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Sustainability Evaluation of Internal Combustion Engine Motorcycle to Electric Motorcycle Conversion

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Abstract: In the last ten years, the number of internal combustion engine (ICE) motorcycles has grown rapidly in Indonesia. It causes the increasing pollution in Indonesia and one of the solutions is with converting them to the electric motorcycle. To support this issue, Government of the Republic of Indonesia has decreed the regulation for accelerating vehicles electrification with a Presidential Regulation. The purpose of this study is to evaluate the replacement of ICE motorcycle to electric motorcycle with electric motorcycle conversion or new electric motorcycle by comparing sustainability performance of 3 alternatives considered. We used Net Present Value (NPV), and Payback Period (PP) as methods for measuring the economical aspect. The environmental aspect was measured by simulating carbon emissions of the three alternatives. The social aspect is measured by comparing the noise level, healthier body, welfare, time to maintain motorcycle of those alternatives. The results show that electric motorcycle conversion is the best alternative to replace ICE motorcycle based on sustainability considerations.

Keywords: Internal Combustion Engine Motorcycle, Electric Motorcycle, Conversion, Sustainability.

1. Introduction

The number of internal combustion engine (ICE) motorcycles in Indonesia has grown rapidly from almost 87 million units in 2015 to almost 113 million units in 2019 as shown on Fig. 1. According to this trend, the number of that motorcycle may continuously increase[1)].

The increasing number of ICE motorcycles will increase carbon emissions enormously, whereas all countries, included Indonesia, are trying to reducing gas emissions from the transportation sector[2)]. The role of governments is significant for carbon emission reduction[3)]. Government of The Republic of Indonesia issued The Presidential Regulation 61 of 2011 with the plan to reduce CO_2 emission up to 0.056 gigatons per year in 2020 from those of base year of 2010 if international support avaliable[4)]. The Government also issued Presidential Regulation Number 55 of 2019 to accelerate and push the replacement of vehicles to electric vehicles in Indonesia[5)].

One of the most pollution sources in the world is the transportation sector[6)]. One type of vehicle from this sector is ICE motorcycles. The conversion to electrical technology is one solution for reducing carbon pollution.

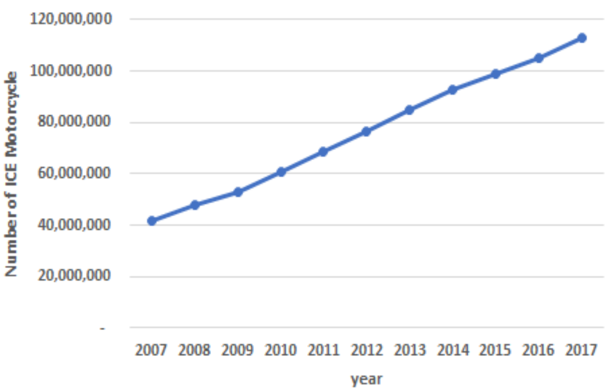

Fig. 1: Number of Motorcycles in Indonesia

This paper will explain the converting program to electric motorcycles from ICE motorcycles with sustainability consideration specifically implementation in Indonesia.

The power source of the electric motorcycle is electricity. The electricity changes the ICE motorcycle gasoline[7)]. Electric motorcycles have high energy saving and a low noise level[8)]. The application of electric vehicles will support the development of electricity establishment and also will reduce gas emissions from transportation[7].

This evaluation is from the user's perspective. It is needed to convince them to switch their ICE motorcycles to electric motorcycles. Some evaluation has been presented, such as Sutopo et al.[9] that studied about techno economic analysis of battery lithium, Fam and Lim[10] that discussed techno economic analysis of a Combined Heat and Power Unit (CHP), Mendu et al.[11] that studied techno economic analysis of integrated energy systems between stand-alone and grid-connected in India, and Mostafa and Sarhan that explained e-waste recycling facility feasibility study from economic aspect in Egypt[12]. The aim of this research is not only to look from an economic aspect but also from the social aspect and environmental aspect as called the sustainability aspect[13].

People in developed countries consider the important for considering sustainable in the decisions. Barai and Saha[14] studied in Japan about energy sustainability and security, and Sato[15] compared the sustainability society in Japan and Germany.

