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# Greenhouse Gas Emissions from Biodiesel Production in Indonesia Based on Life Cycle Analysis

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Cover Photo:
Transporting Oil Palm Fruit Bunches in Riau © Kemal Jufri/Greenpeace

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# List of Abbreviations

| | |
|---|---|
| AFOLU | Agriculture, Forestry and Other Land Use |
| APROBI | Asosiasi Produsen Biodiesel Indonesia (Indonesian Association of Biodiesel Producers) |
| BOE | Barrel of Oil Equivalent |
| CO2eq. | Carbon Dioxide Equivalent |
| CPO | Crude Palm Oil |
| EU | European Union |
| FAO | Food and Agriculture Organization |
| FFB | Fresh Fruit Bunches |
| GAP | Good Agriculture Practice |
| GJ | Giga Joule |
| GHG | Greenhouse Gases |
| GRK | Gas Rumah Kaca |
| Ha | Hectares |
| ILUC | Indirect Land Use Change |
| IPCC | Intergovernmental Panel on Climate Change |
| ISCC | International Standard for Carbon Certification |
| ISPO | Indonesia Sustainable Palm OIl (Standard) |
| Kg | Kilogram |
| Kl | Kiloliter |
| LCA | Life Cycle Analysis |
| LUC | Land Use Change |
| LUCF | Land Use Change and Forestry |
| MC | Methane Capture |
| MJ | Megajoule |
| MPOB | Malaysia Palm Oil Board |
| MT | Million Tons |
| MTOE | Millions Ton of Oil Equivalent |
| MWe | Megawatt Electricity |
| MWh | Megawatt Hour |
| N2O | Nitrogen Dioxide |
| OER | Oil Extraction Rate |
| PBB | Perserikatan Bangsa Bangsa (United Nations) |
| PFAD | Palm Fatty Acid Distillate |
| PKS | Pabrik Kelapa Sawit )Palm oil mill) |
| PLN | Perusahaan Listrik Negara (PT. PLN Persero) - state-owned electricity company |
| POME | Palm Oil Mill Effluent |
| PSO | Public Service Obligation |
| RBD | Refined Bleached and Deodorized |
| RED | Renewable Energy Directive |
| RSPO | Roundtable on Sustainable Palm Oil |
| RPO | Refined Palm Oil |
| SPKS | Serikat Farmer Kelapa Sawit (Association of Palm Oil Smallholder Farmers) |
| SPBU | Gas/Petrol Station |
| TBS | Tandan Buah Segar (Fresh Fruit Bunches) |
| TPH | Tons Per Hour |

## Greenhouse Gas Emissions of Biodiesel from CPO

*Good governance is an absolute prerequisite in order for biodiesel utilization from CPO to achieve targets for energy conservation and greenhouse gas emissions reduction, in accordance with the mitigation strategy of the Government of Indonesia*

~ Traction Energy Asia

# Executive Summary

## Key findings/Highlights

- Indonesia has set a target for its renewable energy mix of 23% - 92.2 MTOE (Million Tonnes of Oil Equivalent) by 2030. One quarter of Indonesia's renewable energy target is planned to come from biofuel.
- It is estimated that 33.5% of Indonesia's oil palm is cultivated on previously forested land, including peat forests, with 26.3% from scrubland including peat scrubland, and 34.1% is from agroforestry. The oil palm plantation and palm oil sectors account for approximately 15% of total national emissions, with the majority resulting from peat oxidation within plantations, land clearing, and palm oil mill effluent (POME).
- This report aims to provide an analysis of GHG emissions of biodiesel production from palm oil in Indonesia, using a Life Cycle Analysis (LCA) to analyze GHG emissions across the entirety of a product's supply chain, all the way to its consumer use (cradle to grave). This analysis delineates the limits of emissions calculations, from the plantation to the blending of B20, from a scenario analysis to the utilization stage.
- GHG emissions from plantations are still the largest contributor to emissions from biodiesel in Indonesia, accounting for over 80% of GHG emissions across the biodiesel supply chain.
- The differentiating factor for total GHG emissions produced through land use change (LUC) lies in the type of land, namely mineral or peat. Biodiesel from palm oil, the production of which entails land use change from peat, will produce a spike in GHG emissions of up to 6.08 kg CO2eq/L B20 for West Kalimantan, and 7.09 kg CO2eq/L B20 for Riau.
- In Riau and West Kalimantan there is a significant difference between GHG emissions produced through LUC for land that was previously grassland, and land that was previously forest. There is a possibility that LUC on mineral and peat lands will cause emissions from the production of B20 to be significantly higher than diesel fuel emissions.
- The use of methane capture in palm oil mills can halve emissions from the milling stage of production.
- Transportation (delivery of fresh fruit bunches (FFB)) is the largest source of emissions for palm oil smallholder farmers. Fuel use for palm oil smallhoder farmers' transportation can contribute up to 39% of emissions in West Kalimantan and 49% in Riau.
- Productivity of palm oil smallholder farmers is lower than plantation companies.

The Government of Indonesia has committed to reduce the nation's GHG emissions by 29% by 2030 through mitigation in the energy sector as well as other sectors. The main mitigation strategy in the energy sector is the development of renewable energy, including biodiesel production from crude palm oil (CPO). In order to fulfill the target for the energy mix in 2025, biodiesel production is targeted to increase from 6.01 million kiloliters in 2018 to 13.8 million kiloliters in 2025. Biodiesel can support efforts to achieve national energy security and reduce national GHG emissions. On the other hand, biodiesel production is inseparable from the energy and land use sectors. Biodiesel production can have environmental impacts, and can actually increase GHG emissions related to deforestation and land use change from peatlands to oil palm plantations.

Using Life Cycle Analysis (LCA) methodology, this report analyzes the GHG emissions of biodiesel from CPO. LCA was selected in order to analyze GHG emissions as a result of biodiesel production from CPO in Indonesia, with research limitations delineated to the plantation, refinery, and B20 blending station production stages. A scenario analysis up to the consumption stage was conducted in order to observe biodiesel GHG emissions across the entirety of the supply chain. Sampling data for the research was obtained through respondents in the corporate sector, as well as from palm oil smallholder farmers. Data for palm oil smallholder farmers' production was obtained through field surveys in the provinces of Riau and West Kalimantan. A review of previous biodiesel LCA studies was also conducted as a reference for the research.

Based on this research, in the absence of LUC, a LCA of B20 biodiesel production from palm oil companies and palm oil smallholder farmers produces a result of 2.67-3.03 kgCO2eq per liter of B20. These GHG emissions are lower compared to diesel emissions of 3.14 kgCO2eq/L. Based on the LCA, GHG emissions from B20 can be between 3-14% lower than conventional diesel. With B20 biodiesel production targeted at 13.8 million kiloliters in 2025, the change in the usage of diesel fuel to biodiesel from CPO is projected to reduce GHG emissions by up to 9.27 million tCO2eq in 2025, or more than 90% of the target for emissions reduction through fuel switching. In order to support the achievement of targets for national GHG emissions reduction, mitigation needs to be conducted through good governance and the establishment of upper limits for GHG emissions from biodiesel production.

# 1. INTRODUCTION

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As a non-Annex I member of the United Nations Convention on Climate Change[1], Indonesia is committed to reduce greenhouse gas (GHG) emissions by 29% by 2030.[2] Mitigation in the land use and energy sectors are projected to contribute a large portion of Indonesia's GHG emissions reduction effort.[3] As a result of Indonesia's GDP and population growth, energy demand is projected to increase to more than 4,500 million Barrel Oil Equivalent (BOE).[4] Indonesia's National Energy Policy[5] targets the renewable energy mix at 23% or equivalent to 92.2 MTOE (Million Tonnes of OIl Equivalent) in 2030. A quarter of the portion of renewable energy, or 23 MTOE, is projected to come from biofuel (Misna, 2018).

**Table 1. Indonesia's Biofuel Target (in MTOE) (Kusdiana, 2014)**

| Fuel | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2025 | 2050 |
|---|---|---|---|---|---|---|---|---|
| Biofuel | 6 | 7 | 7 | 8 | 8 | 9 | 19 | 63 |

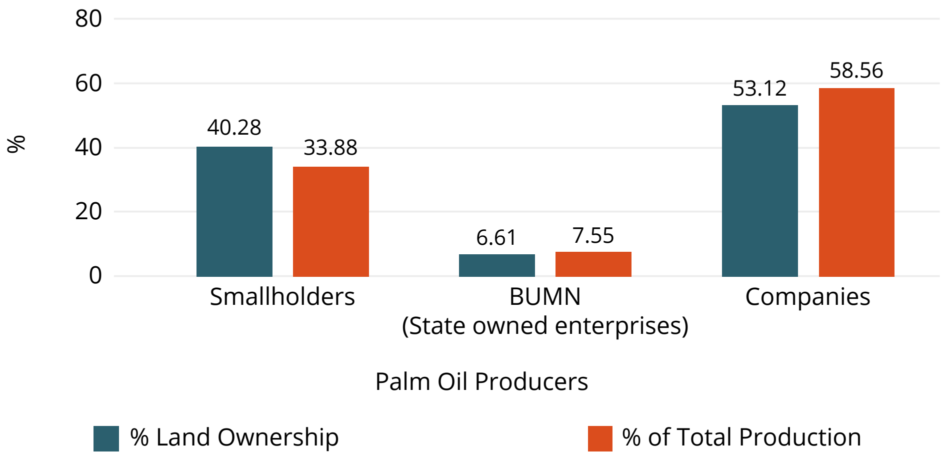
In order to achieve these emission reduction targets, the Government of Indonesia has issued a number of policies and regulations.[6] A target for biodiesel blending for various sectors has also been established, with a progressive target of up to 30% for all sectors in 2020. Indonesia's biodiesel production increased from 3.42 million kiloliters in 2017 to 6.01 million kiloliters in 2018 (Misna, 2018). Production is expected to increase fourfold by 2025 to 13.8 million kiloliters in order to fulfill the targeted portion of biofuel within the national energy mix.

Biofuel refers to fuel produced from a vegetable feedstock. Common forms of biofuel include biodiesel and bioethanol. Currently, biofuel production in Indonesia is still dominated by biodiesel from Crude Palm Oil (CPO), which is categorized as a first generation biodiesel.[7] Current national biodiesel production capacity is around 12 million kiloliters per year, from the islands of Sumatra, Java, Kalimantan, and Sulawesi. The development of biodiesel from CPO can support Indonesia's efforts to realize national energy security, reduce the consumption and import of fossil fuels, create added value from the downstream palm oil industry, and contribute to reducing GHG emissions in the energy sector. However, without improvements to forest governance and sustainable production, biodiesel from palm oil can result in adverse environmental effects. For example, land use change on land that has been newly converted to oil palm plantations, especially on peatland, will drive GHG emissions as well as environmental degradation as a result of LUCF (land use change and forestry). In addition, deforestation can drive the extinction of forest-based biodiversity as well as disrupting the ecosystems. Indonesia's production of biodiesel from palm oil is crucial because of its potential impacts on the country's two biggest sources of GHG emissions in Indonesia, namely LUCF and energy.

The European Union has recently adopted a policy to regulate GHG emissions from biofuel, including biodiesel. From 2021–2023, GHG emissions from biofuel must be 50% lower than emissions from fossil fuels (European Union, 2018). This policy was implemented by the European Union to ensure that biofuel production and usage produces lower GHG emissions than fossil fuels. The Government of Indonesia has not yet issued regulations on sustainable and low-carbon biodiesel production. In order to prevent GHG emissions across the entirety of the biodiesel supply chain from surpassing fossil fuel emissions, it is imperative for producers to avoid CPO that is produced from cultivation on land with high carbon stocks and biodiversity levels.

By 2017 Indonesia had 12.3 million hectares of oil palm plantations (Directorate-General of Plantations, 2018), with 60% - 7.5 million hectares - of the oil palm plantations managed by state-owned and private oil palm companies, and the remaining 4.8 million hectares community plantations, see **Figure 1**. Although community plantations account for 40% of the total area of oil palm plantations they supply only 34% of total national oil palm production. In 2017 Indonesia produced 38.17 million tons of palm oil - 31.05 million tons for export and 4.02 million tons allocated for the national reserve (GAPKI, 2018).

**Figure 1. Land Ownership in the Palm Oil Industry Sector**




Consumption of biodiesel from palm oil reached 2.57 million kiloliters in 2017, and was estimated to contribute to 6.89 million $tCO_2eq$ in GHG emissions reduction (Santoso, 2018). Biofuel is expected to positively contribute to the national energy balance and to reducing national GHG emissions. However, the palm oil sector that produces the feedstock for biodiesel production is often linked to issues of deforestation, land use change (LUC), and increased GHG emissions. Therefore, identification, inventorization, and calculation of GHG emissions of biodiesel production from CPO must be conducted to ensure that the negative effects of biodiesel production do not outweigh the positive contributions it can make.

Indonesia faces a significant challenge to improve the sustainability of palm oil and to minimize the sector's GHG emissions, especially for biodiesel production from CPO. Any assessment of GHG emissions from biodiesel produced from CPO must include the emissions caused by land use change. An estimated 33.5% of Indonesia's oil palm plantations are located in forests, including peat forests, with 26.3% in scrubland, including peat scrubland, and 34.1% from agroforestry (Gunarso, Hartoyo, Fahmuddin, & Killeen, 2013). Plantations and the oil palm sector account for approximately 15% of total national emissions, the majority of which are derived from the oxidation of peatland, land clearing, and palm oil mill effluent (POME) (Ministry of Environment and Forestry, 2018). Simulations conducted by Purnomo *et al.* (2018) show that emissions from plantations and palm oil production could reach 716 million $tCO_2eq$ by 2037. The baseline year for the simulation was 2015, which also assumed that 21% of oil palm plantations are vulnerable to burning, and 5% are intentionally burned during land clearing (Purnomo, Okarda, Dermawan, Ilham, & Bizarani, 2018).

Calculating the upstream GHG emissions of biodiesel from CPO should begin with the cultivation process in plantations, and end at the biodiesel blending station stage. Using Life Cycle Analysis (LCA), calculations for upstream and downstream emissions can be applied all the way to the consumption of biodiesel. The calculation includes all stages that cumulatively contribute to GHG emissions - land clearing, fertilizer use, fossil fuel use, and POME (Bessou *et al.*, 2014). The amount of emissions from the production chain depends specifically on the condition of the supply chain. For example, an LCA conducted by RSPO on 11 of its member companies produced an average emissions level of 1.67 $tCO_2eq$/ton CPO, with figures ranging between -0.02–8.32 $tCO_2eq$/ton CPO (Bessou *et al.*, 2014). The large difference in the range of GHG emissions is primarily caused by differences in initial land use, the type and amount of fertilizer used in plantations, as well as POME management practices in palm oil mills.

The objective of this report is to provide the results of the GHG emissions calculation from CPO biodiesel production in Indonesia, so that this can be taken into consideration in future policy planning. LCA is used to analyze GHG emissions across the entirety of a product's supply chain up to its usage (cradle to grave). This analysis delineates the limits of emissions calculations from the plantation stage all the way to the blending of B20, and from a scenario analysis all the way to the usage stage. A scenario analysis of land use change was also conducted to observe the effects of different scenarios on total GHG emissions from CPO biodiesel. This report also provides a review of previous studies on LCA of biodiesel GHG emissions. The methodology and summary of data provide the technical basis for the GHG calculation and explain how this study was conducted. Based on the research results, this report recommends that the Government of Indonesia and relevant stakeholders quickly adopt an approach of managing GHG emissions from CPO-based biodiesel.

