Land-Use Implications to Energy Balances and Greenhouse Gas Emissions on Biodiesel from Palm Oil Production in Indonesia

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ABSTRACT

The objectives of this study are to identify the energy balance of Indonesian palm oil biodiesel production, including the stages of land use change, transport and milling and biodiesel processing, and to estimate the amount of greenhouse gas emissions from different production systems, including large and small holder plantations either dependent or independent, located in Kalimantan and in Sumatra. Results show that the accompanied implications of palm oil biodiesel produced in Kalimantan and Sumatra are different: energy input in Sumatra is higher than in Kalimantan, except for transport processes; the input/output ratios are positive in both regions and all production systems. The findings demonstrate that there are considerable differences between the farming systems and the locations in net energy yields (43.6 to 49.2 GJ t^{-1} biodiesel yr^{-1}) as well as greenhouse gas emissions (1969.6 to 5626.4 kg CO_{2eq} t^{-1} biodiesel yr^{-1}). The output to input ratios are positive in all cases. The largest greenhouse gas emissions result from land use change effects, followed by the transesterification, fertilizer production, agricultural production processes, milling and transportation. Ecosystem carbon payback times range from 11 to 42 years.

Keywords: Palm oil biodiesel, energy balances, greenhouse gas emissions, land-use change

INTRODUCTION

Most countries in the Asian region are net importers of petroleum fuels. Increasing energy demand and spiraling oil prices are putting financial strain on some countries and are also causing environmental degradation. Energy security has gained greater significance than ever; food production, improved living conditions and environmental quality are interrelated [4]. In this context, the use of biodiesel as an indigenous and renewable energy source can play a vital role in reducing dependence on petroleum imports and can also catalyze the rural economic development [15. 16]. In Indonesia, oil palm production plays a significant role in the country's economy and society [7, 12]. Today, an estimated 1.5 million small farmers grow oil palms in Indonesia and many more are connected with spin-offs [2, 7, 17]. Oil palm production in Indonesia is practiced in diverse farming systems and within different socio-economical contexts. Thus, Indonesia is a particularly interesting case for studying biodiesel production from palm oil.

Oil palm trees (*Elaeis guineensis*) were brought by the Dutch to Bogor (West Java, Indonesia) as ornamental plants and then spread throughout Sumatra in the early 20th century [12]. In the 1960s major oil palm plantations were established in Sumatra by the government of Indonesia within the frame of transmigration programs. Thirty years later, i.e. from 1987 onward, oil palm plantations were introduced in Kalimantan, imitating the plantation schemes implemented in the transmigration programs in Sumatra [2]. Despite the similar organization of oil palm production in Sumatra and Kalimantan, regional disparities persist due to different ecological environments, (e.g. mineral land and peat land composition in palm oil plantation areas), socio-economic settings (e.g. know-how of palm oil processing), infrastructure (e.g. better sustained roads and bridges in Sumatra) and timeframes (e.g. due to longer operating experience - Sumatra's palm oil industry was developed 30 years earlier than in Kalimantan).

Life Cycle Assessment [14] is an internationally known methodology for the evaluation of the environmental performance of a product, process or pathway along its partial or whole life cycle, considering the impacts generated from ''cradle to grave". Biofuel life cycles are often assessed from "cradle to gate". Several authors [24] [25] have noted that the LCA of palm oil industries often led to diverging results due to different approaches and methodologies, especially in the case of biofuels. An assessment focusing on the mere energy balance of biodiesel production from palm oil in Thailand was carried out to provide reliable information for promotion decisions [19]. The energy balance of palm oil biodiesel produced in Colombia and Brazil was determined on the basis of different scenarios [1, 3, 6, 10]. From these studies, it is not possible to verify the greenhouse gas (GHG) emissions or the reduction in fertilizer application due to the use of by-products (e.g. empty fruit bunches EFB), since no information is given on the input assumed in the calculations regarding the agricultural phase. An LCA on the energy balances and GHG emissions of biodiesel from palm oil in Brazil considers the use of co-products for power production, production of organic fertilizers and allocation procedures [22]. In their study, they found that fuel consumption is responsible for 18 % of the GHG emission in palm biodiesel LCA.

