Supply Chain Network Model Development for Conversion Electric Motorcycle Distribution in Central Java using the Mixed Integer Linear Programming Method

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Abstract

An increase in the number of Internal Combustion Engine (ICE) motorcycles will have an impact on increasing carbon emissions in Indonesia. One solution is to convert an ICE motorcycle into a convertible electric motorcycle. This paper will explain the supply chain costs of a convertible electric motorcycle center in terms of manufacturers by develops a mathematical model to make a decision of an electric motorcycle conversion kit manufacturer opening with the Mixed Integer Linear Programming (MILP) model. This paper also considers aspects of economic, social, and environmental sustainability as additional points of view in decision making. The results show that the model can be a decision-making tool for opening a motorcycle conversion kit manufacturer with more optimal results. The NPV value > 0 indicates that the investment that will be carried out can be projected to bring profits to the company with a return on investment of 231.33%. Then, with the reduction of carbon gas emissions by 0.98%, it is expected to improve public health and reduce mortality by 0.08% and increase life expectancy by 0.09%.

Keywords
Electric motorcycle conversion kit, Mixed Integer Linear Programming (MILP), Sustainability.

1. Introduction
According to the Potsdam Institute for Climate Impact Research, Indonesia's annual carbon emissions are 2.4 billion tons of CO2 and are the largest in Southeast Asia (Dunne 2019). The highest source of emissions comes from deforestation and peat forest fires, which is then followed by emissions from burning fossil fuels for energy. In Indonesia, the Internal Combustion Engine (ICE) of motorcycles continues to increase every year. From 2007 to 2017 it increased almost three times more. The Indonesian government is very concerned about reducing carbon emissions from the transportation sector by issuing Presidential Regulation Number 55 of 2019 concerning the Acceleration of the Battery Electric Vehicle (BEV) Program in Indonesia. The program of converting ICE motorbikes to electric motorbikes will reduce carbon emissions (Tuayharn et al. 2015). ICE motorcycles can be converted into electric motorcycle conversions by replacing the engine with several conversion parts, such as the Balance Direct Motor (BLDC), controller, Battery Management System (BMS), battery, and steel to replace the motorcycle swing arm

(Nizam 2019). Convertible electric motorcycles are a new technology for Indonesia so proper commercialization must be implemented (Sutopo et al. 2018).

This research was conducted in Central Java Province, Indonesia. Central Java which has 6 residencies and 35 cities. The center of the electric motorcycle conversion factory is located in the city of Semarang. In this case, the center has to assemble some parts of the conversion electric motorcycle into a conversion kit and sell this conversion kit to a repair shop so that the repair shop can only install that conversion kit to the ICE motorcycle. In this research, domestic suppliers are used to supply BLDC, controller, BMS, battery and steel.

This paper will explain the supply chain costs of an electric motorcycle conversion kit center in Central Java in terms of manufacturers. The main objective of this research is to develop a mathematical model to make a decision to open an electric motorcycle conversion manufacturer with Mixed Integer Linear Programming (MILP). The aim is to determine the maximum allocation capacity of the electric motorcycle conversion kit distribution system with dynamic demand. There have been several papers studied on the opening of facility locations in the supply chain. Yuniaristanto et al. (2010) chose a rattan industrial terminal, and Mathirajan et al. (2011) presents the opening of warehouse decisions on the electronics industry in India. Habibie et al. (2012) and Hisjam et al. (2013) studied the supply chain model in the furniture industry.

1.1 Objectives

The objective of this research is to determine the maximum allocation capacity of the electric motorcycle distribution system conversion kit with dynamic demand so that it will assist the company in reducing the rate of return or the occurrence of lost sales due to inventory that is not in accordance with customer demand.

