

Environmental Assessment of Motorcycle using a Life-Cycle Perspective

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Abstract

Transportation sector contributes as the second largest polluter of the air pollution in Indonesia. Of the transportation sector, road transport has generated 70% of the air pollution, 81% of which is attributable to motorcycles. The motorcycles are currently accounting for 79% of the total motor vehicles. It is predicted that the number of motorcycles will continue to grow at an annual rate of 9-26%. However, due to little attention to the motorcycle's environmental impacts, this present study, therefore, aims to assess and report the environmental impacts of using motorcycles based on life-cycle perspective. Using a functional unit of one passenger per kilometer (pkm), resource consumption and emissions through the entire life-cycle of a motorcycle were estimated. The foreground Life Cycle Inventory (LCI) was compiled through observation, interview, and secondary data, while the background LCI was based on ecoinvent data v.2.0. Results show that the environmental impacts of the chosen function unit constitute Abiotic Resource Depletion Potential (ADP) of 0.515 g Sb-eq, Global Warming Potential (GWP) of 176 g CO₂-eq, Human Toxicity Potential (HTP) of 1.1 g 1,4-DCB-eq, and Acidification Potential (AP) of 0.544 g SO₂-eq, respectively. Operation (usage stage) of the motorcycle has been the most contributor to GWP and AP, while manufacturing stage has been the most contributor to HTP. Potential interventions related to the manufacturing process, fuel, and usage of the motorcycle to reduce the environmental impacts are also discussed.

Keywords: *Life Cycle Assessment (LCA); environmental impact; motorcycle; Indonesia*

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1. INTRODUCTION

Along with the growth of Indonesian population, the number of private transportation is also increasing, particularly in an urban area. Motorcycles are the dominant mean of transportation in Indonesia. The current share of motorcycles is 79%, and it is expected that the motorcycle continues to grow by an annual rate of 9-26%^[1]. The transportation sector is the largest contributor to air pollutions in Indonesia. Of the transportation sector, road transport has generated 70% of air pollution, 81% of which is attributable to motorcycles^[2]. The emissions are likely higher in urban areas. Because the dramatic increase of motor vehicles is not compensated with the increase road length, traffic congestion occurs. Consequently, it results in even higher fuel consumption and the air pollution^[2]. Although the motorcycles have played a role in the transportation sector, the little attention of the motorcycles' environmental impacts has been received. The government has focused more on passenger cars than motorcycles. Regulation on emission has been applied for car manufacturing, but none regulation exists for motorcycles as it has been assumed that the environmental impacts of motorcycle production are far less than those of car production. It can be argued however that even though environmental impacts generated by each motorcycle are smaller than those of cars, the total environmental impacts generated by all motorcycles may not be necessarily smaller than those by all cars due to a high number of motorcycles. It is, therefore, necessary to quantify environmental impacts by the motorcycle.

This present study aims to assess environmental impacts of the motorcycle using a life-cycle perspective. Life Cycle Assessment (LCA), as a tool used in Environmental Management System ISO 14000, was selected as a technique used to measure the energy consumption and environmental aspects associated with a motorcycle during its life cycle. LCA method is widely used in the analysis and evaluation of industrial activities and takes into account the input, process, and output related to the utilization of raw materials, supporting materials, energy use, as well as the management of the waste generated in the industry. Consequently, LCA helps to identify opportunities for improvement on the environmental aspects of the product considering the entire product life cycle. With the information, right energy policy or intervention can be designed in determining the area/process needs to be improved to reduce vehicle emissions. LCA could also be used as a framework to compare various product systems with respect to the impacts on the environment so that it helps to select a more environmentally friendly product.

LCA has been widely applied in assessing environmental impacts of transportation means. Several studies have used LCA to compare different types of two-wheeled vehicles: conventional bicycle, electric bicycle, scooter, and electric scooter^[3]. LCA was also performed to quantify the impacts of transportation means in the United States (US) such as private cars, city buses, trains, and aircraft^[4]. The study analyzes further to evaluate diesel cars, school buses, electric buses, Chicago trains, and New York City trains. Another study was also performed using LCA to compare three types of sport utility vehicles manufactured in Italy in order to identify an improvement area at the motor valve (valve engine)^[5].