The objectives of this study are to assess the energy balance of Indonesian palm oil production, including the stages of land use change, transport and milling and bio-diesel processing, to evaluate potential environmental implications and to estimate greenhouse gas emissions from different production systems: large and small holder plantations either dependent or independent in Kalimantan or in Sumatra.

MATERIALS AND METHODS

The methodology applied in this study is based on the Life Cycle Assessment (LCA). The methodology of this study is based on the ISO 14040 Standard, in so far as it deals with the definition of the objective, function, scope and goal of LCA studies including inventory analysis. Life Cycle Assessment (LCA) is one method for the evaluation of environmental impacts of a good from its raw material production to its use and disposal (from cradle to grave) [14]. It is used as an important decision making tool for promoting alternative fuels. Implementing an LCA the fuel life cycle can be studied systematically in terms of energy efficiencies and environmental impacts. Numerous LCA studies have been carried out on alternative fuels such as biodiesel, methanol, and others [1,19, 23, 24, 25]

The goal of this study is to evaluate the environmental performance of biodiesel production from palm oil. The impact assessment is carried out regarding greenhouse gas emissions only; other LCA impact categories like acidification or eutrophication are neglected in this study.

The life cycle of biodiesel production is divided into three stages: cultivation of palm oil trees and harvest of palm fruits, crude palm oil production and transesterification into biodiesel. Relevant data for resource consumption and emissions to air, water and soil have been collected for all stages. Fig 1 shows the life cycle diagram beginning from the establishment of plantations, processing the fresh fruit bundles to crude palm oil (CPO) and the later to biodiesel. The data analysis includes material and energy inputs and outputs of each stage. The material and energy expenditures are measured per ton of biodiesel product.

The sites for data in this study are as follows:

a. From the oil palm plantations located in Central and in West Kalimantan, in North Sumatra and in Riau, the following data has been included in the assessment:
    - Input: fertilizer, herbicides, water and seeds.
    - Output: emissions to air, emissions to soil, wastewater and fresh fruit bunches (FFB)
b. From the palm oil production facility located in Kalimantan and Sumatra provinces, the following data has been used:
    - Input: FFB, water, steam, diesel, and electricity.
    - Output: fiber, shell, decanter cake, empty fruit bunches (EFB), ash, wastewater, emissions to air, crude palm oil (CPO) and kernel.
c. From the biodiesel production facility located in North Sumatra province, the following data is included:
    - - Input: CPO, water, electricity, methanol and sodium hydroxide.
    - - Output: methyl ester (biodiesel), glycerol and wastewater.

Data Collection

Data collection was carried out on the plantations in Kalimantan and Sumatra. Additional information was taken from published sources. Green house gas emissions from the field in different agricultural stages were determined according IPCC guidelines and [23]. Data from private companies were taken by direct survey, measurement and data collection in the field was carried out from July 2009 until December 2010 .

Methodology

Besides the main stages already mentioned above (plantation, CPO production in the mill, biodiesel production), the analysis also includes land use change and transportation processes. The calculation was carried out with Umberto® [11].

Energy Input

Land-Use Change

The land use change conducted in Kalimantan and Sumatra demands excavator and bulldozer equipment to prepare the secondary forest areas for oil palm plantation establishment. These machines consume large amounts of diesel fuel. In the peat land areas, palm oil companies are using excavators that are capable of cutting off trees, digging out roots and removing the residual biomass. Thus the soil is prepared for planting palm trees.

Palm oil processing

Milling is an integral part of the process to convert FFB into separated crude palm oil, palm kernel oil and by-products or waste. Power is required at several stages for various purposes. It may be used to produce steam for sterilization and processing, to drive the extraction and separation equipment, and to provide processing water (1.2 tons of water per ton FFB). Electricity is needed for ancillary farm and domestic purposes.

The palm oil mill processes 40 t FFB per hour, which is equivalent to a mill processing about 120 000 – 150 000 t FFB per year.

For oil extraction there are two main sources of energy input: production waste for generating steam for mill machinery and kernel crushing, and diesel fuel for engine start-up. For the calculations regarding the CPO production stage, we considered for input FFB, water, steam produced from production waste, diesel fuel for on-site electricity generation, and for output fiber, shells, decanter cake, empty fruit bunches (EFB), ash, palm oil mill effluent (POME), emissions to air, crude palm oil (CPO) and kernel oil.

