows the data taken from [11], the heat rate tests of 400 MW coal power plants based on ASME PTC PM-2010, “Performance Monitoring Guidelines for Power Plants.”
Table 2. Data of Heat Rate Tests of 400 MW Coal Power Plants.

| Load (MW) | Heat Rate (kCal/kWh) | Operation Cost (Rp/h) |
|-----------|----------------------|-----------------------|
| 239,260   | 2795                 | 99,598,338            |
| 280,996   | 2760                 | 115,507,292           |
| 325,748   | 2731                 | 132,496,266           |
| 372,360   | 2669                 | 148,017,061           |

Source: Reprocessed data of PT PJB, 2019 [11]

Figure 1. (a) Characteristic Curve of 400 MW Coal Power Plants. (b) Incremental Cost of 400 MW Coal-Fired Power Plants.

This research uses an assumption that the coal price is Rp. 700/kg and coal heating value is 4700 kCal/kg. Those data can be processed into component C (fuel cost) used as the main variable of merit order. That cost can be formulated as follows:

\[
Component \ C = E \times \frac{NPHR}{HHV} \times FP
\]  

\[
Fuel \ Cost = \frac{NPHR}{HHV} \times FP
\]

Where E is the energy produced by a power plant, NPHR means Net Plant Heat Rate (kCal/kWh), HHV is High Heating Value (kCal/kg), FP is Fuel Price (Rp/kg) and Fuel Cost means cost of electricity made of the used fuel (Rp/kWh).

3.2. Merit Order of The Power Plants

Merit order is a method of processing technical data and economy in order to rank power plants based on their efficiency from the most efficient one. Variables that could affect merit order are fuel cost, heat rate and fuel heating value. The relation of those variables can be simplified in equation (2). From equation (1) and (2), merit order can be determined, as shown in Table 3.

3.3. Power Plant Emission Data

Based on the regulation of the Ministry of Environment and Forestry [12], power plants must report their emissions using CEMS (Continuous Emission Monitoring System) technology or using flue gas measurement through their chimney every 6 months.
Table 3. Merit Order Based on Power Plants’ Capacities.

| Capacity (MW) | Cost of Electricity (Rp/ kWh) | Merit Order |
|---------------|------------------------------|-------------|
| 300           | 431                          | 5           |
| 315           | 431                          | 4           |
| 330           | 373                          | 2           |
| 350           | 395                          | 3           |
| 400           | 365                          | 1           |

The report needs to be sent to the Directorate General of Electricity ESDM as Formula Tier-3 Method 4 [13]. In addition to the previous equations, GHG emission calculation, in accordance with [13] that referred to [14], can be obtained by using the equation of Tier-3 Method 3 of coal fuel as follows:

$$E_{CO2} = F_{BB} \times \left[C_{ar} - (A_{ar} \times C_{ub})\right] \times 44/12$$  \hspace{1cm} (3)

Where $E_{CO2}$ is total CO2 emission (ton CO2), $F_{BB}$ is fuel consumption in a year period (ton), $C_{ar}$ is carbon content as received (%), $A_{ar}$ refers to ash content as received (%) and $C_{ub}$ refers to unburned carbon content (%).

From the secondary data provided by Directorate General of Electricity ESDM [10] and data processed by manual calculation using equation (3), data of carbon dioxide emission equivalent can be made as shown in Table 4. Those data are from Jamali power system in 2019. Emission intensity is a ratio of emissions produced by power plants to the gross energy generated by them [15]. From table 4, it can be calculated that the average of 300 MW to 400 MW coal power plant emission intensity is approximately 0.98 tCO2e/MWh.

Table 4. Emission Data of the 300-400 MW Power Plants.

| Capacity (MW) | Emission (ton CO2) | Gross Emission Intensity (tCO2e/MWh) |
|---------------|--------------------|--------------------------------------|
| 300           | 7,471,938.05       | 1.01                                 |
| 315           | 14,669,553.48      | 0.98                                 |
| 330           | 6,430,040.28       | 0.92                                 |
| 350           | 11,995,667.67      | 0.99                                 |
| 400           | 17,154,557.85      | 0.98                                 |

Source: Data processed from Directorate General of Electricity ESDM [10]

3.4. Carbon Pricing

This research calculates the cost of electricity in a cap and trade system that are varied as follows:

Table 5. Various Scenarios of Cap and Trade of the 300-400 MW Power Plants.

