Collaboration of Power Suppliers in East Kalimantan using Single Echelon Economic Dispatch

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Keywords: Transportation Problem, Economic Dispatch, Optimization, Electricity, Collaboration.

Abstract: The Transportation Model, which has been widely applied in the allocation and distribution of goods, has not been able to be used for the allocation and distribution of electricity. This is because there are differences between the electrical properties and the properties of the goods. The first difference is that electricity cannot be saved; this difference causes excess production to be wasted. The second difference is that electricity must always be available at all times. Power plant scheduling usually uses economic dispatch, but this model has not considered optimization in transmission and distribution networks. Therefore, this research proposes a new model called the Single Echelon Economic Dispatch (SEED). This model is a combination of the transportation model and the economic dispatch model. This model is able to do a joint optimization between the production and transmission/distribution sides. The SEED model is used to develop a collaboration strategy between electricity suppliers in East Kalimantan. Simulation results with cost parameters: The best collaboration when the load is low is PLN + IPP, while at the peak load, the best collaboration is the Joint of all electricity suppliers.

1 INTRODUCTION

East Kalimantan has four electricity suppliers, namely PLN, IPP, Leasing, and Excess Capacity. Each supplier has a different power plant characteristic. These characteristics cause differences in fuel costs and emissions (Mahdi et al., 2018; Muslimin et al., 2019).

The level of fuel consumption is directly proportional to the level of production, where more electricity production, the more fuel is used. While fuel costs and production levels are not directly proportional but rather form a quadratic equation (Bhattacharjee and Khan, 2018; Wahyuda et al., 2018; Gani et al., 2019). The relationship between variables in the fuel cost function is what causes the optimization of fuel costs at the power plant to be optimized.

The level of production is influenced by the amount of demand and the number of losses in the transmission network. Losses are directly proportional to distance, where the longer the distance, the greater the losses that occur in the transmission network. Determination of the level of production is usually done by economic dispatch 2017; Zhou et al., 2017). However, the economic dispatch model has not considered optimization on the transmission side. Transmission side optimization is used to reduce total production costs caused by the long distance from the plant to the customer.

Therefore, this study proposes Single Echelon Economic Dispatch, which is a model that is able to do a combined optimization between the production and transmission sides. The output of this model can be used to determine the collaboration strategy between electricity suppliers in East Kalimantan so that a lower cost is obtained.

2 LITERATURE REVIEW

2.1. Single Echelon Transportation Model

The transportation model is first discussed in (Hitchcock, 1941). In the article, a commodity can be sent from various sources to various destinations. This can be seen through the following picture:

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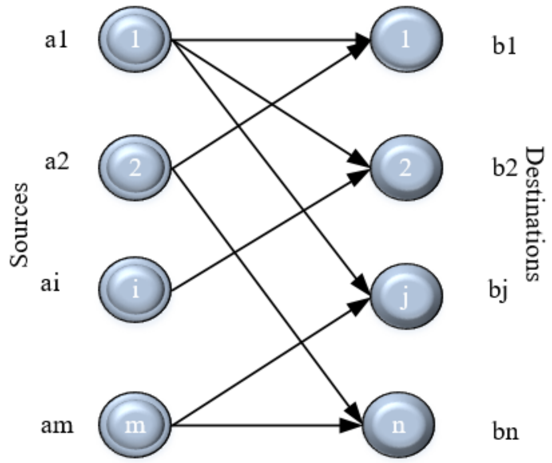

Figure 2.1. The basic concept of the transportation model is m source n destination.

Figure 2.1 provides an illustration of how the transportation model works. In general, the transportation model divides the problem into two groups, namely the source group and the destination group. The source can consist of one or several members, as well as Destination. The transportation model used to calculate transmission costs can be seen in (Pablo et al., 2009) illustrated in (Daskin, 1995) as follows:

$$Minimize \quad \sum_i \sum_j C_{ij} X_{ij} \tag{2.1}$$

Constraints

$$\sum_j X_{ij} \leq S_i \quad \forall i \tag{2.2}$$

$$\sum_i X_{ij} \geq D_j \quad \forall j \tag{2.3}$$

$$X_{ij} \geq 0 \quad \forall i,j \tag{2.4}$$

Where;

S_i= Supply capacity at source i

D_j = Demand at point j.

C_{ij} = Shipping costs from source i to destination j.

X_{ij}= Number of items sent from source i to destination j.

