Environmental and Life Cycle Cost Assessment of Cassava Ethanol in Indonesia

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Abstract: A huge potential for biofuel in Indonesia will have the chance to play an important role in the energy mix since the energy supply is highly dependent on fossil fuels. Ethanol, one of the biofuels with a potential to be developed as an automobile fuel in Indonesia, is targeted to supply 5% of total gasoline consumption in 2006-2010. An analysis of environmental impact and cost from production and utilization of a 10% blend of cassava-based ethanol with gasoline, so called E10, was done using Life Cycle Assessment and Life Cycle Cost method, and compared with gasoline. The results obtained showed that E10 has the potential for reducing the global warming and abiotic depletion potentials when compared with gasoline. However, in terms of acidification and eutrophication potentials, E10 has higher impacts than gasoline. The price of E10 is lower than gasoline on a per liter basis; however when comparing the prices based on fuel economy, E10 is more expensive than gasoline. Including external costs in the calculations brings down the E10 price below gasoline.

Keywords: LCA, LCC, E10, bioethanol, cassava, Indonesia

1. Background, aims and scope

Indonesia's energy supply is highly dependent on fossil fuels as can be seen in Figure 1; 43% of fossil fuels are still imported [1] creating a burden on the national expenditure. The oil price, which reached around US$100 per barrel in early 2008, burdened the state budget due to subsidies, particularly the direct fuel subsidies in the residential and industry sectors. Furthermore, the increasing demand resulted in Indonesia becoming a net oil importer. It subsequently withdrew from OPEC in 2008. To address this situation, energy diversification can be one of solution to the crisis. Diversification will help to come out from fossil energy dependency, which has the potential for the price to keep increasing as the resources keep decreasing.

A huge potential for renewable energy (RE) will have the chance to play an important role in the energy mix. In the short term, Indonesia's utilization of RE is directed towards fulfilling rural energy needs, but, in the longer term, RE is expected to displace petroleum fuels and constitute a significant share of Indonesia's primary energy supply [2].

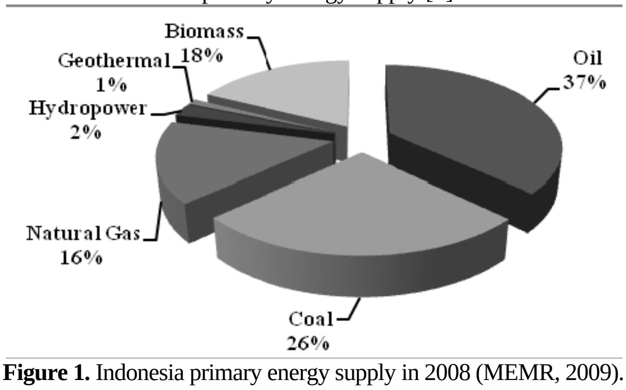

Figure 1. Indonesia primary energy supply in 2008 (MEMR, 2009).

Considering opportunities for renewable energy utilization in automobiles, Indonesia has started to use biofuels as automobile fuels. Ethanol is one of the biofuels which has the potential to be developed in Indonesia; the supply target for 2006-2010 is 5% of the total gasoline consumption [3]. However, in 2008, ethanol concentration that was sold in market by state owned oil and gas company (PERTAMINA) in Java area was only about 1-5% [4], whereas the state ministry of environment of Indonesia believed that high potential for biofuel feedstock supply and land availability suitable for biofuels plantation and production can help create jobs and reduce poverty [1]. Obstacles to biofuels penetration in Indonesia, such as the oil subsidy, which will reduce competitiveness of bioenergy compared with fossil fuel, high investment cost, lack of financial institution interested in bioenergy development, lack of strong and clear action from related institutions (policy, finance, and technology), conflict between bioenergy development and food security, seem to bring less movement to biofuels development. The uncompetitive price of ethanol as compared to gasoline further hinders penetration of the ethanol business into the market. The main economic constraints of the use of biomass are associated with the relatively high capital cost of acquisition, inadequate (financial) incentives and lack of purchasing power on the part of potential users [5]. Furthermore, the non-monetary character of many benefits from adopting a biomass innovation causes them not to be perceived as useful returns on investment.