This paper is structured in the following sections: the LCA methodology as a part of the introduction, the method used in this present study, LCA results and discussion, and conclusion. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a comprehensive tool for evaluating the emissions of a product, from the process of making raw materials until the product is discarded (cradle-to-grave)^[6]. The LCA has been a systematic approach to deal with pollution prevention and life-cycle engineering to analyze the environmental implications of products, processes and services covering various life cycle stages such as design, material, energy source, transportation, manufacturing, construction, use and operation, maintenance, repair/renovation/retrofit, and final treatment (reuse, recycling, incineration, landfilling)^[7]. Thus, LCA can be used as a framework for evaluating and certifying a comprehensive environmental footprint of potential products and services^[8]. This approach is commonly used for identification and quantification emissions and resource consumption that impact on the environment at all stages of the product life cycle as a whole.

According to ISO 14040: 2006^[9] and ISO 14044: 2006^[10], the LCA method consist of four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation which are detailed as the following.

1) *Goal and Scope Definition*

The first phase of the LCA is goal and scope definition. During this stage, a functional unit is determined, and so are types of environmental impacts to be evaluated. For this study, the goal of LCA is to evaluate the environmental impacts of using a motorcycle. The LCA scope involves the life cycle of the motorcycle, from raw materials production to the disposal of the motorcycle.

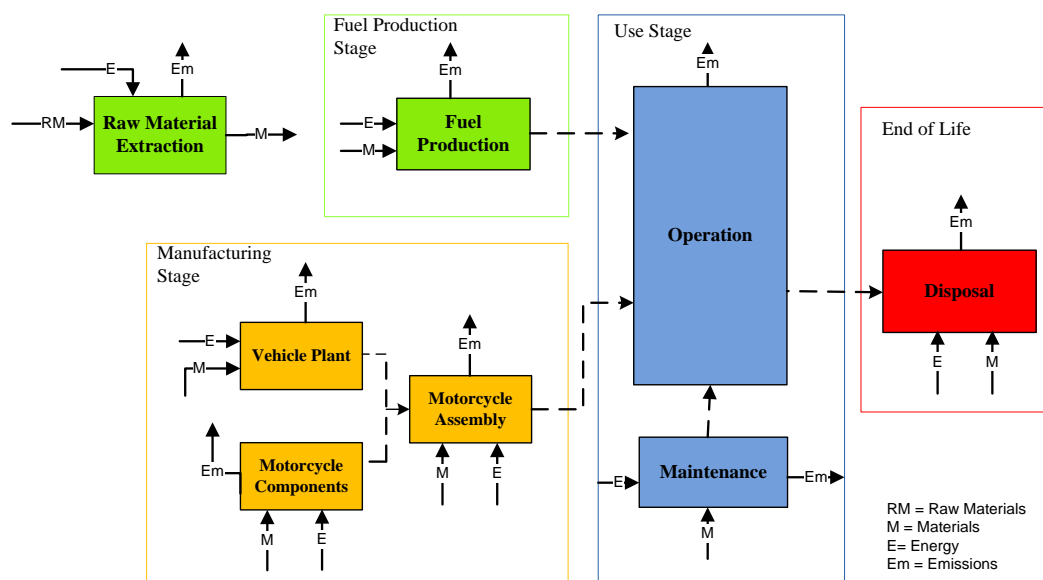


Fig. 1. Life-Cycle Perspective of Motorcycle in Indonesia

A functional unit of passenger per kilometer (pkm) was selected. The fact that most of the environmental problems for transportation context are generated from usage phase has motivated the use of the passenger per kilometer as a functional unit for the present study. Passenger per kilometer measures not only the upstream process (i.e., manufacturing) but also the downstream process (i.e., operation/usage and disposal). Moreover, the functional unit of pkm has been widely used for LCA study in transportation, such as^[3] and^[4].