The main difference between transportation for goods and transportation for electricity is the balance between supply and demand. In the transportation model for goods, suppliers are allowed to send goods greater than demand, but in transportation for electricity, suppliers must send goods as big as demand or called equilibrium. This equilibrium point is called the Balanced Transportation Problem (BTP) (Sabbagh et al., 2015). The difference between the two also occurs in the limits of supplier capacity. The boundary for transporting goods is simpler than the economic dispatch limit.

Model BTP-1:	Model BTP-2:	Model BTP-3:
$Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} \cdot x_{ij}$	$Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} \cdot x_{ij}$	$Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} \cdot x_{ij}$
Subject to	Subject to	Subject to
$\sum_{j=1}^{n} x_{ij} \geq s_i, (i = 1 \dots m)$	$\sum_{j=1}^{n} x_{ij} \leq s_i, (i = 1 \dots m)$	$\sum_{j=1}^{n} x_{ij} = s_i, (i = 1 \dots m)$
$\sum_{i=1}^{m} x_{ij} \leq d_j, (j = 1 \dots n)$	$\sum_{i=1}^{m} x_{ij} \geq d_j, (j = 1 \dots n)$	$\sum_{i=1}^{m} x_{ij} = d_j, (j = 1 \dots n)$
$x_{ij} \geq 0$	$x_{ij} \geq 0$	$x_{ij} \geq 0$

Figure 2.2. Three variations of the Balanced Transportation Problem (BTP)

Where;

c_{ij} : shipping costs from source i to destination j

x_{ij} : the number of items sent from source i to destination j

s_i : the maximum amount of supply of resources i

d_j : demand at destination j.

2.2. Model of Economic Dispatch

Economic dispatch was introduced since 1928. There are 3 researchers who are considered as the originator of the economic principle of the generator (Estrada, 1930; Stahl, 1931; Wilstam, 1928). The initial economic dispatch is called the classic Economic dispatch model. This model uses the concept of the baseload method and the best point load method. How it works, sort generator units based on the highest efficiency level. Furthermore, generator scheduling is given to the generating unit with the highest level of efficiency, and so on until the last generating unit.

When there are differences in the characteristics of each plant, the baseload technique becomes less effective. Therefore, a new technique emerged known as equal incremental cost. The main concern of this technique is the characteristics of each different generator. The way it works, the meeting point of all generators is searched, and the optimal allocation is made based on this meeting point. This equal incremental cost technique is still used today. This technique was introduced by (Steinberg & Smith, 1933). The advantage of this technique is that it can provide a low total cost for all the plants involved in the system. However, this initial model still has shortcomings, namely the losses in the transmission network have not been considered. One of the causes of losses in transmission networks is the length of the transmission network. The longer the transmission distance, the greater the losses will occur. These losses will ultimately affect the total cost of fuel because the plant must produce more electricity than the demand for compensation losses. Furthermore, Economic dispatch that considers losses in the network is introduced by (George et al., 1949). The Economic Dispatch formula is as follows:

$$F_i = a_i P_i^2 + b_i P_i + c_i \qquad 2.5$$

$$P_{i\,min} \le P_i \le P_{i\,max} \qquad 2.6$$

$$P_i = D_i + \text{Losses} \qquad 2.7$$

3 PROPOSED MODEL

Transportation Model has advantages in the field of distribution. The use of this model causes the total shipping costs to be minimal. While the Economic Dispatch model has an advantage in the field of generator loading allocation or generator scheduling. The use of economic dispatch models is able to create a power plant scheduling that results in minimal fuel costs. Combining the advantages of these two models provides several advantages. First, the development of a new transportation model called the Single Echelon Economic Dispatch (SEED). Second, the combined optimization between the generator side and the distribution side. Conceptually, the development of the SEED model can be seen in the following figure:

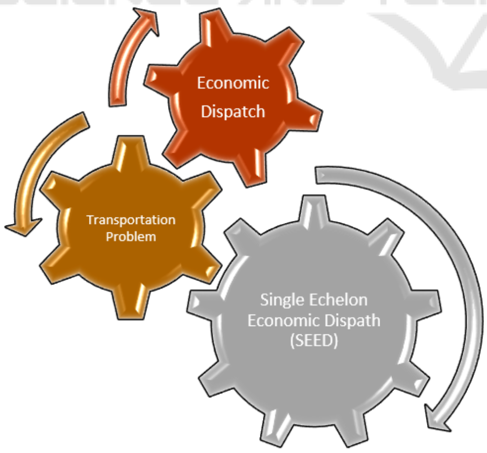

Figure 3.1. Conceptual Model for Single Echelon Economic Dispatch (SEED) development