To make biofuels an attractive option for energy sustainability, environmental impacts have to be considered along with economic aspects. Unsurprisingly for what is, of course, an industrial product, many environmental impacts from biofuels arise from the inefficient design and management of the processing facilities, such as the greenhouse gas (GHG) emissions which can vary a lot based on the operating conditions. Biofuel refineries also have a range of traditional environmental problems, including water and air pollution [6]. Like any industrial facility, ethanol plants can produce a range of pollutants, particularly if they are not properly monitored and held fully accountable to the existing environmental standards.

Among various biomass choices for producing ethanol in Indonesia, cassava is the focus of this study. Cassava is widely grown in Indonesia, there are about 811,422 hectares cassava agriculture in 12 provinces of Indonesia [7]. Cassava is grown for its enlarged starch-filled roots, which contain nearly the maximum theoretical concentration of starch on a dry weight basis among food crops. Therefore cassava is a promising crop for ethanol production because ethanol can be generated from starch [8].

This study investigates the life cycle assessment (LCA) and life cycle cost (LCC) of cassava-based ethanol. The whole life cycle must be assessed to identify the part of the supply chain that can be adjusted to improve cost performance and environmental impacts in ethanol production or even can encourage the Government of Indonesia towards better regulation for E10 development.

2. Experimental

2.1 Goal and scope

The aims of this study are to assess the environmental impacts of cassava-based ethanol (E10) as an alternative transportation fuel in Indonesia compared with conventional gasoline and to evaluate the cost (based on ex-refinery prices of gasoline and ethanol) of driving 100 km of a midsize car using bioethanol fuels (E10) and conventional gasoline. LCA methodology is as per the ISO14040/44 guidelines and the problem oriented (midpoint) method, CML 2001 baseline methodology is used for impact assessment [9]. To avoid the rising of sea level as Indonesia is an archipelagic nation, one of the environmental impact categories of immediate concern is global warming. Eutrophication and acidification are other impact categories being chosen since adequate rainfall happens in Indonesia which may lead to transport of acidifying and eutrophying substances. Furthermore, to account for depleting energy resources, it is also important to consider the impact category, abiotic resource depletion.

2.2 System boundaries and data sources

This study has been focused on the life cycle cost including external cost and potential of the environmental impacts from the cassava based ethanol. The parts of the life cycle included in this study are: plant cultivation, feedstock processing, ethanol and gasoline blending, car driving, and transportation among the processes mentioned above. The procedure for making an LCI of cassava-based E10 is summarized in Table 1.

2.2.1 Crude oil extraction

Extraction is done by Pertamina, a state owned oil company in Indonesia. Onshore oil production is the only common extraction process in its surrounding. During generation, the pumping unit products are 80% saltwater and 20% oil and gas. Products of the oil well are distributed to gathering station and consume diesel for energy. From the gathering station, those products are delivered to a centralized gathering system to collect the crude oil from all the gathering stations around the area. In the gathering system, the products are separated into three parts, namely crude oil, natural gas and saltwater. To transport crude oil (90 km), trunk line is used which requires pumping. Fuel needed for this pump is diesel. Since the amount of natural gas was not provided, comparison of crude oil and natural gas percentage from the city profile can be drawn on to find natural gas value in this research.

In this study, co-product allocation has been made based on energy basis. Since 1 Barrel of crude oil is equal to 5,487 Standard Cubic Feet (SCF), allocation of burdens to the crude oil is 99.83%. This allocation was performed for the upstream emissions from extraction as well. Electricity consumption in Indonesia was 129 TWh [30] and the grid mix of Indonesian electricity was obtained from Mochtar [12].