2) Inventory analysis

At this stage, inventory modeling is carried out to map the chain of life cycle processes. Associated data is also collected in this phase. This study models inventory from raw materials, manufacturing process including infrastructure to support manufacturing, operation of the motorcycle including the chain of fuel used by the motorcycle, maintenance throughout its lifetime, and disposal of the motorcycle. The inventory modeling is conducted based on the defined functional unit. Fig. 1 presents the framework for inventory modeling for life cycle analysis for a motorcycle in the present study. The framework consists of five stages, i.e., raw material extraction, fuel production stage, manufacturing stage, operation/usage stage, and disposal stage. Each stage involves processes which need materials (M) and energy (E) and emits emissions (Em). Section 3.2 details the involved processes, required materials and energy, and emissions.

3) Impact Assessment

Once the inventory modeling is completed, the next step, known as Life Cycle Impact Assessment (LCIA) is to evaluate impacts. The impact assessment

is divided into two steps, namely classification and characterization, as shown in Fig. 2. Classification is to assign or to group the inventory in a different impact category as specified in the Goal and Scope Definition. Characterization is to calculate inventory contribution to the corresponding impact categories to result in the value of environmental impacts.

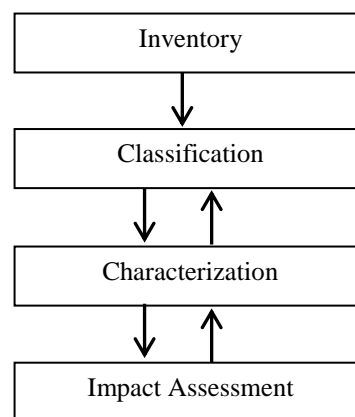


Fig. 2. LCIA Structure

Once the characterization is conducted, the environmental impacts can be then evaluated. The environmental impact to be assessed includes Abiotic Resource Depletion Potential (ADP), Global Warming Potential (GWP), Human Toxicity Potential (HTP), Acidification Potential (AP). Those environmental impacts were selected due to availability data of emission stressors constituting the impacts. Fig. 3 presents the emission stressors used to characterize the impacts following CML 2002^[11].

Table 1. Characterization Matrix ^[11]

	ADP (kg Sb- eq./kg)	GWP (kg CO ₂ - eq./kg)	HTP (kg 1.4- DCB- eq./kg)	AP (kg SO ₂ - eq./kg)
Bauxite	2,10E-09	0	0	0
SO2	0	0	0,096	1
NOx	0	0	1,2	0,7
CH4	0	21	0	0
Crude Oil	0,0201	0	0	0
Iron Ore	4,80E-08	0	0	0
PM10	0	0	0,82	0
Platinum Ore	1,29	0	0	0
CO2	0	1	0	0
N. Gas	0,0187	0	0	0

4) *Interpretation*

Analysis and interpretation of the results are done at every stage in LCA method, using an iterative approach^[6]. When conducting the analysis and interpretation of the results, the most significant contributions of the various processes, of life cycle phase, as well as of sub-systems, are identified, and potential interventions can be proposed.

This paper is structured as the following. Section two presents the LCA methodology implemented for the motorcycle under study, which are then followed by results and discussions on section three, before conclusion in section four.

2. METHODS

This section describes the implementation of LCA discussed in the previous section on the motorcycle. This section is divided into two parts: data collection and inventory modeling for the motorcycle.

2.1. Data Collection

Data was collected from various sources, i.e., primary and secondary data. Primary data regarding motorcycle parts (specification) was obtained from vendor^[12] and Laboratory of Automotive, Mechanical Engineering Diploma Program, Universitas Gadjah Mada. Interviews were also conducted to get data related maintenance and disposal. Operation data was based on actual use and obtained from a survey by Sandra^[13]. Primary data was used to develop foreground Life Cycle Inventory (LCI). Secondary data used for background LCI was obtained ecoinvent database v.2^[14] and literature^{[3],[4],[5]}.