Figure 3.1.a conceptually illustrates that the SEED model is formed from two models, namely the transportation model and the economic dispatch model. Figure 3.1.b. is a conceptual model of the transportation model. While Figure 3.1.c is an economic dispatch conceptual model. In the same way, both models are used for resource allocation. While the difference is in the object faced, where transportation is commonly used in people or goods while ED is used in electricity. The nature of the two objects is different. The main requirement for electricity is in the form of an equation between the supply side and the demand side. Therefore, another approach used is the Balanced Transportation Problem, as shown in Figure 2.2

Three types of BTP, as shown in Figure 2.2, are variations of the transportation model application for real cases. The three variations have the same objective function, namely minimization of costs (min z). While the difference between the three is the model limitation. Cost is the sum of the shipping costs per unit from each source i to destination j denoted by multiplied by the number of items sent from source i to destination j denoted by x_{ij}.

The characteristics of the three variations of BTP are used as a reference for the development of the SEED model. Development is carried out by combining several boundaries so that new variations of BTP emerge. Furthermore, a merger with the Economic Dispatch model was obtained to obtain the SEED model. The result of merging BTP with economic dispatch as in figure 3.2

***Single Echelon Transportation Problem* (Modification BTP)**

$$Min\ z = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} . x_{ij}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} \ge s_{imin}, (i = 1 \dots m)$$

$$\sum_{j=1}^{n} x_{ij} \le s_{imax}, (i = 1 \dots m)$$

$$\sum_{i=1}^{m} x_{ij} = d_j, (i = 1 \dots n)$$

$$x_{ij} \ge 0$$

\+

***Economic Dispatch* (Equations 2.1 – 2.3)**

$$F_i = a_i P_i^2 + b_i P_i + c_i$$

$$P_{i\,min} \le P_i \le P_{i\,max}$$

$$P_i = D_i$$

Proposed Model (*Single Echelon Economic Dispatch*, SEED)

$$Minimize\ Fi = \sum_{i=1}^{I}\sum_{j=1}^{J} a_i P_{ij}^2 + b_i P_{ij} + c_i$$

$$\sum_j P_{ij} \ge P_{i\,min}$$

$$\sum_j P_{ij} \le P_{i\,max}$$

$$\sum_i P_{ij} = L_j + P_{Lij}\ (j = 1 \dots J)$$

$$P_{ij} \ge 0$$

Figure 3.2 Schematic of SEED formation

The SEED model has the objective function of minimizing fuel costs as well as in the economic dispatch model. While the difference between them lies in the coverage of the model. This can be seen from the notation used. The basic model of economic dispatch uses notation P_i which means the amount of electricity produced at the generator i. Whereas the SEED model uses notation P_{ij} which means the amount of electricity produced by the generator i sent to destination j. If this scope is included in the objective function, then this model is prepared to be able to complete two tasks, namely production optimization tasks, and simultaneous distribution optimization tasks. As a guarantee of a feasible solution, the SEED model is also equipped with three constraints.

4 RESULT AND ANALYSIS

4.1 Experiments

Experiments were carried out on five electricity supplier cooperation scenarios. Scenario 1 only uses PLN's power plants. Scenario 2 uses PLN's and IPP's power plants. Scenario 3 uses PLN's power plants and Leases. Scenario 4 uses PLN's power plant and Excess Capacity. Scenario 5 uses PLN's power plants, IPP, Leases, and Excess Capacity

4.1.1 Scenario 1

In this scenario, there are 11 PLN-owned power plants that can be used to supply electricity demand. This scenario has a supply of 346.6 MW. Demand at low load is 194.9 MW while at peak load is 343.4 MW

Table 4.1. SEED Model Simulation Results for scenario 1

Power Plant	Low		Peak	
	Supply (MW)	Util. (%)	Supply (MW)	Util. (%)
P1	23.5	100.0	23.5	100.0
P2	16.0	100.0	16.0	100.0
P3	3.1	100.0	3.1	100.0
P4	3.6	100.0	3.6	100.0
P5	7.8	100.0	7.8	100.0
P6	14.2	100.0	14.2	100.0
P7	56.8	87.5	65.0	100.0
P8	10.0	100.0	10.0	100.0
P9	2.4	100.0	2.4	100.0
P10	1.0	100.0	1.0	100.0
P11	56.8	28.4	199.2	99.6
Total	195.2		345.8	

Based on table 4.1, there is a difference between supply and demand. At low load, there is a difference of 0.4 MW while at peak load, there is a difference of 2.4 MW. At low load, there are two power plants whose production capacity is not used fully, namely P7 and P11. Whereas during peak loads, only the P11 power plant does not have the entire production capacity used.