2.2.2 Refinery

Fuel products in the refinery comprise of: Gasoline (17.63%), Kerosene (8.69%), Automotive Diesel Oil (ADO) (22.89%), Industrial Diesel Oil (IDO) (0.88%), and Fuel oil (IFO) (11.78%) from total refinery products; therefore 17.63% of the raw materials used and emissions produced are allocated to gasoline on a mass basis. Mass basis was used for the allocation as some of heating value for some the refinery products was not available; however, studies have shown that the energy content of the co-products from refining are not substantially different and hence, mass allocation would yield results similar to energy allocation [31]. Energy used in the refinery is from fuel oil, refinery gas and mixed gas, quantities of which were obtained from primary data collection. Secondary data was used in this study as well as identified in Table 1.

2.2.3 Cassava cultivation

Cassava cultivation in Lampung province is done mostly on Yellow-Red Podsolik (YRP) soil. The varieties of cassava in the region are mainly Kasetsart species. Land preparation prior to planting is done by diesel tractors in three steps, plowing is

Table 1. Life cycle inventory of cassava-based E10.

Life Cycle Stage	Data required	Data source	Collecting Method	Data Processing
Crude Oil Extraction	Fuel Energy Production Transport	Pertamina EP	Interview	Waste water: [10] Natural gas flaring: [11] Electricity production: [12] Diesel combustion: Ecoinvent [13]
Refinery	Energy Production	Pertamina RU Pertamina RU	Interview Interview	Emissions: [14-15] Gas Flaring: [16-17] Refinery gas: [18] Waste water: [19] Pipeline emission: [20] Rail transport: [21]
Cultivation	Fuel use Fertilizer use Herbicide use Labour use Transport	Cassava Farmers Cassava Farmers Cassava Farmers Feedstock division in ethanol plant Feedstock division in ethanol plant	Interview Interview Interview Interview Interview	**Emissions**: Machinery: [10] Fertilizer: [22-24] Transport: [25]
Ethanol Conversion	Coal for boiler Diesel for machinery Waste water treatment Urea for fermentation	Ethanol Plant Ethanol Plant Ethanol Plant Ethanol Plant	Interview Interview Interview Interview	**Emissions**: Fuel [15] Machinery [10] Waste water: [26] Fermentation [23]
Fuel combustion	Fuel Energy Fuel Economy	Nguyen [27] Nguyen [27]	Literature review Literature review	Energy used: [27] Emission: [28-29]

done twice followed by application of ridger for making beds. Cassava is propagated vegetatively through stem cuttings prepared from the stalks that remain after the roots are harvested. Planting is done manually. For crop maintenance, commercial fertilizers are applied to enrich soil nutrients. Weeding is performed manually and by herbicides. Cassava harvesting is preferably performed by hand in order to avoid the risk of broken roots. During post harvest, stems are not burnt, but utilized to be planted again.

2.2.4 Ethanol conversion

Data for ethanol conversion from cassava was obtained from a commercial ethanol plant in Lampung province. In the plant, the raw material is directly taken from clean, peeled, fresh cassava roots. To make ethanol from fresh cassava, the root has to be processed in the plant. The ethanol conversion plant consists of several units, such as: pretreatment, hydrolysis, fermentation, and distillation. In the pretreatment process, water is added to cassava to make a slurry after which the liquefaction process is done by adding steam and enzymes. The next process is fermentation of reducing sugar by yeast followed by distillation to make 95% alcohol. For producing fuel ethanol, water content has to be decreased further by dehydration process; the final content of ethanol being 99.5%.

Coal is generally used as the energy carrier for generating power in ethanol conversion plants. The capacity of the commercial plant studied is 190 kL/day needing 0.808 ton coal for producing 1 kL ethanol. Ethanol is transferred via tanker truck of capacity 8,000 gallons to be blended with gasoline.