In the investigated plantations in Sumatra, the POME is conveyed from the mill through ten consecutive ponds equipped with nets in order to filter out the solids and with impellers for aeration. The first two of them are covered to avoid methane emissions to the air. After this cleaning process the water is released to the river that is entering the plantation and is later on used for palm tree irrigation purposes. This activity belongs to a Clean Development Mechanism (CDM) project of the milling company. In the Kalimantan mills, the ponds are still under construction for CDM projects which will be built comparably to the Sumatra mill. Thus, the emissions will also be similar between both regions and therefore, methane emissions from POME were not included in the calculations.

Greenhouse Gas Emission (GHG)

Direct emissions occur from sources owned and controlled by the operator and therefore, in many cases, the company has the most control over these emissions. Emissions associated with fuel consumption at the production site, management of mill wastes and secondary manufacturing operation are considered as direct emission, too. Indirect emissions are emissions come from sources that are not owned or controlled by the operator, but they occur as a result of the industry's activities. Emissions associated with purchased power and methane from landfills is considered indirect emissions.

Emission from the peatland

To account for GHG emission from peatland area, the following calculation from guidelines [13, 23] are applied:

$$LUC\ emission = 3.7 \times [(LUC / (T_{LUC} \times Y) - C_{uptake} / (T_{plant} \times Y)] \qquad \ldots\ldots\ldots \quad [1]$$

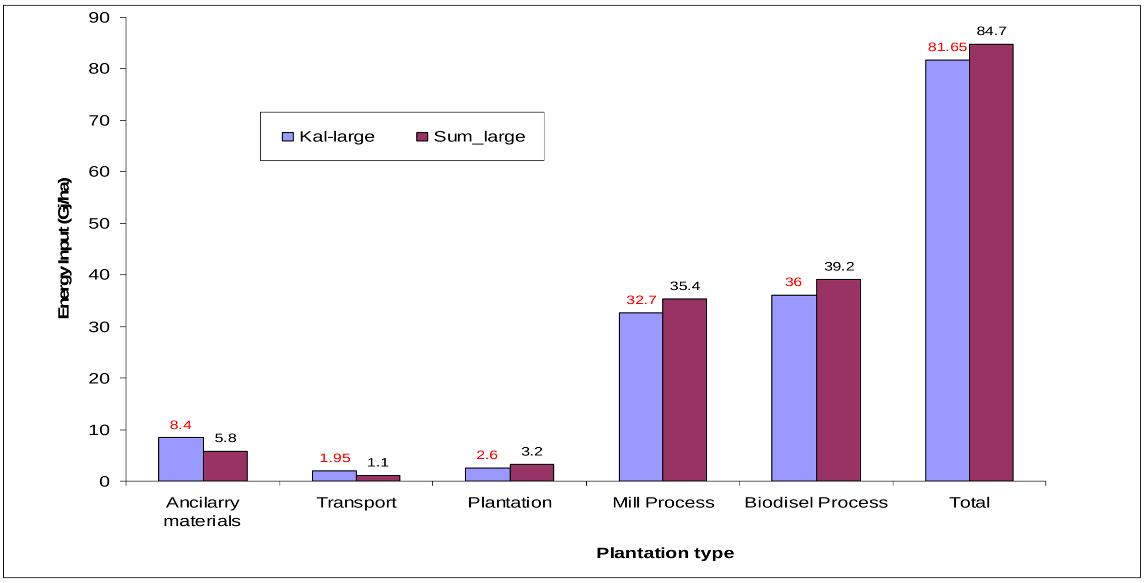
where: LUC emission are the net of emission from LUC (kg CO2 $_{eq.}$ MJ $_{CPO}$
3.7: the molecular weight ratio of CO_2 to C (unit less)
LUC C : the loss of carbon (C) from LUC (C ha^{-1}).
C_{uptake} : the carbon uptake by oil palms during plantation lifetime (C ha^{-1}).
T_{LUC} : the allocation time period of LUC emissions (yr)
T_{plant} : the plantation lifetime (yr)
Y : energy yield (GJ ha^{-1} yr^{-1})

RESULTS AND DISCUSSION

Energy Inputs

The various inputs necessary for an efficient operation of palm oil estates vary as widely as do the conditions and yield expectations under which the crop is grown commercially. These inputs namely are different fertilizers, other agricultural chemicals and machinery in operation. Nevertheless it is possible to assess the level of the overall energy input required to achieve optimum productivity at present.