4.1.2 Scenario 2

In scenario 2, there are 11 PLN-owned power plants and 2 IPP plants that can be used to supply electricity demand. This scenario has a supply of 523.6 MW. Demand at low load is 194.9 MW while at peak load is 343.4 MW.

Table 4.2. SEED Model Simulation Results for scenario 2

Power Plant	Low		Peak	
	Supply (MW)	Utiliz. (%)	Supply (MW)	Utiliz. (%)
P1	19.4	82.7	23.5	100.0
P2	16.0	100.0	16.0	100.0
P3	3.1	100.0	3.1	100.0
P4	3.6	100.0	3.6	100.0
P5	7.8	100.0	7.8	100.0
P6	14.2	100.0	14.2	100.0
P7	19.4	29.9	42.7	65.8
P8	8.5	85.1	10.0	100.0
P9	2.4	100.0	2.4	100.0
P10	1.0	100.0	1.0	100.0
P11	20.0	10.0	42.7	21.4
P24	20.7	25.2	82.0	100.0
P25	58.9	62.0	95.0	100.0

Based on table 4.2, there is a difference between supply and demand. At low load, there is a difference of 0.2 MW while at high load, there is a difference of 0.6 MW. At low loads, there are six power plants whose production capacity is not used at all. Whereas during peak loads, there are two power plants whose production capacity is not fully utilized.

4.1.3 Scenario 3

In scenario 3, there are 11 PLN-owned power plants and five rental plants that can be used to supply electricity demand. This scenario has a supply of 419.1 MW. Demand at low load is 194.9 MW while at peak load is 343.4 MW

Table 4.3. SEED Model Simulation Results for scenario 3

Power Plant	Low		Peak	
	Supply (MW)	Utiliz. (%)	Supply (MW)	Utiliz. (%)
P1	23.5	100.0	23.5	100.0
P2	16.0	100.0	16.0	100.0
P3	3.1	100.0	3.1	100.0
P4	3.6	100.0	3.6	100.0
P5	7.8	100.0	7.8	100.0
P6	14.2	100.0	14.2	100.0
P7	28.9	44.5	65.0	100.0
P8	10.0	100.0	10.0	100.0
P9	2.4	100.0	2.4	100.0
P10	1.0	100.0	1.0	100.0
P11	28.9	14.5	125.1	62.5
P12	12.0	55.8	21.5	100.0
P13	32.5	81.3	40.0	100.0
P14	2.7	100.0	2.7	100.0
P15	5.7	100.0	5.7	100.0
P16	2.6	100.0	2.6	100.0

Based on table 4.3, there is a difference between the amount of supply and demand. At low load, there is a difference of 0.1 MW while at peak load, there is a difference of 0.8 MW. At low loads, there are four power plants whose production capacity is not used at all. Whereas during peak loads there is only one power plant whose production capacity is not fully utilized

4.1.4 Scenario 4

In scenario 4, there are 11 PLN-owned power plants and 5 Excess Capacity plants that can be used to supply electricity demand. This scenario has a supply of 391.4 MW. Demand at low load is 194.9 MW while at peak load is 343.4 MW

Table 4.4. SEED Model Simulation Results for scenario 4

Power Plant	Low		Peak	
	Supply (MW)	Utiliz. (%)	Supply (MW)	Utiliz. (%)
P1	23.5	100.0	23.5	100.0
P2	16.0	100.0	16.0	100.0
P3	3.1	100.0	3.1	100.0
P4	3.6	100.0	3.6	100.0
P5	7.8	100.0	7.8	100.0
P6	14.2	100.0	14.2	100.0
P7	34.3	52.8	65.0	100.0
P8	10.0	100.0	10.0	100.0
P9	2.4	100.0	2.4	100.0
P10	1.0	100.0	1.0	100.0
P11	34.3	17.1	136.2	68.1
P17	6.8	100.0	6.8	100.0
P19	5.0	100.0	5.0	100.0
P20	22.0	100.0	22.0	100.0
P22	6.0	100.0	6.0	100.0
P23	5.0	100.0	5.0	100.0

Based on table 4.4, there is a difference between the amount of supply and demand. At low load, there is a difference of 0.13 MW while at peak load, there is a difference of 1.04 MW. At low loads, there are two power plants whose production capacity is not all used. Whereas during peak loads, there is only one power plant whose production capacity is not fully utilized.