2.2.5 E10 combustion

For tailpipe emissions of CO_2, CO, HC and NOx, emission factors were retrieved from the PTT Emission Test [28], while for CH_4 emissions, the emission factor was taken from the Ecoinvent database. The emissions are dependent on the car type (engine characteristics) and hence can be used even for the case of Indonesia.

Fuel economy comparison reveals that 1 L of E10 is equal to 0.989 L of gasoline. The difference of 0.011 L is due to 10% of ethanol in gasoline. The substitution ratio between ethanol (in E10 form) and gasoline in a motor vehicle engine was derived as 1:0.89 based on fuel economy [27].

Thus, for traveling 100 km, a car using E10 as a fuel will consume 7.51 L of E10 fuel and 7.43 L for gasoline. Considering the carbon balance of CO_2 absorption by plants during growth, CO_2 emission from ethanol in the vehicle combustion will not be counted (for global warming potential).

2.2.6 Transportation

All materials and products involved in the system are hauled by different transport facilities through different distances. Data were collected in one of two ways: (1) information exchange via personal interviews, and (2) educated assumptions/estimations. Distribution systems of gasoline and E10 are presented in Figure 2.

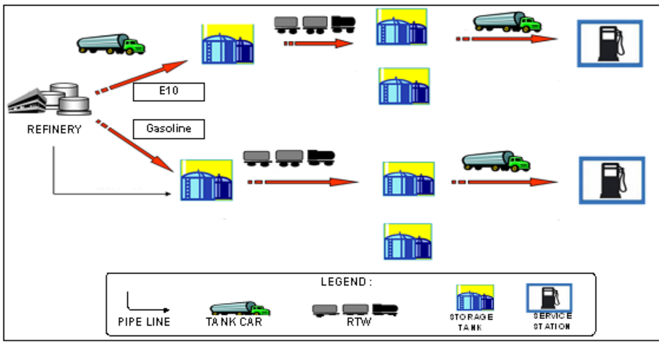

Figure 2. Gasoline and E10 distribution systems.

2.3 Functional Unit

The functional unit used in this study is driving 100 km of light duty vehicle (LGDV) fueled with E10 from cassava-based ethanol and conventional gasoline

3. Results and discussion

3.1 Environmental performance of E10 and gasoline

Table 2 summarizes the emissions from producing E10 per functional unit. Combustion data for gasoline are presented elsewhere [32].

Table 2. Summary emissions from producing 7.51 L of E10.

Emissions and use	Category	Unit	Oil Extraction	Oil Refinery	Cultivation	Ethanol Conversion	Blending	Combustion	Transport
Air emissions	CO_2	kg	3.38E-01	8.19E-01	4.17E-02	9.74E-01	9.07E-05	1.55E+01	2.05E-02
	SO_2	kg	1.37E-03	4.06E-03	1.89E-08	1.83E-02	3.68E-07	0.00E+00	3.68E-05
	NOx	kg	-	1.65E-03	1.71E-04	1.57E-05	1.74E-07	1.10E-02	2.72E-04
	CO	kg	-	3.21E-02	7.46E-06	8.26E-04	1.77E-08	1.01E-01	1.06E-03
	NMVOC	kg	7.72E-12	-	-	-	-	-	-
	CH_4	kg	3.49E-06	6.96E-05	5.14E-05	1.00E-04	9.34E-10	5.31E-07	4.71E-06
	N_2O	kg	5.42E-06	3.26E-07	1.65E-04	3.03E-05	1.45E-09	0.00E+00	1.40E-06
	SO_3	kg	-	5.91E-05	-	-	-	-	-
	NMTOC	kg	-	2.25E-06	-	-	-	-	-
	Ethylbenzene ($C_6H_5CH_2CH_3$)	kg	-	1.88E-10	-	-	-	-	-
	1,1,1-Trichloroethane	kg	-	6.99E-10	-	-	-	-	-
	NO_2	kg	-	1.65E-04	-	5.51E-03	-	-	-
	NH_3	kg	-	1.25E-04	3.36E-03	-	-	-	-
Water emissions	Arsenic	kg	2.13E-08	-	-	-	-	-	-
	Benzene	kg	5.00E-07	1.16E-03	-	-	-	-	-
	BOD	kg	-	4.65E-03	-	-	-	-	-
	COD	kg	-	1.24E-05	-	-	-	-	-
	Phenol	kg	-	-	-	-	-	-	-
	Oil	kg	-	-	-	-	-	-	-
	Heavy metals	kg	-	-	-	-	-	-	-
Abiotic resources	Crude Oil	kg	6.31E-03	-	-	-	-	-	-
	Natural Gas	m^3	1.29E-08	-	-	-	-	-	-