We found some research that implementing sustainability consideration in studying some aspects of electric motorcycle or electric vehicle. Prianjani et al.[16] considered sustainable planning for swap battery systems on an electric motorcycle. Knez[17] reviewed the important role of governments to influence the purchasing decisions of electric vehicles, and this study also confirmed the condition in Slovenia. Peters et al.[18] concluded that the motivation for adopting an EV is very important to make people engage in sustainable energy behavior consistently, and this is key to realize a sustainable energy transition. Eccarius, and Lu[19] studied consumer adoption of electric motorcycles and found that electric motorcycles can be part of a sustainable solution for reducing the impacts of ICE motorcycles by replacing them with electric motorcycles.

Previous related research mostly are for general electric vehicle and very rarely about electric motorcycles. In this paper, we propose a solution considering the condition in developing countries related to the adoption of electric motorcycle with sustainability consideration. We aim to evaluate ICE motorcycle to electric motorcycle conversion using sustainability consideration.

2. Research Method

In this research, sustainability evaluation was conducted to a case for the replacement of ICE motorcycle to an electric motorcycle in Indonesia. This study hopefully can support Government of The Republic of Indonesia to reduce the carbon emission from ICE motorcycle. This study discusses whether replacing ICE motorcycle with an electric motorcycle type gives more benefit for the user, using sustainability evaluation. Sustainable evaluation conducted is based triple bottom line, namely environmental, social, and economic dimensions[20].

There are three alternatives developed in this research. In this study we propose a case that will give an example of the replacement that hopefully can reflect the condition in developing countries. It is assumed that alternative 1 is the existing condition. Other initial conditions can be implemented as existing motorcycle and compared to the existing. All alternatives will be compared based on the economic aspect, social aspect, and environmental aspect. Table 1 shows the main characteristics of the alternatives proposed. The alternatives are:

1. Used ICE motorcycle that produced in 2014. This alternative is chosen because it is assumed that after 6 years using the motorcycle, the use assumed to consider replacing their motorcycle with a new ones or used motorcycle with better condition.
2. Selling the engine of the alternative 1 and then replacing it with electric motorcycle conversion kit.
3. Selling the existing used ICE motorcycle, as additional fund for buying a new electric motorcycle.

Proposing those 2 alternatives aims to give additional fund to help users to switch to electric motorcycles.

Table 1. Specifications of 3 motorcycles under study

Type	**Engine**	**Battery Cap.**	**Power Source**	**Prod. Year**
Alternative 1: ICE Motorcycle	150 cc	-	Gasoline	2014
Alternative 2: Electric Motorcycle Conversion	-	1,500 Wh	Electricity	2020
Alternative 3: New Electric Motorcycle	-	1,500 Wh	Electricity	2020

In this study, ICE motorcycle is replaced with an electric motorcycle. The other modes of transportation are not considered in this paper. The concept of conversion electric motorcycle is by replacing the engine of ICE motorcycle with BLDC (brushless DC) motor, controller, and battery[21]. The battery used in this research is Lithium Iron Phosphate (LFP) battery. The LFP battery is more durable than the lead-acid battery[9]. The limitations of using electric motorcycle conversion is the consumer very dependent on the battery and the charging station is not ready in Indonesia. There are no authorized workshop in Indonesia either for electric motorcycle conversion, maximum speed and maximum load are also lower than ICE motorcycle. We use some metrics of sustainability to measure the sustainability of each alternative. Each metrics considered will be discussed in the next sections.

3. Results and Discussion

3.1 Economic Aspect

Economic aspect is measured by comparing NPV, and PP. It illustrates the cash flow today equal to the cash flow in the future. Generally, NPV is a method that explains the present value from net revenue cash flow[22]. PV stands for Present Value, to mention the equivalent value of one cash flow at a reference point. In this study, we only consider initial cost of the alternative and its yearly cost. We write the formula (1) based on some formulas in Sullivan et al.[23].

$$NPV = I_0 + A(P/A,i\%,N) \qquad (1)$$

NPV : net present value

I_0 : Initial investment

A : end-of-period cash flows (or equivalent end-of-period values) in a uniform series continuing for a specified number of periods, starting at the end of the first period and continuing through the last period.