2. Literature Review

In Indonesia, the Internal Combustion Engine (ICE) of motorcycles continues to increase every year. From 2007 to 2017 it increased almost three times more. The Indonesian government is very concerned about reducing carbon emissions from the transportation sector by issuing Presidential Regulation Number 55 of 2019 concerning the Acceleration of the Battery Electric Vehicle (BEV) Program in Indonesia. The program of converting ICE motorbikes to electric motorbikes will reduce carbon emissions (Tuayharn et al. 2015). Electric motorcycles are motorcycles that use electricity as a source of energy to propel vehicles (Ahmad et al. 2008). Meanwhile, a convertible electric motorcycle is a conventional oil-fueled motorcycle that is converted into an electric motorcycle by adding a conversion kit (Nizam 2019). The electric conversion kit consists of a battery, Brushless Direct Current (BLDC), controller, Battery Management System (BMS) and supporting iron for swing arm modifications on motorcycles.

Convertible electric motorcycle is a new technology in Indonesia. Currently, there is no industry or business in Indonesia that focuses on the electric motorcycle conversion business. Therefore, technology-based entrepreneurs (technopreneurs) are needed so that convertible electric motorcycles can become successful businesses and encourage government programs in reducing carbon gas emissions. A good business requires designing an efficient supply chain network (Watson et al. 2013). The supply chain network involved in the convertible electric motorcycle business are suppliers, conversion kit assembly plants, warehouses, conversion workshops, and consumers. Supply chain management according to Hugos (2003) is the coordination of production, inventory, location, and transportation among the companies involved in the supply chain. The goal of the supply chain itself is to achieve the best responsiveness and efficiency for the market being served. Supply Chain Network Design is the process of determining the network structure and determining various strategic decisions about the location and capacity of facilities to operational and tactical issues regarding transportation policies or inventory management (Farahani et al. 2013). The structure of the supply chain network has a major influence on performance and costs in the future so that the design of supply chain networks is an important concern in supply chain management. From the customer side, a good network must of course be able to provide a high response speed (short lead time) and a high level of service, namely the ability of the chain network to supply with high availability of goods (Sourirajan et al. 2009). From the supply chain side, the costs of providing services with short lead times and high service levels must be carried out efficiently. In this case, Return on Investment (ROI) is a measurement of the company's overall ability to generate profits with the total number of assets available in the company. ROI is also defined as the ability of capital invested in overall assets to generate net profits (Riyanto 2004). Meanwhile, Net Present Value (NPV) is an analytical method that takes into account the difference between the current investment value and net cash receipts in the future (Nurcahyo 2011).

According to Banks et al. (2000) models are divided into static models and dynamic models as well as deterministic models and probabilistic models. Static model is a model that represents the system at a certain time or there is no time variable so that it does not change over time. While the dynamic model is a model that can represent a system that changes over time. A deterministic model is a model whose input variables are known at the beginning or in other words there are no random variables in the input variables. While the probabilistic model is a model in which there are one or more variables that are not known at the beginning as the input model, so it must be generated with a certain probability rule. A mathematical model is a model in which the relationship between entities is expressed through the form of mathematical expressions, such as functions, equations, inequalities and others (Daellenbach et al. 2005). Linear programming uses a mathematical model to describe the problem at hand (Oktyajati 2009). The linear programming model consists of linear relationships that represent company decisions, taking into account objectives and resource constraints. While integer linear programming (ILP) is an integer linear programming model that can produce solutions with both integer and non-integer values (Bernard 2006). Based on the decision variables faced, ILP can be grouped into 2, namely Pure Integer Linear Programming (PILP) and Mixed Integer Linear Programming (MILP) (Kamal et al. 2012). PLP is used if all the decision variables used are integers. There is also a value of 0 or 1 (boolean) where the number means the decision is implemented or not. Meanwhile, MILP is used if the decision variables used are partly integers and partly fractional numbers.

The novelty of this research lies in the opening facilities, area coverage, dynamic demand, and considers three aspects of sustainability, namely economic, social, and environmental. Here is the novelty of this research (table 1).