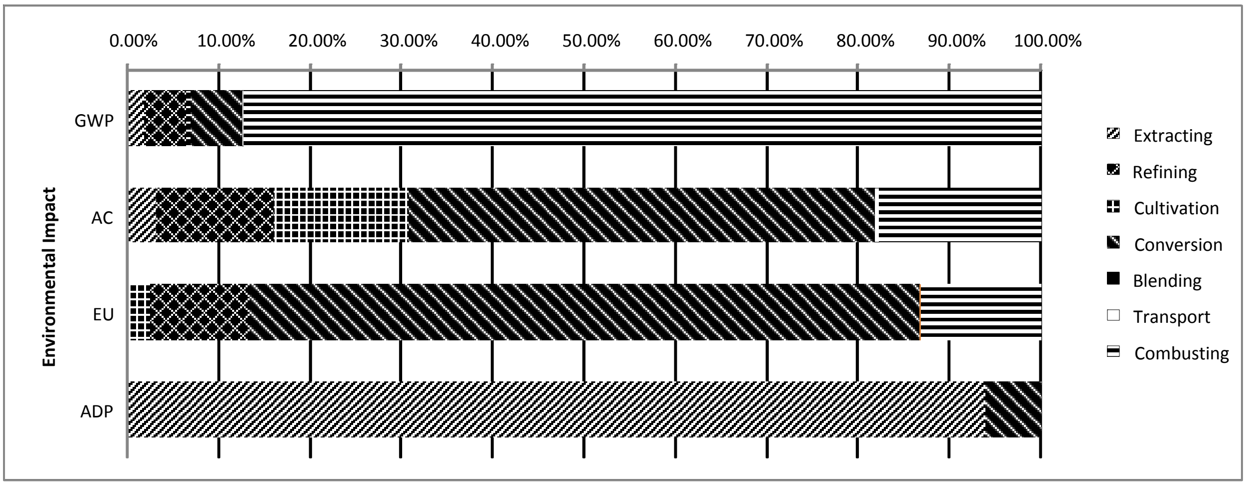

Figure 3. Life cycle stages contributing to the various impact potentials of E10.

Table 3 summarizes the LCA characterization results for E10. Change represents impacts of substituting E10 for gasoline. Negative change implies a reduction in environmental loads compared to gasoline, whereas positive change denotes an increase. The contribution of the various life cycle stages to the different impact categories is presented in Figure 3.

Table 3. E10 characterization results for each impact category.

Impact Category	Gasoline	E10	
		Amount	% change
GWP (kg CO_2-eq)	1.83E+01	1.78E+01	-3.24
AP (kg SO_2-eq)	1.96E-02	4.35E-02	55.03
EP (kg PO_4^{3-}-eq)	2.51E-03	1.10E-02	77.10
ADP (kg antimony-eq)	1.39E-04	1.35E-04	-3.25

