Universidad Politécnica de Madrid

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA
AGRONÓMICA, ALIMENTARIA Y DE BIOSISTEMAS

**Palm Oil and Biodiesel in Indonesia,
Economic and Environmental Feasibility**

Doctoral Thesis

Pablo José Acosta García

Ingeniero Agrónomo

Master of Business Administration

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A Eileen, Daniel, Katie y Chloe

No tenemos otro mundo al que podemos mudar.

Gabriel García Márquez

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ABSTRACT

The establishment of new oil palm plantations on the eastern region of Papua-Indonesia has greatly increased in the last years. New plantation's establishment involves land use change, directly related with primary climax forest loss. Climatic conditions for oil palm cultivation in Papua, due to high precipitation and rich soils, as well as a large amount of available land, make this region attractive for establishing new plantations; on the other side its remoteness and political situation involve higher risks and costs for investors. The palm oil industry can generate employment, promote development of rural areas, and redistribute revenue to society from generated taxes. On the other hand, land use change can produce the loss of ecosystem services, loss of natural habitats and carbon emissions. Papua-Indonesia holds very deep and ancient tribal traditions and has a population in general opposes change. The establishment of new oil palm plantations in Papua, Indonesia is studied looking at existing literature. Local and global consequences are reviewed. Factors influencing the decision-making process are identified in a strengths-weakness-opportunities-threats analysis that frames the process of new oil palm plantations establishment being analyzed in this study.

Land use change emissions from new oil palm plantations establishment represent about 10 % of Indonesia's LUC emissions and 7 % of total Indonesian emissions. Policies to reduce emissions from newly established plantations in Indonesia are required. This study aims at the identification of some possible policies to reduce emissions and improve oil palm plantations' environmental and economic feasibility. Several scenarios were studied, including improvement of agricultural practices, improved genetics, production of advanced biofuels, or avoiding establishment of new plantations in peat and in forested area. The most beneficial alternative scenario, capable of shifting CO₂eq emissions from 168.51 to -7.82 million t per year, is to stop planting in forested area. Other original land uses can replace forested land; our study shows that establishment of plantations in marginal lands yields substantial commercial returns, and therefore it is feasible to avoid plantations on forested lands and shift them to other less fertile areas. Biofuels have the potential to reduce land use change emissions in Indonesia. The relationship between land use change emissions for oil palm plantations established on mineral soil forest and biofuels emissions was 126 and 144 for biodiesel and HVO respectively. Original soil categories such as bare soil, intensive agriculture, upland shrub/grasslands and swamp shrub/grasslands soil categories yield negative emissions due to land use change, when these emissions are added to savings by biodiesel and HVO the first three soil categories comply with the 65 % emissions reduction target and the first two soil categories comply with biodiversity statements from the current EU biofuel regulation. Selection of the original land use is therefore of critical importance when establishing new oil palm plantations. The correct establishment process joined to

the use of biofuels produced from palm oil can generate very high emissions savings and have the potential to reduce climate change.

After analysing the different scenarios, we shall take a closer look to the most critical one, establishment of oil palm plantations in forested land. The aim of this study is to understand the reasons underlying the expansion and to define ways to Indonesia's improve business as usual practices. A case study is addressed in a recently established oil palm plantation in Papua, Indonesia. Based on field work and literature data, a cost benefit analysis comparing original primary forest land use benefits to those of the newly established oil palm plantation was conducted. Development is important to local population; oil palm plantations can bring wealth and improved living standards, on the other hand establishment of new oil palm plantations on forested areas takes away benefits due to the loss of ecosystem services. The benefits from primary forest ecosystem services were estimated at 3,795.44 USD ha⁻¹ y⁻¹ while the profits estimated for the new established oil plantation were 2,153.00 USD ha⁻¹ y⁻¹, therefore the land use change was considered not feasible. Sensitivity analysis revealed that prices of carbon emissions and commodities (Crude Palm Oil and Kernel Oil) have a large impact on the results. The beneficiaries are changing during the transformation process; the local population is the biggest loser and the plantation company the biggest winner. Benefits are transferred from the local and global level to the national level. Case to case feasibility analysis including economic, environmental and social analysis should be required before oil palm projects start.

RESUMEN

El establecimiento de nuevas plantaciones de palma aceitera en la región de Papua al este de Indonesia ha aumentado en los últimos años. El establecimiento de nuevas plantaciones implica cambios de uso del suelo, en muchas ocasiones relacionados con la pérdida de bosques primarios. Las condiciones climáticas para el cultivo de la palma aceitera en Papua, debido a las altas precipitaciones y suelos ricos, a la vez que, a la alta disponibilidad de terrenos libres para el cultivo, hacen que esta región sea atractiva para establecer nuevas plantaciones. Por otra parte, la lejanía y la inestable situación política, implican mayores costes y riesgos para los inversores. La industria del aceite de palma tiene el potencial de generación de empleo, de promoción de zonas remotas y de redistribución de la riqueza generada a la sociedad a través de los impuestos. Sin embargo, el cambio de uso de las tierras produce pérdida de servicios ecosistémicos, pérdida de hábitats naturales y emisiones de dióxido de carbono. La provincia de Papua-Indonesia guarda tradiciones tribales ancestrales y tiene una población que en general se opone al cambio. El establecimiento de nuevas plantaciones de palma aceitera en Papua se ha estudiado haciendo una revisión de la literatura existente. Las consecuencias a nivel local y global se han evaluado. Los factores que influyen en la toma de decisiones se han identificado en una matriz de debilidades-amenazas-fortalezas-oportunidades que enmarque el proceso de establecimiento de nuevas plantaciones.

Las emisiones de cambio de uso de las nuevas plantaciones establecidas representan el 10 % de las emisiones por cambio de uso y el 7 % de las emisiones totales de Indonesia. Se requieren políticas para reducir emisiones por establecimiento de nuevas plantaciones. Este estudio ha identificado algunas políticas que puedan reducir las emisiones y mejorar la viabilidad de nuevas plantaciones de palma aceitera. Se han estudiado diversos escenarios, incluyendo la mejora de las prácticas agrícolas, mejora genética, producción de biocombustibles avanzados, evitar nuevas plantaciones en terrenos boscosos o turberas. El escenario alternativo identificado como el más beneficioso, capaz de reducir las emisiones de 168.51 a -7.82 millones de toneladas de CO₂eq al año es el que implica parar de plantar palma aceitera en terrenos forestales. Otros tipos de terrenos pueden reemplazar a los bosques; nuestro estudio muestra que el establecimiento de nuevas plantaciones en tierras marginales produce beneficios comerciales importantes, y por tanto es posible el evitar plantaciones en bosques y cambiarlas a otros terrenos menos fértiles. Los biocombustibles tienen el potencial de reducir las emisiones por cambio de uso en Indonesia. La relación entre las emisiones por cambio de uso de bosque a palma y las emisiones evitadas por el biodiesel y el HVO es de 126 y 144 veces respectivamente. Usos originales de suelo como el suelo desnudo, agricultura intensiva, pastizales y matorrales de tierras altas, y pastizales y matorrales de humedales generan emisiones negativas cuando son transformados a

cultivos de palma aceitera, los tres primeros escenarios cumplen con los requisitos de ahorro de emisiones del 65 % y los 2 primeros escenarios cumplen también con los requisitos de biodiversidad de la nueva normativa europea de biocombustibles. La selección del tipo de uso del terreno original es de una importancia crítica cuando se establecen nuevas plantaciones de palma de aceite. El correcto establecimiento del proceso unido al uso de los biocombustibles producidos a partir del aceite de palma puede generar grandes ahorros de emisiones y reducir el cambio climático.

Después de haber analizado los distintos escenarios, debemos estudiar en mayor profundidad el más crítico de todos, el establecimiento de plantaciones de palma aceitera en terrenos boscosos. El objetivo de este estudio es entender las razones bajo la expansión y definir maneras de mejorar las prácticas actuales en Indonesia. Se ha realizado un caso de estudio en una plantación recientemente establecida en Papua-Indonesia. En base a los estudios de campo y a los datos bibliográficos, se ha generado un análisis coste-beneficio comparando los beneficios originales generados por el bosque con los beneficios de la nueva plantación establecida. El desarrollo es importante para la población, las plantaciones pueden traer riqueza y mejorar el nivel de vida, pero a su vez pueden destruir los beneficios generados por los servicios ecosistémicos del bosque. Los beneficios de los servicios ecosistémicos del bosque se han valorado en 3,795.44 USD ha⁻¹ y⁻¹ mientras que los beneficios generados por las nuevas plantaciones se han valorado en 2,153.00 USD ha⁻¹ y⁻¹, por tanto, el cambio de uso del suelo se ha considerado no viable. El análisis de sensibilidad revela que los precios de las emisiones, así como de las materias primas (aceite de palma, y aceite kernel) tienen un gran impacto en los resultados del modelo. Los beneficiarios cambian durante el proceso de transformación, siendo la empresa inversora en la plantación el mayor beneficiado. Los beneficios se trasladan del nivel local y global al nivel nacional. Un análisis de viabilidad caso a caso, que incluya un análisis económico, medioambiental y social, debe ser requerido antes del comienzo de cualquier proyecto de plantación de palma aceitera.

FOREWORD

During my last year in Indonesia (2015), I witnessed a terrible series of fires caused by burning of forests and shrubs. I found out that the fires were produced in many cases due to the burning of forest being converted to oil palm plantations. I wanted to understand whether changing the use of the land from forest and other uses to palm oil made sense from a socioeconomic and environmental point of view. At that time, Pertamina (Indonesian National Petroleum Company) was already blending palm oil biodiesel into the diesel mix. Emissions could be reduced, and Indonesia could reduce its fossil fuels dependence, but the production of biofuels was related to forest being burned to produce palm oil. I also wondered how these fires and massive forest clearing could affect communities in rural remote areas in Indonesia. The need in the cities for processed food and biodiesel was making pressure in remote locations where companies were establishing new oil palm plantations.

One day, flying a small propeller plane back from a business trip in Sumatra, I saw massive fires and huge extensions of palm oil, that were in contrast with pictures of Sumatran elephants in the touristic advertisements at the local airport. I wondered whether the development of those remote locations was more important than the preservation of the forest and its flora and fauna biodiversity, as well as the health of the people globally affected by the GHG emissions from the forest burned to produce palm oil.

I became interested in the palm oil industry environmental effects, and decided to conduct doctoral studies about this topic. This thesis tries to answer some of these questions and to determine the reasons why new plantations are being established in forested areas. In order to do so, a real case study has been selected; a new oil palm plantation in Papua has been visited and surveys have been conducted to try to find out the reasons for the plantations' establishment as well as the positive and negative impacts of the plantation in a local, national and global level. Also it is important to determine who are the winners and losers of this process, and how things could be done better. This study has not received any funding.

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
C	Carbon
CAIT	Climate Data Explorer from World Resource Institute
CDM	Clean Development Mechanism
CER _s	Certified Emissions Reductions
CO	Carbon Oxide
CO _{2eq}	Carbon Dioxide Equivalent
COD	Chemical Oxygen Demand
COD	Cost of Debt
COE	Cost of Equity
CPO	Crude Palm Oil
C _{VEG}	Above and below vegetation carbon stock
EU	European Union
FAME	Fatty Acid Methyl Esther
FAME	Fatty Alcohol Methyl Esther
FAO	Food and Agriculture Organization of the United Nations
FFB	Fresh Fruit Brunch
F _{LU}	Land use factor reflecting the difference in soil organic carbon associated with the type of land use compared to the standard soil carbon
F _{MG}	Land use factor reflecting the difference in soil organic carbon associated with the principle management practice compared to the standard soil organic carbon
F _I	Land use factor reflecting the difference in soil organic carbon associated with different levels of carbon input to soil compared to the standard soil organic factor
FSC	Forest Stewardship Council
GDP	Gross Domestic Product
GHG	Green House Gases
ha	Hectare
HBD	Hydro Generated Biodiesel

HC	Carbon-Hydrogen
HVO	Hydrogenated Vegetable Oil
I/O	Input/Output
IDR	Indonesian Rupiah
ILUC	Indirect Land Use Change
IRR	Internal rate of return
ISPO	Indonesia Sustainable Palm Oil Organization
IUCN	International Union for Conservation of Nature
Kg	kilogram
KO	Kernel Oil
LUC	Land Use Change
LUC	Land Use Change
m.a.s.l	Mean average sea level
m ³	cubic meter
Mha	Mega hectare
Mha	Mega hectare
MJ	Megajoules
Mt	Mega ton
NO ₂	Nitrous Oxygen
NO _x	Nitrous Oxide
NPK (B)	Nitrogen Phosphorus Potassium (Boron) Fertilizer
NPV	Net Present Value
°C	Degree Centigrade
PIR-Trans Program	Transmigration Program
PLN	Pekerjaan Listrik Negara – National Electric Company of Indonesia
PM	Particulate Matter
PM	Particulate Matter
PO ₄	Phosphorous Oxygen
POME	Palm Oil Mill Effluent
PPP	Purchase Power Parity

PT RML	Rimba Matoa Lestari Company
PU	Pekerjaan Umum – Public Works Ministry of Indonesia
RM	Malaysian Ringgit
ROI	Return on investment
RSB	International Sustainability and Biomaterials Certification
RSPO	Roundtable on Sustainable Palm Oil
RTFO	Renewable Transport Fuel Obligation
RTRS	Roundtable of Responsible Soy
SAN	Sustainable Agricultural Network
Sc-CO ₂	Social Cost of Carbon
S-O Targets	Strength – Opportunity Targets
SOC	Soil Organic Carbon
S-T Targets	Strength – Threats Targets
SWOT	Strengths, Weaknesses, Opportunities Threats
TORA	National Indonesian Land Reform Program
t	Metric tons
UE-RED	European Union Renewable Energy Directive
UNISDR	United Nations system for disaster risk reduction
USD	United States Dollar
USGCRP	United States Global Change Residual Program
VAT	Value Added Tax
VOCs	Volatile Organic Compounds
WACC	Weighted average cost of capital
W-O Targets	Weakness - Opportunity Targets
W-T Targets	Weakness - Threats Targets
y	year

1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

Indonesia is a developing country with GDP of 3,400 USD per capita and total population of 261.12 million in 2016, equivalent to 144 persons per km² population density (The World Bank, 2016a); 73 % of the population is concentrated in only two Islands (Java and Sumatra), while the country is composed of about 17,504 Islands (Geospatial Information Agency of Indonesia, 2017). Between 1960 and 2016, the Indonesian population increased three-fold (The World Bank, 2016b), resulting in higher pressure on natural resources. Indonesia lost 23.23 % of forested area in the period 1990-2015, compared to a loss of only 3.13 % of forested area worldwide. According to Vijay et al. (2016), annual global carbon emissions from gross tropical deforestation contributes nearly 10 % to total anthropogenic greenhouse gas emissions.

Palm oil represents 17 % of total agricultural revenues, making it the most important agricultural product of Indonesia. In 2016 palm oil represented 2.36 % of Indonesia's GDP (The World Bank, 2016a; Indonesia Investments, 2017). Indonesia is currently expanding its palm oil industry due to its apparently positive economic impact, contribution to an increase in GDP and national development. The Palm Oil Industry in Indonesia meets the four attributes of national competitive advantage (Porter, 1990), blending into an environment that allows international success. This author reported that Indonesia possessed about 27 Mha of 'unproductive forestlands' that could be potentially converted into plantations. Nowadays, the main target for new concessions of oil palm is eastern Indonesia.

New oil palm plantations generate economic development as well as social and environmental problems (Andrianto et al., 2014). In the year 2000, about 657,000 km² or 82 % of New Guinea Island was forested. About 213,627 km² (51.3 %) of Papua (Indonesia) is lowland evergreen forest with only about 15 % of the area considered protected. In the worst case scenario all the lowland forests in Papua will be lost by the end of the 21st century (Beehler and Marshall, 2007). Palm Oil Plantations bring development to remote regions, generating jobs and entrepreneurial opportunities, contribution to regional revenue, creation of infrastructures and economy stimulation (Andrianto et al., 2014). Oil palm has become one of the fastest-growing sectors of the Indonesian economy, increasing eight-fold since 1991, up to 8.9 million hectares in 2011. Close to 70% of oil palm plantations in Indonesia were planted on land that formally fell within Indonesia's state-owned forest (Casson et al., 2014).

According to the Ministry of Environment and Forestry Republic of Indonesia (2018), about 6,800,000 ha of forest had been released for Oil Palm Plantations in Indonesia from 1990-2017. This means an average of 242,857 ha per year. According to Suwandi (2017) a total of 11.91 million ha were planted with oil palm in 2016, and an average of 554,084 ha of oil palm were established per year in the period from 2007 to 2017.

As new oil palm plantations are established, new infrastructures are developed, allowing for more rapid development of the local communities (Andrianto et al., 2014). However, at the same time, plantations destroy the natural ecosystems and the services related to them; access to timber is lost for the local population and forestry activities concentrate in areas nearby (Obidzinski et al. (2014). Further pressure is put in remaining forests and land conflicts disrupt plantations and conservation efforts (Meijaard et al., 2018). In certain cases conflicts arise during oil palm plantation establishment; Abram et al. (2017) quoted that forest land-use related conflicts had affected 12.3-19.6 million people in the period 1990-2000. However, palm oil affects positively the employment in rural areas. Oil palm can represent 63 % of smallholder household incomes, and 22,000-120,000 employment opportunities have been created in East Kalimantan Province (Irawan et al., 2013a).

Papua is an eastern region of Indonesia, rich in natural resources but highly undeveloped, that occupies the west part of New Guinea Island. About 657,000 km² of the Guinea Island (82 % area) was forested in 2000, considered one of the three world low land tropical forest wilderness areas. Forests in low lands are climax forests holding many types of trees and plant species only present on New Guinea island; some of the species of flora and fauna have yet to be discovered (Beehler and Marshall, 2007). Obidzinski et al. (2014) stated that a total of 381,651 ha had been granted in for new plantations in Papua Province up to year 2009. This region has claimed independence from Indonesia in the last years; the central government is trying to develop it to reduce tensions. Monetary transfers from Jakarta to Papua have grown about 1300 % in nominal terms and 600 % in real terms from 2000 to 2009 (The World Bank, 2009a).

At present, a great controversy about oil palm expansion in Indonesia exists. On the one hand, oil palm generates prosperity, increase in GDP and country growth, production of biofuels, jobs creation, establishment of services and infrastructures. Despite this fact, not always the local population can benefit from the plantation job opportunities. Andrianto et al. (2014) stated that two thirds of the jobs were unskilled and temporal jobs at Papua Boven Digoel District plantations; most of the skilled jobs were taken by immigrant workers whereas the unskilled ones were taken by Papuans. According to Obidzinski et al. (2012), many Papuans could not access plantations jobs due to lack of skills; additionally, they are not willing to give up their traditional way of life.

On the other hand, if plantations are not established sustainably, they can bring negative effects such as deforestation, GHG emissions, loss of ecosystem services, pollution and loss of living habitat for the local population. Previous studies tried to assess the problem of oil palm new plantations in Papua in a qualitative way but the value of forest ecosystem services in this region remains unknown. Economic and social benefits brought by new plantations, as well as their distribution, need to be determined. It is of critical importance to quantify if benefits are higher than losses, and to find ways to improve the conversion process.