Comparison between large plantations in Kalimantan and in Sumatra



Annotation:
Kal-large : Large plantations in Kalimantan
Sum_large : Large plantations in Sumatra

Fig 1: Comparison of energy inputs of large plantations in Kalimantan and in Sumatra

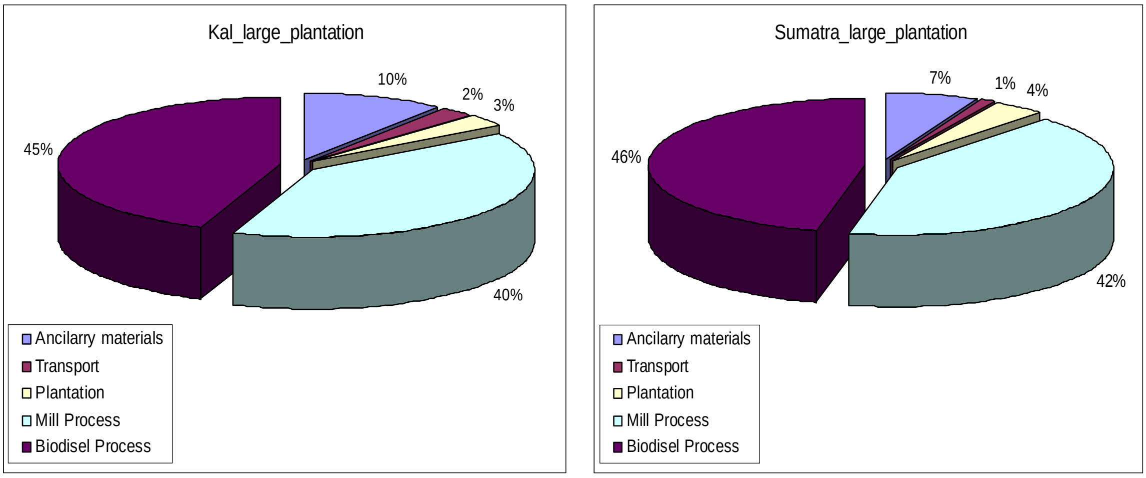
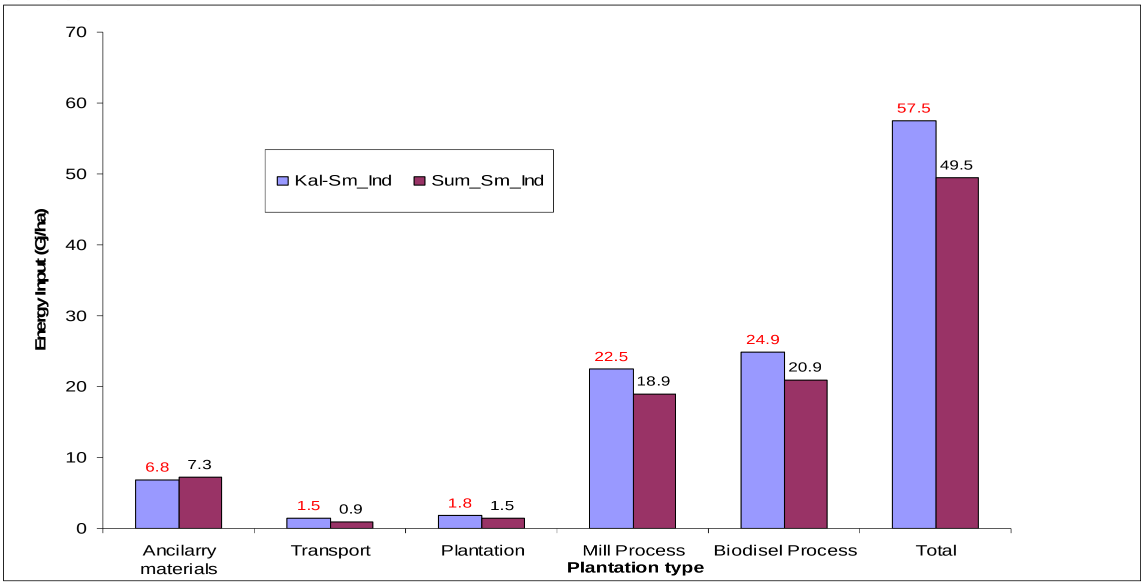