Table 3 shows that E10 has the potential for reducing the global warming when compared with gasoline. The modest 3.24% reduction results mainly due to the direct emissions, an absence of fossil-based liquid fuel and consequently fossil-based CO_2 emissions from the combustion of ethanol portion in the blend (which is only 10% ethanol). However, high CO_2 from coal used in the conversion phase generates almost 98% of the CO_2 emissions. Even for abiotic resource depletion, there are only modest savings of 3.25% as the blend of ethanol is only 10%. Almost 94% of the abiotic resource depletion is from crude oil extraction (mainly for the gasoline part), the remaining 6% from coal use in the ethanol conversion stage. However, E10 has higher acidification potential than gasoline (about 55%), contributed by SO_2 gas emitted from coal boiler in the ethanol conversion, NOx emitted from the combustion of E10 in the car and the application of fertilizer which contributes NH_3 loads to the environment. E10 also has a higher eutrophication potential than gasoline (about 77%) contributed mostly by tailpipe emissions of NOx and NH_3 from fertilizer application in cassava cultivation.

3.2 Cost performance of E10 and gasoline

Life Cycle Cost (LCC) of cassava ethanol production includes feedstock cost, capital cost, operating and maintenance cost and transportation. The prices in the year 2009 were chosen as the base year for the analysis in this study, adjusted by using Indonesian Consumer Price Index (CPI). The maximum, minimum and average cassava prices during years 2007-2009 was obtained from the Ministry of Agriculture database [33], while the interest rate of investment is 8.14% as an average value from 2007-2009 record data (Trading Economic, 2010)

Cultivation costs of cassava consist of 5 categories i.e. (1) land preparation, including costs of hiring tractors and driver, fuel of machineries costs, and renting the land, (2) planting costs, including price of cassava stems (cuttings for propagation), hand planting and replanting, (3) chemicals such as herbicides and fertilizers, (4) harvesting and (5) transportation of stems, fertilizer, herbicides and cassava roots. Total production cost including transportation from the farms to ethanol factories is Rp 442,869 per tonne cassava. Based on the average price of Rp 499,259 a tonne for the year 2009, the farmers can obtain a benefit of about Rp 56,390 a tonne.

Ethanol conversion costs include cost of raw materials (fresh cassava roots), capital investment, operation and maintenance costs and transportation. These costs are included in the price of ethanol as it leaves the factory, termed as the ex-distillery price. Ethanol conversion cost breakdown is shown in Figure 4. The ethanol conversion cost or called ex-distillery price for producing 1 kL is Rp 5,197,461 and cassava price contributes 60.7% for ethanol conversion. To estimate the ethanol ex-refinery cost, ex-distillery price was added to the transportation cost.

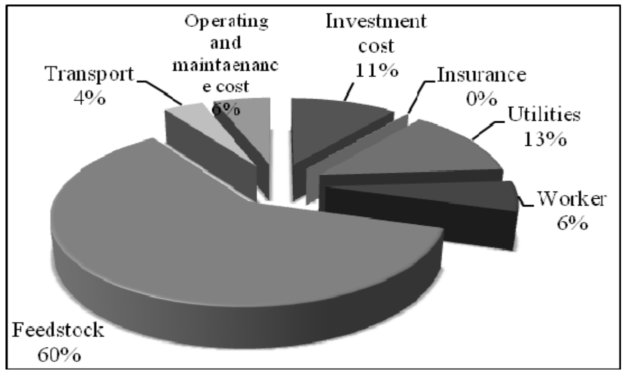

Figure 4. Conversion cost breakdown in the ethanol plant.

The total cost of E10, 10% of ethanol ex-distillery was added to 90% of gasoline price and cost of the blend amounted to Rp 6527.27 per liter. The record of gasoline prices from 2007-2009 were obtained from PERTAMINA (PERTAMINA, 2010) [34]. The most favorable condition for E10 competitiveness with gasoline per liter would be the situation when the lowest cassava price coincides with the highest gasoline price, which will bring E10 to be Rp 435 cheaper than gasoline per liter, however to make a fair comparison, average prices of both cassava and gasoline were chosen for the comparison. This resulted in a total price of E10 at Rp 63.38 less than gasoline on a per liter basis. However, this would not be a fair comparison as the driving distance provided by a liter of E10 and gasoline are not the same. As mentioned earlier that the substitution ratio between E10 and gasoline in a motor vehicle engine is 1:0.989 based on fuel economy, thus when comparing the ex refinery price based on fuel economy, the price of E10 is actually higher by Rp 9.13 than gasoline. The raw material (cassava) cost plays an important role contributing to the high cost in ethanol conversion which is 60% of ex distillery price.