# 2. METHODOLOGY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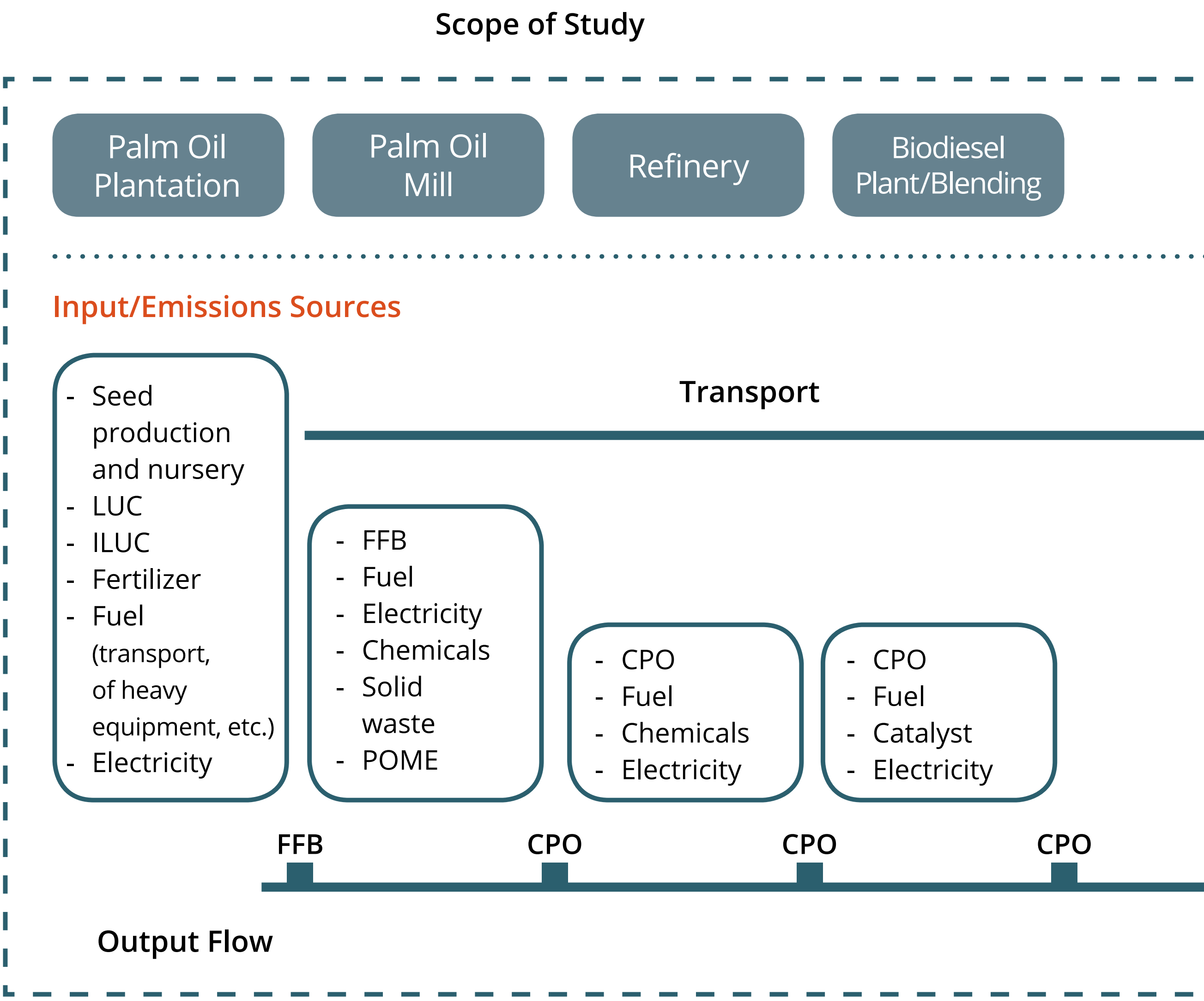
This research uses the LCA method to analyze biodiesel production from CPO in Indonesia. The scope of this study's LCA is delineated to the production stage of oil palm tree seedlings, land clearing, up to the blending station of B20. Several different production scenarios are used to see the effect on GHG emissions from biodiesel production. The Life Cycle Inventory Analysis method is used to conduct a cradle-to-grave assessment, which includes LUC, the oil palm production process, transportation, CPO production, biodiesel production, and biodiesel blending. Data analysis involves material input, energy input, and output from each stage. The LCA was limited to the LUC stage up to B20 blending, see **Figure 2**.

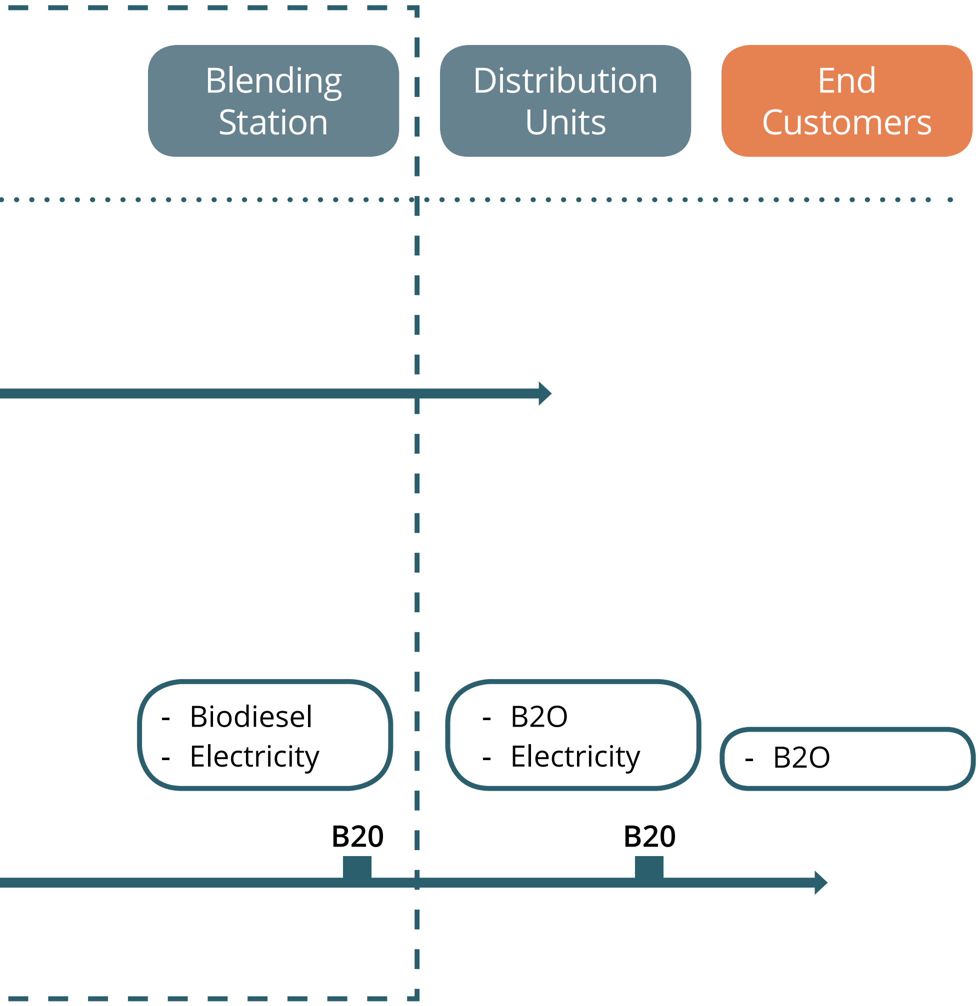
This LCA provides emission figures from current production practices of biodiesel. It does not provide a future projection of emissions because changes in practices currently being implemented across the supply chain will influence the final GHG emissions calculation. A scenario analysis is also conducted for each type of land included in the GHG calculations that factor in land use change. The period of analysis is set at one year for oil palm that is categorized as an annual crop. Emissions

**Figure 2. The scope of (Life Cycle Analysis - LCA) for CPO biodiesel production**



from LUC and land clearing for oil palm plantations are converted to annual emissions using the age of the palm tree. Material and energy inputs are calculated based on production of 1 ton of biodiesel. The unit used is hectares for plantations.

Data used in this research is obtained from both secondary and primary sources. Secondary data is obtained from various literature on the production and LCA of biodiesel in Indonesia and Malaysia, as well as academic and scientific journals and publications. Primary data was sourced from companies, including the Sustainability Reports of four palm oil companies operating in Indonesia. Primary data from palm oil smallholder farmers was obtained through random sampling in two provinces, namely Riau and West Kalimantan. Two regencies (*kabupaten*) from each province were chosen as the sampling locus for the farmers. Obtained data was then interpolated to acquire a depiction of GHG emissions in the production of oil palm from the supply of fresh fruit bunches by palm oil smallholder farmers. Two methods of data collection were used - desk-based research and field surveys.



## a. Desk-based Research

Desk-based research was carried out to obtain a literature review of the LCA of biodiesel, emission factors, and data collection related to research published by various institutions and/or research agencies focusing on the oil palm sector in Indonesia and Malaysia. Data from palm oil companies was obtained through sustainability reports in 2016 or 2017 from respondent companies, or the latest published reports. Company data was obtained based on the following criteria:

1. Availability of GHG emissions datas in the company's annual sustainability report.
2. Reported GHG emissions have been verified or audited by a third party.
3. The company produces or supplies CPO for biodiesel production.
4. Calculation of GHG emissions using the RSPO PalmGHG Calculator or ISCC method.

The literature review was carried out from October to November 2018, encompassing GHG emissions from CPO-based biodiesel.

## b. Field Surveys

Field surveys were conducted to obtain samples and to verify data from palm oil smallholder farmers. Two of Indonesia's five biggest oil palm producing provinces were selected for the field survey - Riau and West Kalimantan. Riau is the largest oil palm producing province in Indonesia, accounting for 21% of total national production, whereas West Kalimantan is the fourth largest producer, at 9% of total national production (Directorate-General of Plantations, 2018). In 2013, Riau had 140 palm oil mills and West Kalimantan had 65 (BUMN, 2014).[8]

The field surveys in the province of Riau were conducted in the Siak and Pelalawan regencies (*kabupaten*), the surveys in West Kalimantan were conducted in the Sintang and Sanggau regencies. Two villages were chosen from each regency, totalling eight villages. These eight locations were selected based on the significant areas of oil palm plantations within their borders in relation to the total portion of plantation area at the provincial level, as well as the number of palm oil smallholder farmers, the majority of whom were members of the Union of Oil Palm Farmers (*Serikat Farmer Kelapa Sawit*/SPKS). Surveys were conducted in December 2018. Interviews were conducted with re-verification of each data obtained. Responses from several respondents were not included due to lack of information, such as data on the amount of fertilizer used, or lack of information about the history of the land prior to its conversion for oil palm plantation. Sixteen palm oil smallholder farmer respondents, owning between 1-32 hectares of land, were selected from each province.

Data obtained encompassed primary data: 1) characteristics of farmers, including name, level of education, area and period of landholding; 2) external characteristics of farmers, including involvement in farmer organizations, as well as workshops or coaching clinics attended; 3) the use of input and production factors such as land use change and use of organic and non-organic fertilizer. Respondents represent farmers who have implemented land use change before and after January 1, 2008.

## c. Calculation of GHG emissions

In general, GHG emissions calculations were conducted using the concept of mass balance. In order to simplify the calculation, a multiplier factor was used, namely the emissions factor, which is a representative value that connects the quantity of emissions released into the atmosphere with activities related to those emissions. The formulation of GHG emissions using the emissions factor (IPCC, 2006) is as follows:

$$\sum Emissions = Actvitity_y \times EF$$ **(equation 1)**

Notes:

∑Emissions = Amount of emisions
Activityy = Data of activity throughout a single period (input amount of emitter)
EF = Emissions factor

Total emissions in a period of analysis is also the sum of emissions from each source of GHG within that period, formulated as follows.

$$\sum Emissions = E_{LUC} + E_{Fertilizer} + E_{Fuel} + E_{POME} + \cdots \ldots + E_{Energy}$$ **(equation 2)**

Notes:

∑LUC = Total emissions from land use change
∑Fertilizer = Total emissions from fertilizer use
∑Fuel = Total emissions from fossil fuel use
∑POME = Total emissions from palm oil mill effluent
∑Energi = Total emissions from energy use (electricity and steam)

The intensity of a product's emissions was obtained by dividing total emissions in one period with the total unit of output produced. In this research, emissions intensity for CPO production and biodiesel is formulated as follows.

$$Intensity\ of\ Greenhouse\ Gas\ Emisisons = \frac{\sum\ Emissions}{\sum\ Output}$$ **(equation 3)**

Notes:

Intensity of GHG Emissions = Per unit of GHG output (tCO2eq/tPO, gCO2eq/l biodiesel, gCO2eq/MJ)
∑Emissions = Total emissions in one period (tCO2eq/year)
∑Output = Total output in one period (tCPO/year, liter of biodiesel/year, MJ/year)

Details of emissions factors are available in each sub-chapter in the Results and Discussion chapter. The tier of data used is tier 1, both for palm oil smallholder farmers and for companies, and the emissions factor is obtained from RSPO and ISCC.

## d. Data Analysis

Data obtained from surveys on palm oil smallholder farmers were analyzed descriptively through a tabulation of respondents' distribution of each variable studied. Data related to production input from palm oil smallholder farmers and palm oil companies were tabulated quantitatively for further use in the LCA. Analysis was conducted using an inventorization of GHGs. Data is provided in units of input and output of 1 ton of biodiesel. In a number of stages, input and output are also provided in units of hectares/year. Data analysis was conducted in January 2019. Scenario analysis on land use change (LUC) was conducted based on the type of land in order to identify the effects of LUC on total GHG emissions in B20 production.

# 3. RESULTS AND DISCUSSION

PT Agriprima Cipta Persada (PT ACP) Palm Oil Concession in Papua
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The results of data analysis of the field research that was conducted in December 2018, with data obtained from the Sustainability Reports of companies and respondent data from palm oil smallholder farmers, is presented as follows:

## 3.1 Companies

Company data was obtained from four private palm oil companies. These companies publish annual sustainability reports that of provide a record GHG emissions throughout the report period, sources of GHG emissions, and emissions intensity per output of product. The four companies are Asian Agri, Golden Agri Resources, Musim Mas, and Wilmar International. These companies operate and own plantations and palm oil factories in Indonesia, as well as own biodiesel plants or supply CPO for biodiesel feedstock. These companies reported two different GHG emissions figures - those that factor in LUC, and those that do not.

### A. Asian Agri

Fresh fruit bunches processed in palm oil factories are sourced from their own plantations (38%), plasma plantations (19%), and external suppliers (43%). External suppliers include palm oil smallholder farmers that possess RSPO and ISCC certifications. The majority (90%) of palm oil smallholder farmers supplying Asian Agri have RSPO certification, and 100% of them have ISCC certification. The total number of plantations owned by Asian Agri comprise 93,574 ha, whereas plasma plantations comprise 52,917 ha. Fresh fruit bunches that are the raw material for the production of CPO are produced from mineral and peatland plantations.

Asian Agri's 2016 sustainability report states that the primary sources of GHG emissions are land conversion, oxidation of peat, and methane emissions from POME. GHG emissions are calculated using RSPO PalmGHG Calculation version 3.0. LUC was factored in due to the presence of land clearing after RSPO's cut off date of 2005. Asian Agri's report of GHG emissions in 2016 can be seen in **Table 2**.

**Table 2. GHG Emissions from CPO Production - Asian Agri**

| Location | GHG Emissions ($tCO_2eq./tCPO$) | |
|---|---|---|
| | Mineral land | Peatland |
| North Sumatera | 0.23 | 16.04 |
| Riau | 0.7 | 9.38 |
| Jambi | 0.56 | n/a |

GHG emissions data in three different locations show the range of GHG emissions to be between 0.23 $tCO_2eq/tCPO$ for CPO produced from mineral land, whereas GHG emissions from CPO produced from peatland in two locations range from 9.38 $tCO_2eq/tCPO$ to 16.04 $tCO_2eq/tCPO$.

## B. Golden Agri Resources (GAR)

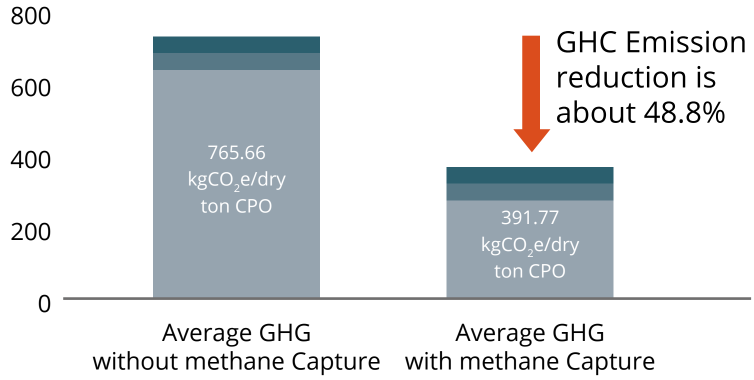
GAR reported GHG emissions without factoring in LUC. GAR's plantations have been opened before 2005, so that their GHG emissions report does not need to factor in LUC. In their 2017 Sustainability Report, GAR reported GHG emissions from CPO production at 795.25 kg$CO_2$eq/tCPO, 799.25 kg$CO_2$eq/tCPO for two locations in Kalimantan, 848.53 kg$CO_2$eq/tCPO for a location in North Sumatra, and 907.68 kg$CO_2$eq/tCPO for a location in Riau. The following is a summary of GHG emissions intensity from CPO produced by GAR.