2.2. Inventory Modeling

This section explains the Life Cycle Inventory (LCI) of the motorcycle. This present study used Honda Supra X 125 as a base for LCA so that material and energy inventory was based on the specification of the selected type. Given the annual distance traveled of 5000 km^{[12],[13]} and the lifetime of the motorcycle of 13 years for the four-stroke type of motorcycle, the lifetime of motorcycle for the study is evaluated to be 65.000 km.

Following Fig. 1 which present the life cycle perspective of the motorcycle to model the inventory, raw material extraction phase was used as background processes which are based on ecoinvent database v.2. The following sub-sections discuss foreground processes of the motorcycle.

2.2.1. LCI Manufacturing Stage

The manufacturing stage consists of the motorcycle's component manufacturing, plant construction, and motorcycle assembly.

2.2.1.1. LCI Motorcycle Components

Most of the part data was obtained directly from the vendor and the automotive laboratory. Some data that were not available from vendors were estimated by extrapolating manufacturing data of the other types of two-wheeled vehicles using weight ratio as shown in Table 2.

Motorcycle components to be considered are a frame, fuel tank, engine, suspension, front fork, wheels, steering stem, seat, pedals, brake, muffler, and accessories.

Table 2.Weight ratio for extrapolation purpose

Motorcycles	Weight (kg)	Weight Ratio
Honda Supra X: Yamaha VMAX	105 : 315 kg	0.33
Honda Supra X: <i>Scooter</i>	105 : 90 kg	1.17
Honda Supra X: <i>Bicycle</i>	105 : 17 kg	6.18

2.2.1.2. LCI Plant Construction

Plant building is assumed to be used throughout its lifetime of 20 years, and with the production capacity of 4.2 million units per year^[12]. Materials and energy requirements for constructing a building is obtained from the ecoinvent database v2.0 for building vehicle infrastructure or vehicle factory plant which requires 361,000 m³ of concrete^[12]. This data is then used to estimate the material needs such as steel, plastic, aluminum, transportation and other energy input requirements using ecoinvent database v.2^[14].

2.2.1.3. LCI Motorcycle Assembly

This process relates to the assembling the components into the motorcycle. The data was acquired from the vendor^[12]. To assemble a unit of the motorcycle, it also requires electricity of 36 kWh, diesel oil of 4 MJ, and natural gas of 109 MJ.

Transportation required for delivering materials, parts and components of motorcycle from the vendors to the assembly plant was estimated using the length of north road of Java Island. This was done because this road has been the main road connecting the vendors of parts which reside distributedly and the assembly plant which is located in the industrial park at the western part of Java. The road length 1,341 km was therefore used to estimate for the required transportation^[1]. It was also assumed that a truck with a payload capacity of 20 tons was used for the transportation.

2.2.2. LCI Fuel Production Stage

Fuel used for the motorcycles is gasoline. This present study used the LCI data of^[15] who carried out LCA of gasoline particularly for Indonesia. The study constitutes two main activities: the extraction of crude oil and the oil refining process.

2.2.3. LCI Use Stage

Use stage consists of two processes, i.e., operation and maintenance which are detailed below.

2.2.3.1. LCI Operation

Operation refers to the usage of the motorcycle. Fuel efficiency was obtained from the survey conducted by Sandra^[13] which is based on the actual operational efficiency of 26.71 km/Liter.

With respect to the number of passengers, a survey conducted by Sandra^[13] in 2012 has indicated the average number passenger was 1.5. Because the motorcycles are normally used by more than one passenger, sensitivity analysis is then conducted for a different number of passengers (i.e., two passengers and three passengers).

2.2.3.2. LCI Maintenance

Maintenance of the motorcycle regards with the replacements of motorcycle parts and tires. Most of the parts contain steel and aluminum, 10% of which are needed to be replaced. These materials are contained in the steel frame and the engine^[12]. In addition, the plastic material used in motorcycle body is also replaced although not all plastic parts are substituted. Tires are assumed to be replaced every 2 years.

2.2.4. LCI End-of-Life/Disposal Stage

Steel and aluminum of motorcycle parts are assumed to be fully reprocessed. It is assumed that this stage does not generate direct emission. This is an over simplifying assumption because steel and aluminum recycling is still energy intensive although substantially

less than the original production. However, if they are recycled, they might replace original material and should be credited for.