Fig 2: Percentage of energy consumption of large plantations in Kalimantan and in Sumatra

Fig 1 shows that the total energy input of plantations in Sumatra is much higher than the one in Kalimantan. This, however, does not apply to the energy input for using fertilizer and transportation. In Sumatra nearly 40 percent of these two energy inputs are saved, because organic fertilizer from fermented POME is used. In additions the infrastructure in Sumatra (e.g. roads and bridges) is developed better than in Kalimantan.

Fig 2 demonstrates that biodiesel processing accounts for the biggest energy input compared to all the other parts of the process chain in Kalimantan as well as in Sumatra.

Comparison between independent smallholders in Kalimantan and in Sumatra



Annotation:
Kal-Sm_Ind : Smallholder Independent plantation in Kalimantan
Sum_Sm_Ind : Smallholder Independent plantation in Sumatra

Fig 3: Energy input of independent smallholder plantations in Kalimantan and in Sumatra

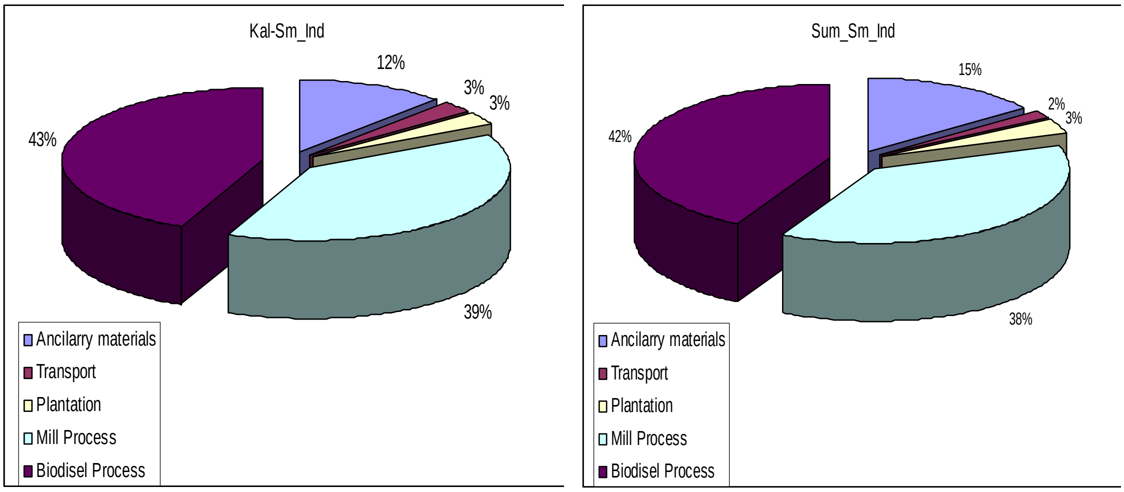


Fig 4: Percentage of energy consumption of independent smallholder plantations in Kalimantan and in Sumatra