**Table 3. GHG Emissions from the Production of CPO - Golden Agri Resources**

| Location | GHG Emissions (kg $CO_2$eq/tCPO) | | |
|---|---|---|---|
| | Verified emissions | POME emissions (ISCC method) | Total emissions |
| Sungai Rungau | 359 | 436.25 | 795.25 |
| Hanau | 363 | 436.25 | 799.25 |
| North Sumatera | 416 | 436.25 | 848.53 |
| Riau | 475 | 436.25 | 907.68 |

All calculations conducted in Kalimantan, North Sumatra, and Riau show GHG emissions ranging from 795–907 kg$CO_2$eq/tCPO. POME emissions from palm oil factories contribute more than 50% of total GHG emissions, except emissions in Riau. Average GHG emissions are 837.7 kg$CO_2$eq/tCPO. Installation of methane capture in GAR's palm oil factories reduce GHG emissions by approximately 40–55% (GAR, 2018). Average GHG emissions from all of GAR's companies, irrespective of these 4 locations, experienced a decline from 765.7 kg$CO_2$eq/tCPO to 391.8 kg$CO_2$eq/tCPO as shown in **Figure 3**. Thus, emissions from palm oil factories (POME) is 373.9 kg$CO_2$eq/tCPO.

**Figure 3. Comparison of GHG emissions from Methane Capture in GAR Palm Oil Mills (GAR, 2018).**




Attempts to reduce GHG emissions through methane capture and usage of biogas have been implemented in six palm oil mills (biogas plants) owned by GAR, with emissions reduction starting from 23,733 t$CO_2$eq/year to 101,001 t$CO_2$eq/year for each location, as shown in **Table 4**. In 2017, GHG emissions were successfully reduced by 431,160.6 MT$CO_2$eq.

**Table 4. GHG emissions reduction from GAR's Methane Capture in 2017 (GAR, 2018).**

| No | Biogas Plant | ER ($tCO_2eq.$) |
|---|---|---|
| 1 | SRUF Biogas Plant | 89,737.0 |
| 2 | SMLF Plant | 96,792.6 |
| 3 | RRMF Biogas Plant | 70,985.7 |
| 4 | PRDF Biogas Plant | 101,001.2 |
| 5 | PLKF Biogas Plant | 23,733.8 |
| 6 | LIBF Biogas Plant | 48,910.3 |
| **Total** | | 431,160.6 |

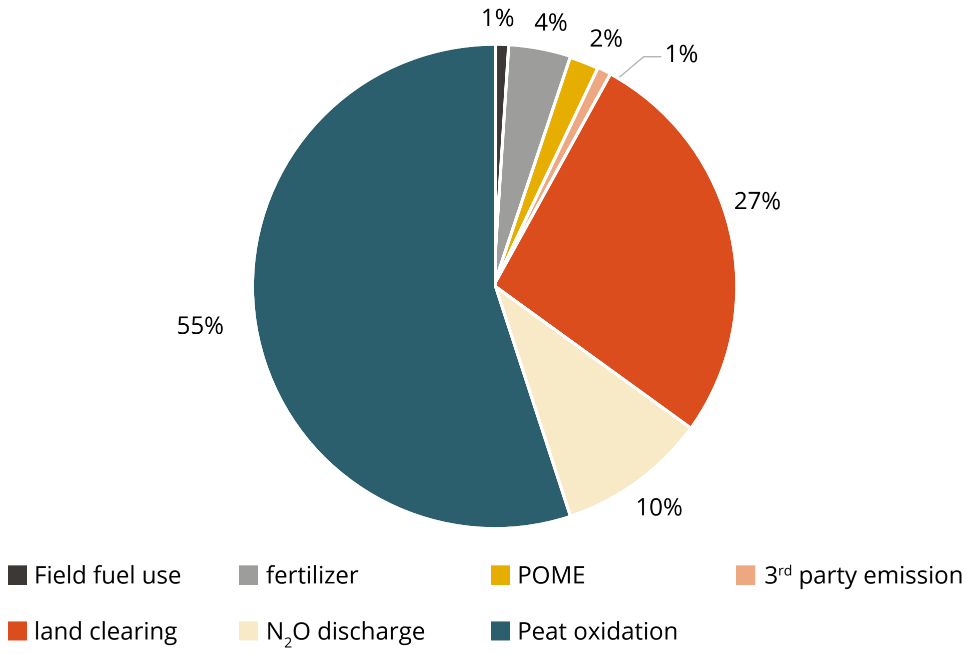
GAR owns a biodiesel plant in Kalimantan with a total capacity of 300,000 tons per year. However, no GHG emissions report from biodiesel production from this plant is available in GAR's 2017 Sustainability Report.

## C. Musim Mas

In their 2017 Sustainability Report, Musim Mas provided GHG emissions that were calculated using the RSPO PalmGHG Calculator. Fresh fruit bunches processed by Musim Mas were obtained from their own plantations (68%), plasma plantations (3%), and palm oil smallholder farmers' plantations (29%) with a total in 2017 of 3.3 million tons of processed fresh fruit bunches. Musim Mas' OER was 22.60% in 2017. Musim Mas reported GHG emissions intensity as group emissions. Their Sustainability Report does not record emissions per palm oil factory or location. Group emissions shifted from 3,330 $kgCO_2eq/tCPO$ in 2016 to 3,390 $kg/CO_2eq/tCPO$ in 2017.

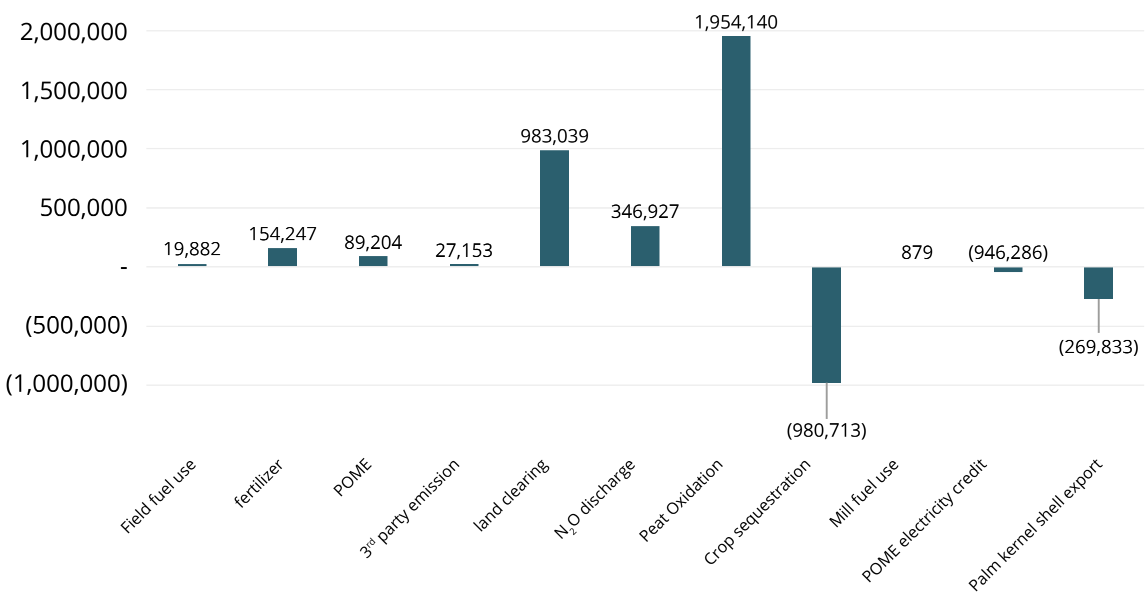
GHG emissions reported by Musim Mas factor in emissions from land conversion after 2005, as well as emissions from peat oxidation. At 92%, the largest source of emissions originated from peat oxidation, land clearing, and $N_2O$. The proportion of emissions based on source is shown in **Figure 4**.

**Figure 4. Percentage of Emissions from CPO Production - Musim Mas**




Musim Mas has installed methane capture technology and reduced GHG emissions from POME, so that the percentage of emissions from POME fell to 2% of total emissions, lower than fertilizer emissions. Biogas produced from methane capture facilities has been utilized for their own electricity production (captive power), as well as the selling of excess power to the National Electricity Company's grid (PLN). This is seen from emission credits from electricity as well as shell sales, as seen in **Table 8**. Musim Mas owns 18 biofuel plants including biodiesel plants. However, the company's Sustainability Report does not report GHG emissions from biodiesel production activities and biodiesel emissions intensity.

**Figure 5. Sources of GHG Emissions - Musim Mas**



## D. Wilmar International

In their 2017 Sustainability Report, Wilmar states their GHG emissions from CPO production as 2.88 tons $CO_2$eq/tCPO, factoring in LUC (Wilmar International, 2018). Meanwhile, their 2016 Sustainability Report states GHG emissions of 2.23 t $CO_2$eq/tCPO. From total GHG emissions of 4.14 million t$CO_2$eq in 2017, as seen in **Figure 6**, the LUC sector contributed 1.73 million $CO_2$eq, and the peat sector contributed 1.26 million t$CO_2$eq. This number is offset by the carbon sequestration sector in oil palm and in conservation plants, numbering 1.87 million MT$CO_2$eq and 58,718 MT$CO_2$eq, respectively. With fresh fruit bunch production at 3,922,904 MT and CPO production at 1,742,618 MT in 2017, Wilmar's average fresh fruit bunch productivity is 19.7 tons/ha, as seen in **Table 5**, with a 20% extraction rate of CPO to FFB.

**Figure 6. Sources of GHG Emissions - Wilmar International 2017 (Wilmar International, 2018)**

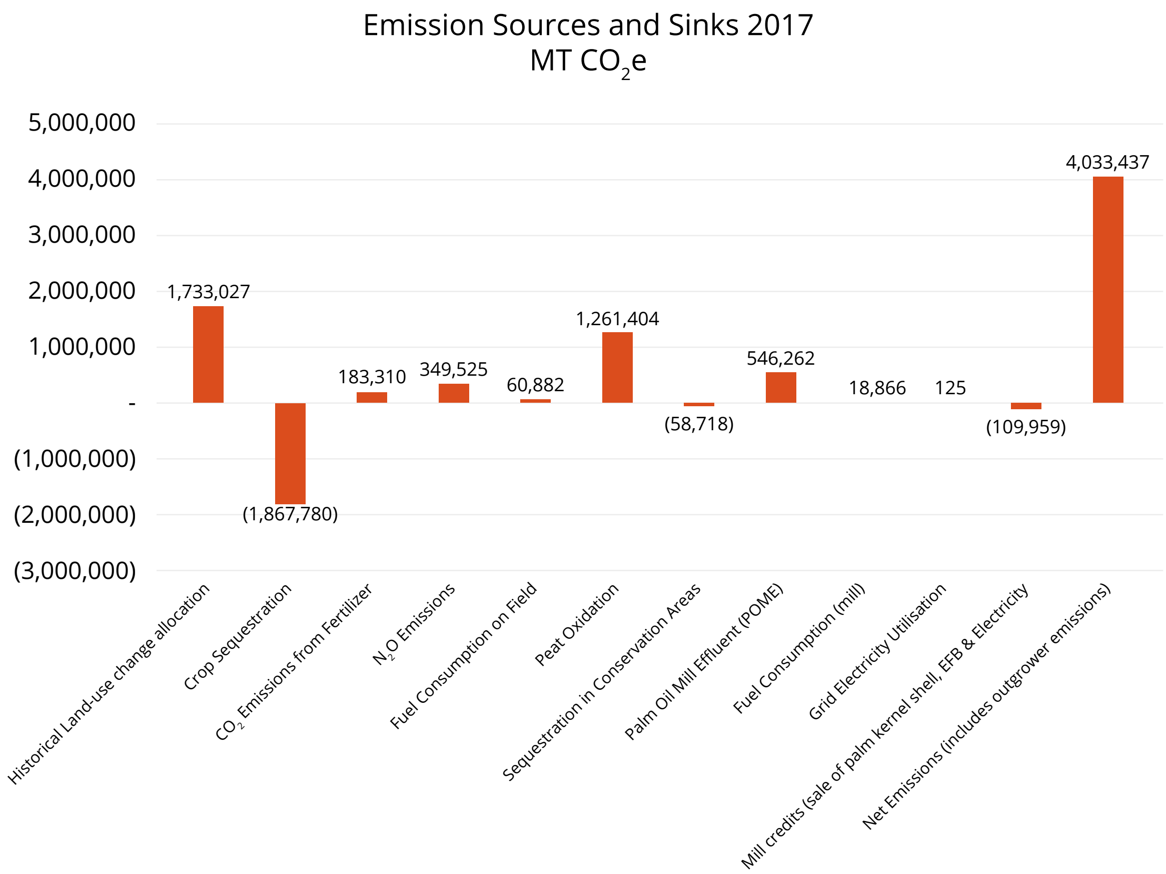
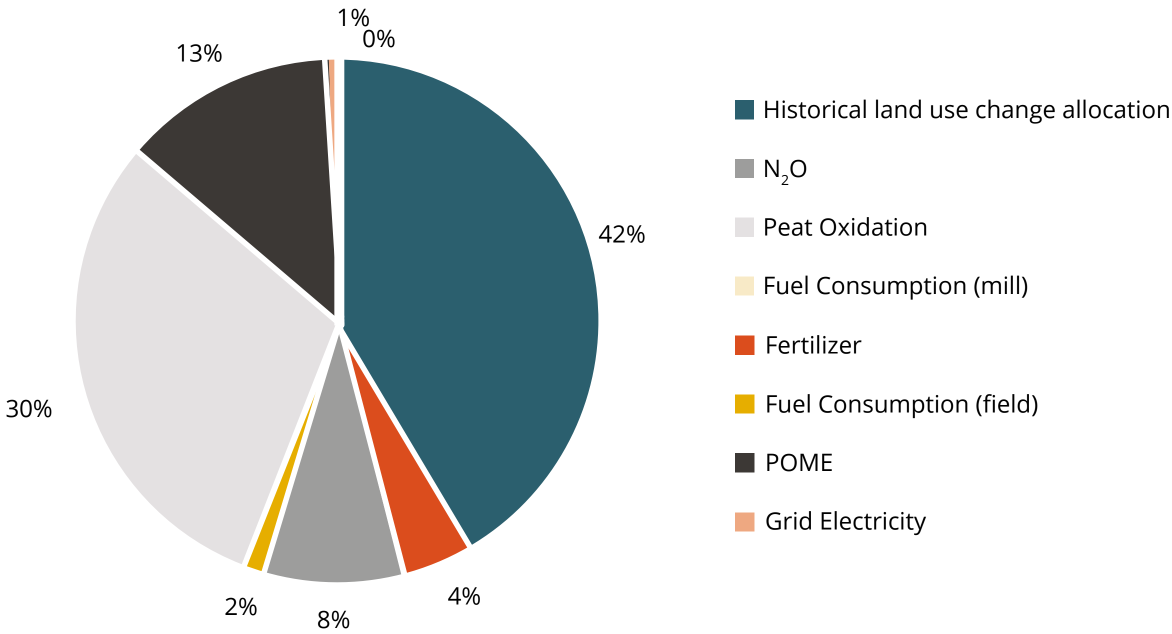


**Figure 7. Sources of Plantation Emissions - Wilmar International**




Looking at the production value of Wilmar's FFB and CPO, it can be concluded that external supplies of FFB greatly surpass FFB from their own plantations. Re-verification is required to obtain the number of FFB bought from external sources, due to different levels of extraction for each FFB supplier, depending on the type of seedling and practice of agronomy implemented. Nonetheless, reported GHG emissions are a result of self-produced FFB and CPO production, as well as FFB and CPO supplied from a third party, namely palm oil smallholder farmers.

**Table 5. Production Data of Wilmar International in 2017 (Wilmar International, 2018)**

| Notes | Value |
|---|---:|
| OER | 20% |
| FFB yield (t FFB/ha) | 19,7 |
| Area (ha) | 229.456 |

Differences in GHG emissions in 2016 and 2017 are caused by an addition of peatland in Wilmar International's plantation area. In 2017, the plantation area from peatland comprised 22,492 ha compared to 22,187 ha in 2016. Using the RSPO PalmGHG Calculator, Wilmar International reported that GHG emissions based on the location of Wilmar International's plantations ranged from 750 $kgCO_2eq/tCPO$ to 16,040 $kgCO_2eq/tCPO$, with average emissions in 2017 at 2,880 $kgCO_2eq/tCPO$. An addition of 305 ha of peatland in 2017 contributed to a rise in total GHG emissions, from 2,230 $kgCO_2eq/tCPO$ in 2016 to 2,880 $kgCO_2eq/tCPO$ in 2017.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These four companies reported different levels of GHG emissions based on location and company group. The range of GHG emissions per ton of CPO from these four companies is displayed in **Table 6**. Referring to **Table 6**, GHG emissions per ton of CPO range from 0.56 $tCO_2eq/tCPO$ to 16.04 $tCO_2eq/tCPO$. Significant differences occur in companies that have converted land after 2005 as well as set up plantations in peatland.

**Table 6. Summary of GHG Emissions from Palm Oil Companies**

| Company | GHG Emissions ($tCO_2eq./tCPO$) | |
|---|---|---|
| | Range of emissions | Company average |
| GAR | 0.80 – 0.91 | 0.84 |
| Wilmar International | 0.75 – 16.04 | 2.88 |
| Asian Agri | 0.56 – 16.04 | n/a |
| Musim Mas | n/a | 3.39 |

Although not all companies provided details of GHG emissions sources, a common pattern can be inferred from these four companies. For companies that cleared land after 2005 and converted plantations from peatland, the largest source of emissions were land clearing and peat oxidation. The next largest sources of emissions were $N_2O$, POME, and fertilizer use.