P : present sum of money; the equivalent value of one or more cash flows at a reference point in time called the present;

i% : effective interest rate per interest period;

N : number of compounding (interest) periods;

We needs PP (Payback Period) evaluation to identify how long it needs to pay back all the capital of this project. PP explain the period of an investment will breakeven[24]. The sooner PP achieved is the better. The PP investment will be compared with the set of payback time.

$$PP = initial\ investment/net\ cash\ flow \qquad (2)$$

PP : payback period

Net Cash flow : net profit or net benefit annual

Initial Investment : the first initiation of investment

We assumed interest rate during the study to be 10% and the evaluation period comparing these three alternative is eight years. The net benefit of this study is the opportunity of saving for using electric motorcycle compared to using ICE motorcycle.

The alternative 1 is keeping using ICE motorcycle. So, there is no initial investment for alternative 1. The alternative 2 converts the ICE motorcycle to electric motorcycle conversion. The initial investment of alternative 2 is the conversion cost of electric motorcycle reduced by ICE motorcycle engine sale. Hence, the initial investment of alternative 2 is -15,000,000 + 3,500,000 = -11,500,000. Alternative 3 is to replace the ICE motorcycle by purchasing the new electric motorcycle. The initial investment of Alternative 3 is -26,301,667 + 10,000,000 = -16,301,667. The costs of alternative 1, 2 and 3 are shown in Table 2. NPV of the alternative 1, 2, and 3 shown in Table 3 are negative because those value are costs.

Table 2. Costs of Alternative 1, 2 and 3

Descriptions	Alternative 1		Alternative 2		Alternative 3	
	Cash (IDR)	**Period**	**Cash (IDR)**	**Period**	**Cash (IDR)**	**Period**
Purchase of new electric motorcycle (a)	-	-	-	-	(26,301,667)*	Once
Sales of ICE motorcycle (b)	-	-	-	-	10,000,000**	Once
Conversion cost (c)	-	-	(15,000,000)***	Once	-	-
Sales of ICE engine sale (d)	-	-	3,500,000****	Once	-	-
Power source (e)	(7,092,000)	/year	(1,188,000,00)	/year	(1,188,000,00)	/year
Maintenance, Spare part & reparation (f)	(1,269,125)	/year	(1,697,500)	/year	(1,697,500)	/year
Yearly tax (g)	(300,000)	/year	(250,000)	/year	(250,000)	/year
Total cost/year	(8,661,125)	e + f + g	(3,135,500)	e + f + g	(3,135,500)	e + f + g
Net benefit/year (compared to Alternative 1)	0	/year	5,525,625	/year	5,525,625	/year

Notes:

*based on the price of one of new electric motorcycle in Indonesia

** the price assumed for used ICE motorcycle produced in 2014 in Indonesia with the condition when the study conducted

*** based on the total cost of installment of conversion kit to ICE motorcycle in Indonesia

**** the price assumed for used engine ICE motorcycle produced in 2014 in Indonesia with the condition when the study conducted

All the yearly costs were assumed to be constant during the study.

PP method can be used to calculate the period return of the investment. PP of the alternative is by dividing its initial investment with its yearly saving because of choosing the alternative. The PP of alternative 2 and alternative 3 shown below:

PP of Alternative 2 = $\frac{11,500,000}{5,525,625}$ = 2.08 years

PP of Alternative 3 = $\frac{16,301,667}{5,525,625}$ = 3 years

Based on PP results, we can see that Alternative 2 is better. It means that after 2.08 years, the user can enjoy “saving” from the replacement.