According to Purnomo et al. (2018), Indonesia aims to reduce emissions by 29 % without international assistance and 41 % with assistance. Sustainability of agricultural plantations, deforestation and forest degradation reduction, as well as promotion of renewable energy are key factors to reduce emissions. According to Cazzolla Gatti et al. (2019), RSPO plantations shall not touch high carbon stock areas, but clearance of forests not considered high carbon stock is allowed; therefore sustainable palm oil is often linked with destruction of habitats that are rich in ecosystem services.

According to Wicke et al. (2011), Indonesia's Land Use Change (LUC) can be characterized by 40 million ha forest cover loss. Oil palm was the mayor contributor to peat land forest fragmentation between 1966-1995. In Indonesia the land requirement could be reduced 50 % if yields increase, assessment of degraded land property and use is required in order to avoid the settlers to move to forested land.

Palm oil is a commodity that is used in Europe for energy production (65%) distributed into biofuels production (53%) and electricity production (12%) (Muzi 2019). The remaining 35 % is used for food, feed and industry applications. According to Eurostat (2019), the European Union (EU) is the second biggest importer of Indonesian palm oil after India. The value of palm oil imports to Europe from Indonesia decreased by 22% in 2018 compared to 2017. Imports have been about 3.5 million tons and €2.2 billion average per year. Palm oil imported from Indonesia into Europe has a market share of 47 % of the total palm oil imports. The European Union (2019) regulation imposes tariffs from 8 to 18 % over biodiesel originated in Indonesia, in order to countervail the subsidy programs to biofuel producers from the government of Indonesia. According to Ecofys (2019), 56 % of European Biodiesel in 2016 came from local produced raw materials. About 13.3% of European biodiesel was generated from Indonesian palm oil, normally being imported as biodiesel.

A biofuel market has been created in Europe since the already-repealed Directive 2003/30/EC (European Union, 2003) was released. Thereafter, Directive 2009/30/EC (The European Parliament and the Council of the European Union, 2009), already set country shares of renewable energy targets for 2020. It also set values of typical greenhouse gas emission savings for palm oil biodiesel and HVO. In 2015, the effect of indirect land use change for biofuels was introduced (The European Parliament and the Council of the European Union, 2015). The Resolution by European Parliament (2017), aimed to make the palm oil industry 100 % sustainable by 2020. In 2008 the EU committed to lessen deforestation by at least 50 % by 2020 and to stop forest cover loss by 2030. Directive (EU) 2018/2001 (The European Parliament and the Council of the European Union 2018) is the current applicable regulation on the promotion of the use of energy from renewable sources setting the targets and sustainability criteria for biofuels in Europe.

The targets set on renewable energy for the transport sector in Europe by Directive (EU) 2018/2001/EC shall be at least 14 % by 2030. According to this Directive in order to comply with the renewable energy regulations and comply with each country's

renewable energy % commitment emissions reductions of biofuels in the transport sector shall be at least 65 %, for plants established after January 1st, 2021. Typical values for CO₂eq emissions savings from palm oil biodiesel and HVO without methane capture are set at 32 % and 34 % respectively. Biofuels coming from agricultural biomass shall not come from lands that after January 2008 have had a biodiversity rich condition, such as forested land, peat soils, biodiversity rich shrublands/grasslands or any other lands with high biodiversity.

The concepts of Land Use Change and Indirect Land Use Change are considered for the purpose of sustainability. Land use change is introduced in Directive (EU) 2018/2001 (The European Parliament and the Council of the European Union, 2018) through the inclusion of the annualized emissions from carbon stock changes caused by land-use change in the calculation for the Greenhouse gas emissions from the production and use of transport fuels, biofuels and bioliquids. Indirect Land Use Change is introduced through The European Delegated Regulation (European Commission, 2019a) supplementing Directive (EU) 2018/2001 on the promotion of renewable energies. The share of the expansion into high carbon land is calculated by a given formula that takes into consideration the share of the crop expansion into forested lands and wetlands. The production area into high-carbon land shall be below 10%, in order not to be considered a high ILUC-risk feedstock. The amount of food and feed crops with high ILUC-risk should be gradually reduced to 0% by 2030 at the latest. The report by the European Commission (2019b) analyzes the percentage of oil palm plantations in Indonesia being planted in forested and peat lands. The values obtained in this report position palm oil as high ILUC-risk feedstock.

Biofuels have the potential to reduce greenhouse gas emissions. According to Živković and Veljković, (2018), biofuels are considered carbon neutral, as long as the CO₂ emissions are balanced by a new plantation able to re-capture the CO₂ by photosynthesis. According to Curt. (2017), viability of oil palm could be achieved through agriculture research and development such as the development of new varieties and increase in crop yield. Also developing of better biofuel technologies, the use of the sub products or automotive application could help increase the viability of biofuels.

According to Rahmanulloh (2018), the Indonesian government has applied a subsidy to biodiesel by using export levies, a mandate to reach a 30 % biodiesel blending into diesel by 2030 has been issued, expecting to reduce emissions by increasing the biofuels ratio. The effective blending rate in 2017 was 8-12 %, with expected 11.3 % biodiesel blending in 2018. Shell (2012) highlights that bioenergy is not only used in transport, bioenergy is an important component in the total energy mix, constituting 10 % of primary energy mainly by traditional applications. In Germany biofuels could cover 20 % of fuel needs, and 70 % by 2050. Biofuels in Germany reduced greenhouse gases by 50 %.

Biodiesel is mainly produced from vegetable oils by transesterification with methanol (Fatty Acid Methyl Esters, FAME). The main advantage of biodiesel is that, in principle, it is carbon neutral and reduces emissions of Sulphur dioxide (SO₂). Its disadvantages are high price, lower availability, decreased fuel economy and increased exhaust emissions (Suresh et al., 2018). According to Sonthalia and Kumar (2019), hydroprocessing of liquid biomass is a newer technology with lower production cost, possibility of existing infrastructures utilization, and flexibility in the use of feedstock. HVO is produced by hydroprocessing technique of vegetable oil, using high temperature and pressure and a catalyst. Properties beneficial for the engine and the environment are achieved, through emissions reductions for NO_x, PM, CO and HC.

This study aims to assess the way to reduce emissions due to palm oil and biofuels production in Indonesia. Emissions from land use change are estimated and compared to potential palm oil biofuel savings. A baseline scenario based in current practices in Indonesia is established. Ways of improvement such as: savings in emissions due to land use change, savings in emissions due to the use of biofuels, improvement in planting strategy, improved practices in the production of palm oil, improved processing of biofuels as well as improved efficiency of biodiesel and HVO are analyzed in different alternative scenarios. Options capable to reduce emissions due to the production of palm oil by using the biofuel potential are explored.

In addition, the most critical transformation scenario from tropical forest in mineral soil to oil palm plantation is further studied. The economic, environmental and social feasibility of transforming primary tropical forest to an oil palm (*Elaeis guineensis* Jacq.) plantation is analyzed. Global and local effects are studied through a case study of a newly established oil palm plantation established in primary forested land in Jayapura Regency, Papua Province, Indonesia, in order to assess if this change in land use makes sense. To answer this question a cost-benefit financial model is developed based on information gathered in site visits and survey and literature data; benefits generated from the oil palm plantation are compared to those of the forest being replaced. Other objectives of this work include: knowing the opinion of Papuan population regarding new palm plantation establishment, understanding the positive and negative effects of the plantation establishment on forested land, and who is winning and losing in the process of land use conversion.

1.2 Objectives

Three main objectives are set in this study, going from a general study based in literature in the first part of the thesis, detailed emissions calculations and economic analysis of new oil plantations in the second part and ending with very detailed ground study and quantitative socio-economic analysis of a case study of forested land transformation in the last part of the study.

1.2.1 Objective 1: To perform SWOT analysis for new Oil Palm Plantations in Indonesia.

Current practices as well as the general frameworks for analysis of new oil palm plantations are determined by using a SWOT matrix. Extensive literature was revised and strengths, weaknesses, opportunities and threats for the new oil palm plantations establishment process in Indonesia are established. This objective sets up the theoretical framework for our study. Based on the obtained information strategies to improve current practices were established. Strengths and opportunities were established as well as the threats and weaknesses for the sector, the analysis is divided in economic, environmental and social and targets. This first objective will set up the study framework and determine the issues currently happening in the oil palm industry, introducing them and setting up the general strategies for improvement. This framework will help the rest of the study, which will focus on quantitative data to quantify the environmental and economic feasibility of newly established plantations in different land uses.

1.2.2 Objective 2: To assess GHG emissions due to the establishment of new oil palm plantations in Indonesia and study their feasibility.

This objective implies emissions calculation for the establishment of new oil palm plantations for the different original land uses. Using these emissions as a basis, a feasibility analysis of new plantations based on emissions is conducted. Based on the cultivated areas of each original land use (initial biosystems) and their emissions from transformation to oil palm plantations, global emissions calculations were generated, and their impact was put in perspective comparing these emissions to the total land use change and total emissions in Indonesia. Savings of emissions, using biofuels instead of their equivalent diesel fossil fuel, are calculated and compared to emissions due to land use change. Different scenarios were created to find possible strategies to improve the current practices. Improvement of plantation establishment, improvement in the agricultural techniques, genetic breeding and improvements in the refining process of biofuels were proposed as feasibility improvement scenarios. Economic and environmental improvements of each scenario were analyzed. The economic consequences of more environmentally friendly practices are also investigated to see the economic impact of these measures.

Biodiesel and HVO benefits, in terms of GHG emissions savings, when being compared to the use of fossil fuel diesel were calculated using official publications from the EU. The effect of land use change is included by adding emissions due to land use change emissions savings of biofuels. Feasible original land uses were determined and compliance with current EU regulations was analyzed. The goal is to study which original land uses are feasible in terms of emissions for biofuels production, study the

economic implications of feasible scenarios and make recommendations for current practices improvement.

1.2.3 Objective 3: To study the feasibility of a new oil palm concession established in forested land in a specific location in Papua, Indonesia.

The most critical land use transformation is the establishment of new oil palm plantation in primary forest. The economic, social and environmental feasibility of a new plantation in Papua, Indonesia was studied. A detailed analysis of the strategies to improve current practices was conducted by field study. This plantation was selected from the palm oil in Papua Atlas Publication (Yayasan Pusaka, 2015), this publication states that a large areas of forested land have been already converted to oil palm plantations. This case study tries to analyze the feasibility of establishing oil palm plantations in forested land, following the following methods:

- Interviews: interviews were conducted to plantation workers and to stakeholders, such as tax inspectors or inhabitants close to the plantation; the aim was to understand the socio-economic frame and the consequences due to land use change of the forested land to convert it into oil palm plantations.
- Surveys: a survey was prepared and given to the local population living close to the oil palm plantation. Participants were selected randomly from different social backgrounds, such as plantation company employees, local politicians, landowners, inhabitants of the influence area, potential land receptors for participation in the plasma scheme. From these surveys tangible and non-tangible benefits derived from the forest and from the established plantation were determined.
- Cost benefit economic model: Benefits obtained from the surveys together with other benefits obtained from literature, were introduced into the cost benefit discounted cash economic model, for the 25-year period of the plantation. Social and economic benefits of the plantation were compared to the ecosystem services benefits from the forest.

Feasibility of the new plantation in forested was analyzed, ways for improvement of the established methodology were assessed, and recommendations were made based on this analysis.

1.3 Document Structure

The Thesis document format is presented in Figure 1. The Thesis document was divided into a general introduction and objectives chapter in which three objectives were defined; then these objectives were developed in the next three chapters corresponding to Methodology, Results, and Discussion. The document wraps up the conclusions, recommendations as well as proposals for required research themes in the Conclusions chapter.

Figure 1: Thesis Document Structure

1.4 Publications related to this Thesis

The following articles have been prepared and/ or published in relation with this thesis:

- "Understanding the expansion of oil palm cultivation: A case study in Papua". The article was accepted on February 2nd, 2019 by the *Journal of Cleaner Production*, journal Q1. Its digital identification (doi) is as follows: 10.1016/j.jclepro.2019.02.029
- "New oil palm plantations in Papua, Indonesia. Challenges in the establishment process". This article was prepared for the European Biomass Conference and Exhibition (EUBCE 2019). It was published in the conference proceedings of EUBCE 2019 (<http://www.etaflorence.it/proceedings/>), and its doi is: 10.5071/27thEUBCE2019-4AV.1.1. The proceedings are open format and are indexed by Scopus y WOS.
- "Feasibility of Oil Palm Plantations in Indonesia". This article has been completed and is ready to be presented to a scientific journal.

2 METHODOLOGY

In this chapter the methodology developed for each objective is summarized.

2.1 SWOT Analysis for new Oil Palm Plantations in Indonesia

The methodology used for this objective was as follows:

Bibliography Review. An extensive review of available bibliography was conducted. Available articles about previous plantation establishment process in the region of Papua were reviewed. Not too much information about Papua's region plantations was found, so additional articles of the oil palm industry in other regions of Indonesia were also reviewed, as well as additional reports, books and online statistics related to the subject, which were analyzed and incorporated into the subject.

SWOT Matrix. Based on the extensive literature review a matrix was constructed, identifying the Strengths and Weaknesses of oil palm plantation establishment in Papua-Indonesia, based on industry, geographical, environmental, as well as socioeconomic criteria. Opportunities and threats related to the subject were then identified. The literature review, broken down into the different categories, is explained in the results section corresponding to this objective. Maps of Indonesia and Papua can be found in Appendix 1.

SWOT Targets. Creation of targets (strategies) allows strategy generation for new oil palm plantation establishment. Methodology was adapted from Reißmann and Thr (2018). A matrix was created for the three main studied aspects of oil palm plantation establishment: Economical, Environmental and Social; success strategies/ targets were defined as follows:

S-O Targets: follow opportunities fitting strengths.

S-T Targets: use strengths counteracting threats.

W-O Targets: eliminate weaknesses using new opportunities.

W-T Targets: develop strategies to avoid weaknesses become threats.

The Target Matrix allows recommendations generation on how to improve business as usual practices. These strategies are elaborated in the discussion section for this objective.

2.2 Emissions and Feasibility of New Oil Palm Plantations in Indonesia

The aim of this second objective is to understand the current practices of the oil palm industry in Indonesia, and to study the Environmental and Economic Feasibility of new plantations establishment. This section is divided into two subsections detailed below.

2.2.1 Environmental Feasibility

The transformation of land uses (soil categories) into oil palm entails changes in land carbon storage potential leading to emissions that should be assessed. In this part of the study the emissions for each of the most important original soil categories in Indonesia are calculated to identify sustainable and non sustainable soil categories.

- Non sustainable soil categories: non sustainable soil category scenarios are those that produce high emissions.
- Sustainable soil category scenarios: are those that produce emission savings.

Assumptions based on current Indonesian practices are made to calculate the emissions due to land use change in the baseline scenario. These current practices can be seen in sub-section 2.2.1.5.1. The methodology for calculations of carbon stocks are according to sub-section 2.2.1.3.

Biofuels (Biodiesel and HVO) produced from crude palm oil have the potential to reduce emissions. This study analyzes the combined effect of the land use change emissions due to the oil palm plantation establishment with the savings in emissions by the use of biofuels instead of conventional fossil fuel diesel. For non sustainable soil categories ratios between LUC emissions and biofuel emissions are calculated. For sustainable categories LUC emissions and emissions savings are added. Assessment of compliance to European Union emissions sustainability requirement is performed. Below in Figure 2 this methodology is summarized.

Figure 2: Methodology for land use change emissions calculation by soil categories and assessment of feasible and non feasible soil categories.

The current legislation in Indonesia as well as the actual level of enforcement has led to a controversial situation. In addition to the Indonesian Government regulations related to oil palm plantations establishment there are non-governmental certifying organizations that also regulate the correct way to establish oil palm plantations. According to Cazzolla Gatti et al. (2019) certified plantations can still be established in forested lands that is considered not high carbon stock. This study proposes new scenarios that can improve the way oil palm plantations are currently established.

Technical current agricultural practices are also studied; current practices demand large areas of land and generate high level of emissions due to land use change. According to Pirker et al. (2016) global oil palm plantations' area has increased from 10 to 17 million ha from 2012 to 2017. The current land requirements in Indonesia are analyzed in this study, and improved scenarios are proposed in order to understand the consequences of improved practices in terms of land use change emissions reduction and economic advantages.

Improved Scenarios: After analyzing the current emissions based on the assumed current practices, new alternative scenarios are generated by modifying the current industry practices. These changes can be due to agricultural techniques improvements, changes due to improvement or enforcement of legislation or new research and development related to genetic breeding. These scenarios represent different levels of emissions compared to the baseline scenario. This way the impacts of each practice change are analyzed.

Many different scenarios that affect the environmental sustainability of new oil palm plantations have been studied, some of them have been selected and included into this study. The reasons for selecting each of the improved scenarios are as follows:

Alternative Scenario 1. Presence of Fire: according to Glauber and Gunawan (2016) in 2015, the cost due to fires in Indonesia was about USD 16.1 billion. Draining of peats, related to oil palm, are seen as a main contributor to fires. This study aims to understand the effect in terms of emissions of changes in the percentage of oil palm plantations in peat established by burning the previous land use.

Alternative Scenario 2. Yield Improvement by improved agricultural practices: Pauli et al. (2014) studies the effect of best management practices on soil properties such as pH, organic carbon and nutrients. These best practices shall be adjusted to site specific conditions that depend of the type of soil, age of palm and meteorological conditions. This scenario tries to understand the effect of application of best practices on emissions due to land use change, improving yield is associated to increase in carbon storage of oil palm plantations and therefore related to reduced land use change emissions.

Alternative Scenario 3: Improvement of Yield by Genetic Modification: many publications talk about the potential to improve the varieties of oil palm and adjust these varieties to the site conditions. According to Barcelos et al. (2015) the best dura x

pisifera varieties combination has 28–32% oil to bunch ratio with potential yield of about 10 t. Potential yield of hypothetical oil palm genotypes that combine could reach 18.5 t. High yields of 12–13 t can be obtained if high performance plants are multiplied. Potential yield stated in this publication are above twice the yield being obtained in current plantations in Indonesia, and therefore is important to study the implications of selecting the best performance species.

Alternative Scenario 4. Improved soil practices: according to ACIAR (2015) oil chemical characteristics for oil palm plantation soils have to be evaluated in order to determine the best management practices. Based on climate, topography, wetness, physical soil conditions and soil fertility conditions the type of soil is evaluated and fertilization practices can be assessed. Application of improved soil practices has the potential to increase the soil stocks and therefore reduce the emissions due to land use change when establishing new oil palm plantations. Understanding the implications of better soil practices could allow the promotion of better practices.

Alternative Scenario 5. No plantations established in Peat Lands: insular Asian peatlands have suffered a very rapid cover change inducing consequences in peatland ecology, biodiversity as well as ecology as well as very high carbon emissions (Miettinen et al., 2016). This study studies the emission implications of stopping planting in peat land.

Alternative Scenario 6. Avoided deforestation: this study studies in detail the yearly deforested area due to oil palm, the results can be followed below in subsection 3.2.1.1. The high carbon stocks stored by forests generate emissions due to land use change when deforestation occur, also loss of ecosystem services is of critical importance. This objective studies in detail the implications in terms of emissions of planting oil palm in forested land. The next objective studies the economic and other environmental implications in detail.

After alternative scenarios are generated and emissions calculated for each of them, the emissions implications are analyzed as well as the relationship between LUC and biofuel saving emissions of each improved scenario are analyzed.