| Scenario | Cap (tCO2e/MWh) | Price (Rp/tCO2e) |
|----------|-----------------|------------------|
| 1,2,3    | 0.98            | 50,000; 150,000; 300,000 |
| 4,5,6    | 0.95            | 50,000; 150,000; 300,000 |
| 7,8,9    | 0.90            | 50,000; 150,000; 300,000 |
3.5. Merit Order Calculation after Cap and Trade Implementation

Reference [8] implied that in order to minimize power plant emissions, emissions must be regulated into an optimal dispatch, which is alternating the high emission power plants to the lower emission power plants. In calculating merit order, power plants will be ranked by their marginal cost MC (Rp/kWh), as illustrated in equation (4), meanwhile the additional cost of electricity from carbon price can be seen in equation (5). Where $\Delta A$ is the increase/decrease of the cost of electricity (%), $F_C$ means fuel cost (Rp), $E_C$ means power plant emission intensity (tCO2e/kWh), $A_C$ refers to Allowance Cost (Rp/tCO2e), and $A$ refers to the baseline of power plant’s electricity price.

$$MC = \frac{F_C}{\eta} + \frac{E_C}{\eta} A_C$$  \hspace{1cm} (4)

$$\Delta A = \frac{A_C \times E_C}{A} \times 100\%$$ \hspace{1cm} (5)

4. Analysis and Result
Based on table 5, scenario 1 – 9 have their own cap value and carbon price. Each power plant will have an obligation to buy carbon deficit if it produces emission intensity above the cap or it will have a privilege to sell its carbon surplus if it produces less emission intensity than the cap. Therefore, the buying and selling schemes will affect the power plants’ cost of electricity and their merit order.

4.1. Scenario 1
In scenario 1, table 6 shows that the 300 MW power plant has the biggest deficit of carbon dioxide, which is 199,936.22 million tons of CO2e. That power plant is obliged to pay Rp 50,000./tCO2e for buying the carbon allowances. Therefore, its cost of electricity will be added by 1.35 Rp/kWh, which initial cost is Rp. 431.00/kWh and its final cost becomes Rp.432.35/kWh. Power plant that gets the biggest surplus is the 330 MW power plant, which surplus is 435,838.08 million tons of CO2e, and had a chance to sell the surplus. The revenue from selling its carbon dioxide surplus is able to reduce its cost of electricity by Rp.3.11/kWh where its initial cost of electricity is Rp.373.35/kWh and its final cost becomes Rp.369.89/kWh. The merit order will be the 400 MW, 330 MW, 350 MW, 315 MW and 300 MW power plant, respectively from the least cost of electricity.

### Table 6. Cap of 0.98 tCO2/MWh and Carbon Price of Rp. 50,000/tCO2e Scenario.

| Capacity (MW) | Surplus/Deficit (TCO2e) | Selling/Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|-------------------------|-----------------------------|-------------|
| 300           | -199,936.22             | -1.35                   | 432.35                      | 5           |
| 315           | -82,416.62              | -0.28                   | 431.28                      | 4           |
| 330           | 435,838.08              | 3.11                    | 369.89                      | 2           |
| 350           | -181,833.15             | -0.75                   | 395.75                      | 3           |
| 400           | 28,347.91               | 0.08                    | 365.04                      | 1           |

4.2. Scenario 2
In scenario 2, as shown in Table 7, there are no carbon dioxide surplus and deficit differences, but there is a change in the carbon price. The power plant with 300 MW capacity has the largest carbon dioxide deficit, which is 199,936.22 million tons of CO2e. That power plant is obliged to pay Rp. 150,000./tCO2e for buying and fulfilling its carbon deficit. That obligation makes the power plant
add its cost of electricity by 4.04 Rp/kWh where its initial cost is Rp. 431.00/kWh and its final cost becomes Rp.435.04/kWh. Power plant that has the largest surplus is the 330 MW power plant, which is 435,838.08 million tons of CO2e, and it has the chance to sell its carbon surplus in order to reduce its cost of electricity. The decrease is Rp.9.32/kWh where its initial cost of electricity is Rp.373.00/kWh and its final cost is Rp.363.68/kWh. The merit order has changed. The previous most economical power plant, the 400 MW power plant, is replaced by the 330 MW power plant. The merit order becomes the 330 MW, 400 MW, 350 MW, 315 MW and 300 MW power plant, respectively.