Table 3. NPV of Alternative 1, 2 and 3

Year	Alternative 1			Alternative 2			Alternative 3		
	Initial investment (IDR)	Cost/year (IDR)	PV (IDR)	Initial investment (IDR)	Cost/year (IDR)	PV (IDR)	Initial investment (IDR)	Cost/year (IDR)	PV (IDR)
0	0			(11,500,000)		(11,500,000)	(16,301,667)		(16,301,667)
1		(8,661,125)	(7,873,750)		5,525,625	5,023,295		5,525,625	5,023,295
2		(8,661,125)	(7,157,955)		5,525,625	4,566,632		5,525,625	4,566,632
3		(8,661,125)	(6,507,231)		5,525,625	4,151,484		5,525,625	4,151,484
4		(8,661,125)	(5,915,665)		5,525,625	3,774,076		5,525,625	3,774,076
5		(8,661,125)	(5,377,877)		5,525,625	3,430,978		5,525,625	3,430,978
6		(8,661,125)	(4,888,979)		5,525,625	3,119,071		5,525,625	3,119,071
7		(8,661,125)	(4,444,527)		5,525,625	2,835,519		5,525,625	2,835,519
8		(8,661,125)	(4,040,479)		5,525,625	2,577,745		5,525,625	2,577,745
	NPV		(46,206,463)	NPV		17,978,802	NPV		13,177,135

3.2 Environmental Aspect

The environmental aspect is measured by carbon emissions simulation model. To describe the behavior of the simulation, we use an influence diagram model for carbon emission produced with some conversion scenarios is shown at Fig. 2. The influence diagram is a basic model that shown the influence of an entity to other ones. To draw the influence diagram, we used tool provided by Visual Diagram[25].