To make E10 competitive with gasoline in terms of cost, the ex-refinery price of ethanol should be reduced from Rp 5,198 to Rp 5,106 per liter. One possible approach for reducing E10 cost is by cassava price reduction, which contributes 60% of the ex-refinery price of cassava ethanol. However, socially this is not a good option since it would lead to less benefit for the farmers. The second option is coal with cheaper fuels to produce power at the ethanol plant. Furthermore, another way to counterbalance the cost in ethanol conversion is utilizing by-products for profit making.

To determine the total external costs, environmental burdens of cassava ethanol and gasoline are accounted for. The default factors of external cost are taken from the EPS model [35-37] which account for the potential environmental impacts e.g. resources use and pollutant emissions. Environmental burdens are obtained from the inventory of this study and the results are represented by willingness to pay (WTP) of the society and transferred into Indonesian WTP via multiplier factor [38-39], as the formula below:

$$WTP_{Indonesia} = \frac{WTP_{Sweden} \times PercapGDP(PPP)_{Indonesia}}{PercapGDP(PPP)_{Sweden}}$$

GDP per capita in Indonesia ($PercapGDP\ (PPP)_{Indonesia}$) and GDP per capita in Sweden ($PercapGDP\ (PPP)_{Sweden}$) is taken from CIA [40] and then converted into Indonesian rupiah (Rp) [41] Table 4 lists the external costs for Sweden and Indonesia (after conversion).

Table 5 shows that after the external cost is included in the accounting, total cost of E10 can be competitive with that of gasoline; the cost of gasoline is Rp 209.39 higher as compared to E10 per functional unit. Thus, it is important to consider the external cost in the result of LCC.

Table 4. External costs per environmental burden categories.

Categories	Unit	WTP Sweden		WTP Indonesia
		EUR/unit	Rp/unit	Rp/unit
CO	kg	0.330	4,480.80	337.17
NOx	kg	2.130	28,921.50	2,176.30
PM10	kg	36	488,814.12	36,782.61
SO_2	kg	3.270	44,400.62	3,341.09
CH_4	kg	2.720	36,932.62	2,779.13
N_2O	kg	38	520,043.91	39,132.61
CO_2	kg	0.108	1,466.44	110.35
VOC	kg	2.140	29,057.28	2,186.52
Fossil oil use	kg	0.507	6,884.13	518.02
Coal use	kg	0.1	23.76	1.79

Table 5. Total cost of various fuels per functional unit.

Fuel	External cost	
	Excluded	Included
Gasoline	Rp 48,967.61	Rp 54,726.96
E10	Rp 49,043.32	Rp 54,517.57

4. Conclusion

The study shows that E10 performs favourably in terms of global warming and abiotic depletion potentials when compared with gasoline. However, this is not so for acidification and eutrophication due to coal usage in the ethanol conversion stage and the releases of fertilizers during the cultivation stage. For the ethanol production cycle, ethanol conversion is the main source of energy use as well as global warming, acidification and eutrophication impacts. Abiotic resource depletion impacts are mainly from the crude oil extraction. The E10 price is lower than gasoline on a per litre basis; however when comparing the price based on fuel economy, gasoline is cheaper. Raw materials, in this case cassava price, contribute 60% of the ethanol production cost. Hence, subsidies are needed from the government to make E10 competitive with gasoline. Adding external environmental costs into the calculations makes E10 cheaper than gasoline. This can in a way be a justification of the subsidies provided by the government as they contribute to overall social welfare.

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