2.2.1.1 Areas being converted to oil palm

The total areas converted to oil palm in Indonesia were based on Suwandi (2017), according to the values in this publication, the land converted in the period from 2008 to 2017 attained 5,540,841 ha, and the average yearly area converted, 554,084.1 ha y^{-1} . The average area of forest released for oil palm was obtained from the Ministry of Environment and Forestry Republic of Indonesia (2018). The proportions between mineral and peat soil forest types were obtained based on the article by Casson et al. (2014).

In order to obtain the forested area released for oil palm plantations, official data from the Ministry of Environment and Forestry Republic of Indonesia (2018) were used. The

total released area for oil palm plantations was divided by the total conversion period of 28 years, to arrive to a total released area per year. The distribution of released forest area during this period by soil category, was used to calculate the proportion between mineral and peat soil. The difference between the released area and the area converted to forest was redistributed proportionally to the rest of land uses based on Gunarso et al. (2013). Based on the areas being converted to oil palm plantations this study will estimate the emissions generated by land use change in the current situation (or baseline scenario as per current Indonesian oil palm industry practices), as well as in several improvement scenarios that could be achieved by improvement of current practices either by changes in policy or technical improvements.

2.2.1.2 Savings in Emissions from Biofuels Methodology

To calculate the emissions from diesel fuel per ha, emissions from one liter of diesel fuel were taken from the study by Lechón et al. (2006); these emissions included the extraction process, transportation and the emissions generated during driving. Emissions from Land Use change of the palm oil raw material were not included. The study by Lechón et al. (2006) is used due to the high quality and methodological detail, which allows very precise merging with the rest of the data. The total liters of biodiesel that can be produced per ha were calculated based on the production rates in plantations in Papua by Andrianto et al. (2014). Using official data for density of diesel and biofuels (HVO and Biodiesel) the volume of biofuel produced per ha was calculated and this amount was multiplied by the emissions per liter. These calculations assumed that one liter of biodiesel can produce the same power and torque as one liter of Fossil Fuel Diesel.

Based on the emissions that diesel would produce per ha of oil palm planted, savings of biofuels were compared to those diesel based on The European Parliament and the Council of the European Union (2018). According to this source, the typical values for the savings of CO₂ emissions of biodiesel compared to diesel were 51 % with methane capture system and 32 % without methane capture system. Savings of CO₂ emissions of HVO compared to diesel were 53 % with methane capture system and 34 % without methane capture system. The reason to use the official standard data of emission savings given by the The European Parliament and the Council of the European Union (2018) rather than calculating the real emissions of biodiesel produced from the case study plantation is data unavailability since all required data for life cycle emissions calculations could not be obtained from the plantation company. This is a limitation of the study and further research is recommended.

In Indonesia about 10 % of biodiesel plants have methane recovery system (Cahyat, 2013) and therefore 32 % emissions savings was used as the reference value for this study. This emissions savings were compared to the data from Lechón et al. (2006), that estimated the savings of biodiesel emissions compared to diesel to be about 54 %.

2.2.1.3 Comparison Between LUC and Biofuel Emissions Methodology

After emissions from land use change for each soil category were calculated, they were compared to savings in emissions from biodiesel and HVO, the relationship between them was calculated to see biofuel recovery potential.

2.2.1.4 Methodology for LUC Emissions Calculation

Palm land use change emissions from the conversion of the different original land uses to oil palm were calculated following the methodology set by The European Parliament and the Council of the European Union (2018) for the factor e_l (yearly emission due to carbon stock reserve change due to land use change) and following the European Commission (2010), and the Intergovernmental Panel on Climate Change (2013) methodology, for carbon stock calculation. The area being converted to oil palm per year was calculated using official conversion data from Suwandi (2017). This Indonesian official publication gives the change in oil palm plantation area from 2007 to 2017; the total increase in plantation area was divided by 10 years to reach the average annually planted oil palm area.

All forest was assumed to be undisturbed in its original land use as that was its original condition, and therefore the total amount of emissions shall be included in the model. All the emissions from the conversion from undisturbed forested land, to the final oil palm land use, were considered. The percentages of the remaining land uses of the article by Gunarso et al. (2013) were escalated linearly to obtain the areas per land use.

Based on these areas, the global Indonesian emissions from oil palm LUC were calculated following the methodology of the European Commission (2010) for Carbon Stock values; for above and below ground vegetation carbon stock (C_{VEG}), values for undisturbed forest in mineral soil being converted to oil palm soil plantation were as follows:

Tropical Forest $C_{VEG} = 230$ tons of C per ha

Oil Palm $C_{VEG} = 60$ tons C per ha

In addition to vegetation carbon stock, the impact of the difference in Soil Carbon Stock was studied. Soil Carbon Stock in Mineral soil (SOC) value, as defined by European Commission (2010), was assumed to remain constant in the baseline scenario after oil palm plantation is established. The soil factors selected were Native Forest (non – degraded) forested land for the mineral primary forest original soil category and “medium – full tillage” perennial crops for the transformed oil palm plantation soil category.

Soil Carbon Stock in Mineral Soil (SOC) Change in SOC = 0 tons C per ha

No emissions from fire were considered for mineral soil categories.

For swamp soil categories emissions calculations the methodology of the Intergovernmental Panel on Climate Change (2013) was used. No fire emissions from fire were considered for peat soil categories.

The detailed calculations for the land use change carbon stock changes from the different soil categories to oil palm plantation for the baseline scenario have been included in Appendix 2.

Sensitivity Due to Soil Degradation

Regarding soil degradation of palm oil plantations according to several publications, carbon losses on palm oil plantations are not too high. Guillaume (2015), states that it takes decades to observe a significant decrease of subsoil carbon. Dislich (2015) states that organic matter of palm oil plantations after soil carbon has reached equilibrium, is only 55 to 65 % of forest soil carbon level. For the purpose of analyzing the effect on emissions of soil degradation, LUC emissions are calculated for a 40 % loss soil carbon when forest in organic soil is converted into a oil palm plantation.

2.2.1.5 Emissions Calculation Methodology of Alternative Scenarios

2.2.1.5.1 Baseline Scenario

The current practices in Indonesia were represented in this scenario. Carbon stocks were calculated based on European Commission (2010), and Intergovernmental Panel on Climate Change (2013), for each original use.

The baseline scenario corresponds to the assumed current practices of the oil palm Industry in Indonesia, these assumptions are as follows:

Agricultural Practices Avoid Fire.

No change of soil carbon stocks due to land use change occur.

No genetic breeding is being implemented.

Plantations are being established in peat lands.

Plantations are being established in forested lands.

Soil categories in which negative emissions changes were experienced were later analyzed by adding the emissions due to land use change and the emissions savings due to the use of biofuels. Results were compared with the requirements from The European Parliament and the Council of the European Union (2018) regulation, that sets a minimum requirement of 65 % emissions savings for oil palm biofuels to be considered for country renewable energy targets in Europe. Results were expressed in tons of emissions savings per ha and year.

Total land use change emissions in Indonesia were calculated and put in perspective by comparing them to global and Indonesian emissions. Global emissions data was

obtained from World Bank, (2014) and Indonesian total and land use change emissions were taken from CAIT (2018).

Also indirect land use change risk potential for the oil palm industry in Indonesia was calculated in this sub-section based on the European Commission (2019a) methodology used to address the ILUC issue, for determining the high ILUC risk feedstock and for certifying biofuels with low ILUC-risk.

2.2.1.5.2 Alternative Scenarios

In this sub-section, the effect of changes in the management of oil palm plantations on the level of emissions was studied. Six scenarios were considered: presence of fires, improved agricultural practices, improved in yield by genetic breeding, improved soil practices, no plantations established in peat lands and avoided deforestation. The variables of the original scenario were modified in order to analyze how changes in the management of oil palm plantations change the level of emissions. The aim was to identify better practices and quantify the positive or negative effect of each of them.

Alternative Scenario 1: Presence of Fire

The first variable was the presence of fire; a 20 % of fire in Peat Land was assumed in order to see the influence of fire in terms of CO₂eq emissions, the presence of fire has the potential to increase GHG emissions, this potential negative effect is analyzed in this study. The value of 20 % was chosen based on the percentage of fires related to oil palm concessions during 2015; in this year 506 thousand ha of oil palm concessions of a total of 2,611 thousand ha burned in Indonesia (Glauber and Gunawan, 2016). The carbon stock changes are calculated for plantations in peat including the variable of natural fire at the time of establishing the plantation using the Intergovernmental Panel on Climate Change (2013) methodology.

Alternative Scenario 2: Yield Improvement by improved agricultural practices

An improvement in yield from oil palm cultivation, representing an increase in carbon storage from 60 to 91 tons of carbon per ha (Casson et al., 2014), was calculated using the European Commission (2010) to find out the CO₂eq emissions from Land Use Change reduction potential by yield improvement.

Alternative Scenario 3: Improvement of Yield by Genetic Modification

According to Barcelos et al. (2015), genetic modification of oil palm could improve the yield from 3.5 tons per ha to a range of 11 to 18 t per ha. The lower value of 11 tons per ha was used as the improved yield in the model for this scenario.

Based on this assumption the increase in carbon storage was calculated as follows:

Relationship FFB/Palm Oil = 0.2325 (Andrianto et al., 2014)

Increase in oil palm Yield: $11 - 3.5 = 7.5$ t/ha (Barcelos et al., 2015)

In Table 1 below, the assumptions and references used for the calculation of carbon increase in the genetic breeding scenario are summarized.

Table 1: Increase in Accumulated Carbon from Genetic Breeding.

	Shell	EFB	Mesocarp	Total FFB	Reference
Relationship FFB/Palm Oil (%)		23.25%			Andrianto et al.(2014)
Increase in oil palm Yield (tons)		7.50 tons			Barcelos et al.(2015)
% of FFB	6%	81%	14%		May (2011)
% Dry Weight	85%	35%	60%		May (2011)
% Carbon	58%	49%	46%		Hamzah et al. (2019)
Increase in Carbon Weight (t/ha)	0.873	4.455	1.212	6.541	Own calculation

The increase in carbon storage was calculated using European Commission (2010) methodology. The increase in aboveground carbon is added to the oil palm vegetation carbon stock to calculate the change in land use emissions, to find the effect of genetic breeding.

Alternative Scenario 4: Improved soil practices

The effect of improving the agricultural practices to increase soil carbon storage was analyzed. Soil management at the oil palm plantations was modified from ‘Full Tillage – Medium’ to ‘No Till with Manure’ for Perennial Crops and Tropical Wet/Moist soils as per the European Commission (2010). Changes in land use change due to emissions savings due to improved soil practices are calculated.

Alternative Scenario 5: no plantations established in Peat Lands

The next scenario considers stopping establishment of oil palm plantations on peat land. Cultivated areas of oil palm plantation on peat land original scenarios were changed to mineral soil and change in carbon stocks calculated as per the European Commission (2010) methodology.

Alternative Scenario 6: avoided deforestation

The next scenario analyses the alternative of avoiding deforestation. The variation of carbon stocks when avoiding plantations in forested land are studied. The methodology to calculate the changes in emissions is according to European Commission (2010). The forest area being converted to oil palm was redistributed proportionately to the rest of the land categories.

2.2.2 Economic Feasibility Methodology

The model used to assess the economic feasibility of oil palm in the baseline scenario was generated from the research conducted in the framework of Objective 3 for a plantation in Papua, Indonesia, established in primary forest in mineral soil. The details

of this economic model are explained in the methodology chapter of Objective 3 (see 2.3.2), and its results, in section 3.3.2.

Alternative Scenarios are, in certain cases able to reduce emissions due to land use change but these alternative scenarios have economic implications that need to be analyzed. Plantations conducted in high carbon stock lands might be established in low carbon soils. The economic implications of planting in low carbon soils such as marginal lands are studied in this sub-section. Changes of agricultural practices such as planting in marginal soils need to be studied, many publications talk about this practice as being recommendable but do not quantify the economic consequences. The research and development for new genetic varieties that can improve yield shall be based in the expected economic benefits that could be obtained from improvement of yield.

Current practices could be due to economic reasons. Changes to the baseline scenario are made to see the effect of different scenarios on the economic results; changes in production costs and revenues generated by changes in agricultural practices and yield are introduced into this model in order to assess how improved sustainability scenarios affect the plantations economic feasibility. The change in the economic results would allow us to see the consequences of sustainable practices and to understand if non-sustainable practices are conducted due to economic reasons.

The use of biofuels can also bring sustainability improvements; the economic implications of using biofuels produced from palm oil should be also assessed. In this study the cost of producing biodiesel in Indonesia and the cost of this biofuel once transported into Europe are calculated, so they can be compared to the costs of the conventional fossil fuel diesel and assess the economic feasibility of using biofuels.

The use of biofuels can also bring sustainability improvements, the economic implications of using biofuels produced from oil palm shall be assessed, the cost of producing biodiesel in Indonesia and the cost of this biofuel once transported into Europe are calculated, so they can be compared to the costs of the conventional fossil fuel diesel and assess the economic feasibility of using biofuels.

2.2.2.1 Economic Feasibility for Plantations Established in Marginal Lands

In the case of converting forest to oil palm, plantation companies take advantage of the fertility of the soil, increase sustainability practices such as planting in marginal soils can be used instead. In this sub-section the economic implications of planting in different type of soils instead of planting in fertile mineral soil are analyzed.

Establishment of plantations in lower carbon intensive soils, such as marginal lands, could lead to lower CO₂eq emissions. According to Simeh (2005) marginal lands such as deep peat, steep and tin tailings imply higher development costs. Development cost for deep peat, steep lands and tin tailings were 8,737, 7,679, 6,807 RM (Malaysian Ringgit) per ha compared to 5,000-6,000 RM per ha of average soil; these values were taken from the study by Simeh (2005) for tropical soils in Malaysia. These values were

converted to USD per ha and introduced into our economic model, this model is described in sub-section 2.3.2. Our economic model simulated the change in establishment costs when planting in marginal soils; the variation in establishments cost from the fertile mineral soil to each of the three marginal land soil categories were introduced into the economic (discounted cash flow) model in year 1.

Also, reduction in yield occurs when marginal soil is used. In Table 2 below the expected decrease in yield for three types of marginal soils are shown.

Table 2: Yield Data for Marginal Lands.

Marginal Soil Type	Tin Tailings	Steep Lands	Deep Peat	Reference
First year FFB (t ha ⁻¹ y ⁻¹)	5.97	8.87	10	Simeh (2005)
Inflorescence Abortion Rates			2-13 %	Woittiez et al. (2017)
Estimated Yield Reduction 2-7 %				
Slope Soils without conservation		10-30 %		Woittiez et al. (2017)

Based on these figures extracted from literature the yield reduction for the three types of marginal soils studied was calculated; a decrease of 7.5 %, 20 % and 44.6 % of yield was estimated for deep peat, steep and tin tailings soils based on the data from Table 2. For the two first soils the average from the article by Woittiez et al. (2017) was taken; based on these average results and the results of the first year FFB weight the reduced yield from tin tailings soil was estimated. This yield reduction was imputed together with the increase in the production costs for each marginal soil type to see how the use of marginal soils influences oil palm plantations profitability.

2.2.2.2 Economic Feasibility of Genetic Breeding

This scenario is studied to see the economic implications of using high yielding varieties originated as a result of genetic breeding. The economic feasibility of this scenario is assessed by comparing the economic results of the improved yield to the average yield.

The average palm oil yield estimated in our economic model was 4.55 t (Svatonová et al., 2015). This average yield was increased to 11 t per ha as a result of genetic breeding and introduced into the economic model; the potential yield was taken from the lower range of 11-18 t per ha based on Barcelos et al. (2015).

2.2.2.3 Economic Feasibility of Biodiesel

Our model calculates the cost of Crude Palm Oil based on the production and the costs of production in Indonesia. Production, administrative and maintenance costs were based in the article by Svatonová et al. (2015). Logistics costs of biodiesel transportation within Indonesia and in Europe were taken from the article by Dominik et al. (2019). Refining costs and commercial profit of biodiesel were taken from Silalertruksa et al. (2012). The amount of emissions saved by palm oil derived biofuels with and without

methane recovery was calculated in our model. The methodology for biofuels emissions savings calculation was explained above in sub-section 2.2.2. The cost of one metric ton of CO₂eq emissions was assumed to be 30.4 USD based on Luckow et al. (2016).

2.3 Feasibility of a new Oil Palm Plantation in Papua, Indonesia

In Objective 2 it can be seen how feasibility is very often related to specific site conditions; design of agricultural practices, selection of bred varieties as well as soil improved practices are all site-specific. At the same time avoiding plantations in forested land shows the best emission savings. Environmental feasibility assessment shall be done not only in terms of emissions but in terms of the loss of ecosystem services of the forest.

Feasibility assessment and new plantations establishment decision making is based on economic analysis, therefore a detailed economic appraisal of forest ecosystem services is required. These ecosystem services shall be valued and their benefits compared to those of oil palm plantations to assess the economic feasibility of new oil palm plantations in forested land.

For this part of the Thesis research a newly established plantation was selected in Papua and conversations with its management staff were held, and authorization to visit the plantation and conduct the study was obtained. Being this a newly established plantation implied that some of the required commercial data referring to cost was still not available, in addition oil palm plantation companies are not always amenable to share insider information of their plantations, especially when they are established in forested land. Being Papua a militarized region due to outbreaks of independence movements, complicates scientific research even further.

The methodology set for this Objective is broken down into three sub-sections; the site-visit specific methodology, followed by the methodology used for the economic model, both for the plantation and the original forested land, and finally, the methodology for emissions calculations for this case study.

The specific methodology for this objective is described for each part of the research as follows:

2.3.1 Location, site visit and survey

The newly established oil palm plantation: PT Rimba Matoa Lestari (PT RML) located in Jayapura Province of Indonesia (2° 27' 41.03" S, 139° 55' 34.89" E; 37 m.a.s.l.) was chosen for this study. The original land condition was primary untouched climax tropical forest in Papua Island, being transformed to oil palm. Information on the value of the forest ecosystem services and on the oil palm plantation establishment costs was

gathered from structured surveys to local population and from the company staff during a site visit conducted in December 2016.

The survey was designed starting with questions about the plantation established in the area, the original use of the as well as the process for plantation establishment. In addition, the respondents were requested to explain if land had been allocated to local people. According to Indonesian law (Ministry of Agriculture of Indonesia, 2013), 20% of the total land shall handed over to the local population. The second part of the survey asked participants to rate their perception about oil palm plantations. The third part of the survey required participants to answer if they worked at the plantation and, if they did, what level of income they could obtain from it. The fourth part of the survey asked participants to name the negative effects of the oil palm plantation, their relationship with the forest and the benefits obtained from it. Boxes were prepared at each question for participants to choose from, and additional space was given below so that participants could share their thoughts. Participants were requested to choose the level of income derived from the forest, both for provisioning services and for non-tangible ecosystem services such as leisure and wellbeing. Boxes with different ranges of income were prepared in the survey in order to obtain standardized results that could be statistically analyzed. (See survey in Appendix 3).

The survey lasted 5 days, at PT RML plantation and the villages surrounding it, including different places such as houses, churches, stores; we interviewed workers, non-workers, plasma participants, local leaders and landlords. The questionnaire was designed in a simple way and explained clearly to participants, who explained the insights about their relationship with the forest, such as the medicines that they could obtain, the leisure activities they practiced and even how they taught their kids in the forest.