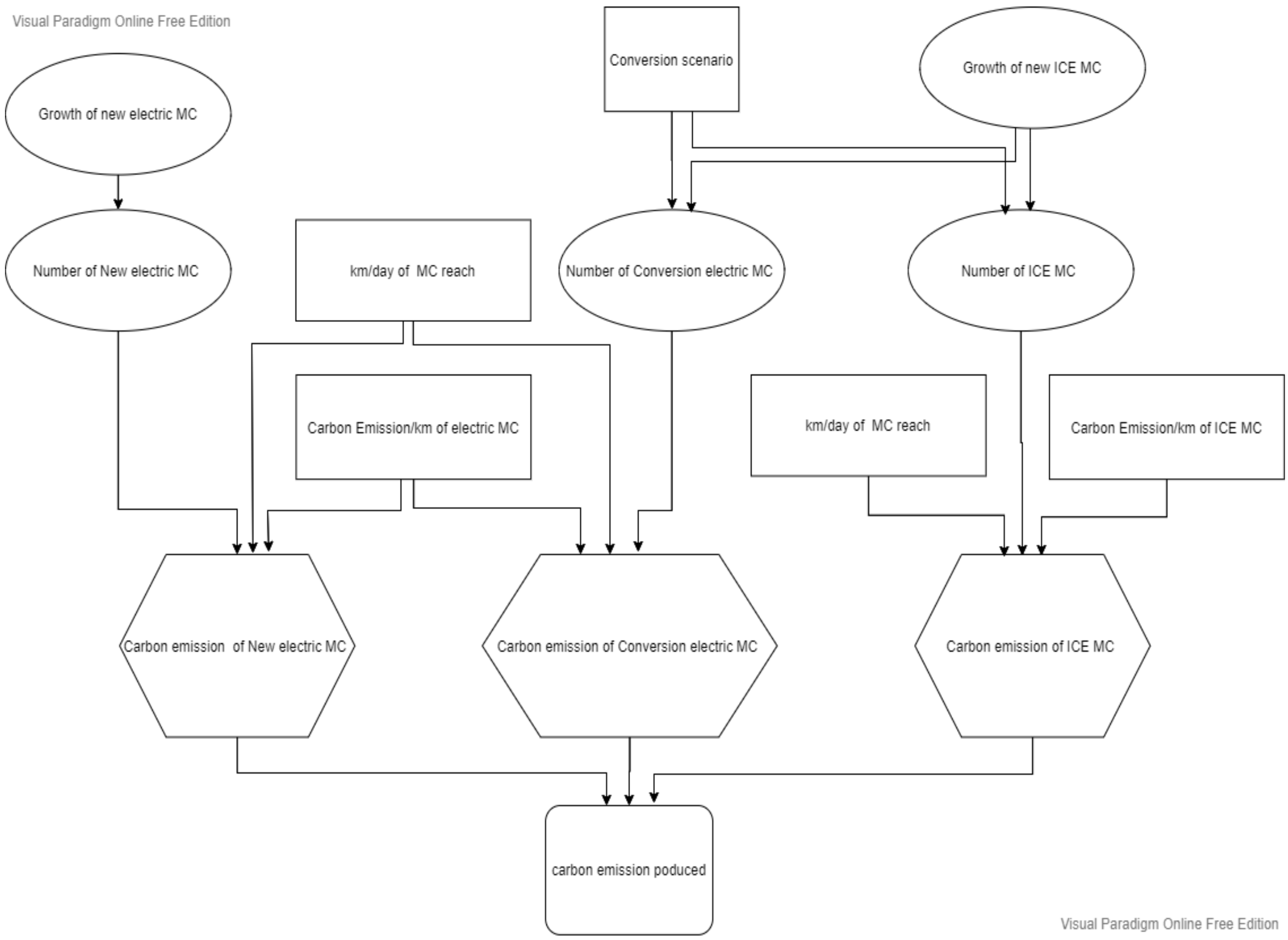

Fig. 2: Influence Diagram Model to Consider Scenarios

The simulation model can be used to evaluate and analysis the short-term and long-term policy impact. The model will be simulated on software for predictions of the model result. We run the simulation, based on that behavior. Then, we enter the values of the input parameters and changing the model structure if needed. The period of simulation in this model is from 2017 to 2026. The average increase in the number of motorcycles at Indonesia is assumed to be 10.46% per year. There are 5 scenarios that will be entered in this simulation model. The scenario for the simulation is based on percentage of conversion rate, those are: (A) 5% per year; (B) 15% per year; (C) 25% per year; (D) 35% per year; (E) 45% per year. The simulation was using software Powersim studio 10. The result from all scenarios can be seen in Fig. 3, 4, 5, 6, and 7. In those figures, “Carbon Produced” is carbon emission occurs during the use of ICE motorcycles or carbon emission during the production of the electricity and measured in CO_2.

The scenario A is to change the conversion rate from ICE motorcycle to electric motorcycle into 5%. By changing at this conversion rate, it shows that total carbon produced from all motorcycle still increase every year as shown in Fig. 3. The scenario B changes the conversion rate by 15% and shows that carbon produced can decrease until last period to around 127 million $MTCO_2e$ as shown in Fig. 4. The scenario C increases the conversion rate by 25%. From this scenario, it shows that the reduction of carbon produced more quickly. At the end of the 10th year, carbon produced is around 49 million $MTCO_2e$, it’s shown at Fig. 5. The scenario D changes the conversion rate by 35%. It shows that at the end of the 10th year, carbon produced is around 19 million $MTCO_2e$, it’s shown at Fig. 6. The last scenario changes the conversion rate into 45%. It shows that at the end of the 10th year, carbon produced is around 8 million $MTCO_2e$, it’s shown at Fig. 7. It is the most optimistic scenario.

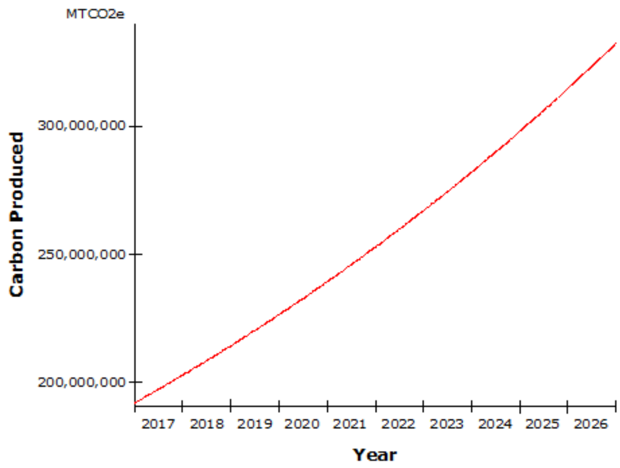

Fig. 3: Model Result of Scenario A.