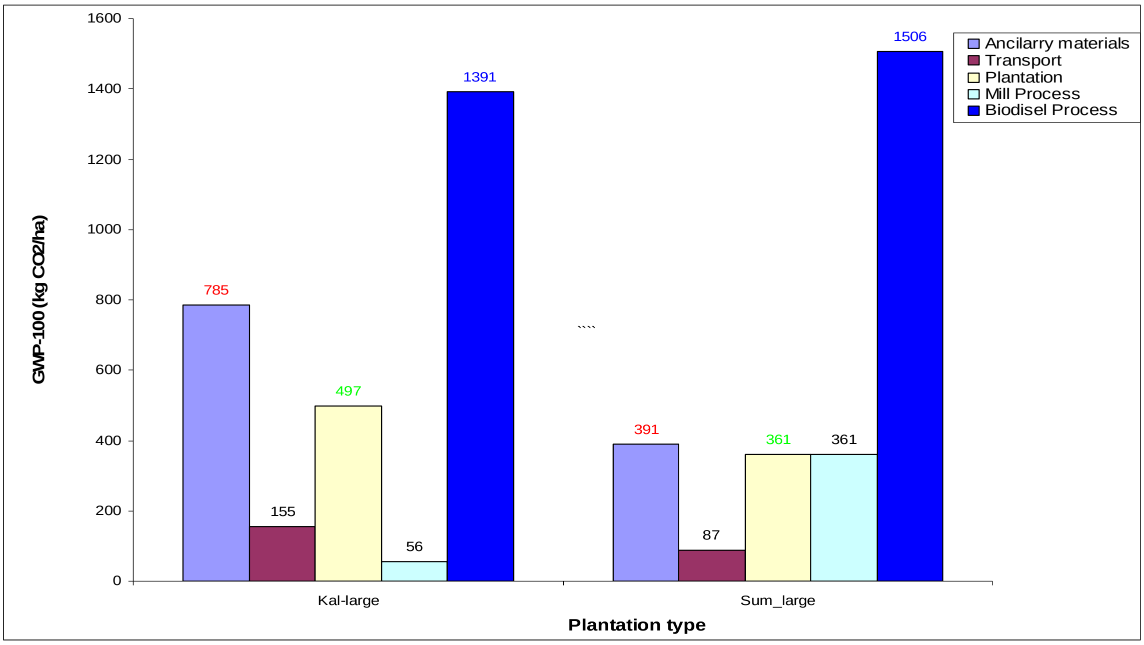
According to different inventory studies [8, 18, 23, 24, 25] the main material input in palm oil mills are FFB from palm oil plantations and water for the processing and steam used. Although occasionally power from diesel as boiler start-up fuel is needed, the mill can still be considered to be self-sufficient concerning energy. Electricity and steam for the mill is produced from fibers and shells, co-products of the CPO extraction process. Process outputs from palm oil milling are CPO, palm kernels, fibers, shells, EFB and POME. The additional outputs of a mill are considered valuable co-products because they are readily used as fuel in electricity and steam production for the mill [21].

Independent smallholders farmer commonly have a considerably smaller input of fertilizers and pesticides than large plantations ad supported dependent smallholders. This is due to the relatively high costs that such inputs would inflict on the small scale producers [9]. Hence a positive and negative impact results: less reliance on fertilizers and pesticides have a positive effect on the environment and reduce ground water pollution. However, on other hand, traditional growing techniques do improve the yield from year to year. Without or with only small amounts of fertilizer and pesticide input the yield stays comparably low and production is far from optimal.

GHG Emissions

Comparison of GHG emissions of large plantations in Kalimantan and in Sumatra.

Fig 5 demonstrates that the production of biodiesel has the highest GWP of all production steps by far. The second highest contribution to GHG emissions of the production chain comes from the ancillary material such as fertilizer production. In Kalimantan, there exists difficulties in producing and providing the fertilizer; the most often come from Java island, using sea-transportation. The third biggest amounts of GHG emissions result from plantations and inland transportation.



Annotation:
Kal-large : Large plantations in Kalimantan
Sum_large : Large plantations in Sumatra

Fig 5: Comparison of GHG emissions of large plantations in Kalimantan and in Sumatra