A total of 26 people accepted to be interviewed, obtaining a total of 24 valid responses; this is not a big amount of interviews but the survey sample represents close to 1 % of the total population living at the plantation area (3457 people according to calculation based in demographics and 3,000 people based on response from the interviews conducted at the plantation), which it is believed to be representative. All surveys were conducted in Indonesian language, using a translator that was present during the whole trip and collaborated in the data processing from the replies, which was translated back into English language. His know-how of the region and interpretation of the results was very useful for our research. The population clearly understood the questions; the questions were written in Indonesian and explained very clearly by our interpreter, who helped the participants while filling in the survey.

About 87 % of the participants were male and 13 % female. Regarding age, 18 % of participants were between 10 and 20 years of age, 32 % between 21 and 30 years of

age, 15 % between 31 and 40, 23 % between 41 and 55 years of age and 14 % above 65 years of age. In terms of income 32 % of the participants declared an income below 500 thousand Indonesian Rupiahs (IDR), 32 % an income between one and two million IDR, 26 % between 2 and 3 million IDR and 5 % above 3 million IDR. Highest income rates were those of plantation employees.

The people interviewed had different origins including: locals (53 %), regional (21 %) and trans-migrant (26 %); and different occupations: hunters/farmers (42 %), plantation workers (21 %), land owners (16 %), local village government officials (5 %), woodcutters (5 %); unemployed (11 %) were also interviewed. Selection of the participants was at random, reaching them at their houses, churches, businesses as well as by approaching them in the street close to the plantation. The plantation was visited several times during this visit and PT RML staff was interviewed regarding the process of plantation establishment, government approvals, transformation process as well as costs and economics.

In order to generate grounded theory (Glaser and Strauss, 1967) previous existing literature on the subject, such as Andrianto et al. (2014) and Obidzinski et al. (2012), were reviewed and obtain further quantitative information. Our study aimed at the assessment of the LUC feasibility and therefore quantitative data on ecosystem provisioning services, was sought during the surveys. The remoteness of the site as well as the low GDP per capita of the region requires easiness of communication with the local population for the best possible accurateness of results, the survey asked the local population the value they obtained from the forest in their day to day life, no willingness to pay or a compensation services methodology are included in order to simplify the communication with the local population.

The methodology framework for valuation of ecosystem services was based on TEEB for National and International Policy Makers, (2009). Our study tried to account for the benefits and costs produced by the plantation establishment, in order to assess its feasibility. Therefore, the survey was designed in a way capable to collect quantitative data on the monetary values of provisioning ecosystem services provided by the forest to the local population. These data, combined with secondary data, were used to obtain the value of forest ecosystem services. Also, value of intangible ecosystem benefits was obtained from survey's answers. In addition, qualitative information on oil palm benefits, such as access to jobs, infrastructures, health and education, as well as on issues such as deforestation or loss of access to forest products in previous studies, were verified by the survey.

Draft reports were prepared previous to the visits and interviews; an outline with all the required information was prepared. After visiting the plantation and interviewing the plantation workers, the plasma scheme participants and the local population, a draft report was created. The required data was filled in and a detailed report prepared. The

draft report was conducted in English, based on the interpretation of each survey conducted by the translator; as English is a language unknown by the survey respondents they were not able to verify the correct data interpretation. This report was discussed with the plantation management staff -fluent in English- and the information verified. Most of the information matched precisely, except for a few things such as the terms of lease of the plantation. The local population considered the land to be leased and the plantation owners to be bought; this is very normal for land agreements in Papua, as villagers do not give up their rights for the land. The agricultural practices that could be understood during the site visit, were verified with the plantation management staff during the interviews. For a better understanding of the survey design the survey is included in Appendix 3.

2.3.2 Economic Model Methodology

A discounted cash flow methodology was used. The benefits of the plantation were compared to those of the forest being established. Benefits of the plantation were of two types, commercial benefits from the sale of the raw materials obtained from the plantation, and social benefits brought by the plantation to the local population such as health or education. The benefits lost from the forest were those related to the loss of ecosystem services. These services are provisioning, social and environmental and regulating.

The benefits of the plantation and the forest were estimated separately and discounted to account for the present value of the services at the moment of transformation for the 25 year period of the plantation; the used discounted cash flow formula is as follows:

$$DCF = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \dots + \frac{CF_n}{(1+r)^n}$$

CF: represents the value of cash flow for each year

r: represents the discount rate

Escalations of the benefits of the plantation and the forest were applied. For the commercial earnings of the plantation escalations were estimated in 3 %, based on the expected growth rate of Indonesia during the 25 year period of the plantation. The costs in Indonesia are estimated to increase based on the growth of the economy as well as the increase in the selling rate of the commodities that are mainly sold in the Indonesian market. Regarding the escalation of the social benefits of the plantation and the ecosystem services of the forest a 1 % rate was estimated based on Gowdy et al. (2010).

Discount rates were also applied both to the plantation and the forest benefits. Discount rate for the commercial plantation was 10 % since this rate is standard for commercial investments and projects in Indonesia due to high interest rates of a fast growing developing country economy. The discount rate for ecosystem services to be preserved was in the lower side, based in different publications (please refer to Table 4) for Indonesia; the discount rate for the forest ecosystem services and the social benefits of the plantation was estimated to be 5 %.

It is very important to understand the relevant period to consider for the analysis of the benefits of the plantation and of the forest. For comparison purposes a one cycle 25 year period was considered. After this period is over it is interesting to study the different possible situations that could occur at that time. At that time the oil palm plantation could be discontinued due to lower productivity of the crop and soil degradation. Soil degradation in oil palm plantations is not too high (please refer to subsection 2.2.1.3) so possibly a new oil plantation would be established or plantation of other type of crops could happen. Alternatively, in an area that is growing, alternative land uses such as establishment of housing or industrial areas could occur as well.

The loss of the forest cannot be recovered, so the loss of the ecosystem services shall be projected for an infinite period. In sub-section 2.3.2.5 the methodology to estimate the economic benefits of forest ecosystem services for an infinite period of time is explained, and results are in sub-section 3.3.2.5.

2.3.2.1 Methodology for Plantation Economics

Economics of the oil palm plantation were studied over the commercial lifespan of the plantation, from the conversion of forest into agricultural land up to the palm oil sale final step.

Revenues: the revenues per year were calculated based in the yield per year, which is variable for oil palm. Yearly yield values of yield were taken from Svatonová et al. (2015), the values of commodities sold in international markets (Crude Palm Oil and Kernel Oil), they were taken from databases (please refer to Table 4). Regarding the revenues from the sell of timber from forest clearing, the values were taken from Andrianto et al. (2014) and introduced into the model in year 1. Costs were divided into variable and fixed costs; a detailed breakdown can be seen below in Table 3.

Table 3: Breakdown of Variable and Fixed Costs of the Plantation.

Variable Costs	Comments
Cost of Fertilizers - labour	Based on yield, Svatonová et al. (2015)
Cost of Fertilizers, machine operation	Based on yield, Svatonová et al. (2015)
Harvesting Costs	Based on yield, Svatonová et al. (2015)
Pruning Costs	Based on yield, Svatonová et al. (2015)
Refining Costs	Based on production, Man and Baharum (2011)
Interests	Based on total costs per year, 7 % (table 5)
Fixed Costs	
Cost of Conversion	Andrianto et al. (2014)
Cost of Land	Interviews with Plantation Staff - Year 1
Other Operational Costs	Svatonová et al. (2015)
Survey	Svatonová et al. (2015)
Cost of Administrative Staff	Svatonová et al. (2015)
Cost of Infrastructure Maintenance	Svatonová et al. (2015)
Transportation Costs	International Trade Centre (2012)

Assumptions and supporting information for this economic assessment are given in Table 4.

Financial results of this case study in terms of return on investment (ROI), internal rate of return (IRR), repayment period, earnings before tax, average yearly earnings and discounted earnings were determined. The weighted average cost of capital (WACC) in Indonesia was calculated as the weighted sum of the cost of equity (COE) and the cost of debt (COD), from the values of the interest rate 6.5% (Bank of Indonesia., 2016), inflation in 2016, 3.02 % (Triami Media BV, 2016), and national growth in 2016, 5.02 % (Indonesia Investments, 2017). These values were used to calculate a 10% discount rate. Taxes distribution at the national, regional and district levels were assessed as well.

Escalations were used to account for the growth of the value of the plantation earnings; being Indonesia a developing country for a 25 years period a 3 % growth of plantation revenues and costs were assumed.

2.3.2.2 Methodology for Social Benefits Brought by the Plantation

Oil palm plantations can bring social benefits to local population in terms of health, education and infrastructures. In our case-of-study these benefits were estimated as follows:

Health: Bloom et al. (2004), estimated that longevity contributed to a 4 % in output. Based in this value, the social benefit associated with health was assessed by increasing the GDP per capita of the population living close to the plantation. This value was

expressed per ha from the data of population living close to the plantation and at the plantation area. The GDP of the local population measured in USD per year is increased by 4 %, this increase is multiplied by the total population living close to the plantation and divided by the number of plantation ha. These calculated benefits are introduced into the model as a yearly basis value of USD per ha.

Infrastructures: According to Ansar et al. (2017), the benefit to cost ratio of infrastructures investments falls below 1.0. A value of 1 was used for this study. The value of infrastructures from the plantation was taken from Svatonová et al. (2015). The value of this investment was allocated to the first five years and it was assigned as a social benefit in the model. The total infrastructure investment value is divided by 5 as the infrastructures investment happens mainly in the first 5 years of the plantation and introduced into the model terms of USD per ha and year.

Education: According to Hanushek and Wobmann (2007), a 5 % of GDP increase is expected in 20 years when an education reform is introduced. In our study, the 5 % increase in GDP assumed was converted to benefits per ha by multiplying the increase in GDP per capita by the total population living close to the plantation and divided by the total plantation area to obtain a yearly basis value of USD per ha, and was progressively introduced into the model by 0.25 % increase intervals up to year 20, when 5 % of GDP was reached, and was assumed flat from year 20 to 25.

2.3.2.3 Economic appraisal of forest ecosystem services

Economic services provided by the forest were categorized into provisioning, social and environmental services, regulating and supporting services. Each category was broken down into different items that were separately assessed either by calculation from own data gathered during the site visit (surveys and interviews), calculated based on site conditions using support data from literature or estimated by assuming data in relevant literature, using the benefit transfer method, that consists on estimating economic values by transferring existing benefit estimates from existing studies at other location. Similar sites have been used and only values without a big weight have been obtained following this method (ecosystemvaluation.org., 2020). Further research is required to calculate this ecosystem service values in Papua, Indonesia. Below an explanation for the basis of using each of the values taken from literature is given:

Monetary values obtained from surveys were converted to end of 2016 World Bank GDP per capita Purchasing Power Parity (PPP) by means of a conversion factor, which was calculated by dividing the value of this PPP (The World Bank, 2015) by the GDP in Jayapura (Knoema, 2010). The reason for using PPP purchasing parity is that ecosystem services obtained from the forest such as wood or food have a very high value for the

local population that cannot be captured entirely if results are given in local GDP terms. Below the methodology for the assessment of ecosystem services benefits is detailed:

Provisioning Services: they were calculated based on the replies from the survey. Local people were requested to give a monetary value (IDR currency) to the services they obtained from the forest. A range of values to choose from, were included in the survey. An average value of provisioning services was calculated and the total value was broken down into provisioning services such as wood, medicine, food and fiber based on the importance rating of each of these provisioning services to the local population.

The details for each provisioning service are as follows:

Wood: the average value of provisioning service given by the survey participants was 2,000,000 IDR per month and the weight assigned to this resource was 45 % of total based on the importance factor assigned to this resource. This value was converted to USD per ha using the exchange rate, the area of the plantation and the total population.

Food: the average value of provisioning service given by the survey participants was 2,000,000 IDR per month; the weight assigned to this resource was 35 % of total based on the importance factor assigned to this resource. This value was converted to USD per ha using the exchange rate, the area of the plantation and the total population.

Fiber: the average value of provisioning service given by the survey participants was 2,000,000 IDR per month and the weight assigned to this resource was 10 % of total based on the importance factor assigned to this resource. This value was converted to USD per ha using the exchange rate, the area of the plantation and the total population .

Medicine: the average value of provisioning service given by the survey participants was 2,000,000 IDR per month and the weight assigned to this resource was 10 % of total based on the importance factor assigned to this resource. This value is converted to USD per ha using the exchange rate, the area of the plantation and the total population.

Global Biochemical Resources: Medicinal Value of the forest was considered important not only as a service for locals but also as a resource for genetic material provision that could be utilized both by the traditional and the conventional medicine industries; the value of the industry was multiplied by the royalties (assumed 12.5 %) (data from Hanafi et al. (2013) and Pearce and Moran (1994)) and divided by the forest area in Indonesia to get to a per ha value.

Water Provisioning Services: The value of the water provisioning services was obtained by calculating the area of the different ecosystems (rivers/waterflows, inland

and coastal wetlands and tropical forest) present in the plantation concession and multiplying these areas by the provisioning service values.

Social Wellbeing Services: the following services calculated based on site conditions using support data from literature was the methodology used as follows:

Ecotourism and Recreation: The value of the tourism was calculated separately from the rest of wellbeing services, based on the tourism in Jayapura region. The number of tourists and their daily expenditures were estimated from the flights arriving per day; values were expressed on a per ha basis by dividing by the total area of Jayapura. If forests were lost, tourism would be diminished. The share of the plantation was calculated based on its area.

The following services were estimated based on the results from the survey:

Wellbeing/Aesthetic: Likewise, participants were asked to give a monetary value to the non-tangible wellbeing services obtained from the forest -such as fishing, hunting, knowledge, spiritual wellbeing and others- and an average value was calculated. The average value of provisioning service given by the survey participants was 1,000,000 IDR per month. This value was converted to USD per ha using the exchange rate, the area of the plantation and the total population.

Environmental, regulating and supporting ecosystem services: The following services were calculated based on site conditions using support data from literature. The methodology used was as follows:

Climate Change Prevention: the value of the climate change prevention was calculated from the amount of carbon stored by the forest and the soil above the carbon stored by the oil palm plantation $623.3 \text{ t CO}_2 \text{ eq ha}^{-1} \text{ y}^{-1}$ (European Commission, 2010) multiplied by the value of one ton of $\text{CO}_2 \text{ eq}$ was assumed to be 30.4 USD t^{-1} , from Luckow et al. (2016), based on the value for the next 25 years.

Reduction of Tsunami Risk: The PT RML plantation was about 6 km from the sea; as the forest close to the sea acts as a protection barrier, this service was valued. It was estimated assuming 50-year return period for Tsunami and 50% decrease in GDP per capita as Tsunami damage cost to the people living at the plantation (UNISDR, 2015). A reduction of probability of 2 % in the GDP per capita (11,057 International PPP USD) of the region is multiplied by the people living at the plantation area (3,457 people) and divided by the plantation area (28,000 ha).

Protection against fire: Fire protection services by the forest were calculated as the difference between the probability of having fire on tropical forest and the probability of having fire in oil palm plantations (van Beukering et al., 2003). The risk was reduced from a 5 year return period to a 50 years return period multiplied by the potential cost of having fire. The total cost of fire (16 billion USD for El Niño year) was multiplied by

the total potential area related to oil palm (941,442 ha) and divided by the total burnt area (2,425,210 ha). These data were obtained from The World Bank (2016c). This amount was divided by the total area planted with oil palm assuming the value of land planted with oil palm in Indonesia by Price Waterhouse Coopers (2010), (approximately 7,000,000 ha) to arrive to the total value of fire damage per ha. The fire risk reduction obtained from the forest was estimated to change from a 5 year return period to a 50 years return period; this difference in risk was multiplied by the damage per ha to obtain the fire risk reduction benefit from the forest.

Water Cycle: Water regulating services were assessed by calculating the areas of the different ecosystems (inland wetlands and tropical forest) present in the plantation concession and multiplying them by the regulating service values given by de Groot et al. (2012).

Soil formation/soil fertility regulation: these services were calculated from the emissions value lost from the storage of carbon in the forest soil that were lost when transformed to oil palm, based on the methodology by European Commission (2010). The value of SOC was reduced from 86 to 44 CO₂ eq ha⁻¹ y⁻¹ (European Commission, 2010) and multiplied by the value of one ton of CO₂ eq, assumed to be 30.4 USD t⁻¹ from Luckow et al. (2016), based on the value for the next 25 years.

Forest ecosystem services estimated assuming data in relevant literature, using the benefit transfer method. The total value of this ecosystem services represented only 5.5 % of the total value of forest ecosystem services. Further research is required to estimate these values for forests in Papua-Indonesia:

Air Purification: air quality value of ecosystem services was taken from values for tropical forest from Groot et al. (2012). This value was based on 665 values so they are believed to be sound for the represented biome.

Waste Management System: the value for this ecosystem service was based on the article by Moratilla (2010) concerning treatment of continental wastes by forests in Spain, no data could be found for Papua or Indonesia despite the extensive literature review performed.

Pollinization: pollinization value of ecosystem services was taken from the article by Olschewski et al. (2006). This article states that complete deforestation would lead to a pollination service loss of 47 USD per ha of forest in Indonesia.

Flora and Fauna Conservation: the value for this ecosystem service was based on the article by Moratilla (2010). Flora and Fauna conservation value from forests in Spain was taken; no data could be found for Papua or Indonesia despite an extensive literature review performed.

Nutrient Cycle: nutrient cycle value of ecosystem services was taken from values for tropical forest from Groot et al. (2012).

Biological Control: biological control value of ecosystem services was taken from values for tropical forest from Groot et al. (2012).

Habitat Service: habitat service value of ecosystem services was taken from TEEB (2009) publication.

Existence Value: air quality value of ecosystem services was taken from TEEB (2009) publication. Non-users willingness to pay for protection of the Brazilian Amazonia forest was USD 43 per hectare per year. This value was extrapolated to the Papua forest considered to have the same importance than Amazonas forest at a global level.

Maintenance of genetic diversity: about half of the species in New Guinea were assumed to be native (IUCN, 2008), and therefore the average value estimated by de Groot et al. (2012) for the tropical forest biome was doubled to account for native and non native species.

Escalations were used to account for the growth of the value of the forest ecosystem services; a 1 % growth of forest ecosystem services was assumed based on Gowdy et al. (2010).

2.3.2.4 Methodology for Cost Benefit Analysis

The cost benefit analysis aimed to determine if the establishment of new oil palm plantations on forest land was feasible or not, in monetary, environmental and social terms. Feasibility was assessed by comparing the benefits/costs of the development scenario (oil palm plantation) to those of the conservation scenario (forest preservation). Results from the preservation scenario were subtracted from those of the development scenario. Results from both scenarios were projected for a 25 year period. Revenues and costs were projected by using expected growth rates, and discounted with specific discount rates (see Table 5) appropriate for each model. The results were first subtracted without applying a discount rate, later the discounted results were subtracted to see which scenario was more beneficial, based on the economic benefits it provided in USD ha⁻¹ for a 25 years period. If the benefits-costs of the development scenario were higher than the benefits-costs of the sustainable use of the forest (forest preservation scenario), the plantation would be more beneficial than the forest and if they were lower (negative values) the forest would be more beneficial.

2.3.2.5 Methodology for Sensitivity Analysis

A sensitivity analysis was conducted to study the effect of magnitude changes of important variables in the model, given the fact that any economic appraisal is subjected to certain level of uncertainty.