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/ Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|-------------------------|------------------------------|-------------|
| 300           | -199,936.22             | -4.04                   | 435.04                       | 5           |
| 315           | -82,416.62              | -0.83                   | 431.83                       | 4           |
| 330           | 435,838.08              | 9.32                    | 363.68                       | 1           |
| 350           | -181,833.15             | -2.26                   | 397.26                       | 3           |
| 400           | 28,347.91               | 0.24                    | 364.88                       | 2           |

4.3. Scenario 3
In scenario 3, as shown in Table 8, there are no carbon dioxide surplus and deficit differences, but there is a change in the carbon price. The power plant with 300 MW capacity gets the largest carbon dioxide deficit, which is 199,936.22 million tons of CO2e. That power plant must pay Rp. 300,000./tCO2e for buying and fulfilling its carbon deficit. That obligation makes the power plant add its cost of electricity by 8.07 Rp/kWh where its initial cost is Rp. 431.-/kWh and its final cost becomes Rp. 439.07/kWh. Power plant that has the largest surplus is the 330 MW power plant, which amount is 435,838.08 million tons of CO2e, and it has the chance to sell its carbon surplus to reduce its cost of electricity. The reduction is Rp. 18.64/kWh where its initial cost of electricity is Rp.373.00/kWh and its final cost is Rp. 354.36/kWh. The merit order has changed. The initial most economical power plant, the 400 MW power plant, is still replaced by the 330 MW power plant. The merit order becomes the 330 MW, 400 MW, 350 MW, 315 MW and 300 MW power plant, respectively.

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/ Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|-------------------------|------------------------------|-------------|
| 300           | -199,936.22             | -8.07                   | 439.07                       | 5           |
| 315           | -82,416.62              | -1.66                   | 432.66                       | 4           |
| 330           | 435,838.08              | 18.64                   | 354.36                       | 1           |
| 350           | -181,833.15             | -4.52                   | 399.52                       | 3           |
| 400           | 28,347.91               | 0.48                    | 364.64                       | 2           |

4.4. Scenario 4
In scenario 4, table 9 shows that the 350 MW power plant has the biggest deficit of carbon dioxide, which is 531,727.42 million tons of CO2e. That power plant is obliged to pay Rp 50,000./tCO2e for buying the carbon allowances. Therefore, its cost of electricity will be added by 1.73 Rp/kWh, which initial cost is Rp. 395.00/kWh and its final cost becomes Rp.397.20/kWh. Although it has the biggest
amount of carbon deficit, the highest increase of cost of electricity occurs in the 300 MW power plant, which gets Rp.2.80/kWh increase. It happens because electric energy generated by the 300 MW power plant is significantly lower than the 315 MW power plant. Power plant that gets the biggest surplus is the 330 MW power plant, which produces 232,489.08 million tons of CO2e, and it is the only power plant that gets the chance to sell the surplus. The revenue from selling its carbon dioxide surplus can reduce its cost of electricity by Rp.1.66/kWh where its initial cost of electricity is Rp.373.97/kWh and its final cost becomes Rp.371.34/kWh. The merit order will be the 400 MW, 330 MW, 350 MW, 315 MW and 300 MW power plant, respectively from the least cost of electricity.

**Table 9. Cap of 0.95 tCO2/MWh and Carbon Price of Rp.50,000/tCO2e Scenario**

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/Buying Cost Of Electricity (Rp/kWh) | Merit Order |
|--------------|---------------------------|---------------------------------------------|-------------|
| 300          | -415,313.51               | -2.80                                       | 433.80      | 5 |
| 315          | -514,448.70               | -1.73                                       | 432.73      | 4 |
| 330          | 232,489.08                | 1.66                                        | 371.34      | 2 |
| 350          | -531,727.42               | -2.20                                       | 397.20      | 3 |
| 400          | -480,563.92               | -1.37                                       | 366.49      | 1 |

4.5. **Scenario 5**

In scenario 5, as shown in Table 10, there are no carbon dioxide surplus and deficit differences from scenario 4, but there is a change in the carbon price. Power plant with 350 MW capacity has the largest carbon dioxide deficit, which is 531,727.42 million tons of CO2e. That power plant is obliged to pay Rp. 150,000./tCO2e for buying and fulfilling its carbon deficit. That obligation makes the power plant add its cost of electricity by 6.61 Rp/kWh where its initial cost is Rp. 395.68/kWh and its final cost becomes Rp.401.61/kWh. However, the highest increase of carbon price every kWh belongs to the 300 MW power plant because the amount of energy produced is lower than the 315 MW, 350 MW and 400 MW power plants. The only power plant that has the carbon dioxide surplus, which is the 330 MW power plant and has 232,489.08 million tons of CO2e surplus, gets the chance to sell its surplus. The sales of its surplus can decrease the cost of electricity by Rp.4.97/kWh where its initial cost of electricity is Rp.373.97/kWh and its final cost becomes Rp.368.03/kWh. Therefore, the merit order has changed. The previous most economical power plant, the 400 MW power plant, is replaced by the 330 MW power plant. The merit order becomes the 330 MW, 400 MW, 350 MW, 315 MW and 300 MW power plant, respectively.