## 3.2 Palm Oil Smallholder Farmers

Based on field data obtained in the provinces of Riau and West Kalimantan in December 2018, several interesting facts were found related to GHG emissions from the LUC sector, fertilizer and pesticide use in plantations, and transportation.

### 3.2.1 GHG Emissions from Land Use Change (LUC)

Palm oil smallholder farmer respondents in Riau are located in two regencies, namely Pelalawan and Siak, and two villages from each regency were chosen as survey locations. There are 16 respondents from four villages, with land ownership ranging between 1 ha to 20 ha, and with more than half of the respondents owning land between 2 and 4 ha.

Respondents in West Kalimantan were chosen from the Sintang and Sanggau regencies. Two villages were chosen from each regency and four palm oil smallholder farmer respondents were chosen from each village, with a total of 16 respondents from the province of West Kalimantan.

**Table 7. Land Use Change Data from Palm Oil Smallholder Farmer Respondents in Riau**

| No | Respondent | Land area (hectare) | Period of Land Ownership | Planting Year | | Prior History of Land |
|---|---|---|---|---|---|---|
| | | | | Productive | Not Yet Productive | |
| **Provinsi Riau** | | | | | | |
| 1 | Farmer R.1 | 18 | Between 10–20 years | 1997: 4 hectares | | Scrub |
| | | | | 2000: 7 hectares | | |
| | | | | 2002: 7 hectares | | |
| 2 | Farmer R.2 | 2 | Over 20 years | 2005: 1 hectares | | Rubber Plantation |
| | | | | 2007: 1 hectares (gambut) | | |
| 3 | Farmer R.3 | 4 | Historically inherited | 1998: 4 hectares | | Rubber Plantation |
| 4 | Farmer R.4 | 2 | Over 20 years | 2007: 2 hectares | | Forest |
| 5 | Farmer R.5 | 4 | 10–20 years | 2004: 4 hectares | | Scrub |
| 6 | Farmer R.6 | 6 | Over 20 years | 1994: 2 hectares | | Forest |
| | | | | 2005: 2 hectares | | |
| | | | | 2010: 2 hectares | | |
| 7 | Farmer R.7 | 20 | 10–20 years | 1996: 4 hectares | | Scrub |
| | | | | 1998: 4 hectares | | |
| | | | | 2000: 6 hectares | | |
| | | | | 2002: 6 hectares | | |
| 8 | Farmer R.8 | 6 | 10–20 years | 2005: 6 hectares | | Scrub |
| 9 | Farmer R.9 | 4 | Historically inherited | 1998: 4 hectares | | Farmland |
| 10 | Farmer R.10 | 4 | Historically inherited | 2014: 1,3 hectares | 2015: 2,7 hectares | Farmland |
| 11 | Farmer R.11 | 2 | 10–20 years | 2004: 2 hectares | | Scrub |
| 12 | Farmer R.12 | 1 | Between 10–20 years | 2004: 1 hectares | | Farmland |
| 13 | Farmer R.13 | 2 | Over 20 years | 1999: 2 hectares | | Scrub |
| 14 | Farmer R.14 | 3 | Over 20 years | 1999: 3 hectares | | Scrub |
| 15 | Farmer R.15 | 10 | Between 10–20 years | 2005: 10 hectares | | Scrub |
| 16 | Farmer R.16 | 4 | Over 20 years | | 2015: 4 hectares | Scrub |
| | **Total** | **92** | | | | |

LUC data in **Table 7** and **Table 9** show that two farmers in Riau and one farmer in West Kalimantan own oil palm plantations that were previously forest. The majority of plantations owned by palm oil smallholder farmers were formerly rubber plantations, scrub, and farmland. The period of land ownership for previously forested land in Riau is more than 20 years, and for the farmer in West Kalimantan is historically inherited. Therefore, calculations of GHG emissions no longer need to factor in LUC. In accordance with ISCC terms, LUC is not factored in for oil palm plantations that existed before 1 January 2008. Whereas the RSPO calculates LUC if land clearing for oil palm plantations was conducted after 2005. For a better comparison between palm oil smallholder farmers and companies, LUC is calculated from after 2005.

**Table 8. Carbon Stocks of Biomass from Palm GHG Calculator (RSPO, RSPO GHG assessment procedure for new developments, 2016)**

| Land cover classes | Carbon stocks in tonne C/ha |
|---|---|
| Primary forest | 268 |
| Logged forest | 128 |
| Tree Crop | 75 |
| Oil palm | 57.5 |
| Shrubland | 46 |
| Food crops | 9 |
| Grassland | 5 |

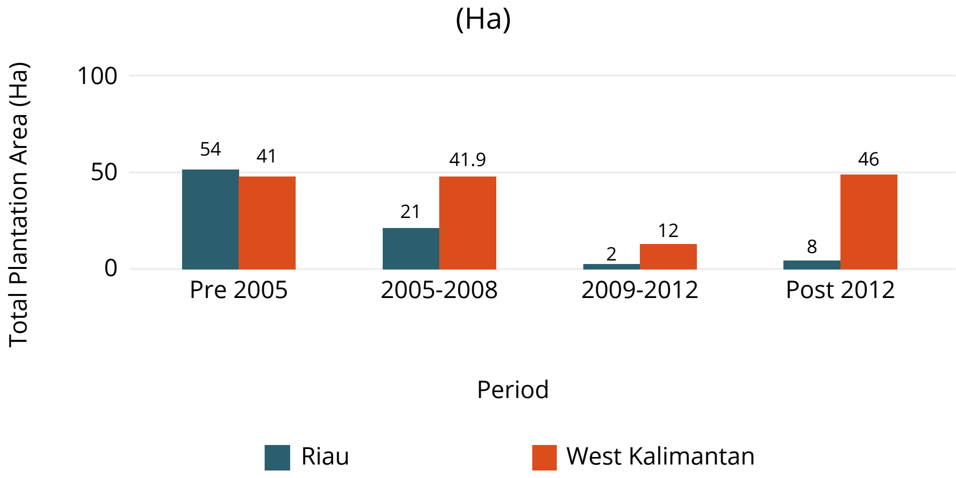
From a total of 92 hectares of land owned by palm oil smallholder farmers in Riau, 32 hectares of oil palm was planted after 2005. For West Kalimantan, 42 hectares of oil palm was cleared before 2005, whereas the remaining 97.9 hectares was planted in or after 2005, thus necessitating GHG emissions from LUC to be factored in. In the LUC analysis, there is LUC from palm oil smallholder farmers before oil palm plantations, namely from primary forests, secondary forests, plants, scrub, as well as secondary cropland and grassland, as seen in the value of carbon stocks in **Table 8**. Peatland calculations are not factored in because there are no land use changes from peatland in the plantations of palm oil smallholder farmers in Riau and West Kalimantan.

**Table 9. Land Use Change Data for Palm Oil Smallholder Farmers in West Kalimantan**

| No | Name | Land area (hectare) | Period of Land Ownership | Planting Year | | Prior History of Land |
|---|---|---|---|---|---|---|
| | | | | Productive | Not Yet Productive | |
| | **Province of West Kalimantan** | | | | | |
| 1 | Farmer K.1 | 12 | Over 20 years | 2006: 8 hectares | 2017: 4 hectares | Rubber plantation |
| 2 | Farmer K.2 | 11 | Historically inherited | 2005: 4 hectares | | Rubber plantation |
| | | | | 2007: 7 hectares | | |
| 3 | Farmer K.3 | 7 | Less than 10 years | 2008: 3 hectares | | Scrub |
| 4 | Farmer K.4 | 2 | Less than 10 years | 1997: 1 hectares | 2015: 1 hectares | Scrub |
| 5 | Farmer K.5 | 2 | Between 10-20 years | 2007: 2 hectares | | Farmland and Scrub |
| 6 | Farmer K.6 | 10 | Between 10-20 years | 2012: 6 hectares | 2016: 4 hectares | Scrub |
| 7 | Farmer K.7 | 18 | Less than 10 years dan antara 10-20 | 1997: 14 hectares | 2015: 4 hectares | Farmland and Scrub |
| 8 | Farmer K.8 | 4 | Over 20 years | 1997: 4 hectares | | Farmland and Scrub |
| 9 | Farmer K.9 | 6 | Historically inherited | 2007: 6 hectares | | Forest |
| 10 | Farmer K.10 | 2,3 | Between 10-20 years | 2008: 2,3 hectares | | Scrub |
| 11 | Farmer K.11 | 1,7 | Between 10-20 years | 1999: 1,7 hectares | | Rubber plantation |
| 12 | Farmer K.12 | 3,6 | Between 10-20 years | 1999: 2 hectares | 2007: 1,6 hectares | Scrub |
| 13 | Farmer K.13 | 2,3 | Historically inherited | 2000: 2,3 hectares | | Farmland and Scrub |
| 14 | Farmer K.14 | 2 | Between 10-20 years | 2008: 2 hectares | | Farmland and Scrub |
| 15 | Farmer K.15 | 32 | Between 10-20 years and Less than 10 years | 1999: 4 hectares; 2008: 4 hectares | 2011: 6 hectares | Scrub |
| | | | | | 2012: 6 hectares | |
| | | | | | 2013: 6 hectares | |
| | | | | | 2014: 4 hectares | |
| | | | | | 2017: 2 hectares | |
| 16 | Farmer K.16 | 24 | Historically inherited | 1992: 5 hectares; 1995: 2 hectares; 2002: 2 hectares | 2015: 15 hectares | Farmland and Scrub |
| | | | | | | Scrub |
| | | | | | | Rubber plantation |
| | **total** | **139.9** | | | | |

Data obtained from respondents in two provinces show a total land area of 231.9 ha. From this figure 42% - 92 ha - was cleared before 2005 28% - 62.9 ha - was cleared between 2005 and 2008 6% - 14 ha - was opened between 2009–2012, and 24% - 54 ha - was cleared after 2012. The distribution of annual land clearing in Riau and West Kalimantan can be seen in **Figure 8**.

**Figure 8. Distribution of annual land clearing by Palm Oil Smallholder Farmers in Riau and West Kalimantan**




### 3.2.2 GHG emissions from plantations

GHG emissions from plantations are calculated as the amount of GHG emissions produced through plantation activity in a year, divided by plantation productivity, namely the amount of FFB produced. FFB productivity greatly depends on the type of seedling used, as well as the usage of fertilizer and pesticide. **Table 10** portrays FFB productivity of palm oil smallholder farmers in Riau. The lowest amount of productivity is 6 tons of FFB/ha/year, the highest is 18 tons of FFB/ha/year. Three farmers have a productivity of 6 tons of FFB/ha/year, and only four farmers have a productivity above 10 tons of FFB/ha/year. One farmer does not have information related to productivity because the plants have not yet produced fruit. Total production is 960.6 tons of FFB for an area of 92 hectares, with an average of 10.4 tons of FFB/ha/year. Productivity levels of palm oil smallholder farmers in Riau are only half of the average productivity of plantations belonging to Wilmar, namely 19.7 tons of FFB/ha (Wilmar International 2018), and 20.5 tons of FFB/ha for plantations belonging to GAR (GAR, 2018).

**Table 10. Productivity of Palm Oil Smallholder Farmers in Riau**

| No | Name | Land Area (ha) | Harvest Cycle/ Month | Productivity/ month (ton FFB/ha) | Source of Seedling | Type of Seedling | Yield ( ton FFB/ ha/ year) | Production (FFB ton) |
|---|---|---|---|---|---|---|---|---|
| | **Provinsi Riau** | | | | | | | |
| 1 | Farmer R.1 | 18 | 3 times | 1.5 | Seedling | Non-hybrid | 18 | 324 |
| 2 | Farmer R.2 | 2 | 2 times | 1 | PT. Guna Dodos | Hybrid | 12 | 24 |
| 3 | Farmer R.3 | 4 | per 20 days | 0.625 | PT. Guna Dodos & Seedling | Hybrid and non-hybrid | 7,5 | 30 |
| 4 | Farmer R.4 | 2 | per 20 days | 0.5 | PT. Guna Dodos | Hybrid | 6 | 12 |
| 5 | Farmer R.5 | 4 | 3 times | 1.25 | Seedling | Non-hybrid | 15 | 60 |
| 6 | Farmer R.6 | 6 | 3 times | 0.75 | Seedling | Non-hybrid | 9 | 54 |
| 7 | Farmer R.7 | 20 | 3 times | 0.7 | Seedling | Non-hybrid | 8.4 | 168 |
| 8 | Farmer R.8 | 6 | 2 times | 1 | PT. Guna Dodos | Hybrid | 12 | 72 |
| 9 | Farmer R.9 | 4 | 2 times | 1.25 | PT. Guna Dodos | Hybrid | 15 | 60 |
| 10 | Farmer R.10 | 4 | 2 times | 0.5 | KKPA (Coop Credit) | Hybrid | 6 | 24 |
| 11 | Farmer R.11 | 2 | 2 times | 0.75 | Dinas Perkebunan | Hybrid | 9 | 18 |
| 12 | Farmer R.12 | 1 | 2 times | 0.7 | Donated | Hybrid | 8.4 | 8.4 |
| 13 | Farmer R.13 | 2 | 2 times | 0.8 | Seedling | Non-hybrid | 9.6 | 19.2 |
| 14 | Farmer R.14 | 3 | 2 times | 0.75 | Seedling | Non-hybrid | 9 | 27 |
| 15 | Farmer R.15 | 10 | 2 times | 0.5 | Seedling | Non-hybrid | 6 | 60 |
| 16 | Farmer R.16 | 4 | n/a | n/a | Agent | Non-hybrid | n/a | n/a |
| | **total** | **92** | | | | | | **960.6** |

*Notes: Farmer R.16's plantation has not yet produced fruit*

Productivity of oil palm plantations owned by palm oil smallholder farmers in West Kalimantan range from 6 to 19.6 tons of FFB/ha/year, with an average of 13.5 tons of FFB/ha/year. This average is relatively higher than the average productivity of palm oil smallholder farmers in Riau. This is due to several factors, such as the age of the oil palm plant for the productive period in West Kalimantan, at a relatively recent planting year (7–15 years), compared to Riau, with a relatively aged planting year (15–27 years), which thus requires rejuvenation as shown in **Table 10** and **Table 11**. In addition, factors that impact the productivity of oil palm is the consumption of fertilizer, which is relatively better in West Kalimantan compared to Riau.

Although the productivity of palm oil smallholder farmers in West Kalimantan is higher than that of farmers in Riau, the general average of farmers' productivity in these two provinces is 20% to 50% lower than the productivity of palm oil companies. A palm oil smallholde farmer in West Kalimantan has a land productivity nearing that of a palm oil company, namely 19.6 tons/ha/year. Aside from the quality of seedling, low levels of productivity can also be caused by fertilizer use in palm oil smallholder farmers' plantations. Fertilizer use in palm oil smallholder farmers is highly influenced by knowledge of good agricultural practice (GAP) and the individual financial capabilities of each farmer.

**Table 11. Productivity of Palm Oil Smallholder Farmers in West Kalimantan**

| No | Name | Land Area (ha) | Harvest Cycle/ Month | Productivity/ month (ton FFB/ha) | Source of Seedling | Type of Seedling | Yield (ton FFB/ ha/ year) | Production (FFB ton) |
|---|---|---|---|---|---|---|---|---|
| | **Province of West Kalimantan** | | | | | | | |
| 1 | Farmer K.1 | 12 | 2 times | 1 | Seedling | Non-hybrid | 12 | 144 |
| 2 | Farmer K.2 | 11 | 2 times | 1.1 | PPKS Perindo | Hybrid | 13.2 | 145.2 |
| 3 | Farmer K.3 | 7 | 2 times | 1 | PPKS Perindo | Hybrid | 12 | 84 |
| 4 | Farmer K.4 | 2 | 2 times | 1.25 | Lyman Agro | Hybrid | 15 | 30 |
| 5 | Farmer K.5 | 2 | 2 times | 1.25 | Gov't Office of Plantations | Hybrid | 15 | 30 |
| 6 | Farmer K.6 | 10 | 2 times | 1 | PPKS Perindo | Hybrid | 12 | 120 |
| 7 | Farmer K.7 | 18 | 2 times | 1 | Company | Hybrid | 12 | 216 |
| 8 | Farmer K.8 | 4 | 2 times | 0.5 | Lyman Agro | Hybrid | 6 | 24 |
| 9 | Farmer K.9 | 6 | 2 times | 0.5 | PPKS Perindo | Hybrid | 6 | 36 |
| 10 | Farmer K.10 | 2.3 | 2 times | 0.7 | Company | n/a | 8.4 | 19.32 |
| 11 | Farmer K.11 | 1.7 | 2 times | 1.25 | PPKS Parindu | Hybrid | 8.8 | 14.96 |
| 12 | Farmer K.12 | 3.6 | 2 times | 0.75 | PPKSP parindu | Hybrid | 9 | 32.4 |
| 13 | Farmer K.13 | 2.3 | 1 times | 1 | PTPN 13 | Hybrid | 12 | 27.6 |
| 14 | Farmer K.14 | 2 | 2 times | 0.75 | Gov't Office of Plantations | Hybrid | 9 | 18 |
| 15 | Farmer K.15 | 32 | 2 times | 1.4 | PPKS Parindu | Hybrid | 14.8 | 473.6 |
| 16 | Farmer K.16 | 24 | 2 times | 1.6 | PPKS Parindu | Hybrid | 19.6 | 470.4 |
| | **total** | **139.9** | | | | | | **1.885.48** |

Emissions from fertilizer refers to **Table 12** based on data from ISCC (ISCC, 2016). Consumption of fertilizer and pesticide is shown in **Table 13** and **Table 14** for each palm oil smallholder farmer in Riau and West Kalimantan. Pesticide consumption refers to amount in kilogram of active material contained in the pesticide, with pesticide density assumed to be equivalent to water, namely 1 kilogram equivalent to 1 liter.