Table 1. Previous Research

Publication	Parameters								
	Opening Facilities		Area Coverage		Demand		Sustainability		
	Without Opening Facilities	With Opening Facilities	With Coverage	Without Coverage	Static	Dynamic	Economy	Social	Environment
Yuniaristanto (2010)		v	v			v	v		
Mathirajan (2011)	v		v		v		v		
Hisjam et al. (2013)	v			v		v	v	v	v
Song et al. (2015)		v		v	v		v		
Habibie et al. (2021)		v	v		v		v	v	v
This Research		v	v			v	v	v	v

3. Methods

The research method stage carried out in this study was in the form of data collection, data processing using the Mixed Integer Linear Programming (MILP) method. Here is a flowchart of this research (Figure 1).

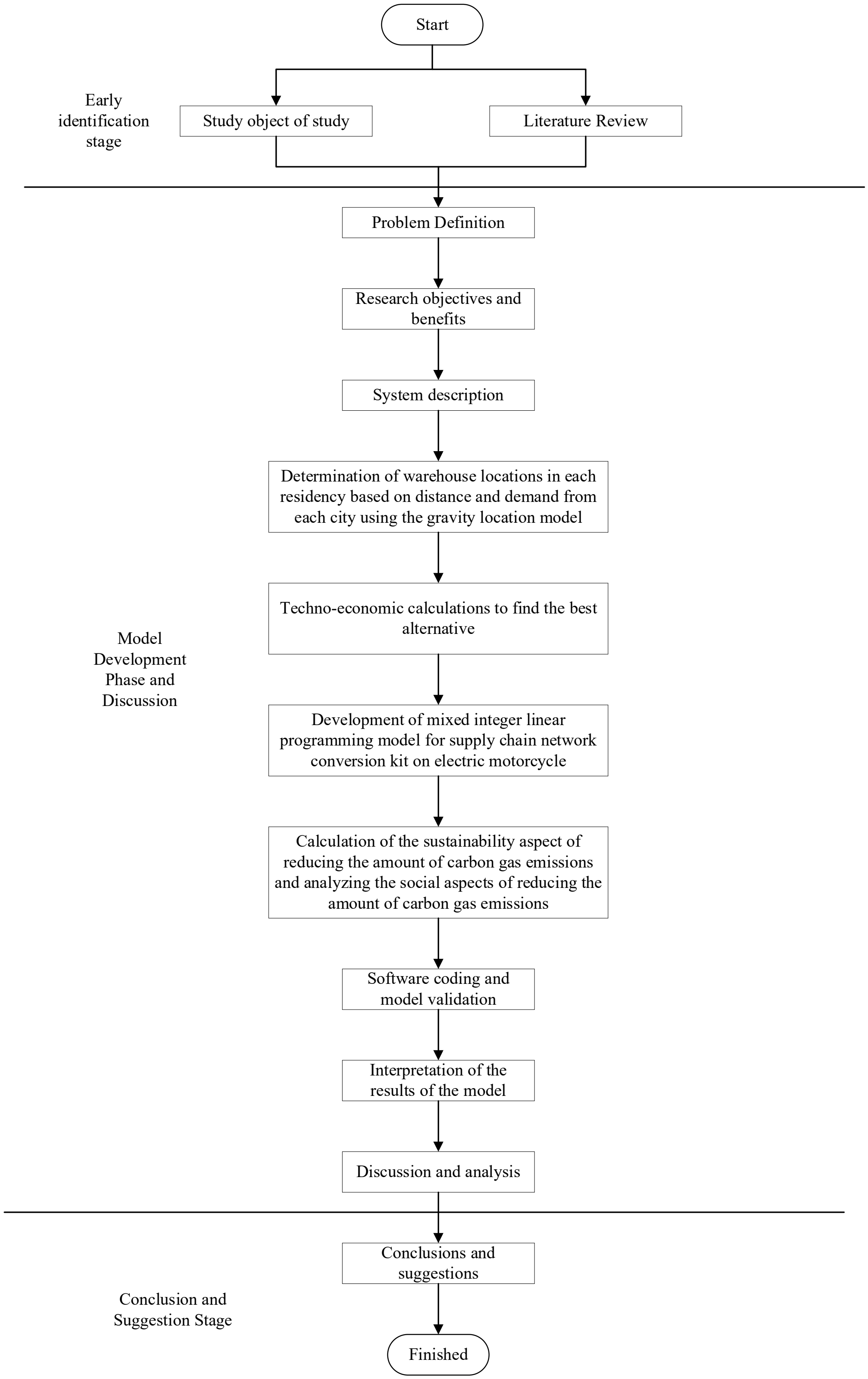

Figure 1. Research Flowchart

Here is the influence diagram of this research.

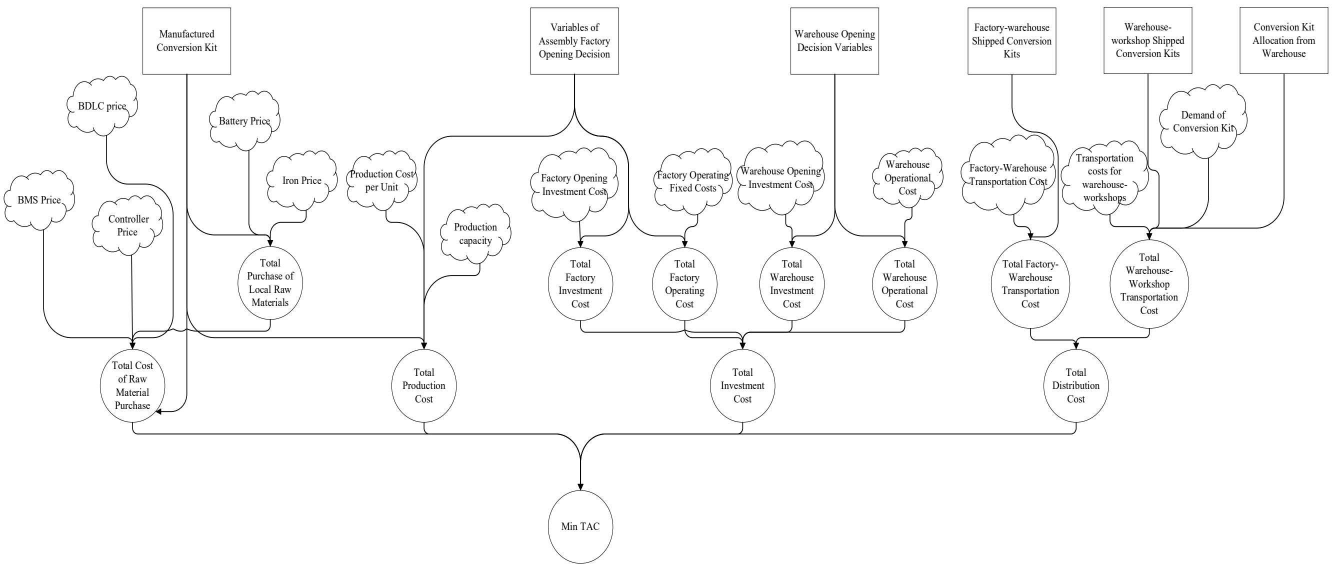

Figure 2. Influence Diagram

Based on the figure 2 above, the objective function of this paper is the maximization of the total cost in an electric motorcycle conversion kit manufacturer using MILP. The notation of parameters, decision variables, and objective functions used to formulate MILP in this model are:

Index :
i : factory index
j : warehouse index
k : workshop index
t : time index

Parameters :
CAP_{it} : factory capacity i in period t
CAP_{jt} : warehouse capacity j in period t
$TACt$: total cost in period t
IC_i : plant opening investment cost i
IC_j : warehouse opening investment costs j
FC_{it} : factory operating fixed costs i
FC_{jt} : warehouse operational fixed costs j
$PRCt$: production cost per unit conversion kit in period t
PBL : BLDC price
PC : controller price
PB : battery price
PS : iron price
Pt : maximum number of warehouses that can be opened in period t
D_{kt} : demand for workshop k in period t
TC_{ij} : transportation cost from factory to warehouse in period t
TC_{jk} : transportation cost from warehouse to workshop in period t

Decision variables :
Y_{it} : value 1 if factory i will be opened in period t and value 0 otherwise
Y_{jt} : value 1 if warehouse j will be opened in period t and value 0 otherwise
X_{jkt} : value 1 if the conversion kit for workshop k is sent from warehouse j in period t and value 0 otherwise
Q_{it} : conversion kit produced at plant I in period t
Q_{ijt} : conversion kit shipped from factory i to warehouse j in period t

Q_{jkt} : conversion kit shipped from warehouse j to workshop k in period t

Objective Function :

$$Min\,TAC = \sum_{i}^{I} (PBL + PC + PB + PS) * Q_{it}) + \sum_{i}^{I} (PRCt * Q_{it} * Y_{it}) + \sum_{i}^{I} (IC_{it} * Y_{it}) + \sum_{i}^{I} (FC_{it} * Y_{it}) + \sum_{j}^{J} (IC_{j} * Y_{jt}) + \sum_{j}^{J} (FC_{jt} * Y_{jt}) + \sum_{i}^{I} \sum_{j}^{J} (TC_{ij} * Q_{ijt}) + \sum_{j}^{J} \sum_{k}^{K} (TC_{jk} * D_{kt} * X_{jkt}) \quad (1)$$

Constraint :

$$\sum_{k}^{K} X_{jkt} = 1 \quad (2)$$

$$\sum_{j}^{J} \sum_{k}^{K} D_{kt} * X_{jkt} \leq \sum_{j}^{J} Y_{jt} * CAP_{jt} \quad (3)$$

$$\sum_{j}^{J} Y_{jt} \leq Pt \quad (4)$$

$$\sum_{j}^{J} \sum_{k}^{K} D_{kt} * X_{jkt} \leq \sum_{i}^{I} \sum_{j}^{J} Q_{ijt} \quad (5)$$

$$\sum_{i}^{I} \sum_{j}^{J} Q_{ij} \leq CAP_{i}\, t \quad (6)$$

$$\sum_{j}^{J} \sum_{k}^{K} Q_{jkt} = \sum_{i}^{I} \sum_{j}^{J} Q_{ijt} = \sum_{i}^{I} Q_{it} \quad (7)$$

$$Q_{it}, Q_{ijt}, Q_{jkt} \geq 0 \quad (8)$$

$$Y_{it}, Y_{jt}, X_{jkt} \in \{0,1\} \quad (9)$$

Objective function : (1) has units of rupiah. Constraint (2) guarantees that the conversion kit at workshop k is only delivered by one warehouse j. Constraint (3) ensures that the balance of demand for workshop k can be met by warehouse j. Limitation (4) is the maximum limit of warehouse j that can be opened. Limit (5) is the limiting demand from the workshop k. Constraint (6) ensures that the conversion kit sent from factory i to warehouse j does not exceed the capacity of factory i. Constraint (7) ensures that the balance of the conversion kits sent from warehouse j to workshop k are the same as those sent from factory i to warehouse j and the same as those produced at factory i. Constraint (8) is a non-negative constraint for the decision variable. Constraint (9) guarantees that it is a binary constraint for the decision variable.

4. Data Collection

The data collection process required in this paper, in the form of factory and warehouse investment cost data, raw material prices, total fixed costs, and total variable costs refers to the thesis reference of Habibie et al. (2020) regarding the development of a supply chain network of conversion electric motorcycle distribution systems and demand assumption data for each workshop (Table 2- table 7) using the single exponential smoothing method.