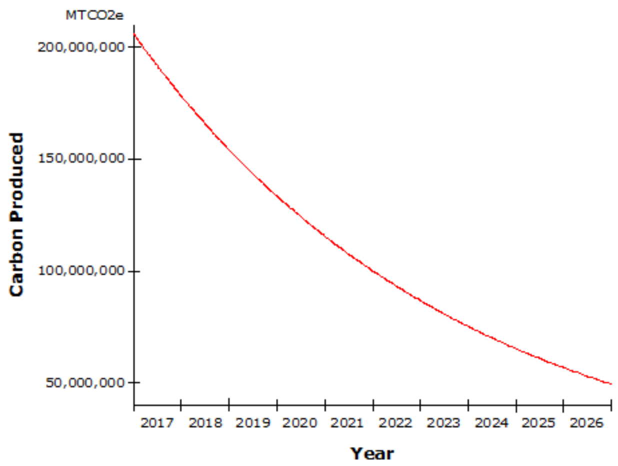

Fig. 5: Model Result of Scenario C

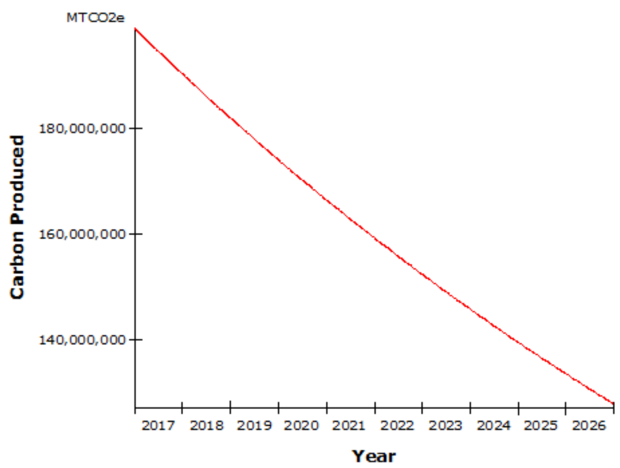

Fig. 4: Model Result of Scenario B

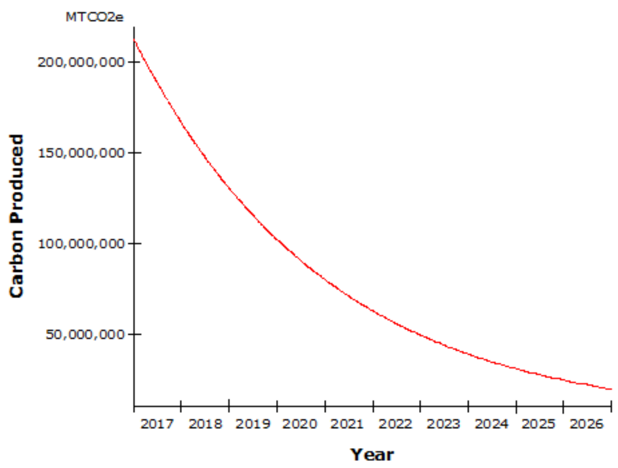

Fig. 6: Model Result of Scenario D

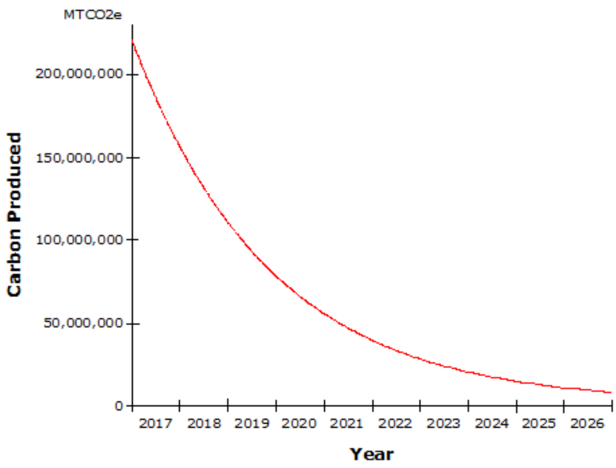

Fig. 7: Model Result of Scenario E.

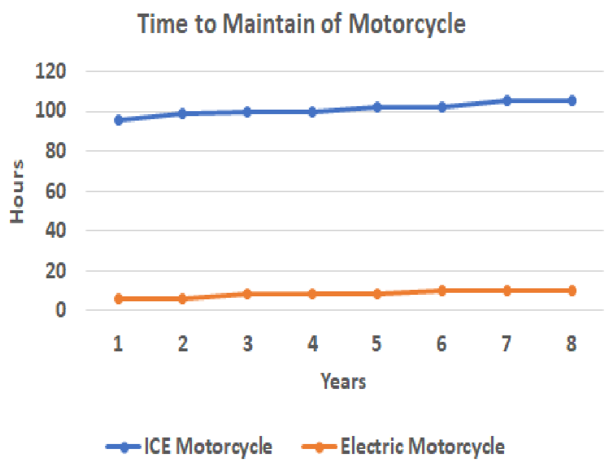

Fig. 8: Comparison of maintenance time between ICE motorcycle and electric motorcycle

3.3 Social Aspect

Social aspects in this paper are measured by comparing the noise level of all motorcycle, reducing road accidents by speed locked, healthier body of people because of carbon-reducing in air, increasing wealthy because of cost savings, and reduced maintenance time of all motorcycle.