**Table 12. GHG Emission Factors from Fertilizer and Pesticide (ISCC, 2016).**

| Materials | Value | Unit | Source |
|---|---|---|---|
| N-fertilizer | 5.881 | kgCO2eq/kg | European Commision |
| P2O5-fertilizer (Diammonium Phosphate) | 1.011 | kgCO2eq/kg | European Commision / ISCC |
| K2O-fertilizer (Pupuk MOP) | 0.576 | kgCO2eq/kg | Ecoinvent 2010 / ISCC |
| Urea | 1.92 | kgCO2eq/kg | Biograce 2011 / ISCC |
| TSP | 0.54 | kgCO2eq/kg | Biograce 2014 / ISCC |
| Rock Phosphate | 0.09 | kgCO2eq/kg | Biograce 2015 / ISCC |
| Pesticide | 10.97 | kgCO2eq/kg air | European Commision / ISCC |

Use of fertilizer by palm oil smallholder farmers varies in type and quantity. The type of fertilizer used includes organic and inorganic fertilizer obtained from fertilizer shops and cooperatives. Organic fertilizer used by farmers is comprised of empty bunch (*janjang kosong*) and compost from livestock faeces, such as cow manure. Palm oil smallholder farmers in West Kalimantan and Riau use between 4 to 180 liters of pesticide per year, however, some farmers do not use any pesticide at all.

**Table 13. Use of Fertilizer and Pesticide by Palm Oil Smallholder Farmers in Riau**

| No | Name | Fertilizer supplier | Fertilizer type (kg)/ha/year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | NPK | N | $P_2O_5$ | $K_2O$ | Urea | Pesticide (L) | Pesticide a.i. (L) | Other |
| | **Riau Province** | | | | | | | | | |
| 1 | Farmer R.1 | Shop | | 0 | 0 | 0 | 600 | | | Empty bunch 200 kg/4 months |
| 2 | Farmer R.2 | Shop | 675 | 101.25 | 101.25 | 101.25 | | Round up 4 | 1.44 | |
| 3 | Farmer R.3 | Shop | | 0 | 0 | 0 | | Round up 4 | 1.44 | Livestock manure 300 kg/ year |
| 4 | Farmer R.4 | Shop | | 0 | 0 | 0 | 50 | Gramoxone 7 | 1.4 | |
| 5 | Farmer R.5 | Shop | 1000 | 150 | 150 | 150 | 500 | Round Up 60 | 21.6 | |
| 6 | Farmer R.6 | Shop | | 0 | 0 | 0 | 1200 | | | Empty bunch 2 ton/year |
| 7 | Farmer R.7 | Shop | 150 | 22.5 | 22.5 | 22.5 | 150 | | | |
| 8 | Farmer R.8 | Shop | 300 | 45 | 45 | 45 | | Gramoxone 40 | 8 | Kieserite 150 kg/6 months |
| 9 | Farmer R.9 | Shop | | 0 | 0 | 0 | 600 | Gramoxone 25 | 5 | Empty bunch |
| 10 | Farmer R.10 | Shop | | 0 | 0 | 0 | 600 | Gramoxone 15 | 3 | TSP 150 kg/6 months |
| 11 | Farmer R.11 | Shop | | 0 | 0 | 0 | 400 | Round up 1 | 0.36 | RP 200 kg/6 months |
| 12 | Farmer R.12 | Shop | | 0 | 0 | 0 | 800 | | | |
| 13 | Farmer R.13 | Shop | | 0 | 0 | 0 | | Round up 20 | 7.2 | Compost 130 kg/3 months |
| 14 | Farmer R.14 | Shop | 1200 | 180 | 180 | 180 | | Round Up 5 | 1.8 | |
| 15 | Farmer R.15 | Shop | | 0 | 0 | 0 | | | | Empty bunch 300kg |
| 16 | Farmer R.16 | Shop | | 0.0 | 0.0 | 0.0 | | | | |
| Total (kg) | | | 3,325.0 | 498.8 | 498.8 | 498.8 | 4,900.0 | | 51.2 | TSP 300 kg and RP 400 kg |
| **GHG ($kgCO_2eq$)** | | | | **2,933.1** | **504.2** | **287.3** | **9,408.0** | | **562.1** | **198.0** |

GHG emissions from fertilizer use by palm oil smallholder farmers in Riau in **Table 13** show that organic fertilizers such as empty fruit bunches and livestock manure, are used to (complement) complementing inorganic fertilizer such as NPK, urea, dolomite, etc. Some farmers only use livestock manure for their plantations. With total GHG emissions at 13.69 tons of $CO_2$eq, and total FFB produced at 960.9 tons, the total GHG emissions for palm oil smallholder farmers in Riau is 14.26 kg $CO_2$eq/ton FFB. As farmers use different quantities of NPK fertilizer, these calculations assume that the NPK fertilizer used contains 15% of N mass, 15% of $P_2O_5$ mass, and 15% of $K_2O$ mass. Other NPK fertilizer components include sulphur and zinc, but these are ignored because of their relatively low mass percentage, namely 9% and 0.002%, respectively; furthermore, they are not included in the ISCC emission factors.

GHG emissions from fertilizer use in palm oil smallholder farmers in West Kalimantan are shown in **Table 14**. palm oil smallholder farmers in West Kalimantan use inorganic fertilizer, with or without organic fertilizer added in. Based on data in Table 18, GHG emissions are at 28.03 tons $CO_2$eq. With a total production of 1,885.48 tons FFB, GHG emissions of fertilizer use by palm oil smallholder farmers in West Kalimantan amount to 14.87 kg$CO_2$eq/ton FFB. This figure is slightly higher than GHG emissions from fertilizer use by farmers in Riau.

**Table 14. Use of Fertilizer and Pesticide by Palm Oil Smallholder Farmers in West Kalimantan**

| No | Name | Source of Fertilizer | Type of fertilizer (kg)/ha/year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | NPK | N | $P_2O_5$ | $K_2O$ | Urea | Pesticide (L) | Pesticide active ingredients (L) | Others |
| | West Kalimantan Province | | | | | | | | | |
| 1 | Farmer K.1 | Shop | 600 | 90 | 90 | 90 | 600 | Round up 180. Gramoxone 150 | 94.8 | |
| 2 | Farmer K.2 | Shop | 600 | 90 | 90 | 90 | 600 | | | |
| 3 | Farmer K.3 | Shop | 600 | 90 | 90 | 90 | 2400 | | | |
| 4 | Farmer K.4 | Shop | 1000 | 150 | 150 | 150 | | Round up 20 | 7.2 | |
| 5 | Farmer K.5 | Shop | | 0 | 0 | 0 | | | | |
| 6 | Farmer K.6 | Shop | 900 | 135 | 135 | 135 | 900 | Roundup 30. Gramoxone 30 | 16.8 | |
| 7 | Farmer K.7 | Shop | 600 | 90 | 90 | 90 | | Gramoxone 10 | 2 | |
| 8 | Farmer K.8 | Shop | 300 | 45 | 45 | 45 | 300 | Gramoxone 20 | 4 | |
| 9 | Farmer K.9 | Shop | 800 | 120 | 120 | 120 | | Gramoxone 12 | 2.4 | |
| 10 | Farmer K.10 | Shop | 300 | 45 | 45 | 45 | 350 | Gramoxone 12. Roundup 12 | 6.72 | |
| 11 | Farmer K.11 | Cooperative | 1500 | 225 | 225 | 225 | 500 | | | |
| 12 | Farmer K.12 | Cooperative | 1000 | 150 | 150 | 150 | 500 | Gramoxone 10. Roundup 5 | 3.8 | |
| 13 | Farmer K.13 | Cooperative | 1000 | 150 | 150 | 150 | | Gramoxone 48 | 9.6 | |
| 14 | Farmer K.14 | Cooperative | 350 | 52.5 | 52.5 | 52.5 | 400 | Gramoxone 15. Roundup 15 | 8.4 | |
| 15 | Farmer K.15 | Shop | 798 | 119.7 | 119.7 | 119.7 | 708 | Round up 48 . Supretox 48 | 26.88 | TSP 133kg/4 months |
| 16 | Farmer K.16 | Shop | 133.00 | 19.95 | 19.95 | 19.95 | 133.00 | Round up 24 | 8.64 | |
| Total (kg) | | | 10,481.0 | 1,572.2 | 1,572.2 | 1,572.2 | 7,391.0 | | 191.2 | TSP 399 kg |
| **GHG (kg$CO_2$eq.)** | | | | **9,244.2** | **1,587.9** | **911.8** | **14,190.7** | | **2,097.9** | **215.5** |

### 3.2.3 GHG emissions from transportation

GHG emissions from transportation refers to FFB transported from palm oil smallholder farmers' plantations to the palm oil factory or collectors. The amount of fuel consumption is based on the Hino FG 235 JK truck that is commonly used to transport fruit to palm oil factories/collectors/cooperatives. This truck has a capacity of 9 tons of FFB and a standard fuel efficiency of 2.9 km ton/L diesel fuel. This type of truck can travel 2.9 km for each ton per liter of diesel fuel. The GHG emissions calculation is based on the assumption that the truck does not carry a load when returning from transporting FFB, so that fuel consumption factors in the truck's fuel consumption with and without load. **Table 15** and **Table 16** shows that the distance between palm oil smallholder farmers' plantations and palm oil factories/collectors/cooperatives in Riau is shorter than in West Kalimantan 2–26 km in Riau compared to 2–100 km in West Kalimantan.

The amount of fuel consumption per ton of FFB (L/ton FFB) transported is calculated by dividing the average distance of farmer plantations from the palm oil factory, with a standard fuel efficiency of 2.9 km/L. Total diesel fuel consumption for each farmer is calculated by multiplying the consumption of fuel per ton FFB (L/ton FFB) by FFB production. GHG emissions from transportation are calculated by multiplying total fuel consumption for transporting FFB by the emissions factor for diesel fuel for transportation. Next, total GHG emissions from transportation is divided by total FFB production in order to obtain GHG emissions per ton of FFB for transportation.

**Table 15. Transportation of FFB to Palm Oil Factory - Palm Oil Smallholder Farmers in Riau**

| No | Name | Distance of FFB sale (km) | | | | Diesel (L/ton FFB) | Production (ton FFB) | Total diesel (L) | GHG emissions (kg$CO_2$eq.) |
|---|---|---|---|---|---|---|---|---|---|
| | | Factory | Collector | Cooperative | Average | | | | |
| **Riau Province** | | | | | | | | | |
| 1 | Farmer R.1 | | 5 | 3 | 8 | 2.8 | 22.1 | 60.9 | 191.6 |
| 2 | Farmer R.2 | 6 | | | 12 | 4.1 | 49.7 | 205.5 | 645.7 |
| 3 | Farmer R.3 | 13 | | | 26 | 9.0 | 233.1 | 2,089.9 | 65,622.6 |
| 4 | Farmer R.4 | 6 | | | 12 | 4.1 | 49.7 | 205.5 | 6,451.7 |
| 5 | Farmer R.5 | | 7 | | 14 | 4.8 | 67.6 | 326.3 | 10,245.1 |
| 6 | Farmer R.6 | 1,5 | | | 3 | 1.0 | 3.1 | 3.2 | 100.8 |
| 7 | Farmer R.7 | 4 | | | 8 | 2.8 | 22.1 | 60.9 | 1,911.6 |
| 8 | Farmer R.8 | | 6 | | 12 | 4.1 | 49.7 | 205.5 | 6,451.7 |
| 9 | Farmer R.9 | 5-12 | | | 17 | 5.9 | 99.7 | 584.2 | 18,343.4 |
| 10 | Farmer R.10 | 8 | | | 16 | 5.5 | 88.3 | 487.0 | 15,293.0 |
| 11 | Farmer R.11 | 6 | | | 12 | 4.1 | 49.7 | 205.5 | 6,451.7 |
| 12 | Farmer R.12 | 6 | | | 12 | 4.1 | 49.7 | 205.5 | 6,451.7 |
| 13 | Farmer R.13 | | 1 | | 2 | 0.7 | 1.4 | 1.0 | 29.9 |
| 14 | Farmer R.14 | 2 | | | 4 | 1.4 | 5.5 | 7.6 | 239.0 |
| 15 | Farmer R.15 | 8 | | | 16 | 5.5 | 88.3 | 487.0 | 15,293.0 |
| 16 | Farmer R.16 | n/a | | | n/a | n/a | n/a | n/a | n/a |
| Total | | | | | | | | | 161,248.9 |

**Table 15** shows that total GHG emissions in the transportation sector for palm oil smallholder farmers in Riau is 106,556.4 tCO2eq. With a total production of 960.6 tons FFB, GHG emissions for transporting FFB by farmers in Riau is 110.9 kgCO2eq/ton FFB. Transportation of FFB to palm oil factories or collectors in West Kalimantan is shown in **Table 16**. Total GHG emissions from transportation by palm oil smallholder farmers in West Kalimantan is 136.85 tons CO2eq for transporting 1,885.5 tons FFB. Therefore, GHG emissions for FFB transportation in West Kalimantan is 72.6 kgCO2eq/ton FFB. Based on the calculation of GHG emissions from transportation, it can be seen that although the average distance from palm oil smallholder farmers' plantations to palm oil factories in Riau is less than that in West Kalimantan, GHG emissions per ton FFB in the transportation sector is higher in Riau. GHG emissions from transportation by palm oil smallholder farmers in Riau are higher than those in West Kalimantan. This is due to the higher productivity of respondents in West Kalimantan, so that the load (tonnage) per truck is more efficient, and trucks can transport more FFB on each trip.

**Table 16. Transportation of FFB to Palm Oil Factories in Palm Oil Smallholder Farmers in West Kalimantan**

| No | Name | Distance of FFB sale (km) | | | Average | Diesel (L/ton FFB) | Production (ton FFB) | Total diesel (L) | GHG emissions (kg$CO_2$eq.) |
|---|---|---|---|---|---|---|---|---|---|
| | | Factory | Collector | Cooperative | | | | | |
| **West Kalimantan Province** | | | | | | | | | |
| 1 | Farmer K.1 | 50 | | | 100 | 34.5 | 144.0 | 4,965.5 | 1,559.7 |
| 2 | Farmer K.2 | 50 | | | 100 | 34.5 | 145.2 | 5,006.9 | 15,721.7 |
| 3 | Farmer K.3 | 50 | | | 100 | 34.5 | 84.0 | 2,896.6 | 9,095.2 |
| 4 | Farmer K.4 | 42 | | | 84 | 29.0 | 30.0 | 869.0 | 2,728.6 |
| 5 | Farmer K.5 | 6 | 2 | | 8 | 2.8 | 30.0 | 82.8 | 259.9 |
| 6 | Farmer K.6 | 42 | | | 84 | 29.0 | 120.0 | 3,475.9 | 10,914.2 |
| 7 | Farmer K.7 | 42 | | | 84 | 29.0 | 216.0 | 625.6 | 19,645.6 |
| 8 | Farmer K.8 | 42 | | | 84 | 29.0 | 24.0 | 695,2 | 2,182.8 |
| 9 | Farmer K.9 | 50 | | | 100 | 34.5 | 36.0 | 1,241.4 | 3,897.9 |
| 10 | Farmer K.10 | 7 | 2 | | 9 | 3.1 | 19.3 | 60.0 | 188.3 |
| 11 | Farmer K.11 | 20 | | | 40 | 13.8 | 15.0 | 206.3 | 647.9 |
| 12 | Farmer K.12 | 20 | 15 | | 35 | 12.1 | 32.4 | 391.0 | 1,227.8 |
| 13 | Farmer K.13 | | 1 | | 2 | 0.7 | 27.6 | 19.0 | 59.8 |
| 14 | Farmer K.14 | 6 | 2 | | 8 | 2.8 | 18.0 | 49.7 | 155.9 |
| 15 | Farmer K.15 | 5 | 5 | 5 | 10 | 3.4 | 473.6 | 1,633.1 | 5,127.9 |
| 16 | Farmer K.16 | 15-50 | 10-40 | 10-20 | 97 | 33.4 | 470.4 | 15,734.1 | 49,405.0 |
| | Total | | | | | | 1,885.5 | | 136,850.2 |

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## 3.3 Distillation and Blending

In the distillation and blending stages, a study in 2010 provided material data used in the processing of CPO into biodiesel in refineries and biodiesel blending with diesel fuel (Nazir & Setyaningsih, 2010). For calculating total emissions, GHG emission factors for biodiesel refer to ISCC in their guidebook for calculating GHG, which contains a list of GHG emission factors for biodiesel production (ISCC, 2016). For calculating CPO conversion to biodiesel, a study by Silalertruksa & Gheewala (2012) states that 0.832 kg CPO is required to produce 1 liter of biodiesel with an energy content of 33.5 MJ/L.