Table 2. Recap of Assumptions for Workshop Demand Data for 2022

Period (Year)	1	2	3	4	5
Quantity (pcs)	53,416	93,997	192,227	293,861	400,380

Table 3. Assumptions of Factory Production Capacity Data

Period (Year)	1	2	3	4	5
Factory Production Capacity (pcs)	50,070	100,140	200,280	300,420	400,560

Table 4. Assumption of Warehouse Storage Capacity Data

Warehouse	1	2	3	4	5	6
Cost of Storage Capacity(pcs)	42,075	52,075	62,075	72,075	82,075	92,075

Table 5. Factory and Warehouse Investment Costs

Item	Investment Costs	
Factory	IDR	520,180,000,000
Warehouse 1	IDR	8,000,000,000
Warehouse 2	IDR	7,850,000,000
Warehouse 3	IDR	7,550,000,000
Warehouse 4	IDR	8,050,000,000
Warehouse 5	IDR	10,600,000,000
Warehouse 6	IDR	7,850,000,000
Total Investment	IDR	570,080,000,000

Table 6. Conversion Kit Raw Material Prices

No	Item	Cost/Unit (IDR/Unit)		Cost/year (IDR/year)	
1	Raw material cost	IDR	11,700,000	IDR	4,686,552,000,000
2	Indirect labor cost	IDR	3,367	IDR	1,348,685,520
3	Transportation cost	IDR	29,632	IDR	11,869,393,920
Total		IDR	11,732,999	IDR	4,699,770,079,440

Table 7. Total Fixed Costs

No	Item	Cost/year (IDR/year)		Cost/Unit (IDR/Unit)
1	Depreciation	IDR	30,080,000,000	IDR 75,095
2	Capital Interest	IDR	30,008,000,000	IDR 74,915
3	Maintenance	IDR	2,850,400,000	IDR 7,116
4	Employee salary	IDR	5,707,471,980	IDR 14,249
5	Overhead	IDR	1,320,000,000	IDR 3,295
Total		IDR	69,965,871,980	IDR 174,670

5. Results and Discussion

5.1 Running Model

The mixed integer linear programming model that has been formulated is then written into the ILOG CPLEX software and uses the parameters that have been defined. Writing data using the ILOG CPLEX programming language, which begins by writing down the parameters used, decision variables, objective functions, and problem constraints used. After writing down the variables used, then input data into the software.

Table 8. Binary Decisions on Warehouse Allocation

Warehouse	Period (Year)				
	1	2	3	4	5
1	0	1	0	0	0
2	1	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0

Table 9. Allocation of conversion kits shipped from factory to warehouse

Warehouse	Period (Year)				
	1	2	3	4	5
1	0	48,755	0	0	0
2	7,920	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0

Based on the results (Table 8 and table 9) of running the model using ILOG CPLEX, it can be seen that in the first year there were 7,920 units of conversion kits allocated to warehouse 2. Meanwhile in the second year there were 48,755 units of conversion kits allocated to warehouse 1. However, in the third, fourth, and fifth year, the conversion kit allocation process did not occur due to the lack of warehouse capacity to store converter kits and the high operational costs of warehouses and factories. Therefore, it is recommended to create a warehouse with a storage capacity of more than 400,000 units so that the converter kit allocation can be maximized when there is a spike in converter kit demand.