4.1.5 Scenario 5

In scenario 5, there are 11 PLN power plants, 2 IPP plants, five rental plants, and 5 Excess Capacity plants, which can be used to supply electricity demand. This scenario has a supply of 391.4 MW. Demand at low load is 194.9 MW while at peak load is 343.4 MW

Table 4.5. SEED Model Simulation Results for scenario 5

Power Plant	Low		Peak	
	Supply (MW)	Utiliz. (%)	Supply (MW)	Utiliz. (%)
P1	14.0	59.6	19.5	82.9
P2	16.0	100.0	16.0	100.0
P3	3.1	100.0	3.1	100.0

P4	2.0	55.6	3.6	100.0
P5	7.8	100.0	7.8	100.0
P6	8.3	58.2	14.2	100.0
P7	8.3	12.7	19.5	30.0
P8	7.0	70.0	8.5	85.5
P9	2.4	100.0	2.4	100.0
P10	1.0	100.0	1.0	100.0
P11	20.0	10.0	20.0	10.0
P12	12.0	55.8	12.0	55.8
P13	32.5	81.3	32.5	81.3
P14	2.7	100.0	2.7	100.0
P15	2.3	40.9	5.7	100.0
P16	2.6	100.0	2.6	100.0
P17	1.0	14.7	6.8	100.0
P19	0.0	0.0	5.0	100.0
P20	10.0	45.5	22.0	100.0
P22	1.0	16.7	6.0	100.0
P23	1.0	20.0	5.0	100.0
P24	20.0	24.4	32.8	40.0
P25	20.0	21.1	95.0	100.0

Based on table 4.5, there is a difference between the amount of supply and demand. At low load, there is a difference of 0.1 MW while at peak load, there is a difference of 0.26 MW. At low loads, there are 60% power plants whose production capacity is not used at all. Whereas during peak loads there are only 30% power plants whose production capacity is not fully utilized

4.2 Analysis

The SEED model succeeded in scheduling a more detailed power plant and distribution. Power plant scheduling is done using the economic dispatch model. In addition to scheduling a power plant, the SEED model also simultaneously optimizes distribution lines and losses as well as the goal of minimizing total fuel costs. The total fuel cost is influenced by the characteristics of the plant, the amount of electricity demand, and losses in the transmission/distribution network. The longer the distance that must be traveled by electricity from the generator to the customer, the greater the losses that will occur. In this case, the losses on the transmission/distribution network are affected by mileage.

Minimizing losses can be an effort to reduce total fuel costs. However, minimizing losses does not always produce the smallest total cost. This can occur due to different generator characteristics. If the electric power system has the same generator characteristics, reducing losses will automatically reduce the total fuel cost.

Based on experiments using five scenarios, it is known that: Scenario 1: If losses can be minimized, PLN's power plants are able to meet electricity demand at low load and peak load. Electricity demand during peak load is 343.4 MW, while the production capacity of all PLN-owned power plants is 346.6 MW, meaning that if losses on the entire transmission network can be reduced below 3.2 MW, the PLN-owned power plant can serve demand at the time peak load. However, if losses cannot be controlled, then the electricity demand must be supplied from other plants through a cooperation mechanism. Cooperation between generators as electricity suppliers must be calculated in detail. This is due to differences in the characteristics and location of each power plant owned by electricity suppliers. Differences in generator characteristics cause differences in total fuel costs and emissions.

Based on the simulation results for scenario 2, cooperation between PLN's power plant and IPP can supply electricity during low load and peak load. This is because the combined production capacity of PLN + IPP is greater than the total demand and losses. When the load is low, the production capacity of PLN and IPP's power plants is used in a balanced manner. During peak load, all IPP's power plant production capacity is used, while PLN's power plant production capacity is 55% used. Although the percentage of PLN's power plant capacity usage is smaller, losses and emissions generated are greater than IPP's.

In scenario 3, cooperation between PLN's power plants and rental plants can meet electricity during low and peak loads. As a percentage, the cooperation between the two prioritizes the use of rental power plants compared to PLN's power plants during peak loads, the production capacity of rental plants is used entirely

In scenarios 4 and 5, the same pattern is found. Production priority is always given to the Excess capacity generator. Even in scenario 4, both under low load and peak load conditions, the Excess Capacity generator is the main generator.