**Table 17. Materials and inputs needed to producing 1kg Biodiesel (Nazir & Setyaningsih, 2010)**

| Activity | Material | Value | Unit | GHG value (kg$CO_2$eq/ kg biodiesel) | GHG value (kg$CO_2$eq/ l biodiesel) |
|---|---|---|---|---|---|
| Refinery | Methanol | 0.09892 | Kg | 0.12 | 0.11 |
| | NaOH | 0.00998 | Kg | 0.00 | 0.00 |
| | Electricity | 0.036826 | KWh | 0.03 | 0.03 |
| | Steam | 0.18 | Kg | 0.00 | 0.00 |
| **Total refinery** | | | | **0.17** | **0.15** |
| Blending | Truck | 60 | km | | |
| | Diesel | 0.021 | liter | **0.07** | **0.06** |

**Table 18. Emission Factors in Material for Distillation and Blending (ISCC 205 Greenhouse Gas Emissions, 2016)**

| Material | Value | Unit | Source |
|---|---|---|---|
| Methanol | 1.25 | kg$CO_2$eq/kg | BLE 2010 |
| NaOH | 0.47 | kg$CO_2$eq/kg | Biograce 2011 |
| Electricity | 0.9 | kg$CO_2$eq/KWh | Ecoinvent 2010 |
| Steam | 0.02 | kg$CO_2$eq/KWh | Biograce 2011 |
| Truck | 0.49 | L/ km | BLE 2010 |
| Diesel oil | 3.14 | kg$CO_2$eq/L | Biograce 2011 |

**Table 19. Conversion Factors of CPO to Biodiesel (Silalertruksa & Gheewala, 2012)**

| Material | Value |
|---|---|
| CPO | 0.832 kg/L biodiesel |
| Biodiesel density | 0.88 kg/L |
| Biodiesel energy content | 38.07 MJ/ kg |
| | 33.5 MJ/L |

The energy content of biodiesel is 38.07 MJ/kg or 33.5 MJ/L, lower than that of diesel fuel, namely 45.6 MJ/kg or 38.6 MJ/L.[9] Because biodiesel has a lower energy content, biodiesel fuel consumption tends to be higher than that of diesel fuel.

## 3.4 Total Greenhouse Gas Emissions

Total GHG emissions in this study are calculated by conducting a LCA, using data obtained from respondents in companies as well as palm oil smallholder farmers in Riau and West Kalimantan. To calculate GHG emissions from palm oil smallholder farmers, factoring in that these farmers only contribute supply chain emissions up to the factory stage, the calculation of emissions from the CPO factory location up to the blending of B20 uses assumptions and numbers from company data. In this study, some date were unobtainable data concerning palm oil smallholder farmers. For example, data on the CPO extraction rate for palm oil smallholder farmers is unobtainable, instead a company extraction rate of 20% is used in this study. The total area used for calculations in this study factors in the plantation area of company and palm oil smallholder farmer respondents, totalling 770,058.9 ha, with palm oil smallholder farmers accounting for only 0.03% of the total production area included in this study.

**Table 20. Plantation Area and Oil Extraction Rate (OER)**

| Producer | Area (ha) | CPO Extraction Rate (OER) % |
|---|---|---|
| Palm oil smallholder farmers in Riau | 92 | 20.0 |
| Palm oil smallholder farmers in West Kalimantan | 139.9 | 20.0 |
| Asian Agri | 93,574 | n/a |
| GAR | 502,847 | 19.2 |
| Musim Mas | 194,204 | 22.6 |
| Wilmar International | 263,980 | 20.0 |

The total area as well as the assumptions used to calculate GHG emissions is portrayed in **Table 20**. Total GHG emissions in each process of production, from LUC to the blending station (finalized as B20) by companies and palm oil smallholder farmers are shown in **Table 21** and **Table 22**. It should be noted that the LUC explained in section 3.1 is only calculated for oil palm plantations that were cleared after 2005, in accordance with the RSPO's certification criteria. Asian Agri, Musim Mas, and Wilmar International calculate emissions from LUC after 2005. GAR does not own any plantations that were cleared on or after November 2005, thus eliminating the need to factor in LUC in accordance with the RSPO regulations. Some company sustainability reports show detailed GHG emissions per emission source at the plantation and palm oil factory stages, however emission intensity is only calculated based on the output per ton of CPO. Based on data obtained from the Sustainability Reports, only Wilmar International's emission intensity can be shown in accordance with emission sources via reverse calculation. The emission intensity used by Wilmar is the overall GHG emissions of the company. In this study, Asian Agri's plantation emissions uses data from Riau which includes mineral land, with GHG emissions of 700 kg$CO_2$eq/tCPO, as well as peatland at 9,380 kg$CO_2$eq/tCPO. GHG emissions in B20 production from the four companies show results between 2.67 kg$CO_2$eq/L B20 and 4.11 kg$CO_2$eq/L B20.

### Table 21. GHG Emissions from Biodiesel Production by Company

| Source of GHG Emissions | | Asian Agri | | GAR | Musim Mas | Wilmar | Unit |
|---|---|---|---|---|---|---|---|
| Type of land | | Mineral | Peat dev | No peat | Peat dev | Peat dev | |
| LUC | primary forest | n.a | n.a | n.a | n.a | 1,200 | kg $CO_2$eq/ t TBS |
| | secondary forest | n.a | n.a | n.a | n.a | | kg $CO_2$eq/ t TBS |
| | rubber | n.a | n.a | n.a | n.a | | kg $CO_2$eq/ t CPO |
| | Scrub | n.a | n.a | n.a | n.a | | kg $CO_2$eq/ t TBS |
| | farmland | n.a | n.a | n.a | n.a | | kg $CO_2$eq/ t TBS |
| | grassland | n.a | n.a | n.a | n.a | | kg $CO_2$eq/ t TBS |
| Peat | good management | n.a | n.a | n.a | n.a | 870 | kg $CO_2$eq/ t CPO |
| Machinery | | - | - | - | - | - | kg $CO_2$eq/ t TBS |
| Plantation | fertilizer + 'pest' | - | - | - | - | 370 | kg $CO_2$eq/ t TBS |
| Transport | diesel | - | - | - | - | 40 | kg $CO_2$eq/ t TBS |
| **Total plantation** | | - | - | - | - | - | kg $CO_2$eq/ t TBS |
| | | - | - | - | - | 2,490 | kg $CO_2$eq/ t CPO |
| | | - | - | - | | - | kg $CO_2$eq/ L biodiesel |
| Palm oil factory | Fuel | | | | | 10 | kg $CO_2$eq/ t CPO |
| Palm oil factory | POME | n/a | 9,380 | 373,9 | n/a | 390 | kg $CO_2$eq/ t CPO |
| Palm oil factory | POME | - | - | 0,31 | - | - | kg $CO_2$eq/ L biodiesel |
| **Total Plantation** | | 700 | 9,380 | 837.8 | 3,390 | 2,880 | kg $CO_2$eq/ t CPO |
| **Total Plantation** | | 0.58 | 7.80 | 0.7 | 2.82 | 2.4 | kg $CO_2$eq/ L biodiesel |
| Refinery | Methanol | 0.109 | 0.109 | 0.109 | 0.109 | 0.109 | kg $CO_2$eq/ L biodiesel |
| | NaOH | 0.004 | 0.004 | 0.004 | 0.004 | 0.004 | kg $CO_2$eq/ L biodiesel |
| | Electricity | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | kg $CO_2$eq/ L biodiesel |
| | Steam | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | kg $CO_2$eq/ L biodiesel |
| Total Refinery | | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | kg $CO_2$eq/ L biodiesel |
| **Total biodiesel** | | 0.73 | 7.95 | 0.84 | 2.97 | 2.54 | kg $CO_2$eq/ L biodiesel |
| Blending | diesel | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | kg $CO_2$eq/ L biodiesel |
| **Total biodiesel+blend** | | 0.79 | 8.01 | 0.9 | 3.03 | 2.6 | kg $CO_2$eq/ L biodiesel |
| **Diesel Fuel** | | 3.14 | 3.14 | 3.14 | 3.14 | 3.14 | kgCO2eq/L diesel |
| Total B20 | | 2.67 | 4.11 | 2.69 | 3.12 | 3.03 | kg $CO_2$eq/ L B20 |

**Table 22. GHG Emissions from Biodiesel Production by Palm Oil Smallholder Farmers**

| Sources of GHG emissions | | Palm Oil Smallholder Farmers | | | | Unit |
|---|---|---|---|---|---|---|
| | | Riau (No LUC) | | West Kalimantan (No LUC) | | |
| Types of land | | mineral | peat | mineral | peat | |
| LUC | primary forest | n.a | n.a | n.a | n.a | kg $CO_2$eq/ t TBS |
| | secondary forest | n.a | n.a | n.a | n.a | kg $CO_2$eq/ t TBS |
| | rubber | n.a | n.a | n.a | n.a | kg $CO_2$eq/ t TBS |
| | scrub | n.a | n.a | n.a | n.a | kg $CO_2$eq/ t TBS |
| | farmland | n.a | n.a | n.a | n.a | kg $CO_2$eq/ t TBS |
| | grassland | n.a | n.a | n.a | n.a | kg $CO_2$eq/ t TBS |
| Peat | good management | n.a | 5,229.89 | n.a | 4,050.45 | kg $CO_2$eq/ t TBS |
| Machinery | | 27.97 | 27.97 | 21.66 | 21.66 | kg $CO_2$eq/ t TBS |
| plantation | fertilizer +pest | 14.25 | 14.25 | 14.87 | 14.87 | kg $CO_2$eq/ t TBS |
| Transport | diesel | 110.9 | 110.9 | 72.6 | 72.6 | kg $CO_2$eq/ t TBS |
| **Total Plantation** | | 153.12 | 5,383.01 | 109.13 | 4,159.58 | kg $CO_2$eq/ t TBS |
| | | 765.6 | 26,915.05 | 545.65 | 20,797.9 | kg $CO_2$eq/ t CPO |
| | | 0.64 | 22.39 | 0.45 | 17.3 | kg $CO_2$eq/ L biodiesel |
| Palm oil factory | POME | 373.9 | 373.9 | 373.9 | 373.9 | kg $CO_2$eq/ t CPO |
| Palm oil factory | POME | 0.31 | 0.31 | 0.31 | 0.31 | kg $CO_2$eq/ L biodiesel |
| **Total Plantation** | | **1,139.5** | **27,288.95** | **919.55** | **21,171.8** | kg $CO_2$eq/ t CPO |
| **Total Plantation** | | **0.95** | **22.7** | **0.77** | **17.61** | kg $CO_2$eq/ L biodiesel |
| Refinery | Methanol | 0.11 | 0.11 | 0.11 | 0.11 | kg $CO_2$eq/ L biodiesel |
| | NaOH | 0.004 | 0.004 | 0.004 | 0.004 | kg $CO_2$eq/ L biodiesel |
| | Electricity | 0.029 | 0.029 | 0.029 | 0.029 | kg $CO_2$eq/ L biodiesel |
| | Steam | 0.003 | 0.003 | 0.003 | 0.003 | kg $CO_2$eq/ L biodiesel |
| Total Refinery | | 0.15 | 0.15 | 0.15 | 0.15 | kg $CO_2$eq/ L biodiesel |
| **Total biodiesel** | | 1.09 | 22.85 | 0.91 | 17.76 | kg $CO_2$eq/ L biodiesel |
| Blending | diesel | 0.06 | 0.06 | 0.06 | 0.06 | kg $CO_2$eq/ L biodiesel |
| **Total biodiesel+blend** | | 1.15 | 22.91 | 0.97 | 17.82 | kg $CO_2$eq/ L biodiesel |
| **Diesel Fuel** | | 3.14 | 3.14 | 3.14 | 3.14 | kgCO2eq/L diesel |
| **Total B20** | | **2.74** | **7.09** | **2.71** | **6.08** | kg $CO_2$eq/ L B20 |

Notes: Biodiesel density is 0.88 kg/L

If there is no oil palm development on peat, with the assumption that all land development is based on mineral land, emissions from palm oil smallholder farmers in Riau and West Kalimantan amount to 2.74 kg $CO_2$eq/L B20 and 2.71 kg $CO_2$eq/L B20, respectively. Differentiating factors lie in the type of land cultivated by palm oil smallholder farmers, namely mineral or peat. If all palm oil smallholder farmers' plantations were cultivated on peatland, there would be a spike in GHG emissions of up to 6.08 kg $CO_2$eq/L B20 in West Kalimantan, and 7.09 kg $CO_2$eq/L B20 in Riau. These emissions are within the range of company GHG emissions, namely 2.67 kg $CO_2$eq/L B20 for non-peatland, but lower than company emissions for plantation development on peatland - 3.03 and 4.11 kg $CO_2$eq/L B20.

GHG emissions for internal use of diesel fuel and machinery during land clearing assumes a mid-point of 292 $kgCO_2eq$/ha/year, referring to literature on MPOB, namely 180–404 $kgCO_2eq$/ha/year (Choo, *et al.*, 2011). This figure is divided by plantation productivity using the unit of tFFB/ha to arrive at 10.44 $kgCO_2eq$/t FFB for Riau and 13.48 $kgCO_2eq$/t FFB for West Kalimantan.

Company reports only provide total GHG emissions for the final CPO product, referring to the 2016 and 2017 Sustainability Reports. Plantation emissions explained in section 3.2 are calculated from the use of NPK fertilizer, urea, TSP, and RP, as well as pesticide. GHG emissions explained in section 3.3 are calculated from the amount of fuel used for transporting FFB to palm oil factories/collectors/cooperatives. Total emissions in palm oil mills are calculated from Palm Oil Mill Effluent (POME). The POME emission data sourced from GAR's report - 373.9 $kgCO_2eq$/tCPO - accounts for 44.6% of GAR's total plantation emissions. A reverse calculation of Wilmar's GHG emissions estimates POME emissions of 390 $kgCO_2eq$/tCPO.

The refinery/distillation and blending process, explained in detail in section 3.3, shows that the contribution of the distillation process to biodiesel GHG emissions is smaller compared to emissions from plantations (plantation and palm oil mill). GHG emissions for the refinery and blending stages are 0.15 $kgCO_2eq$/L biodiesel and 0.06 $kgCO_2eq$/L biodiesel, respectively.

GHG emissions for diesel are 3.14 kgCO2eq/L diesel. B20 is a mixture of 20% biodiesel volume and 80% diesel oil volume. Therefore, GHG emissions for the end B20 product ranges from 2.67 $kgCO_2eq$/L B20 to 7.09 $kgCO_2eq$/L B20. Biodiesel from palm oil cultivated in plantations and cleared before 2005, therefore absent of new land use change, contributes GHG emissions of 2.67 $kgCO_2eq$/L B20. GHG emissions of 7.09 $kgCO_2eq$/L B20 occurs when there is land use change from peatland to oil palm plantation. The fivefold increase in range is obtained from the LUC factor in palm oil smallholder farmers in Riau and West Kalimantan. If there is no LUC, GHG emissions from B20 Biodiesel produced by companies is similar to GHG emissions from palm oil smallholder farmer production, as shown in **Table 23**. Wilmar, which inputs LUC as part of its plantation area, contributes 12.6% higher GHG emissions compared to GAR's GHG emissions, which does not need to factor in LUC because their land development was conducted before November 2005, in accordance with RSPO terms.

In the scenario for palm oil smallholder farmers' oil palm plantations on peatland, total emissions from farmers is much higher than those from company plantations. This is caused by two factors, namely a percentage of peatland area on total cultivated land, as well as plantation productivity. In company plantations, the peatland area is relatively small compared to the total plantation area. Company plantation productivity is also higher compared to palm oil smallholder farmers. Although total emissions are higher, total FFB as the divisor is also larger, making emissions per ton of FFB smaller.[10] Plantation emissions contribute 80% or more of total biodiesel production, as seen in information portrayed in **Figure 9**. LUC after 2005 and cultivation on peatland are the largest sources of emissions that greatly influence the final figure of GHG emissions for biodiesel.