Escalations: all escalations (3 % increase in revenue prices and costs of oil palm plantation, 1 % increase in the value of the social benefits of the plantation, 1 % increase in ecosystem services value) were removed; these values were changed to 0 %.

Changes in commodity prices: Commodity market price variations of +/- 10% for crude palm oil and kernel oil area were applied.

Yields: Fourthly, the oil palm yield was modified within the 3.92 – 6.04 t ha⁻¹ y⁻¹ range for Crude Palm Oil and within the 0.74-1.24 t ha⁻¹ y⁻¹ range for Kernel Oil, taken for plantations in Papua from the article by Andrianto et al. (2014).

Changes in Water Ecosystem Services: a variation in the value of the water ecosystem services benefits by +/- 10 % was applied.

Infinite period for social benefits: it was analyzed as forest if preserved could render services globally for an infinite period. For this sensitivity scenario the infinite period discounted cash flow formula was applied, this formula is as follows:

$$PV = \text{Cash Flow (year 25)} \times (1+g) / (r-g)$$

r: discount rate

g: escalation

This calculation is very dependent of the discount rate as well as the escalations used. First the assumptions of 1 % escalation and 5 % discount rate were applied. Later the effect of no escalation together with different discount rate was analyzed. Rates of discount of 3 % and 1 % were applied. Also a 0 % discount rate for the initial 25 year period was analyzed.

2.3.2.6 Methodology for Switching Values of Emissions

A switching value of an input parameter is the value rendering a net present value equal to zero. The CO_{2eq} emissions price required for project breakeven was found by iterating the price of CO_{2eq} emissions (switching value) making benefits from the plantation equal to the benefits of the change in ecosystem services from the land use change.

2.3.2.7 Methodology for Wealth Redistribution. Winners and Losers

The earnings from the commercial plantation, the social benefits of the plantation and the benefits from the ecosystem services were broken down into Local, Regional, National and International categories. The distribution of the benefits of ecosystems describes the original situation whereas the distribution of the social and commercial benefits of the plantation shows the situation after the plantation establishment has occurred.

2.3.3 Methodology for LUC Emissions Calculation

Emissions from LUC from Indonesian forests to oil palm were calculated in order to assess the global impact of this concept. The area converted from forest to oil palm was

taken from official sources (Ministry of Environment and Forestry Republic of Indonesia, 2018). Changes in carbon stock per ha for forest in organic and peat soil were calculated based on European Commission (2010) and Intergovernmental Panel on Climate Change (2013). The value found for the Indonesian LUC emissions -due to forest conversion to oil palm- was divided by the value of the Indonesian total emissions as well as by value of the world global emissions, based on the data from CAIT (2018), in order to calculate the share of the Indonesian LUC emissions due to forest conversion to oil palm. Details of the assumptions made, and information sources used for LUC emissions calculation are shown in Table 4.

Table 4: Working data and supporting information for the calculation of Indonesian emissions from LUC from forest to oil palm plantation.

Working data	Value	Supporting information
Area of Undisturbed Mineral forest converted to oil palm (Mha)	140.10	Ministry of Environment and Forestry Republic of Indonesia (2018)
Area of Undisturbed Peat forest converted to oil palm (Mha)	102.75	Ministry of Environment and Forestry Republic of Indonesia (2018)
LUC Emissions from Forest in Mineral Soil to Oil Palm (Mt CO _{2eq} ha ⁻¹)	623.30	Own calculation based on European Commission (2010)
LUC Emissions from Forest in Peat Soil to Oil Palm (Mt CO _{2eq} ha ⁻¹)	832.80	Own calculation based on Intergovernmental Panel on Climate Change (2013)
LUC emissions from forest to oil palm (Mt CO _{2eq})	172.90	Own calculation based on above data
Indonesian LUC Emissions (Mt CO _{2eq})	1,682.16	CAIT (2018)
Indonesian Total Emissions (Mt CO _{2eq})	2,471.64	CAIT (2018)
World Total Emissions (Mt CO _{2eq})	48,892.00	CAIT (2018)

Table 5: Working data of the plantation and assumptions for economic model

Working data for the economic model	Value	Supporting information
Economic assumptions:		
Exchange rate (IDR per USD)*	13,400	XE, rounded value.
Discount Rate Commercial	10%	Irawan et al. (2013)
Discount Rate Social	5%	Irawan et al. (2013); Pascual et al. (2010); Gowdy et al. (2010)
Duration of the cycle	25 years	Commercial lifespan of the plantation
Area for study	28,000 ha	Yayasan Pusaka (2015); Personal communication with company staff.
Increase in Revenue Prices per year	3%	Based on average expected growth rate
Increase in Price of Materials per year	3%	Based on average expected growth rate
Increase in Operational Cost per year	3%	Based on average expected growth rate
Increase in value of ecosystem services	1%	Gowdy et al. (2010)
Interest Rate in IDR currency assuming all investment is borrowed	7%	Indonesia (2016); June 2016 – 6.5 % + 0.5 % commercial bank mark up
Manpower costs:		
Manpower Cost increase per year	4%	Long term - 25 year period assumption
Annual cost of 1 worker	30,000,000 IDR y ⁻¹	PT RML staff information
Workers per ha	0.34 persons per ha	Svatonová et al. (2015)
Local cost of labor (IDR)	10,187,259 IDR ha ⁻¹	salaries from site survey
Cost of labor (USD)	1,432.84 USD ha ⁻¹	
Timber revenue and development cost assumptions:		
Compensation for wood in Papua when removing forest	50,000 IDR m ⁻³	Andrianto et al. (2014)
Price of wood	600,000 IDR m ⁻³	Andrianto et al. (2014)
Production of wood	17.58 m ³ ha ⁻¹	Andrianto et al. (2014)
Profit from wood cutting	786.97 USD ha ⁻¹	Andrianto et al. (2014)
Development cost	1804.55 USD ha ⁻¹	Andrianto et al. (2014)
Transport and refining costs and revenues:		
Transport to Mill	96 USD ha ⁻¹	International Trade Centre (2012)
Refining cost palm oil	10 USD t ⁻¹	Man and Baharum (2011)
Price of Crude Palm Oil (CPO)	644.56 USD t ⁻¹	Indexmundi (2016a)
Price of Kernel Oil (KO)	1,230 USD t ⁻¹	Indexmundi (2016b)
Production of CPO	4.55 t ha ⁻¹	Svatonová et al. (2015)
Production of KO	0.90 t ha ⁻¹	Svatonová et al. (2015)
Percentage of CPO on Fresh Fruit Bunch (FFB)	23.25%	Andrianto et al. (2014)
Percentage Kernel Oil on FFB	4.61%	Andrianto et al. (2014)
CPO to kernel weight ratio	19.83%	Svatonová et al. (2015)
Recurrent costs:		
Land cost	149.25 USD ha ⁻¹	Communication with PT RML staff
Costs of agricultural operations	Linear with the production	Function developed from Svatonová et al. (2015)
Taxes:		
Land value tax	40%	Irawan et al. (2013)
Vehicle, heavy machinery and equipment's taxes	5%	Irawan et al. (2013); equipment value from Svatonová et al. (2015)
Corporate income tax	28%	Government tax official in Papua; personal interview.
VAT	10%	Indonesian market
Personal income tax over plantation salaries	10%	Irawan et al. (2013); cost of salaries from Svatonová et al. (2015)

* Indonesian Rupiahs (IDR) per United States Dollar (USD)

Table 6: Working data and supporting information on the values assumed for the economic assessment of the ecosystem services.

Working data for the economic model	Value	Supporting information
Tangible provisioning services:		
Wood	Own calculation (Results section)	Data from survey at PT RML site
Food (all products for eating, fish, meat)	"	Data from survey at PT RML site
Fiber	"	Data from survey at PT RML site
Local medicinal resources	"	Data from survey at PT RML site
Global biochemical and pharmaceuticals (provision of genetic material)	"	Calculation uses data from Hanafi et al. (2013); Pearce and Moran (1994)
Fresh water, groundwater recharge	Own calculation (Results section)	Calculation based on data by de Groot et al. (2012)
Social services:		
Ecotourism and recreation	Own calculation (Results section)	Data from survey at PT RML site
Aesthetic; value of the beauty	Own calculation (Results section)	Data from survey at PT RML site
Environmental, Regulating and Supporting services:		
Climate change prevention	Own calculation (Results section)	European Commission (2010), Hiraishi et al. (2013), Luckow et al., (2016)
Air purification, air quality, air quality regulation	12.00 USD ha ⁻¹ y ⁻¹	de Groot et al. (2012)
Waste management/treatment	8.20 USD ha ⁻¹ y ⁻¹	Moratilla (2010)
Reduction of Tsunami risk	Own calculation (Results section)	Calculation based on data from UNISDR (2015)
Protection against fire	Own calculation (Results section)	Calculation based on data from Glauber and Gunawan (2016)
Water cycle (supporting service)	Own calculation (Results section)	Calculation based on data by de Groot et al. (2012)
Pollination services	47 USD ha ⁻¹ y ⁻¹	Olschewski et al. (2006)
Flora and fauna conservation	22.56 USD ha ⁻¹ y ⁻¹	Moratilla (2010)
Soil formation/soil fertility regulation	Own calculation (Results section)	European Commission (2010)
Nutrient cycle (supporting service)	3 USD ha ⁻¹ y ⁻¹	de Groot et al. (2012)
Biological control	11 USD ha ⁻¹ y ⁻¹	de Groot et al. (2012)
Habitat service	16 USD ha ⁻¹ y ⁻¹	de Groot et al. (2012)
Existence value	43 USD ha ⁻¹ y ⁻¹	TEEB (2009)
Maintenance of genetic diversity	46 USD ha ⁻¹ y ⁻¹	de Groot et al. (2012)

3 RESULTS

In this chapter the results for each of the three objectives are summarized.

3.1 SWOT Analysis for new Oil Palm Plantations in Indonesia

The results for this objective are presented in this section. The category breakdown for the SWOT Matrix can be found in Table 7. Results are as follows:

3.1.1 Strengths

S1. Business Opportunity: according to Svatonová et al. (2015), economic indicators for oil palm plantations in Indonesia have an expected return on investment of 73.5 %, internal rate of return of 14.83 % and payback period of 6.75 years with a return per ha, for a 25 year cycle and 10 % discount rate, of USD 10,670. This means that oil palm plantations have the potential of being very profitable business in Indonesia.

S2. Abundant Available Land: according to Caroko et al. (2011), 13.7 million ha of convertible production forest are available in the islands of Papua and Maluku. Permits up to 100,000 ha can be granted to one company; in Papua the initial concession area can reach 40,000 ha. According to the law of the Indonesian Government (1999), production forest is a type of forest that can be converted to other uses. Therefore, Papua has abundant available land, mainly forested, available to be converted into oil palm plantations.

S3. Clean Energy Generation: biodiesel coming from oil palm gives Indonesia the opportunity of having an alternative renewable energy, enhancing the country's energy security (Rahmadi and Aye, 2015). According to Mujiyanto and Tiess, (2013), domestic energy production in Indonesia cannot satisfy the existing demand; Indonesian Government Regulation 5 /2006 aims to increase renewable energy to 17 % by 2025. National studies estimate the electricity generation potential for biomass in Indonesia to be 50 GW.

S4. Competitive Price: according to Rifin (2014) Indonesian producers often offer better prices than their Malaysian competitors. The good climate conditions, available land and corporate know-how allow them to produce with lower costs that can be transferred into a more competitive price. This fact is diminished by the levies imposed to palm oil exports, the levies of exported CPO -amounting USD 50 per ton- are halted when commodity prices heavily decline (Jakarta Post, 2018).

S5. Climate adequate for Palm Oil: according to Pirker et al. (2016), oil palm requires

specific weather conditions, in general wet and warm conditions. Temperature should be between 24 and 28 ° C and precipitation between 2,000 and 2,500 mm per year. According to Climate-data.orgn (2018) the average temperature in Jayapura (the capital of Papua Province) is 26.9 ° C and the average yearly precipitation is 2,425 mm. These are perfect weather conditions for oil palm cultivation.

S6. Corporate Know-How: Indonesia production of palm oil reached 28.49 million tons of CPO in 2016 (Suwandi, 2017), the highest in the world. According to Obidzinski et al (2014), a total of 14 companies had been granted concessions in Papua-Indonesia in 2009. The existing corporate know-how makes Papua-Indonesia a suitable place for oil palm cultivation.

S.7 Investment in the Region: according to Obidzinski et al (2014), oil palm investments help to develop the region through the economy creation, job development and poverty reduction. Monetary transfers from Jakarta to Papua and West Papua provinces have greatly increased, by 600 % in real terms and 1300 % in nominal terms from the year 2000 to the year 2009. Investment in infrastructures is seen to promote development.

3.1.2 Weaknesses

W1. Unstable area due to politics: Papua and West Papua provinces were adhered to Indonesia in 1969. Papua prepared an independence declaration based on different ethnicity and religion than Indonesia. Papua is accepted to be part of Indonesia by the international community, but independence aims shake the region with frequent armed riots, that became more intense after Indonesia entered democracy in 1998 (Viartasiwi, 2013). The fact of the political instability creates a certain risk over the plantation establishment process, and during the implementation phase.

W2. High costs due to remote location: the remoteness of Papua, the lack of infrastructures and supplies make imports very expensive. Road development is required in order to lower project imports and export costs (The World Bank, 2009).

W3. Local Population Oil Palm Cultivation Know-How: slow progress of plantation development is due to lack of know-how on oil palm cultivation by local Papua population and lack of willingness to engage in oil palm cultivation activities. Companies have managed to build oil palm plantations in Papua in partnership with Papuan and Transmigrant population. Oil palm plantations facilitate transmigration programs (Andrianto et al., 2014).

W4. Population Opposition to Plantations: customary lands are a focus of Papua's separatist movement. Constitutional Court Decision 35/2013 has granted recognition of

customary forests (Sloan et al., 2019). According to Caroko et al. (2011), Indonesia Law 41/1991 recognizes jurisdiction of customary communities over forests, they can manage the forests as long as their presence is evident. Investor companies should approach the local communities and engage into mutually acceptable land use agreements. Conflicts emerge at certain plantation sites between the local population that claims customary rights to land and the companies establishing new plantations (Yayasan Pusaka, 2015).

W5. International Community Monitoring: Indonesia has gained international attention on human rights abuses in Papua by military forces; a conflict resolution between the Indonesian Government and Papuan population is of critical importance to reach stability in the region (Viartasiwi, 2013).

3.1.3 Opportunities

O1. Job Creation: according to Andrianto et al. (2014), the creation of new oil palm plantations has a positive impact in job creation and improving workers' incomes and constitutes an stimulus to the local economy. According to Caroko et al. (2011) the Indonesian Ministry of Energy and Mineral Resources believes that one million jobs have been created in the oil palm plantation industry.

O2. Wealth Redistribution Through Taxes: oil palm plantations make an important contribution to national and regional revenues in the form of taxes. Taxes include corporate income tax, increment value tax, personal income tax to employees, vehicle and property taxes (Andrianto et al., 2014). Also export taxes to CPO and Biodiesel as explained above, contribute to government income.

O3. Alternative Source of Energy: about 2,950 million liters of biodiesel were consumed in Indonesia in 2018, corresponding to about 11.3 % blend rate. Indonesia imposes exporting variable taxes as well as fixed levies to Crude Palm Oil (CPO) and Biodiesel exports of 50 and 20 USD per ton respectively. These levies are used to subsidize the use of biodiesel as an alternative transport fuel. Indonesia as per Regulation 12/2015 has imposed biodiesel targets for transport, industry and energy sectors of 30 % for 2020. These incentives promote the use of palm oil as biofuel, pulling the demand (Rahmanulloh, 2018).

O4. Increase in GDP: oil palm is the most important agriculture commodity and the one with the highest exports. In 2016 palm oil revenues were USD 22,044,000,000 and exports USD 18,600,000,000 (Indonesia Investments, 2018) representing 2.47 % and 2.09 % of Indonesia's GDP (The World Bank, 2016a) (Indonesia Investments, 2018). Oil palm represents a major driver of economic development and an alternative source of energy (Sheil et al., 2009).

O5. Development of Rural Areas: oil palm plantations contribute to poverty reduction. Poor districts engaged in agriculture were found to receive greater benefits from newly established plantations (Ernah, 2015). Oil palm is seen as a commodity that promotes economic development and rural livelihoods (Obidzinski et al., 2012). The oil palm sector represents a source of income and economic development for the rural poor, providing developing nations a path towards out of poverty (World Growth, 2011).

O6. More Open Society: oil palm plantations can contribute to opening isolated regions in Papua and West Papua Provinces. Villages close to plantations have improved services and infrastructures (Andrianto et al., 2014). According to Obidzinski et al. (2012), the local Papuan population experienced higher income and a broader social network and improved infrastructures due to the establishment of oil palm plantations.

O7. Entrepreneurship (plasma scheme): the plasma scheme involves large plantations that become the nucleus that guides the smallholder plasma plantations; this scheme has been going on since Suharto era as part of the PIR-Trans Program (Andrianto et al., 2014). The government of Indonesia has sponsored the plasma scheme with a proportion of 80 % for the plantation companies and 20 % for smallholders (Caroko et al., 2011).

O8. Improved Infrastructures: investment for infrastructure creation has greatly increased in the last decade, with transfers for infrastructure planning to local and regional Papua and West Papua Governments amounting IDR 21.8 trillion in 2008 up from IDR 1.6 trillion in year 2000 (The World Bank, 2009). Around previous plantations in Papua (Boven Digoel) medical, education and sporting facilities are available (Andrianto et al., 2014).

O9. Energy Security: several countries have renewable energy targets in order to reduce greenhouse gas emissions. To achieve renewable energy targets and ensure food security, marginal land is an interesting option for biomass energy production (Liu et al., 2011). Biodiesel from palm oil seems to be a solution for dropping palm oil prices and an opportunity to provide an alternative renewable energy source able to strengthen Indonesia's energy security (Rahmadi and Aye, 2015).

O10. Biodiesel Emissions Savings: according to The European Parliament and the Council of the European Union (2018), the use of biodiesel instead of fossil fuel diesel has the potential to save 32 % of CO₂eq emissions without methane capture and 51 % with methane capture.

3.1.4 Threats

T1. Deforestation: based on FAO data, 53.8 % of oil palm planted area in Indonesia in the period from 1989 to 2013 came at the expense of deforestation (Vijay et al., 2016). Lowland Forest in Papua amounting about 61 % of total area, is not protected. Only 15 % of the area is protected, having the highest risk of being degraded due to human activity; in the worst-case scenario most of Papua's lowland forest will be lost by the end of the 21st century (Beehler and Marshall, 2007). The value of timber of one ha of forested land is estimated at USD 13,500. The young and peat soils of Papua are unable to sustain sustainable economic activity after deforestation (The World Bank, 2009).

T2. Loss of Ecosystem Services: Ecosystem services consist of flows of material, energy and information from natural stocks that combined with human capital produce human welfare. Ecosystem services provide an important part of total human welfare and are critical to the earth's life support services (Costanza et al., 1998). According to The World Bank (2009) the economic value of one ha of Papuan or West Papuan forest is 5,700 USD. According to Bassi et al. (2015), forest services and non-tangible ecosystem services are very important for the livelihoods of the poor in local communities, being the share of ecosystem services in the economy of the poor about 74.6 % in Indonesia. According to Schoneveld et al. (2019), smallholders in certain cases do not comply with sustainability standards when transforming other land uses to oil palm plantations, planting in peat and fire are some of the non-sustainable practices.