5.2 Comparison Before and After Optimization

After optimization using the mixed integer linear programming model, here is the comparison :

Table 10. Comparison Before and After Optimization

Item	Before Optimization		After Optimization	
Investment Fee	IDR	570,080,000,000	IDR	536,030,000,000
Fixed Cost	IDR	69,965,871,980	IDR	69,063,461,240
Variable Cost	IDR	4,699,770,079,440	IDR	4,699,316,645,520
Price	IDR	15,000,000	IDR	15,000,000
ROI		217.28%		231.33%
NPV	IDR	4,124,456,744,118	IDR	4,163,645,395,380

Based on the results of cost calculations both before optimization and after optimization (table 10), it can be concluded that model optimization can reduce investment costs, fixed costs, and also variable costs with the same selling price of IDR 15,000,000. The NPV value > 0 indicates that the investment that will be carried out can be projected to bring profits to the company with a return on investment of 231.33%. However, the investment in establishing a warehouse capable of storing more than 400,000 units of converter kit needs to be considered so that the distribution of converter kit allocation for the next 5 years can be optimal.

5.2 Sustainability Aspect

The environmental sustainability aspect in this study is the reduction of carbon gas emissions from the electric motorcycle conversion program. The reduction of carbon gas emissions is expected to improve public health. This public health improvement will be measured as a social aspect in this study. Based on data from the Intergovernmental Panel on Climate Change (IPCC) in 2006 carbon gas emissions produced from conventional motorcycles and electric motorcycles are:

- Conventional motorcycles
  Carbon gas emission = 2.598 kgCO_2 / liter of gasoline
  Assumed distance = 50 km / day
  Gas = 2 liter / day
  Carbon gas emission per month = 155.88 kgCO_2
  Carbon gas emissions per year = 1,870.56 kgCO_2
- Electric motorcycle
  Carbon gas emission = 0.986 kgCO_2 / KWH
  Assumed distance = 50 km / hari
  Electricity = 2 KWH
  Carbon gas emission per month = 59.16 kgCO_2
  Carbon gas emissions per year = 709.92 kgCO_2

From the data above, it can be concluded that by changing conventional motorcycles, it can reduce carbon gas emissions by 62.05% or 1,160.64 kgCO2 per year for each motorcycle.

- Reducing the amount of carbon gas emissions in a year
  Number of converted motors = 400,560 unit
  Emissions reduction per unit = 1,160.64 kgCO_2
  Emission reduction per year = 464,905,958 kgCO_2

According to previous information, the social aspect in this research is the improvement of public health by reducing carbon gas emissions. Hailemariam and Pan (2019) say that a 10% increase in carbon gas emissions per capita can lead to a 2.2% increase in mortality and a 0.6% decrease in life expectancy.

- Indonesia's per capita emissions = 10,500 kgCO_2
  Central Java population = 36,516,035 people
  Central Java's carbon gas emissions = 25,923,463,567 kgCO_2
  Carbon gas emission reduction = 464,905,958 kgCO2 or 0.98%

With the reduction of carbon gas emissions by 0.98%, it is expected to improve public health and reduce mortality by 0.08% and increase life expectancy by 0.09%.

6. Conclusion

This research has succeeded in developing a supply chain network distribution system model for stakeholders. For manufacturers, this model can help make decisions in determining the investment in establishing an electric motorcycle conversion kit factory. For the government, this model can evaluate tax incentive policies so that they can attract investors to invest in the electric motorcycle conversion development sector. For consumers, with optimal costs from the producer side, it can reduce the selling price so that consumers get an efficient selling price but producers also still get the appropriate profit. This research succeeded in developing a mathematical model as a tool to formulate a distribution system policy for the supply chain network of convertible electric motorcycles. From the results of the mathematical model, it is obtained the decision to establish an electric motorcycle conversion kit factory, the number of conversion kits that must be produced, the number of warehouses and the location of the warehouse to be established, the number of conversion kits sent to each warehouse and each conversion workshop. In the next supply chain model development, it is necessary to develop a model that can measure the three aspects of sustainability simultaneously so that it can provide better results. In addition, it is necessary to develop a dynamic system simulation model taking into account the raw material tax and income tax to see the resilience of the electric motorcycle conversion project so that it can provide additional information on how long the conversion project can be carried out.

It is recommended in further research to create a warehouse with a storage capacity of more than 400,000 units so that the converter kit allocation can be maximized when there is a spike in converter kit demand.

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