**Figure 9. Comparison of GHG Emissions from Company B20 Production**

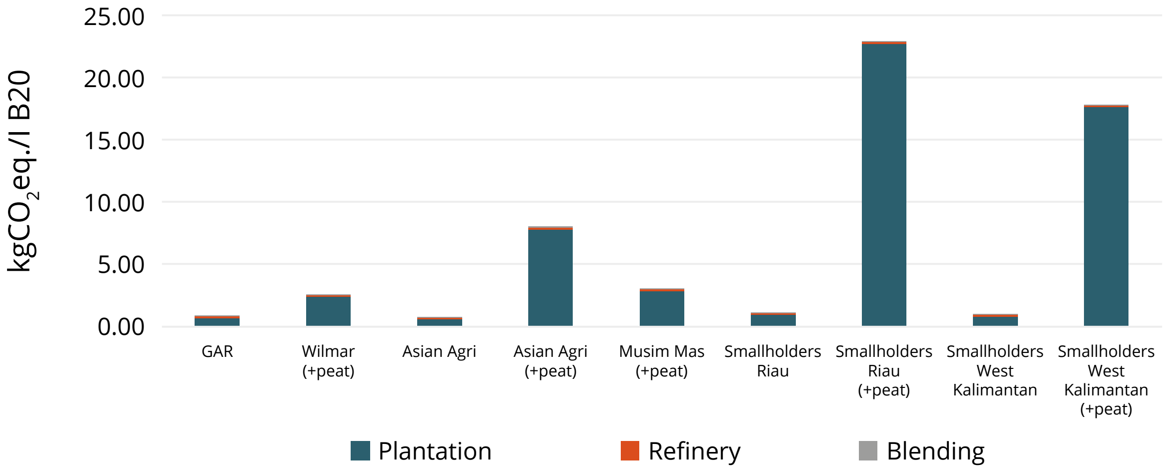



**Figure 10. Comparison of GHG emissions in B20 compared to conventional diesel**

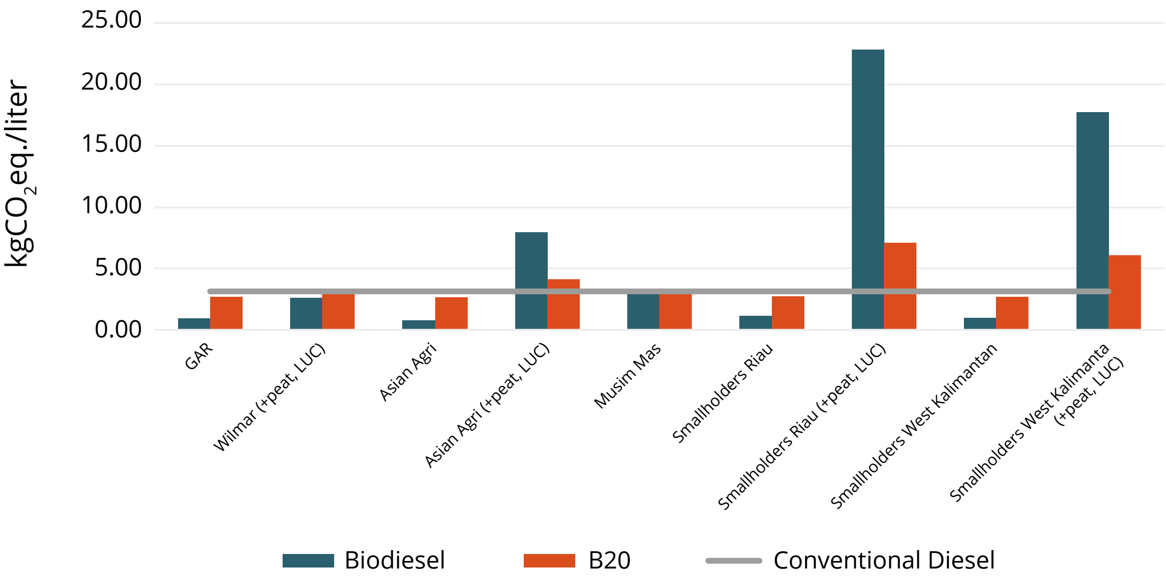
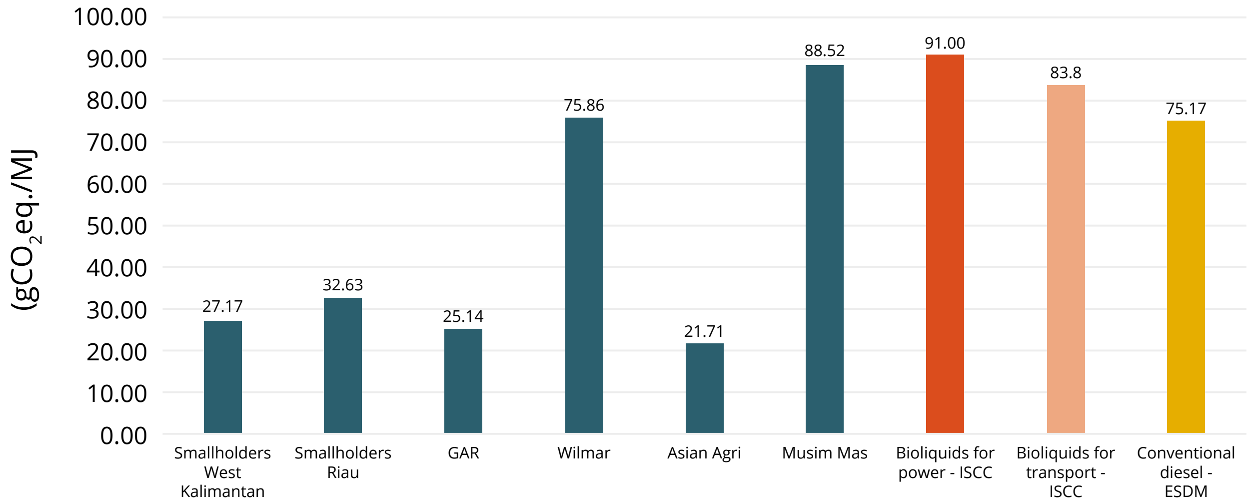



Figure 10 portrays a comparison of GHG emissions per liter of B20 produced by each respondent company, compared to GHG emissions from conventional diesel. Wilmar and Musim Mas, factoring in GHG emissions from peatland and LUC, produce GHG emissions below that of diesel. Asian Agri emissions are still below those from diesel, however biodiesel production from peatland results in higher GHG emissions than diesel. Subsistence farmers in Riau and West Kalimantan also show GHG emissions below those of diesel. However, if there is LUC after 2005, GHG emissions from palm oil smallholder farmer production will greatly surpass emissions from diesel - 7.09 $kgCO_2eq/L$ B20 and 6.08 $kgCO_2eq/L$ B20, compared to 3.14 $kgCO_2eq/L$ for diesel. A large proportion of GHG emissions from palm oil smallholder farmer production in Riau and West Kalimantan is caused by LUC from forest to oil palm plantation, in which the calculation assumes that all farmers' land is peatland.

If the LCA is extended to the consumption stage for power generation and transportation, emission intensity based on energy content can then be reviewed. Next, this intensity figure can be compared to the emission limits or GHG emissions of other fuels. In this study, the comparison of emission intensity based on energy content is conducted using biodiesel (not B20) and ISCC standards for the upper limit of biofuel emission intensity (for transport and power generation), as well as industrial diesel oil emissions from the Ministry of Energy and Mineral Resources (ESDM). This comparison assumes that biodiesel and other fuels are transported from the production location to the same consumption location, so that GHG emissions at the downstream level (transportation and distribution) are the same, and thus ignored. The comparison of GHG emissions is shown in **Figure 11**. The diagram in **Figure 11** shows that biodiesel for each producer is still below the ISCC's GHG emissions limit for power - 91.00 $gCO_2eq/MJ$. Compared to the ISCC's GHG emissions limit for transportation, biodiesel from Musim Mas is below the limit. Compared to GHG emissions from diesel, based on ESDM data, biodiesel produced by Musim Mas and Wilmar surpass the GHG emissions threshold. Nonetheless, it should be noted that this study uses the same GHG emissions for the biodiesel plant stage, whereas GHG emissions from biodiesel plants belonging to Wilmar and Musim Mas may be lower than the assumptions used in this study.

**Figure 11. Comparison of GHG emissions from CPO biodiesel compared to other fuels**



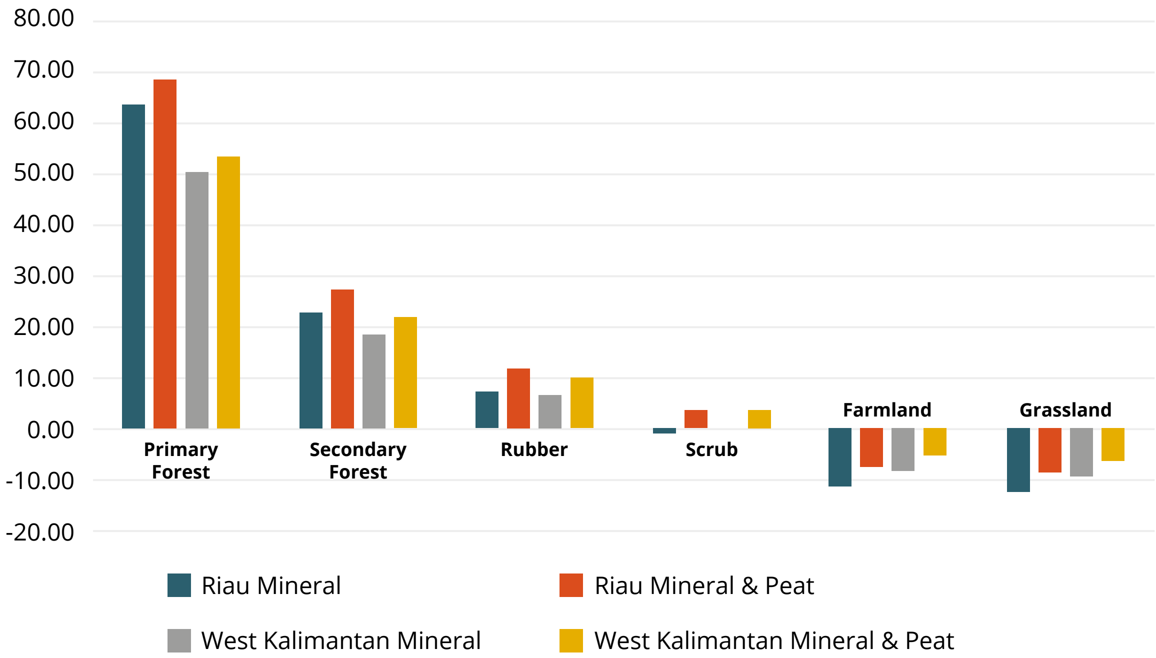

## 3.4.1. LUC Scenario Analysis for Palm Oil Smallholder Farmers

In order to further observe the impact of LUC on total GHG emissions from B20 production, a scenario analysis of B20 production is conducted using data from palm oil smallholder farmers in Riau and West Kalimantan. Two scenario groups encompass B20 production involving LUC from mineral land and peatland. Scenarios for LUC from mineral land include six land types - primary forest, secondary forest, rubber plantation, scrub, farmland, and grassland. The result of this scenario analysis can be seen in **Table 23** and **Figure 12**.

**Table 23. Total GHG Emissions from LUC in Palm Oil Smallholder (Farmers)**

| Original land function | Riau ($tCO_2eq/l$ B20) | | West Kalimantan ($tCO_2eq/l$ B20) | |
|---|---|---|---|---|
| | Mineral | Mineral & Peat | Mineral | Mineral & Peat |
| Primary forest | 64.26 | 68.61 | 50.35 | 53.72 |
| Secondary forest | 23.34 | 27.69 | 18.66 | 22.03 |
| Rubber | 7.86 | 12.21 | 6.67 | 10.04 |
| Scrub | -0.61 | 3.74 | 0.11 | 3.48 |
| Farmland | -11.43 | -7.08 | -8.27 | -4.90 |
| Grassland | -12.60 | -8.25 | -9.18 | -5.81 |

**Figure 12. Scenario Analysis of LUC on GHG Emissions of B20 Production by Palm Oil Smallholder Farmers**




Based on the scenario analysis, total GHG emissions from LUC in addition to peatland from palm oil smallholder farmers produces the largest difference in total GHG emissions. Total GHG emissions from mineral land LUC are significantly high, but still less than LUC from peatland. GHG emissions range from a minimum of -8.25 kgCO2eq/L B20 for former grassland and peatland, up to a maximum of 68.61 kgCO2eq/L B20 for former primary forest and peatland in Riau. In West Kalimantan, this ranges from -5.81 kgCO2eq/L B20 for former grassland and peatland, to a maximum of 50.35 kgCO2eq/L B20 for former primary forest and peatland. Considering that the GHG emission figure for diesel is 3.14 kgCO2eq/L, the scenario analysis shows that changes in LUC and cultivation on peatland can result in B20 emissions being far higher than emissions from conventional diesel. Therefore, while promoting the production and use of CPO biodiesel to reduce GHG emissions from the energy and transportation sectors, the government and industry stakeholders also need to take into account the entirety of the supply chain, and also include LUCF emissions.

It should also be noted that emissions can be reduced in certain types of LUC for oil palm. For palm oil smallholder farmers in Riau, LUC from mineral land such as scrub, farmland, and grassland produce GHG emissions of -0.61 kg$CO_2$eq/L B20, -11.43 kg$CO_2$eq/L B20, and -12.60 kg$CO_2$eq/L B20, respectively. In this scenario, palm oil production from land that was previously farmland, scrub, and grassland, could support the government's efforts to reduce national emissions.

### 3.4.2. Projection of GHG Emissions from B20 Based on Production Target

GHG emissions projections were also conducted for 2019 to 2025, based on the government target for biodiesel use, albeit with a number of prevailing assumptions and limitations, which will most likely differ from the actual future GHG emissions. Prevailing assumptions and limitations within this projection include the fulfillment of the target for biodiesel usage according to the volume and blending mandate. On the other hand, fulfillment of production volume can be influenced by a number of factors, including the condition of the CPO market, the palm oil industry, government policies, as well as global oil prices.

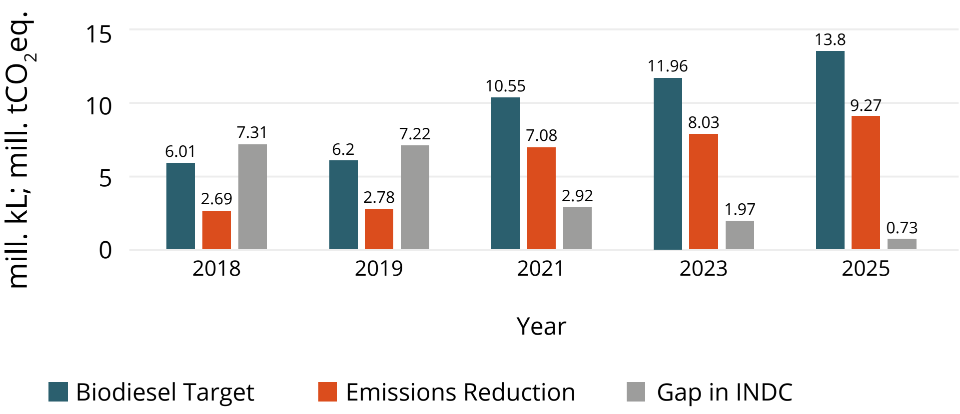
Based on the latest data from the Ministry of Energy and Mineral Resources, B20 consumption in Indonesia is 6.01 million kiloliters (Jonan, 2019). Assuming GHG emissions from biodiesel are 2.69 kgCO2eq/L B20 and 2.69 kgCO2eq/L B30, projections for GHG emissions reductions are 0.45 kgCO2eq/L (~14%) for B20 and 0.67 kgCO2eq/L (~21%) for B30. This emissions reduction is obtained from fuel switching from diesel fuel - 3.14 kg$CO_2$eq/L - into biodiesel. Therefore, national GHG emissions reduction was 2.69 million tons of $CO_2$eq from B20 in 2018.