**Table 10. Cap of 0.95 tCO2/MWh and Carbon Price of Rp.150,000/tCO2e Scenario.**

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/Buying Cost Of Electricity (Rp/kWh) | Merit Order |
|--------------|---------------------------|---------------------------------------------|-------------|
| 300          | -415,313.51               | -8.39                                       | 439.39      | 5 |
| 315          | -514,448.70               | -5.18                                       | 436.18      | 4 |
| 330          | 232,489.08                | 4.97                                        | 368.03      | 1 |
| 350          | -531,727.42               | -6.61                                       | 401.61      | 3 |
| 400          | -480,563.92               | -4.11                                       | 369.23      | 2 |
4.6. Scenario 6

In scenario 6, as shown in Table 11, there are no carbon dioxide surplus and deficit differences from scenario 4 and 5, but there is a change in the carbon price. Power plant with 350 MW capacity had the largest carbon dioxide deficit, which is 531,727.42 million tons of CO2e. That power plant has to pay Rp. 300,000.00/tCO2e for buying and fulfilling its carbon deficit. That obligation makes the power plant add its cost of electricity by 13.22 Rp/kWh where its initial cost is Rp. 395.00/kWh and its final cost becomes Rp.408.22/kWh. However, the highest increase of carbon price every kWh becomes Rp.9.95/kWh. Therefore, the merit order is the 330 MW, 400 MW, 350 MW, 315 MW and 300 MW power plant, respectively.

### Table 11. Cap of 0.95 tCO2/MWh and Carbon Price of Rp.300,000/tCO2e Scenario.

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/ Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|--------------------------|-----------------------------|-------------|
| 300           | -415,313.51             | -16.77                   | 447.77                      | 5           |
| 315           | -514,448.70             | -10.36                   | 441.36                      | 4           |
| 330           | 232,489.08              | 9.95                     | 363.05                      | 1           |
| 350           | -531,727.42             | -13.22                   | 408.22                      | 3           |
| 400           | -480,563.92             | -8.21                    | 373.33                      | 2           |

4.7. Scenario 7

In scenario 7, table 12 shows that the 400 MW power plant had the biggest deficit of carbon dioxide, which was -1,358,142.55 million tons of CO2e. That power plant must pay Rp 50,000/tCO2e for fulfilling its carbon deficit. Therefore, its cost of electricity will be added by 3.87 Rp/kWh, which initial cost is Rp. 365.00/kWh and its final cost becomes Rp.369.99/kWh. Although it has the biggest amount of carbon deficit, the highest increase of the cost of electricity occurs in the 300 MW power plant. It happens because electric energy generated by the 300 MW power plant is the lowest among all power plants. There is no surplus in this scenario, but the 330 MW power plant has the least deficit, which is 118,170.36 million tons of CO2e. The merit order becomes the 400 MW, 330 MW, 350 MW, 315 MW and 300 MW power plant, respectively from the least cost of electricity.

### Table 12. Cap of 0.90 tCO2/MWh and Carbon Price of Rp.50,000/tCO2e.

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/ Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|--------------------------|-----------------------------|-------------|
| 300           | -786,714.80             | -5.30                    | 436.30                      | 5           |
| 315           | -1,259,454.22           | -4.23                    | 435.23                      | 4           |
| 330           | -118,170.36             | -0.84                    | 373.84                      | 2           |
| 350           | -1,135,092.69           | -4.70                    | 399.70                      | 3           |
| 400           | -1,358,142.55           | -3.87                    | 368.99                      | 1           |
4.8. Scenario 8
In scenario 8, as shown in Table 13, the 400 MW power plant has the largest carbon dioxide deficit, which amount is 1,358,14.55 million tons of CO2e. However, the highest increase of carbon price every kWh belongs to the 300 MW power plant because it produces the least energy. There is no power plant that has the carbon dioxide surplus, but the 330 MW power plant makes the least carbon dioxide deficit, which is 118,170.36 million tons of CO2e. Therefore, the merit order is the 330 MW, 400 MW, 350 MW, 315 MW and 300 MW power plant, respectively.