T3. Loss of Natural Habitats: Papua-Indonesia holds abundant biodiversity, being about 50 % of its flora and fauna species native from this island. The number of plant species not found anywhere else in the world (endemic) are up to 90 % for certain groups (IUCN, 2008). Conversion of forests to oil plantations has destroyed natural habitats in Papua (Andrianto et al., 2014).

T4. Displacement of Local Population: indigenous population life is still very dependent of forest products. Traditional livelihoods are being threatened by land transformation from forest to oil palm plantations previously available for traditional activities. Transition to plantation works is not simple for the local communities of Papua (Andrianto et al., 2014).

T5. Conflicts and Riots: conflicts between local population and plantation workers occur due to the lack of recognition of customary rights by the indigenous communities. Some companies cleared the forest but had to cease operations due to conflicts with the local population. Also conflicts arise when transmigrant programs turn over to plasma developers without taking into consideration customary rights (Obidzinski et al., 2012). Forest dependent communities are likely to oppose the establishment of oil palm

plantations, they are seen negatively for having a bad impact over the environment and their own livelihoods (Abram et al., 2017).

T6. Global CO₂eq Emissions: Agus et al. (2010) established emission factors for above ground carbon in 189 tons of C per ha for undisturbed forest, 104 tons of C per ha for disturbed forest, 30 tons of C per ha for shrubland, and 36 tons of C per ha for oil palm. This means that when oil palm substitutes higher carbon type of ecosystems, CO₂eq emissions to the atmosphere occur. Land use change emissions in Indonesia represent 1,682 million tons of CO₂eq, representing about 68 % of Indonesia's total emissions (CAIT, 2018).

T7. Climate Change: the social cost of carbon is an economic metric to measure the climate change impacts resulting from the carbon change in the atmosphere. An estimate of the benefits of avoiding emissions of one ton of CO₂ in year 2020 is USD 42, based on a 3 % discount rate in 2007 USD (National Academies of Sciences Engineering and Medicine, 2017).

T8. Wealth Redistribution (Winners and Losers): the main reason for biodiversity loss is that there is a disparity between the private and social benefits and the benefits of biodiversity loss and conservation. If social, global and private interest differ there will be a strong incentive for land transformation to a different use (Pearce and Moran, 1994). Oil palm plantations have previously made an important contribution to the national and regional revenues through the payment of taxes. Some of the associated taxes of oil palm plantations are property tax, income tax for companies, personal income tax for employees and increment value tax (Andrianto et al., 2014). Local Papua population receives one-time payment for their forested land; sometimes this cash payment is not evenly distributed. Clearly the local population is the big loser when deforestation occurs (The World Bank, 2009).

T9. Fires: about 2.6 million ha burned in Indonesia due to fires in the period from January to October of 2015. Draining and conversion of peatlands, driven by palm oil and other land use changes, increase fire intensity. Indonesian sustainable oil palm certification (ISPO) prohibits the use of fire for establishment of oil palm plantations larger than 25 ha (Glauber and Gunawan, 2016).

Table 7: SWOT - New plantation establishment in Papua.

	STRENGTHS (S)	WEAKNESSES (W)
INTERNAL	S1. Business opportunity S2. Abundant Available Land S3. Clean Energy Generation S4. Competitive Price S5. Climate adequate for Palm Oil S6. Corporate know-how S7. Investment in the Region	W1. Unstable area due to Politics W2. High costs due to remote location W3. Local Population Oil Palm Cultivation know-how W4. Population Opposition to plantations W5. International Community Monitoring
EXTERNAL	OPPORTUNITIES (O) O1. Job creation O2. Wealth redistribution through Taxes O3. Alternative Source of Energy O4. Increase in GDP O5. Development of Rural Areas O6. More Open Society O7. Entrepreneurship (plasma scheme) O8. Improved Infrastructures O9. Energy Security O10. Biodiesel Emissions Savings	THREATS (T) T1. Deforestation T2. Loss of Ecosystem Services T3. Loss of Natural Habitats T4. Displacement of Local Population T5. Conflicts and Riots T6. Global CO ₂ eq Emissions T7. Climate Change T8. Wealth Redistribution (Winners and Losers) T9. Fires

3.2 Emissions and Feasibility of New Oil Palm Plantations in Indonesia

Following the methodology of section 2.2, results are calculated in this section. The results are divided into 2 subsections corresponding to the environmental and economic feasibility of new oil plantations in Indonesia.

3.2.1 Environmental Feasibility

The environmental feasibility of new oil palm plantations in terms of emissions is studied in this subsection.

3.2.1.1 Areas being converted to oil palm

Based on the average area transformed to oil palm plantations in Indonesia of 554,084 ha per year (please see sub-section 2.2.1), the original land use distribution was estimated; calculation can be followed in Table 8. The area of forest released for oil palm was obtained from the Ministry of Environment and Forestry Republic of Indonesia (2018).

Table 8: Forest Released for new oil Palm Plantations.

Parameter	Value
Released forest area for palm oil up to 2017 (28 years period)	6,800,000 ha
Total palm oil area (Suwandi, 2017).	11,672,861 ha
% of forest from total	58%
Average forest area per year released for palm oil	242,857 ha
Average palm oil new area per year	554,084 ha

According to Casson et al. (2014), between the period from 2007 to 2011, a total of 5.2 million forest ha were released for oil palm. The distribution of released forest area during this period was 3 million ha of forest in mineral soil and 2.2 million ha of forest in peat soil; from these data it was obtained the proportion of 57.7 % or 140,110 ha of mineral forest and 42.3 % or 102,747 ha of peat land forest converted to oil palm plantations.

From the above results, the areas by land use being converted to oil palm plantations in Indonesia were calculated (Table 9).

Table 9: Land Original Uses of new oil palm plantations. Results based on data from Ministry of Environment and Forestry Republic of Indonesia, (2018), Gunarso et al., (2013) and Suwandi (2017).

Land Use	Indonesia converted area (ha y ⁻¹)	% Indonesia area
Undisturbed Upland Forest	140,109.89	25.29%
Upland Shrub & Grasslands	93,008.67	16.79%
Undisturbed Swamp Forest	102,747.25	18.54%
Swamp Shrub & Grasslands	30,147.13	5.44%
Agroforest & Plantation	159,611.09	28.81%
Intensive Agriculture	15,550.35	2.81%
Bare Soil	5,427.95	0.98%
Others	7,481.77	1.35%
	554,084.10	100.00%

According to these results the average area being converted from forest (242,857 ha y⁻¹) and peat lands (102,747.25 ha y⁻¹) to oil palm (554,084.10 ha y⁻¹) represents 43.83 % of total and 23.98 % of the total converted area, based on data up to 2017. These percentages were compared to those of the European Commission (2019b), that estimated that depending on the authors 20 % to 70 % of new oil palm plantations were converted from forested areas. A 23 % of new oil palm plantations were estimated to have been planted in peatlands (European Commission, 2019b). Our estimates were in line with official data.

3.2.1.2 Savings in Emissions from Biofuels Results

The approach followed for calculation of emissions from conventional fossil fuel diesel per ha when compared to biodiesel is shown in Table 10. Table 11 shows the calculation followed for the biodiesel emissions savings with and without methane recovery system. The calculation of emissions from conventional fossil fuel diesel per ha when compared to HVO per ha can be followed in Table 12. Table 13 shows the calculation followed for the HVO emissions savings with and without methane recovery system. Results from the above calculations show that higher emissions savings are achieved by using HVO instead of Biodiesel.

Table 10: Diesel emissions calculation for biodiesel production.

Parameter	Value	Source
Emissions Diesel expressed in g CO ₂ eq L ⁻¹	2840.53	Lechón et al. (2006)
Emissions Diesel expressed in g CO ₂ eq kg ⁻¹	3392.88	Own calculation
Density diesel (t m ⁻³)	0.84	Ministerio de Industria (2013)
Density biodiesel (t m ⁻³)	0.89	Ministerio de Industria (2013)
Conversion yield (kg biodiesel per kg of CPO)	0.87	Alkabbashi et al. (2009)
CPO per ha (t ha ⁻¹ y ⁻¹)	4.88	Andrianto et al. (2014)
Liters biodiesel per ha	4762.79	Own calculation
Emissions Diesel (for an equivalent amount of biodiesel) expressed in t CO ₂ eq ha ⁻¹ y ⁻¹	13.53	Own calculation

Table 11: Biodiesel Emissions Savings Calculation.

Diesel emissions per ha (t CO ₂ eq ha ⁻¹ y ⁻¹) [1]	Savings of Biodiesel compared to diesel based on source, type of fuel and biodiesel treatment (%) [2]	Source	Biodiesel savings (t CO ₂ eq ha ⁻¹ y ⁻¹) [1] x [2]
13.53	0.54	Lechón et al. (2006)	7.28
	0.32	The European Parliament and the Council of the European Union (2018) without Methane recovery	4.33
	0.51	The European Parliament and the Council of the European Union (2018) with Methane recovery	6.90
	0.52	Vasquez et al. (2017)	7.03

Table 12: Diesel emissions calculation for HVO production.

Parameter	Value	Source
Emissions Diesel (g CO ₂ eq L ⁻¹)	2840.53	Lechón et al. (2006)
Emissions Diesel expressed in g CO ₂ eq kg ⁻¹	3392.88	Own calculation
Density diesel (t m ⁻³)	0.84	Ministerio de Industria (2013)
Density HVO (t m ⁻³)	0.77	Ministerio de Industria (2013)
Conversion yield (kg HVO per kg of CPO)	0.81	Institute for Energy and Environmental Research (IFEU) (2019)
CPO per ha (t ha ⁻¹ y ⁻¹)	4.88	Andrianto et al. (2014)
Liters HVO per ha	5138.51	Own calculation
Emissions Diesel (for an equivalent amount of HVO) expressed in t CO ₂ eq ha ⁻¹ y ⁻¹	14.60	Own calculation

Table 13: HVO Emissions Savings Calculation.

Diesel emissions per ha (t CO ₂ eq ha ⁻¹ y ⁻¹)[1]	Savings of HVO compared to diesel based on source, type of fuel and biodiesel treatment [2]	Source	HVO savings (t CO ₂ eq ha ⁻¹ y ⁻¹) [1]x[2]
14.60	0.34	The European Parliament and the Council of the European Union (2018) without Methane recovery	4.96
	0.53	The European Parliament and the Council of the European Union (2018) with Methane recovery	7.74

3.2.1.3 Comparison Between LUC and Biofuel Emissions

The calculation for savings of CO₂eq from the use of biofuels (Biodiesel and HVO) instead of conventional fossil fuel (Diesel) in energy terms, and their relationship to land use emissions in the soil category (primary tropical forest in mineral soil) can be followed below in Table 14 and Table 15, respectively. In the basic tropical forest in fertile mineral soil category the relationship between the emissions generated by land use change and the savings by the use of biodiesel and HVO resulted to be 144 and 126 times higher, respectively, therefore it would take more than 100 years to recover the emissions generated by the clearing of primary forest in new plantations in Indonesia.

Table 14: Calculation of biodiesel CO₂eq savings per energy unit and relationship between LUC emissions and biodiesel savings.

Parameter	Value	Source
Energy content of diesel (MJ kg ⁻¹ diesel)	43	The European Parliament and the Council of the European Union (2018)
Energy content of biodiesel (MJ kg ⁻¹ biodiesel)	37	The European Parliament and the Council of the European Union (2018)
Diesel emissions (kg CO ₂ eq kg ⁻¹ biodiesel produced)	3.18	Own calculation
Biodiesel emissions (kg CO ₂ eq kg ⁻¹ biodiesel)	2.17	Own calculation
Emissions saving (diesel-biodiesel) (kg CO ₂ eq savings kg ⁻¹ biodiesel produced)	1.02	Own calculation (diesel emissions-biodiesel emissions)
Forest to oil palm LUC emissions per plantation area (t CO ₂ ha ⁻¹)	623.3	Own calculation (see Table 15)
Forest to oil palm LUC emissions per ton of biodiesel (t CO ₂ eq t ⁻¹ biodiesel)	146.7	Own calculation
Forest to oil palm LUC emissions per MJ biodiesel (t CO ₂ eq MJ ⁻¹ biodiesel)	3.97	Own calculation
LUC emissions/ Savings Biodiesel	143.98	Own calculation

Table 15: Calculation of HVO CO₂eq savings per energy unit and relationship between LUC emissions and HVO savings.

Parameter	Value	Source
Energy content of diesel (MJ kg ⁻¹ diesel)	43	The European Parliament and the Council of the European Union (2018)
Energy content of HVO (MJ kg ⁻¹ HVO)	44	The European Parliament and the Council of the European Union (2018)
Diesel emissions (kg CO ₂ eq kg ⁻¹ HVO produced))	3.68	Own calculation
HVO emissions (kg CO ₂ eq kg ⁻¹ HVO)	2.43	Own calculation
Emissions saving (diesel-HVO) (kg CO ₂ eq savings kg ⁻¹ HVO produced)	1.25	Own calculation
Forest to oil palm LUC emissions per plantation area (t CO ₂ ha ⁻¹)	623.3	Own calculation (see Table 15)
Forest to oil palm LUC emissions per ton of HVO (t CO ₂ eq t ⁻¹ HVO)	157.0	Own calculation
Forest to oil palm LUC emissions per MJ HVO (t CO ₂ eq MJ ⁻¹ HVO)	3.57	Own calculation
LUC emissions/ Savings HVO	125.6	Own calculation

3.2.1.4 LUC Emissions Calculation

Below in Table 16 the results of emissions due to Land Use Change are shown. All calculations of land carbon stocks were based on the European Commission (2010) and Intergovernmental Panel on Climate Change (2013).

Table 16: Land Use Change Emissions by original land use change to oil palm plantation baseline scenario.

Land Use Category	t CO ₂ ha ⁻¹
Undisturbed Upland Forest	623.3
Upland Shrub & Grasslands	-190.3
Undisturbed Swamp Forest	832.8
Swamp Shrub & Grasslands	-81.3
Agroforest & Plantation	124.8
Intensive Agriculture	-190.3
Bare Soil	-220.0

Sensitivity Analysis for Soil Degradation.

Sensitivity analysis has been conducted for soil degradation when transforming tropical forest to oil palm in mineral soils. A 40 % reduction of soil carbon, based on Dislich (2015), has been used to calculate land use change emissions. Emissions increase from 623.3 to 749.5 t CO₂ ha⁻¹.

Negative Emissions Soil Categories

Soil categories for negative emissions from land use change were analyzed, by adding LUC emissions savings to the savings of emissions due to using the biofuel instead of the fossil diesel fuel (values in Tables 11 and 13). Emissions for the use of the biofuels were calculated for biodiesel and HVO without methane capture, based on savings from The European Parliament and the Council of the European Union (2018) regulation. Results of total emissions savings for biodiesel and HVO are given in Tables 17 and 18, respectively.

Table 17: Emissions savings from Land Use Change Biodiesel Fuel.

Original land use	Emissions savings from Land Use Change (t CO ₂ ha ⁻¹ y ⁻¹)	Biodiesel emissions savings (t CO ₂ ha ⁻¹ y ⁻¹)	Total emissions savings (t CO ₂ ha ⁻¹ y ⁻¹)	% SAVINGS
Bare soil	8.80	4.33	13.13	97%
Intensive agriculture	7.61	4.33	11.94	88%
Upland shrub or grasslands	7.61	4.33	11.94	88%
Swamp shrub or grasslands	3.52	4.33	7.58	56%

Table 18: Emissions savings from Land Use Change and HVO Fuel.

Original land use	Emissions savings from Land Use Change (t CO ₂ ha ⁻¹ y ⁻¹)	HVO emissions savings (t CO ₂ ha ⁻¹ y ⁻¹)	Total emissions savings (t CO ₂ ha ⁻¹ y ⁻¹)	% SAVINGS
Bare soil	8.80	4.96	13.76	94%
Intensive agriculture	7.61	4.96	12.57	86%
Upland shrub or grasslands	7.61	4.96	12.57	86%
Swamp shrub or grasslands	3.52	4.96	8.21	56%

Total Indonesian Land Use Change Emissions

Total Indonesian LUC emissions were calculated from the results in Table 9 (area annually converted to oil palm), Table 16 (LUC emissions per original land use), Table 11 (biodiesel emissions savings) and Table 13 (HVO emissions savings). Results of total Indonesian emissions according to current Indonesian Practices are shown in Table 19.

Table 19: Total Indonesian emissions of the Baseline Scenario according to current Indonesian Practices.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	623.3	87.34	-4.33	-4.96	86.73	86.64
Upland Shrub & Grasslands	93,008.67	-190.3	-17.70	-4.33	-4.96	-18.10	-18.16
Undisturbed Swamp Forest	102,747.25	832.8	85.56	-4.33	-4.96	85.12	85.05
Swamp Shrub & Grasslands	30,147.13	-81.3	-2.45	-4.33	-4.96	-2.58	-2.60
Agroforest & Plantation	159,611.09	124.8	19.91	-4.33	-4.96	19.22	19.12
Intensive Agriculture	15,550.35	-190.3	-2.96	-4.33	-4.96	-3.03	-3.04
Bare Soil	5,427.95	-220.0	-1.19	-4.33	-4.96	-1.22	-1.22
SUM	546,602.33*		168.51			166.14	165.79

*Please note emissions from other land uses are not included into the model.

Emissions put in perspective

In order to estimate the total land use emissions due to conversion of land with other original uses to oil palm plantations in Indonesia, the emissions from land use change for each original land use were multiplied by the estimated conversion area, this way a total emissions estimate was calculated. The impact of the total emissions due to oil palm plantations establishment was put in perspective by comparing oil palm emissions in Indonesia to World and Indonesian total emissions; results are shown in Table 20. The estimate found for total oil palm emissions represented about 6.82 % of the total Indonesians emissions, 10.02 % from total Indonesian Land Use Change emissions, and 0.47 % of World Emissions.

Table 20: Impact of oil palm plantations emissions at national and global level.

Type of Emissions	Value	Supporting information
Global Emissions (t CO ₂ eq y ⁻¹)	36,138,285,000	World Bank (2014)
Indonesian Emissions (t CO ₂ eq y ⁻¹)	2,471,640,000	CAIT (2018)
Indonesian LUC Emissions (t CO ₂ eq y ⁻¹)	1,682,160,000	CAIT (2018)
Indonesian Emissions from new oil palm plantations (t CO ₂ eq y ⁻¹)	168,506,733	Own calculation
Indonesian Emissions from new oil palm plantations in forested land (t CO ₂ eq y ⁻¹)	172,898,100	Own Calculation
Palm oil as % of total Indonesian LUC emissions	10.02 %	Based on above data
Palm oil as % of Indonesian emissions	6.82 %	Based on above data
Palm oil as % of Global emissions	0.47 %	Based on above data

ILUC risk on the baseline scenario

The European Delegated Regulation (European Commission, 2019a) supplementing Directive 2018/2001 on the promotion of renewable energies addresses the indirect land use change (ILUC) issue and gives rules for determining high ILUC risk feedstocks and for certifying biofuels with low ILUC-risk. According to that regulation, the share of the expansion into high carbon land is calculated by the following formula:

$$X_{hcs} = (X_f + 2.6 X_p) / PF$$

X_{hcs} = expansion into land with high carbon stock

X_f - share expansion into forest land

X_p - share expansion wetlands including peat

PF - Productivity Factor

The estimates of converted lands areas (see sub-section 3.2.1) needed to this approach were the following: Total converted land = 554,084.1 ha, Forest in peat soil = 102,747.25 ha, Forest in mineral soil = 140,109.89 ha, and Swamp shrub and grasslands = 30,147.10 ha. Therefore, X_f and X_p were calculated as follows:

$$X_f = (102,747.25 + 140,109.89) / 554,084.10 = 43.83$$

$$X_p = (102,747.25 + 30,147.10) / 554,084.10 = 23.98$$

Utilizing the above mentioned formula, and knowing that PF = 2.5 for oil palm as per article 3 of the European Commission (2019a), the high carbon land share for our baseline scenario was calculated as follows:

$$X_{hcs} = (X_f + 2.6 X_p) / PF = (43.83 + 2.6 \times 23.98) / 2.5 = 42.48 \%$$

Therefore, the observed expansion of the production area into land with high-carbon stock was found significant (EU Delegated Regulation sets 10% limit) and feedstocks produced can be considered with high indirect land-use change risk.