3. RESULTS AND DISCUSSION

3.1. Environmental Impacts

Based on the environmental impact assessment, results indicate that for each passenger per kilometer (pkm) of the reference motorcycle, the motorcycle contributes to the potential environmental impacts as presented in Table 3.

Table 3. Potential environmental impacts of the motorcycle for each passenger kilometer (pkm)

Impact Category	Environmental Impact
Abiotic Resource Depletion Potential (ADP)	0.515 g Sb-eq
Global Warming Potential (GWP)	176 g CO ₂ -eq
Human Toxicity Potential (HTP)	1.1 g 1,4-DCB-eq
Acidification Potential (AP)	0.544 g SO ₂ -eq

The table indicates that the motorcycle used by one passenger traveling for one kilometer would contribute to the environment in terms of global warming, human toxicity, acidification, and abiotic resource depletion (ordered from the biggest to the least).

3.2. Contribution Analysis

It is also necessary to identify processes contributing to the impacts. The use of motorcycles throughout the life cycle through several stages are then analyzed based on the stages of the manufacturing process, plant construction, operations, fuel production, maintenance, and motorcycle disposal. The second analysis for identifying the contributors for each impact category and each stressor is conducted and presented in Fig. 3.

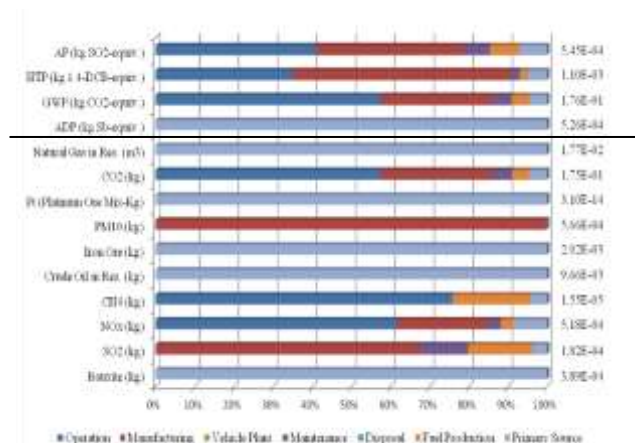


Fig. 3. Contributors by Impact Category and Stressor

Fig. 4 shows that in most environmental impact categories, use stage appears particularly operation to

be the most contributor, while manufacturing stage to be the second largest contributor. Operation (use stage) are the most contributors for GWP (as much as 57%) and AP, whereas manufacturing stage is the most contributor for HTP which is as much as 56%. Therefore, measures controlling emissions can be directed to this stage. As expected, plant construction is the least contributor for all impact categories.

That the operation of the motorcycle is the most contributor to the GWP implies that the operation is the most CO, CO₂, NO_x, and NH₃ emitters. It appears that replacing the fuel more environmentally friendly such as bio-ethanol^[16] or non-fossil fuel^[17] might be an alternative solution to reduce the environmental impacts. Another alternative might work on increasing fuel efficiency by better technology or be reducing the weight of the motorcycle. Some behavioral intervention may focus on reducing the use of motorcycle by promoting bicycle or walking for short distance trips.

Further analysis was therefore conducted to identify detail processes within manufacturing stage which contribute to the emissions. Fig. 5 shows that the manufacturing stage includes assembly process, frame production, fuel tank production, engine production, suspension production, front fork production, wheel production, steering stem production, seat production, pedal production, brake production, muffler production, plant construction, and transportation.

It was found that the assembly process is found to be the process impacting the environment most. These results suggest that in order to reduce emissions from the motorcycle, the improvement area is in the process of assembling motorcycles. It implies that the intervention is required to make the assembly process more efficient.

In addition, each of the main components of the motorcycle also provides a considerable contribution to the environment. The highest contribution is the engine production followed by suspension and frame production. Another intervention to reduce the impact on the environment is developed modification on motorcycle model^[5].