Table 13. Cap of 0.90 tCO2/MWh and carbon price of Rp.150,000/tCO2e scenario.

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/ Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|--------------------------|-----------------------------|-------------|
| 300           | -786,714.80             | -15.89                   | 446.89                      | 5           |
| 315           | -1,259,454.22           | -12.68                   | 443.68                      | 4           |
| 330           | -118,170.36             | -2.53                    | 375.53                      | 1           |
| 350           | -1,135,092.69           | -14.11                   | 409.11                      | 3           |
| 400           | -1,358,142.55           | -11.61                   | 376.73                      | 2           |

4.9. Scenario 9
In scenario 9, as shown in Table 14, the 400 MW power plant has the largest amount of carbon dioxide deficit, which is 1,358,142.55 million tons of CO2e. However, the highest increase of carbon price every kWh belongs to the 300 MW power plant because it produces the least energy. There is no power plant that has the carbon dioxide surplus, but the 330 MW power plant has the least carbon dioxide deficit, which amount is 118,170.36 million tons of CO2e. Therefore, the merit order becomes the 330 MW, 400 MW, 350 MW, 315 MW and 300 MW power plant, respectively.

Table 14. Cap of 0.90 tCO2/MWh and carbon price of Rp.300,000/tCO2e scenario.

| Capacity (MW) | Surplus/Deficit (tCO2e) | Selling/ Buying (Rp/kWh) | Cost Of Electricity (Rp/kWh) | Merit Order |
|---------------|-------------------------|--------------------------|-----------------------------|-------------|
| 300           | -786,714.80             | -31.77                   | 462.77                      | 5           |
| 315           | -1,259,454.22           | -25.36                   | 456.36                      | 4           |
| 330           | -118,170.36             | -5.05                    | 378.05                      | 1           |
| 350           | -1,135,092.69           | -28.22                   | 423.22                      | 3           |
| 400           | -1,358,142.55           | -23.21                   | 388.33                      | 2           |

4.10. Analysis of the increases and decreases in cost of electricity based on power plants’ capacities
Figure 2(a) shows that the amount of emission produced by every power plant will affect its cost of electricity, Figure 2(b) and 2(c) also illustrates the same things. Only in scenario 7, 8 and 9 shown in Figure 2(c), all power plants rise their cost of electricity because the cap is under their actual emission intensity. The changes of the power plant merit order between 330 MW and 400 MW power plant happen at the intersection of their line in Figure 2(a), 2(b) and 2(c).
Figure 2. (a) Chart of the relationship between the carbon prices and the cost of electricity in scenario 1, 2 and 3. (b) Chart of the relationship between the carbon prices and the cost of electricity in scenario 4, 5 and 6. (c) Chart of the relationship between the carbon prices and the cost of electricity in scenario 7, 8 and 9.

Figure 3 gives a clear illustration about increase/decrease percentages of the power plants’ cost of electricity. Only in Figure 3 (c), all power plants increase their cost of electricity. As explained before, the amount of increase/decrease percentage is affected by the cap/permitted emission limit and how many rupiahs the carbon price is.

Figure 3. (a) Chart of the increase/decrease percentages of the power plants’ cost of electricity in scenario 1, 2 and 3. (b) Chart of the increase/decrease percentages of the power plants’ cost of electricity in scenario 4, 5 and 6. (c) Chart of the increase/decrease percentages of the power plants’ cost of electricity in scenario 7, 8 and 9.

5. Conclusion

In this research, it can be concluded that power plants which has actual emission intensity above the cap will increase their cost of electricity, as happened for the 300 MW, 315 MW, and 350 MW power plant. The highest increase of the cost of electricity occurs in scenario 9, where the cap is 0.90
tCO2/MWh and the carbon price is Rp.300,000. That cost belongs to the 330 MW power plant which initial cost is Rp.431.00/kWh and rises into Rp.462.77/kWh or grows by 7.37%. On the other hand, the deepest decrease of the cost of electricity happens in scenario 3, where the cap is 0.98 tCO2/MWh and the carbon price is Rp.300,000. That cost reduction belongs to the 330 MW power plant which initial cost is Rp.373.00/kWh and becomes Rp.35.76/kWh or drops by 5.00%.

The most optimal alteration of merit order occurs when the carbon price is in the range of Rp.130,165 to Rp.130,183 where the power plant merit order changes in this range. The 400 MW power plant which earlier was in the first position of the merit order is replaced by the 330 MW power plant which is the most economical power plant.

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