3.2.1.5 Alternative Scenarios Emissions

3.2.1.5.1 Baseline Scenario

This scenario, based on current Indonesian oil palm industry practices, meant a total of 168.51 million CO₂eq tons of land use emissions. The results of this scenario are used as a basis to quantify the current level of emissions to be compared to other possible alternative scenarios.

3.2.1.5.2 Alternative Scenarios

Alternative Scenario 1: Presence of Fire

Below in Table 21, yearly total emissions due to oil palm plantations establishment in the fire scenario in Indonesia are summarized. An increase of emissions occurs when fire is used for conversion to oil palm plantations. Increase of CO₂eq from 168.51 to 176.59 million tons per year from establishment of new oil palm plantations occurs when 20 % of the peat land is burned during the conversion forest.

Alternative Scenario 2: Yield Improvement by improved agricultural practices

The next variable modified was the yield of the oil palm plantation; by improving the agricultural practices the yield achieved for oil palm can be improved. Below in Table 22, the effect of an improvement on the yield over emissions was analyzed. According to this approach the emissions were reduced from 168.51 to 99.16 million tons of CO₂eq per year.

Alternative Scenario 3: Improvement of Yield by Genetic Modification

Below in Table 23, yearly emissions due to oil palm plantations establishment in the improved yield by genetic modification scenario were summarized. Emissions of CO₂eq from 168.51 to 147.16 million tons per year from establishment of new oil palm plantations can be achieved with genetic modification practices.

Alternative Scenario 4: Improved Soil Practices

Table 24 shows the yearly emissions due to oil palm plantations establishment in the improved soil practices scenario. A great reduction of emissions was achieved by improving the soil practices in oil palm plantations. Reduction of CO₂eq from 168.51 to 112.22 million tons per year from establishment of new oil palm plantations can be achieved with improved soil management practices.

Alternative Scenario 5: no plantations established in Peat Lands

Yearly emissions due to oil palm plantations establishment in the avoided peat land plantations scenario are given in Table 25. As it can be seen, a reduction of emissions was achieved by avoiding planting in peat; CO₂eq emissions were reduced from 168.51 to 143.7 million tons per year from establishment of new oil palm plantations.

Alternative Scenario 6: avoided deforestation

Estimates of the yearly emissions due to oil palm plantations establishment in the avoided deforestation scenario are shown in Table 26. This scenario was found very advantageous for land use emissions avoidance since CO₂eq emissions were reduced from 168.51 to -7.82 million tons per year. Below in Table 27, the results of these 6-oil palm plantation conversion scenarios, as well as their relationship with biodiesel and HVO potential savings, were summarized.

Table 21: Scenario 1: Total Indonesian emissions for the Fire scenario.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	623.3	87.34	-4.33	-4.96	86.73	86.64
Upland Shrub & Grasslands	93,008.67	-190.3	-17.70	-4.33	-4.96	-18.10	18.16
Undisturbed Swamp Forest - Mechanical Conversion	82,197.80	832.8	68.45	-4.33	-4.96	68.09	68.04
Undisturbed Swamp Forest - Fire Conversion	20,549.45	1226.3	25.20	-4.33	-4.96	25.11	25.10
Swamp Shrub & Grasslands	30,147.13	-81.3	-2.45	-4.33	-4.96	-2.58	-2.60
Agroforest & Plantation	159,611.09	124.8	19.91	-4.33	-4.96	19.22	19.12
Intensive Agriculture	15,550.35	-190.3	-2.96	-4.33	-4.96	-3.03	-3.04
Bare Soil	5,427.95	-220.0	-1.19	-4.33	-4.96	-1.22	-1.22
SUM	546,602.33		176.59			174.23	173.88

Table 22: Scenario 2: Total Indonesian emissions for the improved agricultural practices scenario.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	509.7	71.41	-4.33	-4.96	70.72	70.59
Upland Shrub & Grasslands	93,008.67	-289.0	-26.88	-4.33	-4.96	-27.33	-27.41
Undisturbed Swamp Forest	102,747.25	719.3	73.91	-4.33	-4.96	73.40	73.31
Swamp Shrub & Grasslands	30,147.13	-194.8	-5.87	-4.33	-4.96	-6.02	-6.05
Agroforest & Plantation	159,611.09	-27.2	-4.35	-4.33	-4.96	-5.13	-5.27
Intensive Agriculture	15,550.35	-407.2	-6.33	-4.33	-4.96	-6.41	-6.44
Bare Soil	5,427.95	-502.9	-2.72	-4.33	-4.96	-2.14	-2.76
SUM	546,602.33		99.16			96.46	95.99

Table 23: Scenario 3: Total Indonesian emissions for the scenario of Improved Yield by Genetic Modification.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	600.13	84.1	-4.33	-4.96	83.48	83.39
Upland Shrub & Grasslands	93,008.67	-213.50	-19.9	-4.33	-4.96	-20.26	-20.32
Undisturbed Swamp Forest	102,747.25	809.59	83.2	-4.33	-4.96	82.74	82.67
Swamp Shrub & Grasslands	30,147.13	-104.46	-3.1	-4.33	-4.96	-3.28	-3.30
Agroforest & Plantation	159,611.09	63.07	10.1	-4.33	-4.96	9.38	9.27
Intensive Agriculture	15,550.35	-316.78	-4.9	-4.33	-4.96	-4.99	-5.00
Bare Soil	5,427.95	-412.48	-2.2	-4.33	-4.96	-2.26	-2.27
SUM	546,602.33		147.16			144.79	144.45

Table 24: Scenario 4: Emissions of Improved Soil Practices scenario.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	384.7	53.90	-4.33	-4.96	53.29	53.20
Upland Shrub & Grasslands	93,008.67	-375.3	-34.91	-4.33	-4.96	-35.31	-35.37
Undisturbed Swamp Forest	102,747.25	832.8	85.56	-4.33	-4.96	85.12	85.05
Swamp Shrub & Grasslands	30,147.13	-81.3	-2.45	-4.33	-4.96	-2.58	-2.60
Agroforest & Plantation	159,611.09	124.8	19.91	-4.33	-4.96	19.22	19.12
Intensive Agriculture	15,550.35	-493.6	-7.68	-4.33	-4.96	-7.74	-7.75
Bare Soil	5,427.95	-389.3	-2.11	-4.33	-4.96	-2.14	-2.14
SUM	546,602.33		112.22			109.86	109.51

Table 25: Scenario 5: Emissions of avoided plantations in peat lands scenario.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	623.3	87.34	-4.33	-4.96	86.73	86.64
Upland Shrub & Grasslands	93,008.67	-190.3	-17.70	-4.33	-4.96	-18.10	-18.16
Undisturbed Swamp Forest	102,747.25	623.3	64.05	-4.33	-4.96	65.98	65.91
Swamp Shrub & Grasslands	30,147.13	-190.3	-5.74	-4.33	-4.96	-8.20	-8.22
Agroforest & Plantation	159,611.09	124.8	19.91	-4.33	-4.96	19.22	19.12
Intensive Agriculture	15,550.35	-190.3	-2.96	-4.33	-4.96	-3.03	-3.04
Bare Soil	5,427.95	-220.0	-1.19	-4.33	-4.96	-1.22	-1.22
SUM	546,602.33		143.70			141.38	141.04

Table 26: Scenario 6: Emissions of avoided deforestation scenario.

	Converted area (ha y ⁻¹)	LUC emissions (t CO ₂ ha ⁻¹)	Indonesian LUC emissions (Mt CO ₂ eq y ⁻¹)	Biodiesel emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	HVO emissions savings (CO ₂ eq ha ⁻¹ y ⁻¹)	Total Emissions including potential savings from biodiesel (Mt CO ₂ eq y ⁻¹)	Total Emissions including potential savings from HVO (Mt CO ₂ eq y ⁻¹)
Undisturbed Upland Forest	140,109.89	623.3	0.00	-4.33	-4.96	0.00	0.00
Upland Shrub & Grasslands	93,008.67	-190.30	-31.85	-4.33	-4.96	-32.23	-32.33
Undisturbed Swamp Forest	102,747.25	832.8	0.00	-4.33	-4.96	0.00	0.00
Swamp Shrub & Grasslands	30,147.13	-81.30	-4.41	-4.33	-4.96	-4.60	-4.63
Agroforest & Plantation	159,611.09	124.76	35.83	-4.33	-4.96	34.22	34.04
Intensive Agriculture	15,550.35	-190.30	-5.33	-4.33	-4.96	-5.39	-5.41
Bare Soil	5,427.95	-220.00	-2.15	-4.33	-4.96	-2.17	-2.17
SUM	546,602.33		-7.82			-10.16	-10.50

Table 27: Scenarios for Oil Palm LUC Emissions Improvement.

	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹)	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹)	LUC Emissions/HVO Savings
BASELINE SCENARIO	Without methane recovery	168,506,732.56	308.30	4.33	71.2	4.96	62.1
	With methane recovery	168,506,732.56	308.30	6.90	44.7	7.74	39.9
	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹)	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹)	LUC Emissions/HVO Savings
EMISSIONS FROM FIRE CONSIDERED	Without methane recovery	176,594,893.55	318.70	4.33	73.6	4.96	64.2
	With methane recovery	176,594,893.55	318.70	6.90	46.2	7.74	41.2
	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions/HVO Savings
IMPROVED OIL PALM PLANTATION YIELD TO 91 TONS OF CARBON PER HA DUE TO IMPROVED AGRICULTURAL PRACTICES	Without methane recovery	99,158,687.64	178.96	4.33	41.3	4.96	36.1
	With methane recovery	99,158,687.64	178.96	6.90	25.9	7.74	23.1
	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions/HVO Savings
IMPROVED OIL PALM PLANTATION DUE TO GENETIC MODIFICATION	Without methane recovery	147,161,207.13	265.59	4.33	61.3	4.96	53.5
	With methane recovery	147,161,207.13	265.59	6.90	38.5	7.74	34.3
	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions/HVO Savings
IMPROVED OIL PALM PLANTATIONS SOIL MANAGEMENT	Without methane recovery	112,224,600.13	202.54	4.33	46.8	4.96	40.8
	With methane recovery	112,224,600.13	202.54	6.90	29.4	7.74	26.4
	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹) ¹	LUC Emissions/HVO Savings
CULTIVATION IN PEAT SHIFTED TO MINERAL SOIL	Without methane recovery	143,751,166.64	259.44	4.33	59.9	4.96	52.3
	With methane recovery	143,751,166.64	259.44	6.90	37.6	7.74	33.5
	POME EMISSIONS RECOVERY	Total LUC emissions (t CO ₂ eq y ⁻¹)	Average LUC emissions (t CO ₂ eq ha ⁻¹ y ⁻¹)	Biodiesel Savings (t CO ₂ eq ha ⁻¹ y ⁻¹)	LUC Emissions / Biodiesel Savings	HVO Savings (t CO ₂ eq ha ⁻¹ y ⁻¹)	LUC Emissions/HVO Savings
NO DEFORESTATION	Without methane recovery	-7,818,046.39	-14.11	4.33	N/A	4.96	N/A
	With methane recovery	-7,818,046.39	-14.11	6.90	N/A	7.74	N/A

1. Biofuel savings are based on The European Parliament and the Council of the European Union (2018), therefore an adjustment for agricultural inputs variations has not been considered. This is a limitation of the study and further research is recommended.

2. For this scenario of improved agricultural soil practices of the oil palm plantation factors reflecting change in soil carbon for perennial crops F_{LU} , F_{MG} and F_i are changed from values of $F_{LU}=1$, $F_{MG}=1$, $F_i=1$ corresponding to Full-tillage, medium management to $F_{LU}=1$, $F_{MG}=1$, $F_i=1$ corresponding to no till, high with manure.

3.2.2 Economic Feasibility

3.2.2.1 Economic Feasibility for Plantations Established in Marginal Lands

Results from the model for the three soil categories of new oil palm plantations establishment in deep peat, steep land and tin tailings showed that the Internal Rate of Return (IRR) of the plantations decreases when established in marginal land. From a fertile mineral soil category IRR of 38.48 %, IRR goes down to 31.44 %, 28.22 % and 18.04 % for the marginal land soil categories of original peat, steep land and tin tailings condition.

3.2.2.2 Economic Feasibility of Genetic Breeding

An improvement of the genetics could allow an improvement of the plantation yield, leading to an improvement of the plantation investment returns. The internal rate of return of the model is increased from IRR of 38.48 % to IRR 73.96 %.

3.2.2.3 Economic Feasibility of Biodiesel

Below in Table 28, the results of the cost of biodiesel and the saved emissions from biodiesel are summarized. The results show that the cost for biodiesel based on our model's assumptions would be 0.649 euros in Europe and 8,301.74 IDR in Indonesia, without considering the benefits of saved emissions.

Table 28: Biodiesel Costs Breakdown.

	Euros/kg CPO	kg CPO/Biodiesel liter	Euros/liter	USD/liter	IDR/liter	Reference
Cost of Biodiesel without transport	0.359	0.975	0.350	0.403	5,400.63	Our model
Transportation cost Indonesia to Europe	0.137	0.975	0.134	0.154	2,059.33	Dominik et al. (2019)
Transportation inside Indonesia	0.024	0.975	0.023	0.027	360.76	Dominik et al. (2019)
Refining cost - 31 %	0.117	0.975	0.114	0.131	1,758.70	Silalertruksa et al. (2012)
Profit Margin - 10 %	0.052	0.975	0.051	0.058	781.64	Silalertruksa et al. (2012)
Cost of biodiesel (EUROPE)			0.649	0.746	10,000.31	
Cost of biodiesel (INDONESIA)			0.539	0.620	8,301.74	
Cost of emissions (no methane recovery emissions)			0.024	0.027	370.38	Our model
Cost of emissions (methane recovery emissions)			0.038	0.044	590.13	Our model
Maximum Diesel Cost EU - no methane recovery emissions			0.625	0.719	9,630.03	
Maximum Diesel Cost EU - methane recovery emissions			0.611	0.702	9,410.18	
Maximum Cost of Diesel EU not considering emissions			0.649	0.746	10,000.31	
Maximum Diesel Cost Indonesia- no methane recovery emissions			0.515	0.592	7,931.46	
Maximum Diesel Cost Indonesia- methane recovery emissions			0.500	0.575	7,711.61	
Maximum Cost of Diesel Indonesia not considering emissions			0.539	0.620	8,301.74	

3.3 Feasibility of a new Oil Palm Plantation in Papua, Indonesia

3.3.1 Location, Site Visit and Survey Results

3.3.1.1 Plantation Data

Relevant information gathered during the site visit is given next. This information was obtained from interviews conducted to local professionals of the palm oil industry, such as company staff as well as company management, and from the site visits conducted. This qualitative description allows a better understanding of ground and regional conditions, supporting the economic analysis of this study.

Company: According to PT Rimba Matoa Lestari staff, the company was owned by a Chinese-Indonesian holding based in Jakarta. They did not have a roundtable on Sustainable Palm Oil (RSPO) certification, but they were planning to request it.

Plantation Data: The feasibility studies started in 1999, clearing began in 2005 and the start of plantation operations in 2010. According to company staff the plantation started in 2011, and only 5,000 ha were developed at the end of 2016. Due to the financial crisis the investment was slow and that was the reason that the commercial production of the plantation had not begun. In Figure 3, a sequence of Google Earth historical images showing the transformation of the first 5,000 ha from forest to oil palm is given.

Figure 3: PT Rimba Matoa Lestari development evolution images. Source: Google Earth.

Location: Main reasons mentioned by the Company to choose Jayapura were: available land, suitable weather, and low population density. A river for irrigation was present upstream. Infrastructures were expected to be improved in the following years. The

cost of land was low, only 2 million IDR per ha (149.25 USD ha⁻¹). Also, the license to start the plantation could be finished in 2 years.

Permits: This area was considered by the Indonesian Forestry Ministry as convertible land as the soil was organic without the presence of peat. Apparently local permits were issued without too many problems. The permits were issued in two years: 2008 to 2009. The Environmental Impact Assessment study was recommended locally. There was village, regional (Jayapura Government), provincial (Papua) and final approval from the Indonesian central government.

Agricultural Practices: the information below was obtained from the interviews with the company management staff as well as from the observations during the plantation visit. Please refer to plantation pictures in Appendix 4.

- Plantation density: 10 x 6 m configuration.
- Nursery: Nursery with different sectors and levels of development by year.
- Weeding: Not very good in certain areas, planting of low vegetation was conducted to avoid erosion.
- Time for first harvesting: After 4 years, fruits were not ready for harvesting, probably after 1-2 more years harvest would start. A 6-7 years period was expected to get production.
- Yield was still not certain, but prediction was good.
- Machinery utilized: big equipment with cutting and shear capabilities was utilized for clearing. Weeding was manual by saw. For planned harvesting, manual saw and chisel; all manual cutting.
- Types of fertilizers: N P K(B) 12-12-8 (2)
- Origin of fertilizers: China.
- Type of soil: Sandy organic, organic soil in the first layer, followed by alluvial organic soil in layers below. The Ministry of Forestry assigned the permits based on soil type.
- Mulching: Vegetation was planted between palm trees to avoid erosion; no erosion was occurring.
- Irrigation: By water channels; there was a system of gates to control water level and inundate the different plots.
- Drainage systems: Channels network.
- Water: Enough year-round due to the presence of a river at the plantation.
- Needed labor, skilled and unskilled: 50 skilled workers (permanent employees) and 700 workers (temporary with yearly renewable contracts) were working on the 5,000 ha of plantation already established. Employees had to complete weeding for about 0.5 ha per day to receive their full salary. There were about 0.12 workers per ha, to be increased up to a normal 0.3-0.64 workers per ha range after start of harvesting and Crude Palm Oil (CPO) production.

- Plantation Management: construction of channels for irrigation, erosion control by mulching planting, and experienced management and labor are believed to guarantee a correct management of the plantation. Workers were requested a minimum output to get the full salary, guaranteeing that the weeding operations were conducted. Possibly a higher investment in machinery could improve the efficiency of the operations, that were relying mainly on labor.

These practices are believed to be correct and in line with FAO (2010) for modern plantations that include practices such as to plant with a green-manure crop, apply potassium rich fertilizers, conduct mulching to avoid erosion, use tenera varieties to improve yield and use suitable weather locations to set up plantations.

Economics:

Elkington's triple bottom line logic (Elkington, 1997) was followed in order to present qualitative information on Economics that were gathered during the site visits.