Based on the target determined by the Ministry of Energy and Mineral Resources - 6.2 million kiloliters of biodiesel in 2019, and 13.8 million kiloliters in 2025 - it is estimated that biodiesel consumption will grow by approximately 6.5 percent per year. This assumes that B30 will be implemented in 2021. GHG emissions reduction from biodiesel could amount to 2.78 million tons of $CO_2$eq in 2019, and up to 9.27 million ton $CO_2$eq in 2025, as shown in **Table 24** and **Figure 13**. The Government of Indonesia has determined the target for emissions reduction from biofuel at 10 million tons of CO2eq in 2025, a gap of 7.22 million tons of $CO_2$eq in 2019, 1.97 million tons of $CO_2$eq in 2023, and 0.73 million tons of $CO_2$eq in 2025. Reduction of this gap is driven by an increase in production volume and blending, from 20% in 2019 to 30% in 2021

**Table 24. Projection of GHG Emissions Reduction Based on Biodiesel Production Targets**

| Year | Biodiesel production target (million kL) | Emissions reduction from biodiesel (t$CO_2$eq./year) | Gap in INDC target (t$CO_2$eq./tahun) |
|---|---|---|---|
| 2019 | 6.2 | 2.78 | 7.22 |
| 2021 | 10.55 | 7.08 | 2.92 |
| 2023 | 11.96 | 8.03 | 1.97 |
| 2025 | 13.8 | 9.27 | 0.73 |

**Figure 13. Comparison of GHG Emissions Reduction and Gap in Intended Nationally Determined (Emissions Reduction) Contributions (INDC)**

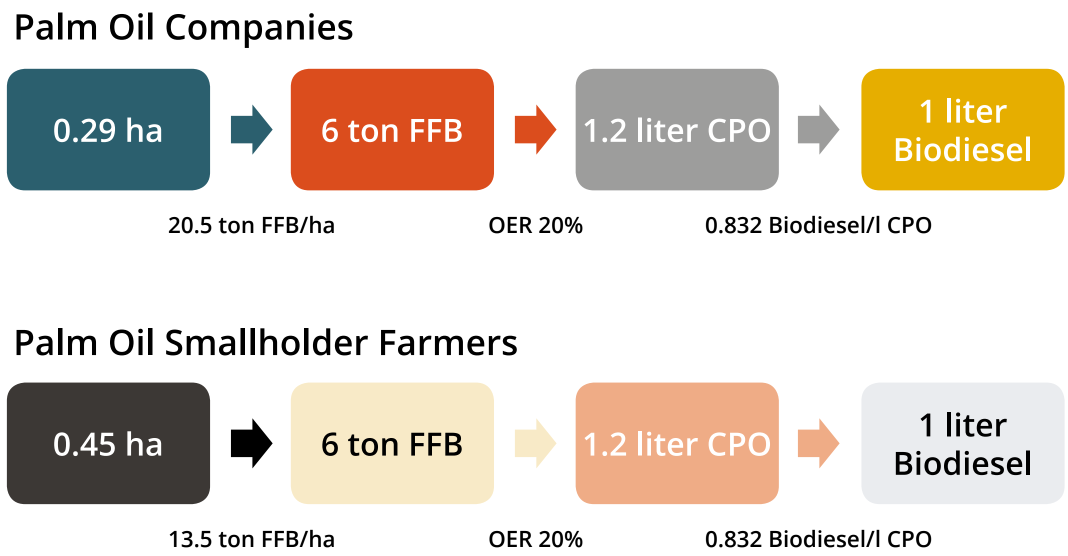



Based on the LCA, with data from company and palm oil smallholder farmer respondents, GHG emissions from CPO biodiesel are lower than GHG emissions from conventional diesel (efficiency value between 3% and 14%). Domestic biodiesel use from CPO can support the Government of Indonesia's efforts to achieve national emissions reduction targets in the energy and transportation sector. However, this emissions reduction can only be achieved if FFB used as the feedstock for biodiesel is obtained from land that was not previously forest, and was cleared before 2005. For this reason, it is important to scrutinize and ensure that FFB are not sourced from new LUC with high carbon stocks.

Aside from the LUC sector contributing to GHG emissions in the CPO production stage, another sector that also greatly contributes to total GHG emissions is palm oil mill effluent (POME) from palm oil mills. Utilization of methane capture facilities has proven effective in reducing emissions from POME in some palm oil mills. For this reason, apart from scrutinizing the LUC sector, it is important to ensure that CPO is produced by palm oil mills that are equipped with methane capture facilities.

Reviewing data from palm oil smallholder farmers, it is clear that there is a disparity in productivity compared to company plantations. In order to fulfill national biodiesel production targets, the role of palm oil smallholder farmers in supporting the supply chain needs to be supported and increased. According to data obtained from this study's respondents productivity levels of palm oil smallholder farmers are less than half those of company plantations. Palm oil smallholder farmers need twice the area of land required to produce the same output as companies, as shown in **Figure 14**.

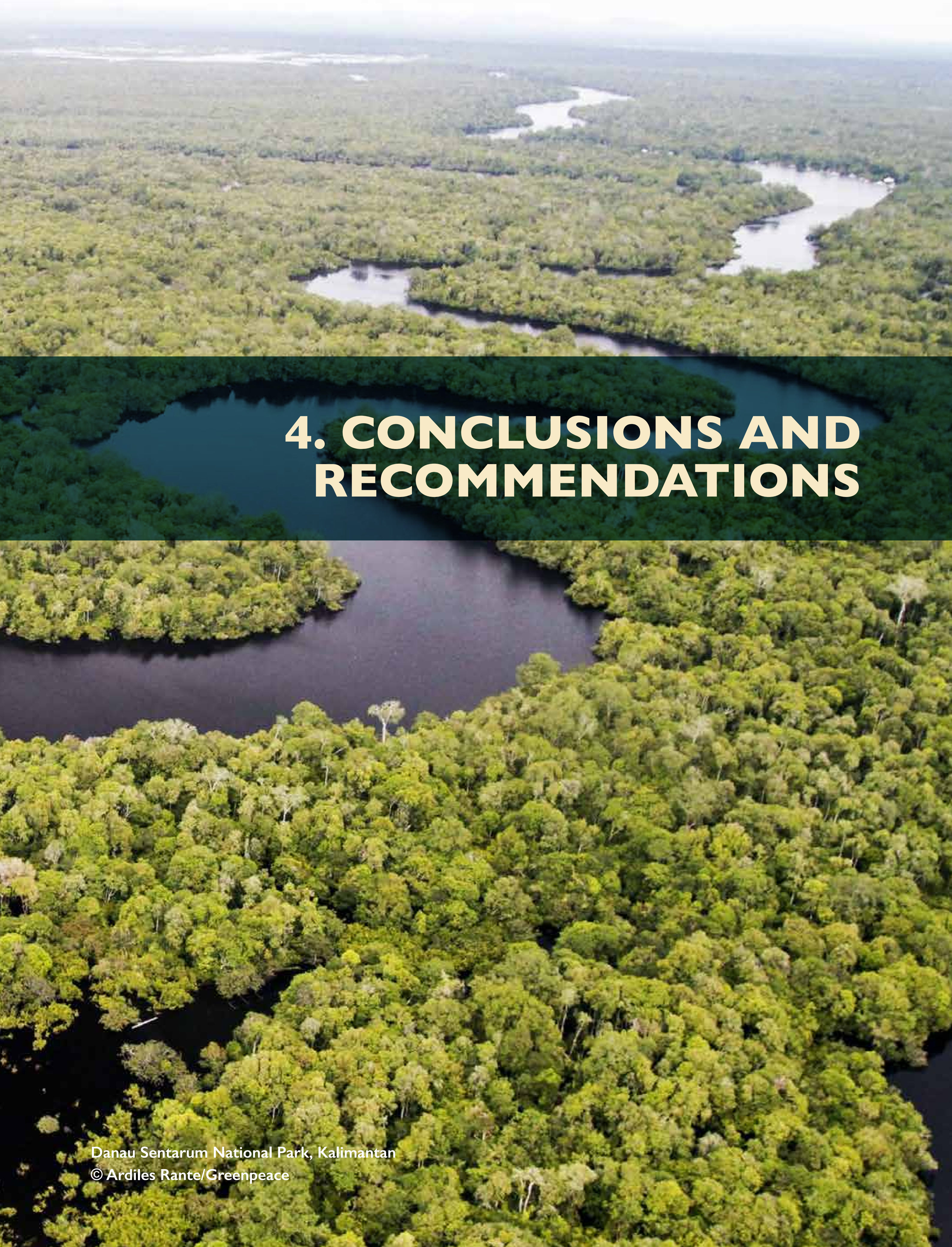
**Figure 14. Comparison of Productivity of Palm Oil Smallholder (Farmers) and Palm Oil Companies**




Low levels of productivity in palm oil smallholder farmers' plantations show that there are limitations concerning the technical capabilities and financial support needed to encourage the use of the best sustainable agricultural practices to ensure that no more CPO is cultivated in forests or on peatland. There needs to be oversight in order to increase the capacity and technical capabilities of palm oil smallholder farmers, such as training in good agriculture practice (GAP), provision of quality seedlings, etc. Providing access to financing will also increase the farmers' capabilities; soft loan facilities for replanting and fertilization will aid farmers in increasing plantation productivity, as well as improving their livelihoods. In addition, capacity building for farmers needs to be conducted in institutional settings such as small farmer associations or cooperatives. Institutions that oversee or represent palm oil smallholder farmers will enable them to cooperate on FFB supply with palm oil companies, and to attain the production capacities required to access funding facilities.

Conversion of new land by companies and palm oil smallholder farmers, increase of plantation productivity, and POME management need to be scrutinized, managed and given policy support by the government and business actors across the entirety of the biodiesel supply chain. This is necessary to prevent a biodiesel paradox, in which the primary objective of biodiesel use to reduce GHG emissions is undermined by increased GHG emissions from deforestation and peatland destruction caused by unsustainable CPO biodiesel production practices. The government and biodiesel business actors need to provide technical support and financing for palm oil smallholder farmers in order for them to increase their contribution compared to the current condition. In the larger framework of national GHG emissions reduction there needs to be coordination between the LUCF sector and the energy sector in order to ensure that there is no emissions leakage from one sector to another.

# 4. CONCLUSIONS AND RECOMMENDATIONS



Danau Sentarum National Park, Kalimantan
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## Conclusions

This study of GHG emissions from downstream B20 production, calculated from LUC to the palm oil mill stage, concludes the following:

1. **Greenhouse Gas (GHG) emissions from CPO plantations and palm oil mills contribute 83% - 95% of GHG emissions from B20 production.** The plantation stage is the largest contributor to emissions from biodiesel in Indonesia, accounting for over 80% of GHG emissions across the biodiesel supply chain. For plantations, GHG emissions for companies that factor in LUC range from 2.67 kg$CO_2$eq/L B20 to 4.11 kgCO2eq/L B20. In comparison, the GHG emissions range from LUC by palm oil smallholder farmers is considerably wider, from a minimum of -8.25 kg$CO_2$eq/L B20 (former grassland) to a maximum of 68.61 kg$CO_2$eq/L B20 (former primary forest) for Riau; and ranging from a minimum of -5.81 kg$CO_2$eq/L B20 (former grassland) to a maximum of 50.35 kg$CO_2$eq/L B20 (former primary forest) for West Kalimantan. Given that GHG emissions for conventional diesel is 3.14 kg$CO_2$eq/L, there is a possibility that LUC on mineral land and peatland can drive B20 emissions far higher than diesel emissions. Adopting the RSPO's November 2005 cut off date, there is a considerably larger difference in GHG emissions from production of B20 by palm oil smallholders, depending on whether or not there was any LUC, both in Riau (2.74 vs 7.09 kg$CO_2$eq/L B20) and in West Kalimantan (2.71 vs 6.08 kg$CO_2$eq/L B20).

2. **Use of methane capture in palm oil mills can approximately halve emissions from the plantation/mill supply chain.** This is evident in plantations owned by GAR, in which emissions from POME - 0.31 kg$CO_2$eq/L biodiesel - can be reduced by using methane capture.

3. **Productivity of palm oil smallholder farmers is lower than the productivity of companies.** With productivity levels up to 50% lower than palm oil companies, palm oil smallholder farmers require up to twice the area of land needed to produce the same CPO output as companies. The low productivity in palm oil smallholder farmer plantations reveals limitations in the technical capabilities as well as lack of financial support to facilitate the best agricultural practices needed to both increase productivity and sustainability.

4. **Transportation (transport of Fresh Fruit Bunch (FFB)) is the largest source of emissions from palm oil smallholder farmers.** Fuel use by palm oil smallholder farmers' for FFB transportation ranges from 39% of the total for West Kalimantan, to 49% for Riau. GHG emissions from transportation for palm oil smallholder farmers in Riau is higher than for farmers in West Kalimantan. This is due to the higher productivity of farmers in West Kalimantan, so the load (tonnage) per truck per trip is more efficient and the trucks can carry more FFB for each trip.

## Recommendations

Production of biodiesel from CPO can support the Government of Indonesia's efforts to achieve energy security, through domestic use of CPO and achievement of GHG emissions reduction targets. However, B20 biodiesel produced unsustainably, causing deforestation and peat destruction, and with poor governance can undermine the government's emissions reduction efforts. This study recommends the following measures to improve governance and increase the sustainability of B20 biodiesel production:

1. In order for Indonesia to meet its carbon emissions reduction commitments under the Paris Climate Agreement, it must first accurately measure all sources of emissions. The measurement, reporting and verification (MRV) of carbon emissions from the production, milling, refining and distribution of biodiesel from crude palm oil (CPO) are not currently included in Indonesia's National Carbon Accounting System (INCAS). Ignoring emissions from the CPO production process enables the government to continue promoting CPO biodiesel as a clean fuel that can paradoxically help the nation to reduce its carbon emissions. Including emissions from the production of CPO biodiesel in the MRV system for INCAS will increase the accuracy of Indonesia's carbon reporting, and its ability to meet its commitments, as well as providing the basis for Indonesia to improve traceability and verification to ensure a more sustainable supply chain.

2. While Indonesia has made some improvements in forest governance to address land use change and deforestation, including the moratorium on new licences for palm oil plantations and establishing the Peat Restoration Agency (BRG), much more needs to be done to move the country towards sustainable supply chains for commodities such as CPO. For CPO this must include extending and strengthening the moratorium on new licences for palm oil plantations and the Indonesia Sustainable Palm Oil System (ISPO), and only permitting expansion of palm oil plantations on degraded lands.

3. In order to move Indonesia towards a verifiably sustainable supply chain for CPO, it is crucial that small-scale palm oil farmers, who account for around 40% of total production, are given the support they need to learn and to implement best agricultural practices. With the right level of support and tools small-scale palm oil farmers can quickly learn the techniques they need to increase productivity in a sustainable way to improve yields, including replanting on degraded lands.

4. Palm oil mill effluent (POME) accounts for the majority of carbon emissions from the mill stage of CPO production, as most mills merely store the liquid waste from the mill process in open ponds, emitting huge amounts of methane, another greenhouse gas. The government should require all companies to install methane capture equipment in their mill operations as this is proven to reduce emissions at mill stage by between 50% and 80%.

5. Given the risks of producing first generation biofuels from CPO plantations, including deforestation and increased carbon emissions, it is important that CPO biodiesel is seen only as a transition fuel. The production of CPO for biodiesel should be short-term while the government incentivizes the use of much more sustainable non-plant based alternative fuels, e.g. 2nd generation biofuels from waste, such as used cooking oil.

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# Endnotes

[1] Non-Annex I signatory countries to the Kyoto Protocol, the majority of which are developing countries. Non-Annex I countries are not legally bound to reduce emissions.

[2] Indonesia is committed to reduce emissions by 29% from a baseline of 1.8 GtCO2e (Ministry of Environment and Forestry, 2018). The commitment is recorded in the Nationally Determined Contribution (NDC).

[3] In the Third National Communication on Indonesian Climate Change, the largest contributors of emissions in Indonesia are  land use change and the forestry sector (LUCF) (38%), peatland fires (25%), and energy (21%).

[4] https://www.esdm.go.id/assets/media/content/outlook_energi_indonesia_2016_opt.pdf Reduction of GHG emissions in the energy and transportation sector is formulated in Presidential Regulation No. 61/2011, which targets a 37.93% reduction by 2030 compared to Business as Usual using a baseline of 2010.

[5] Presidential Regulation No. 22 of 2017

[6] In Presidential Regulation No. 22 of 2017 the biofuel production target is set at 19 million TOE in 2025 (Misna, 2018).

[7] vii Biofuel produced from raw materials that can be used as foodstock is categorized as first generation. Second generation biofuel is produced from plants and plant parts, not for foodstock, such as agricultural waste and forest. Third generation biofuel is produced from non-foodstock material and from agricultural waste (such as algae).

[8] http://www.bumn.go.id/ptpn5/berita/11206/Ini.Sebaran.Pabrik.Kelapa.Sawit.di.Indonesia

[9] IOR Energy. List of common conversion factors (Engineering Conversion Factors).

[10] Carbon/ha/y = Total emissions from land use change: Total land area. Carbon/ t FFB = Total plantation emissions : Total result of FFB production

TRACTION
ENERGY ASIA