The noise level of the electric motorcycle is 22.7% lower than the ICE motorcycle[26]. This lower noise level is expected to reduce traffic noise and can make road users feel more comfortable. The speed of the electric motorcycle is locked by battery capacity. The maximum electric motorcycle speed is around 60 km/hour[20]. It's different from the maximum of ICE motorcycle speed, which is around 100 km/hour. This differentiation is expected to reduce the road accident because of the maximum speed.

By using an electric motorcycle, the carbon emissions produced can be reduced, as explained before. Automatically it will make a healthier environment and a healthier body. Due to a healthier body, one's social pleasure will increase as well. In terms of cost savings, using an electric motorcycle is less cost rather than using ICE motorcycle, and it will increase social welfare.

People who replaces their ICE motorcycle to electric motorcycle conversion will have more lenient time as due to the comparison time as shown in Fig. 8[27]. Using an ICE motorcycle needs to queue at the gas station for its gasoline. Other than that, they have to provide time to maintain its engine and other parts at a motorcycle workshop, while electric motorcycle owners only need to maintain the other parts of a motorcycle. Electric motorcycle actually has more time to maintain because every day it must be charged for about 3 hours. But, it can be ignored because usually charging time of electric motorcycle at night when someone is sleeping so at the day people can utilize their loose time.

3.4 The Best Alternatives

From the discussion above, it can be simplified in Table 4. Table 4 shows that alternative 2 (electric motorcycle conversion) is the best alternative from the economic aspect, environmental aspect, and social aspect.

4. Conclusion

From this paper, it can be concluded that the electric motorcycle conversion is the best alternative for the replacement of ICE motorcycle in Indonesia based on sustainability consideration. From the economical aspect shows that electric motorcycle conversion NPV is IDR 17,978,802. The payback period is just 2.08 years. From the environmental aspect if the scenario of conversion rate into 45%, it shows that at the end of the 10^{th} year, carbon produced is around 8 million $MTCO_2e$. It can be implemented in Indonesia if infrastructure has been prepared, and the Government gives incentives to the customer. From the social aspect, electric motorcycle conversion can reduce the noise level until 22.7% than an ICE motorcycle. The accident opportunity can be reduced by its maximum speed. Electric motorcycle conversion also makes people body healthier and just need lower time to maintain the motorcycle than using ICE motorcycle. These results can make consumers more aware of the advantages of electric motorcycle conversion from economical aspect and social aspect. It also helps the government from environmental aspect about carbon emissions reducing.

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Table 4. Alternatives Comparison with Sustainability Metrics of Each Aspects Considered

Aspect	Metric	ICE Motorcycle	Electric Motorcycle Conversion	Electric Motorcycle
Economic	NPV	IDR (46,206,463)	IDR (17,978,802)	IDR (13,177,135)
Economic	PP	-	2.08 years	3 years
Environmental	Carbon emission	1.69×10^3 $MTCO_2e$/year*	6.48×10^2 $MTCO_2e$/year**	6.48×10^2 $MTCO_2e$/year**
Social	Noise level	Higher	22.7% lower	22.7% lower
Social	Accident opportunity	Higher	Lower	Lower
Social	Healthier body	Lower	Higher	Higher
Social	Welfare	Lower	Higher	Higher
Social	Time to maintain motorcycle	Higher	Lower	Lower

Notes:
*based on the assumption of consuming 60 liter/month, and 1 liter gasoline produce 2.35×10^3 $MTCO_2e$ [28)]
**based on the assumption of consuming 60 kWh/month, and to produce 1 kWh, its carbon footprint is 9.00×10^2 $MTCO_2e$ [29)]

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