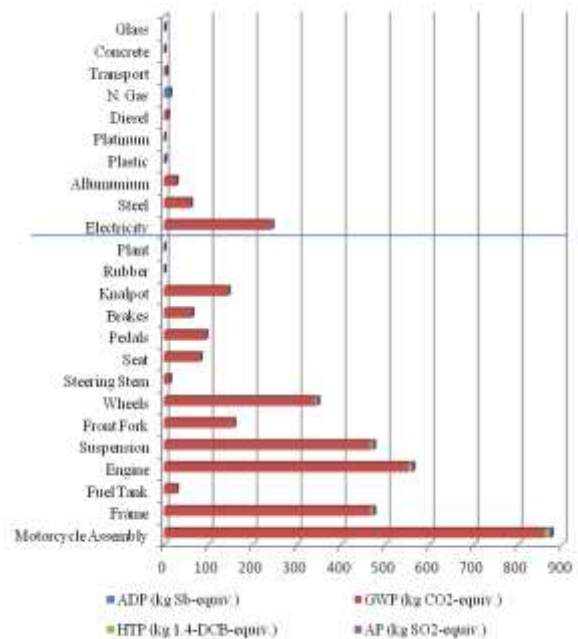


Fig. 4. Contributors of Manufacturing Stage

3.3. Sensitivity Analysis

Sensitivity analysis is conducted to evaluate the effect of the number of passengers on the environmental impacts. Since the motorcycle was actually designed for two passengers, while the LCA was calculated based on one passenger, LCA of motorcycle for two passengers are also necessary. Sensitivity analysis was then conducted for two and three passengers because more passengers are not allowed by regulation due to safety reason. Fig. 6 presents the results of the effect of various passenger kilometer on the environmental impacts.

Fig. 5 indicates that the number of passengers affects the environmental impact. The figure shows that two passengers appear to reduce Global Warming Potential (GWP) by 19%, and three passengers may reduce GWP by 25%. For other environmental impacts such as ADP, HTP and AP, the reductions are even higher. It is also interesting to notice that the reduction of the environmental impacts by one more passenger is not linear. Two passengers riding the motorcycle seems to be best with respect to both environmental and safety aspects.

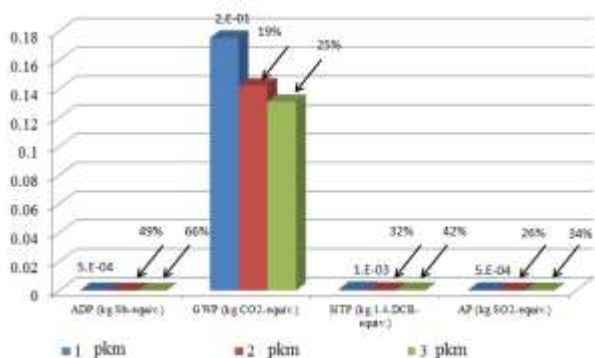


Fig. 5. Sensitivity Analysis for Various Passenger per Kilometer (pkm)

4. CONCLUSIONS

It is concluded that the potential environmental impact resulted from one passenger riding a motorcycle for one kilometer are Abiotic Resource Depletion Potential (ADP) of 0.515 g Sb-eq., Global Warming Potential (GWP) of 176 g CO₂-eq, Human Toxicity Potential (HTP) of 1.1 g 1,4-DCB-eq, and Acidification Potential (AP) of 0.544g SO₂-eq, respectively. Hence, the most of the environmental impact of the motorcycle is Global Warming.

The process which gives the highest contribution to the environment is the operation (use stage), followed by the manufacturing of the motorcycle. The operation appears to be the most contributor of Global Warming Potential (GWP) and Acidification Potential (AP), whereas the manufacturing stage is the most contributor of Human Toxicity Potential (HTP).

Potential interventions that can be used to reduce environmental impacts of the motorcycle are to use a more environmental benign fuel such as bioethanol or non-fossil fuel, to reduce the usage of motorcycles and to promote riding the motorcycle with two passengers (from behavioral perspective), to use better engine technology, to reduce the weight of motorcycle, and to make assembly process more efficient (for instance, by modifying the model of motorcycle).

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