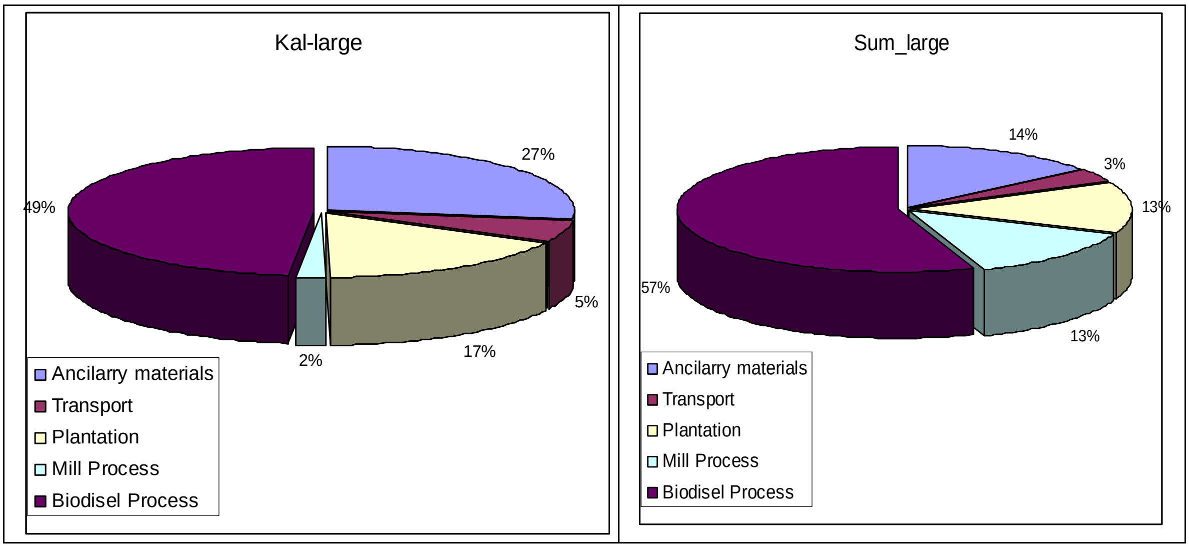


Fig 6: Percentage of GHG emissions of large plantations in Kalimantan and in Sumatra

Fig 6 demonstrates that biodiesel production has the highest GWP of all activities, resulting from methanol production. Ancillary materials such as fertilizer production contribute second highest. In Kalimantan, there exists difficulties in producing and providing the fertilizer; the most often come from Java island, using sea-transportation. The third biggest amounts of GHG emissions result from plantations and inland transportation.

Fig 5 and 6 above demonstrate that independent smallholders in Kalimantan produce higher GHG emission than independent smallholders in Sumatra. Considering dependent smallholders, however, only the ancillary materials and transportation produce higher emission in Kalimantan. While plantation and mill process emissions in Kalimantan are lower than in Sumatra.

The most significant contribution during the industrial phase can be attributed to the production of methanol due to the use of fossil fuel as energy source. GHG emissions from methanol production are highest compared with ancillary material production, mill process and transport. The according proportions of the emissions are 41%, 24%, 15%, 15% and 5% respectively, in Kalimantan. In Sumatra the the production parts similarily contribute to the overall GHG emission accounting for 42%, 24%, 16%, 16%, and 2% respectively.

GHG emissions could be avoided by substituting waste stream of raw materials in the production for energy or materials taken from outside the studied system boundary. Emissions can be avoided by using less GHG emitting practices instead of GHG intensive practice to produce energy (Henson, 2009; Brinkman, 2009). A good example is the substitution of the fossil fuels with biofuels or by the incineration of production waste. In addition, emissions can be avoided by material substitution or by changes in the end-of-life treatment.

Carbon payback

The payback estimated in dependent and independent large and smallholders in Kalimantan and Sumatra are different. In Kalimantan as well as in Sumatra, large plantations show longer payback time compared with smallholder plantations. While in Kalimantan ECPT takes longer than in Sumatra. This might be due to the fact that in Kalimantan more peatland areas have changed into palm oil plantations as in Sumatra, 37% to 33%, respectively. Table 3 also demonstrates that smallholders in Kalimantan also have longer payback times compared with smallholders in Sumatra.

Table 1: Ecosystem Carbon Payback Time (ECPT)

	Kalimantan (t C/year)			Sumatra (t C/year)		
	Large	SH_Dep	SH_Indep	Large	SH_Dep	SH_Indep
Sum of LUC	156.51	70.76	63.70	143.81	39.00	39.00
Saving	3.73	3.55	2.55	4.03	3.51	2.15
ECPT (year)	42	20	25	36	11	18

CONCLUSION

The overall energy input is higher in plantations in Sumatra compared with plantations in Kalimantan. Production of biodiesel based on palm oil requires its largest energy input during the industrial phase. The largest greenhouse gas emissions are produced by land use change especially if planted on peatland, followed by the industrial phase, fertilizer production, agricultural production activities, milling and transportation. LUC by converting peat land and forests to oil palm plantations results in long ECPT.

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