In general, it can be said that PLN's power plants are the ones with the lowest fuel costs. This can be seen in the utilization of plants, which are almost always 100%. However, the production capacity of PLN's power plants has never been used at 100%. In the case of optimization with the objective function of minimizing fuel costs, the use of production capacity reaching 100% means that the power plant becomes the main priority because it has the lowest total fuel cost compared to other plants. Such conditions are an impact of the characteristics of power plants. This characteristic difference causes P11 to be the only PLN-owned power plant, which is the last choice in the allocation of loading because this plant requires more expensive fuel costs. The use of P11 generators is possible when serving peak loads.

Based on the five scenarios above, determining the best scenario depends very much on the considerations used by the decision-maker. This is because the selection of the best scenario based on the lowest cost will increase emissions, and vice versa. Not only that, but the best scenario based on cost minimization also depends on the condition of the electricity load during low load or peak load.

When the load is low, the best scenario is scenario 2. This scenario is the allocation of PLN and IPP's power plant loading. Whereas during peak load, the best scenario is scenario 5. Scenario 5 is the allocation of loading with a combined power plant as the best parameter is the smallest cost.

Table 4.6. Comparison Between Scenarios for Peak load and low load conditions

Scenario	Low		
	Fuel Cost (Rp)	Emission (kg)	Losses (MW)
1	215,377.36	96.59	0.36
2	125,097.58	99.02	0.21
3	170,404.88	90.43	0.10
4	133,922.78	96.18	0.13
5	173,085.63	174.39	0.10
Scenario	Peak		
	Fuel Cost (Rp)	Emission (kg)	Losses (MW)
1	1,374,744.50	185.59	2.36
2	307,643.35	169.42	0.64
3	753,771.91	165.75	0.80
4	783,584.72	166.78	1.04
5	304,797.97	320.58	0.26

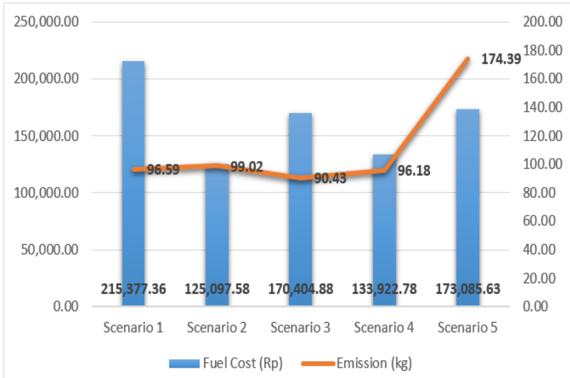

Figure 4.1: Comparison between scenarios with parameters Fuel costs and emissions under low load conditions

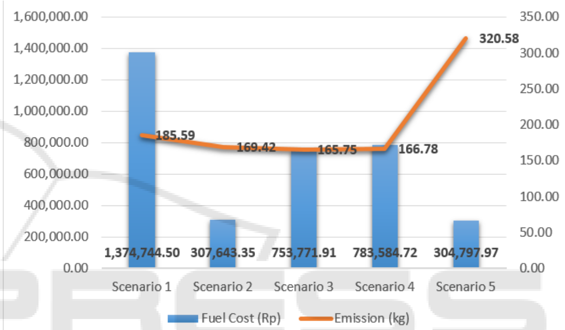

Figure 4.2: Comparison between scenarios with parameters Fuel costs and emissions under Peak Load conditions

5 CONCLUSIONS

The SEED model is a new variation of the transportation model. SEED is a combination of the transportation model with the economic dispatch model. The combination of these two models causes the transportation model can be used for the allocation of electricity production and distribution. SEED is able to optimize the combination of production and distribution. The output of the SEED model is the allocation of power plants, the distribution of electricity from a source to a destination, the distance of electricity from the plant to the customer, losses incurred by each plant and emissions

In the case of the centralization of electricity using the SEED model, the allocation of loading is divided into two conditions, namely low load and peak load. When the load is low, the best allocation of expenses from a cost perspective is a collaboration between PLN's power plant and IPP. However, this choice will have an impact on increasing emissions and losses.

The combination of these two plants generates greater emissions and losses when compared to the other three scenarios, namely scenario 1 (only using PLN's power plant), scenario 3 (combined PLN and Lease), and scenario 4 (combined PLN and EC). Whereas during peak load, the best allocation of expenses from the standpoint of costs and losses is when using scenario 5, which is a combination of all power plants belonging to all parties in the Mahakam system. However, the selection of this scenario has the worst impact on the environment because the emissions produced are highest when compared to the other four scenarios

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