Economic Value:

The main motivation for the Company was to obtain economic income from the plantation. Some of the factors affecting profitability that were highlighted during the site visits are the followings:

- Transportation: The cost to transport the palm oil from Jayapura was expected to be high due to the lack of proper infrastructures. A bad condition national asphalted road connected the plantation with Jayapura.
- Refining: The Company was building a crude palm oil (CPO) processing facility that would only process the palm fruit up to CPO level. No methane recovery or palm oil mill effluent (POME) treatment facilities had been planned.
- Oil price: CPO Price was expected to be set by international markets; no certification was available (as of December 2016) so probably in the first stages the CPO could not be sold at the highest price. It was stated that it was not possible to sell to Europe or USA, so probably it would be sold within Asia.

Environmental impact:

The new plantation entailed very important environmental consequences due to the transformation from forest to oil palm. Information on the Company environmental practices are reflected in this sub-section.

- Establishment: The expected establishment costs were 50 million IDR per ha until production started. This cost included the clearing of the forest, construction of irrigation channels, construction of roads, camps, provision of electricity, fertilizers,

nursery and planting, as well as the cost of labor for agricultural operations such as weeding. There was no cost of pesticides as manual weeding was conducted. Clearing of the forest, which represents the main environmental consequence of the plantation, was done mechanically. This is a much more sustainable practice than burning.

- Wood: Revenues from wood selling when clearing the forest were obtained; 1 m³ of good quality wood was 5.8 million IDR (Indonesian Rupiahs). The company sold the wood and paid a small fee, so a good profit was made. The wood was sold raw in the local market. The Company did not clear additional forest before planting in order to obtain additional profits from wood selling, which is a common non-sustainable practice, not present in this plantation.
- Renewable Energy: It was not clear if the CPO from the oil palm plantation would be used for biodiesel. The company did not have a certification so it would be complicated to sell it for this purpose.

Social Responsibility:

This is a very important issue when establishing new plantation; respecting the rights of customary communities as well as workers and the local population is of critical importance.

Land Use Change: The land was leased for 35 years. There were about 15 land owners; each of them had received an initial 80 million IDR payment. The land before the change to oil palm plantation was primary forest. A socialization process was conducted among the landlords. Once an agreement was reached with the landlords the project passed to the local government for approval. No conflicts occurred when purchasing the land, due to Company socialization and discussion with landlords and local leaders. The company had to fulfill the plasma scheme commitment, in order to avoid riots and problems with local community and workers. Low population density allowed for an easier process. The plantation had no fence, only an open gate; people were permitted to pass freely.

Labor: The Company had legal contracts with employees; conditions were competitive according to Indonesian standards. The cost of labor was 2.5 million IDR per worker (104,000 per day by average 24 days, Monday to Saturday work). One worker had to take care of the weeding of 8 ha per month, so the cost of weeding was about 312,000 IDR ha⁻¹ month⁻¹. The number of workers in the oil palm plantation was reduced from 1,000 to 700 (as of December 2016) due to economic issues. Labor reduction had made the implementation process slower as weeding operations had been reduced and plantation of additional area had been slowed down. Most workers were trans-migrants from other Indonesian regions. Drivers and security guards were local workers. Some locals said they had

been rejected due to lack of qualifications. In this sense the plantation would have to make a greater effort to engage local workers, by conducting oil harvesting training programs.

Access to the clinic for the community had been provided. No education had been provided yet, but a school bus had been provided by the Company to take worker's kids to the local school outside the plantation. Some new local businesses, that sold supplies to the plantation and their workers, had been established. This benefit was part of the social responsibility of the Company.

Plasma Scheme: There was a planned plasma scheme, which meant that land would be given to local farmers to develop their own plantations, selling later the production to the Company. Financial support from the Company would be obtained. There was a plan for 700 families that would get 4 ha each; a total of 2,800 ha (10 % of the total land) would be given to the local community for plasma plantation. The families would pay 50,000 IDR per month until reaching 1,050,000 IDR to get their certificate of lease for 35 years. According to the Company 20 % of total plantation area was committed for plasma, so up to 5,600 ha could be given to the local population. The company had tried to integrate the community into the plantation.

Industries: There were no downstream industries in the area. Upstream local industries benefited from the plantation by the purchase of construction materials. For food and other basic supplies, few products were available; plantation supplies were primarily imported or came from Jakarta.

Infrastructures inside the plantation: These infrastructures were developed by the plantation Company to give service to the plantation; they were developed prior to the start of the plantation operations. Common infrastructures were developed only inside the plantation such as roads, houses, mosque, church, workers housing complex, office building and clinic to give service to plantation and irrigation channels required for oil palm irrigation. Social facilities included religious buildings, houses, wells for drinking water supply and electricity by diesel generators. Water supply was only for consumption inside the plantation; it was supplied by wells for plantation workers use. Electricity supply by diesel generators was only for consumption inside the plantation. The company shares these infrastructures with the local population, becoming a social benefit for them.

Infrastructures outside the plantation: The Ministry of Public Works (PU) was present in the region and bridges were constructed along the road to Jayapura; this road was being improved. This was part of the Government's plan to develop the region, regardless of the plantation. The road going to Jayapura is of critical

importance in order to allow palm oil transportation to Jayapura's port. The new infrastructures help promote regional growth and reduce isolation.

Plantation future strategy:

Plans for future expansion were up to the licensed 28,000 ha. The plantation would be producing in a few years; in about 5 years the whole licensed area was expected to be planted and CPO production was expected to start in a few years.

Associated upstream and downstream industries were expected to develop as the plantation went into production.

3.3.1.2 Survey Results

Concerning the oil palm establishment, respondents stated that there had been a new plantation established in the past years; in 1999 surveys were conducted, and in 2005 equipment was mobilized.

All the respondents stated the plantation was established in forest land. The clearing seemed to be of about 5,000 ha and was being conducted gradually.

About half of the respondents (58%) stated that the establishment of the plantation was smooth (Figure 4). At the beginning there were tensions that were resolved during the negotiations between the Company and the local leaders and landlords, based on the promise to give plasma to 700 families, with an area of 4 ha per family. As the production had not started yet, final acceptance by the population was still pending. Respondents stated they would accept the plantation if they were given a share through the plasma scheme. Most respondents (79%) believed that compensation had been paid to land owners; 75% of the respondents believed land had been allocated to local communities but only 42% of the respondents believed that the required 20% had been allocated.

Figure 4: Establishment Process at new oil palm plantation.

Respondents were asked their opinion of oil palm plantations; 46 % of respondents had a good or very good perception, 33 % a neutral perception and 13 % a bad or very bad perception (Figure 5). Those having a bad perception were generally locals with Papua origins, people that make a living from the forest and after its removal had lost this asset. The plantation could bring economic benefits for those that were willing to engage in its activities, but the loss of the forest could not be replaced.

Figure 5: Perception and Relationship of local population with the plantation.

In contrast, positive perception came from plantation workers; many of them trusted they would be given some land to become an oil palm plasma entrepreneur. Plasma entrepreneurs are locals given a small land area (4 ha at this plantation) by the Company to start up their own oil palm plantation business. They are given financial support by the Company, which buys their production at an agreed price.

The low population in the region would allow the plantation owners to give land to most of the local people. This would create a good relationship with the local indigenous population. Small holders and plantation workers were the primary types of relationships the local population had with the plantation.

Participants were requested to highlight the benefits they obtained from the plantation including education, healthcare, access to jobs and a more open society. They were also requested to address the negative effects of the plantation: Deforestation, followed by the decrease in wood and other forest products, was perceived by the local population as the most important negative effect from the plantation (Figure 6).

Figure 6: Benefits and negative effects of the plantation.

Next questions in the survey tried to determine if local population depended on the forest to make a living and the importance of the forest for them. It was found that 83% respondents depended on the forest, and 71% rated its importance as very high (Figure 7).

Figure 7: Dependency and forest Importance for the local population.

In order to evaluate the value of provisioning ecosystem services, respondents were asked which tangible services they obtained from the forest, as well as the level of income derived from these services. Wood and food were identified as the most important tangible services, while hunting and fishing were identified as the most important non-tangible ones (Figure 8). The value of provisioning services was more easily perceived than the one of non-tangible services (Figure 9). A positive relationship was observed between the income level of participants and the level of tangible (provisioning) and non-tangible ecosystem services. Interestingly, the oil palm plantation workers gave high value to benefits obtained from the forest.

Figure 8: Tangible and non-tangible ecosystem services obtained from the forest.

Figure 9: Monthly income and represented monthly value of wellbeing forest services.

Lastly local villagers were asked to recommend potential improvements for the plantation. Access to education (50 %), profit sharing (50 %) and access to health (46 %) were the main recommendations given by the local population to the oil palm company (Figure 10).

Figure 10: Plantation improvements recommended by the local population.

3.3.2 Economic Model Results

3.3.2.1 Plantation Economic Results

In Table 29 the financial results of the economic model for the oil plantation are summarized. The average yearly earnings amounted to 3,924.56 USD y⁻¹ha⁻¹. Plantation earnings over time are depicted in Figure 11; earnings are negative the first three years, breakeven is reached in year 6, increase steadily from year 6 to year 12, then start descending progressively until the end of the cycle.

Table 29: Financial results of the oil palm plantation.

	Financial Results
Return on Investment (ROI)	174%
Internal Rate of Return (IRR)	38.48%
Repayment period	6 years
Earnings before tax	98,113.94 USD ha ⁻¹
Average yearly earnings	3,924.56 USD y ⁻¹ ha ⁻¹
Discounted earnings 10 %	22,754.00 USD ha ⁻¹

Figure 11: Accumulated commercial plantation earnings.

The distribution of taxes into the national, regional and district categories is shown in Table 30. About 80 % of the taxes are paid at the national level; this fact would explain the apparent interest of the central government to allow the development of oil palm plantations in forested areas. Beneficial aspects have to be compared with the benefits that the forest gives to society and see which benefits are higher.

Table 30: Taxes Distribution.

Taxes Distribution for a 25-year period	National	Region	District
Property tax, taxable sale value of the company			
land - 50 % of Land Value	10.0%	16.2%	73.8%
Personal Income Tax	80%	12%	8%
Corporate Tax	80%	12%	8%
Value added tax -10 % of Revenue	100%	0%	0%
Property tax, taxable sale value of the company			
land - 50 % of Land Value (USD ha ⁻¹)	457	740	3,372
Personal Income Tax (USD ha ⁻¹)	2,447	367	245
Corporate Tax (USD ha ⁻¹)	26,818	4,023	2,682
Value added tax -10 % of Revenue (USD ha ⁻¹)	15,362		
	45,083	5,130	6,298

3.3.2.2 Social Benefits Brought by the Plantation

The improved life expectancy resulted in 54.61 USD ha⁻¹ y⁻¹ social benefit in terms of health. This value was introduced into the model from year one as the clinic had been made available by the Company from the beginning. Likewise, the value of the investment in infrastructures, amounting 447.00 USD ha⁻¹, was introduced into the model as a benefit to the local population. It was distributed in the first 5 years of the project. The education plans had the potential to increase GDP by 5 % in a period of 20 years. The value of 0.25 % of GDP of the local population was equal to 3.41 USD ha⁻¹ y⁻¹. This value was progressively increased to a maximum of 68.26 USD ha⁻¹ y⁻¹ for the period between year 20 and year 25.

3.3.2.3 Economic appraisal of forest ecosystem services

As explained in the Methods section, the value of eleven out of twentyfour ecosystem services were calculated from site visit data and/or survey results; the remaining ecosystem services were assessed assuming literature values (see Table 6). Results of own calculation services are commented next.

Provisioning Services

The value of the provisioning ecosystem services from the forest was estimated at 1,586.41 USD ha⁻¹ y⁻¹ from calculations based on the mean value given by survey respondents to the provisioning services (36,000,000 IDR per person and year); tangible provisioning services represented two thirds of the total, based on survey data. The mean value was adjusted by the 2016 prevailing World Bank PPP (12,849.79 USD per person and year) and this value was referred to area (ha) taking into account the area of Jayapura (1,115,715 ha), the area of the plantation (28,000 ha, according to survey) and

the population living near the plantation (3,456 people). From this value and the importance given by the respondents to the different ecosystem services, the calculated values of provisioning services were as follows:

Wood: wood provisioning services were calculated at 475.92 USD ha⁻¹ y⁻¹.

Medicine: medicine provisioning services were calculated at 105.76 USD ha⁻¹ y⁻¹.

Food: food provisioning services were calculated at 370.16 USD ha⁻¹ y⁻¹.

Fibre: fibre provisioning services were calculated at 105.76 USD ha⁻¹ y⁻¹.

Provision of genetic material: to be utilized both by the traditional and the conventional medicine industries was estimated at 112.60 USD ha⁻¹ y⁻¹, following the approach described in sub-section 2.3.2.3.

Water provisioning ecosystem service: from the forest was calculated from the value of the different ecosystems present in the area of the plantation, amounting to 100.73 USD ha⁻¹ y⁻¹.

The complete calculation for provisioning services can be followed in Appendix 5.

Social Wellbeing Services

With regard to social services, the forest provides aesthetic, leisure, spiritual and wellbeing both to the local population and to the global population in the form of tourism; the plantation area is very beautiful with important touristic destinations such as Sentani Lake that is still nearly untouched. Site remoteness does not allow capturing the full potential value of the climax forest in this region.

Wellbeing/ Aesthetic: The value of non-tangible wellbeing services to the local population were estimated at 528.80 USD ha⁻¹ y⁻¹, based on survey data. These services represent the possibility to hunt and fish, views for resting and a place to go with the family; also the place for knowledge.

Ecotourism/recreation: Sentani Lake, which is the most notorious touristic destination of this area, is about 50 km away from the plantation. Following the methodology described in sub-section 2.3.2.3, a value of 70.66 USD ha⁻¹ y⁻¹ was reached for the tourism ecosystem service. The complete calculation for social services can be followed in Appendix 5.

Environmental, regulating and supporting services

Within the environmental, regulating and supporting services, four services (climate change prevention, reduction of Tsunami risk, protection against fire and water cycle) were assessed by own calculation.

Environmental, regulating and supporting ecosystem services: the calculations are as follows:

Climate Change Prevention: The value of the climate change prevention service was assumed to be equal to the value of the Land Use Change (LUC); it was calculated as the product of CO₂ eq emissions due to LUC (623.3 t CO₂ eq ha⁻¹ y⁻¹, following the methodology of The European Parliament and the Council of the European Union (2018) and the European Commission (2010), and the value assumed for CO₂ eq (30.4 USD t⁻¹, based on the mid case price forecast by Luckow et al. (2016). The calculated value amounts 758.40 USD ha⁻¹ y⁻¹.

Reduction of Tsunami Risk: was valued based on a reduced risk of tsunami due to the presence of forest, amounting to 27.30 USD ha⁻¹ y⁻¹.

Protection against fire: Possible damage caused by fire related to oil palm was estimated at 6,211,038,219 USD y⁻¹ or 887.29 USD ha⁻¹ during El Niño phenomenon years, from fire statistics by Glauber and Gunawan (2016), (16,000,000,000 USD total fire damage cost in Indonesia and 39% fired area possibly related to oil palm). The return period of fire occurrence was assumed to be reduced from a return period of 5 years in case of oil palm plantation to a return period of 50 years if the natural tropical forest was in place (van Beukering et al., 2003). Therefore, the benefit from the forest was estimated at 159.7 USD ha⁻¹ y⁻¹.

Water Cycle: was valued from the value of the different ecosystems present in the plantation, amounting to 586.40 USD ha⁻¹ y⁻¹.

Soil formation/soil fertility regulation services: The ecosystem service of soil formation/soil fertility regulation was assessed as the value of loss of forest soil carbon storage based on European Commission (2010); additional fertility was not included in this calculation. The amount of CO₂ eq avoided by retaining the organic matter in the soil (153.72 t ha⁻¹) was multiplied by the value of CO₂ eq and divided by the 25 year plantation period, reaching to a value of 184.50 USD ha⁻¹ y⁻¹.

Forest ecosystem services estimated assuming data in relevant literature, using the benefit transfer method.

Air Purification: was estimated based on literature values, amounting to USD 12.00 ha⁻¹ y⁻¹.

Waste Management System: was estimated based on literature values, amounting to 8.20 USD ha⁻¹ y⁻¹.

Flora and Fauna Conservation: was estimated based on literature values, amounting to 22.56 USD ha⁻¹ y⁻¹.

Nutrient Cycle: was estimated based on literature values, amounting to 3.00 USD ha⁻¹ y⁻¹.

Biological Control: was estimated based on literature values, amounting to 11.00 USD ha⁻¹ y⁻¹.

Habitat Service: was estimated based on literature values, amounting to 16.00 USD ha⁻¹ y⁻¹.

Existence Value: was estimated based on literature values, amounting to 43.00 USD ha⁻¹ y⁻¹.

Maintenance of genetic diversity: was estimated based on literature values, amounting to 46.00 USD ha⁻¹ y⁻¹.

The summary of regulatory Forest Ecosystem Services calculations can be found in Appendix 5.

From the abovementioned values, and the values taken from literature (Table 6), the total ecosystem benefits of climax tropical forest in Papua, above those of the oil palm plantation, were valued at 3,795.44 USD ha⁻¹ y⁻¹ (Table 31). If the benefits from oil palm are added back, the value of forest ecosystem services amounts to 4,449.13 USD ha⁻¹. De Groot et al. (2012) estimated the value of the tropical forest at 5,264 USD ha⁻¹ y⁻¹. The estimate by (The World Bank, 2009) for the value of Papuan or West Papuan forest was 5,700 USD ha⁻¹ y⁻¹. These values are slightly higher than the ones obtained in this study, probably due to the remoteness of the site and the low GDP per capita in the region.

Table 31: Socioeconomic matrix of the ecosystem benefits of Jayapura climax forest in mineral soil.

Ecosystem services	Benefit (USD ha ⁻¹ y ⁻¹)
Economic provisioning benefits/cost:	
Wood	475.92
Food	370.16
Fiber	105.76
Local medicinal resources	105.76
Global biochemical and pharmaceuticals	112.60
Fresh water, groundwater recharge	100.73
Total provisioning services	1,270.94
Social benefits/costs:	
Ecotourism and recreation	70.66
Wellbeing/ Aesthetic	528.80
Total social services	599.46
Environmental, regulating and supporting benefits/costs	
Climate change prevention	758.40
Air purification, air quality, air quality regulation	12.00
Waste management/treatment	8.20
Reduction of Tsunami risk	27.30
Protection against fire	159.70
Water cycle	586.40
Pollination services	47.00
Flora and fauna conservation	22.56
Soil formation/soil fertility regulation	184.50
Nutrient cycle	3.00
Biological control	11.00
Habitat service	16.00
Existence value	43.00
Maintenance of genetic diversity	46.00
Total Environmental, regulating and supporting services	1,925.03
Total value of the ecosystem services	3,795.44

3.3.2.4 Cost Benefit Analysis Results

After analyzing the benefit values of the commercial plantation and of the forest independently, a discounted cash flow, cost benefit analysis, was run. The cash flow was discounted for each scenario (see Figure 12), the top figure represents plantation earnings and forest ecosystem services without discounting and the bottom figure represents discounted plantation earnings and forest ecosystem services.

Figure 12: Accumulated Commercial Plantation Earnings and Benefits of Ecosystem Services.

The benefits from the plantation were subtracted from those of the forest ecosystem services for a 25 year plantation cycle. Benefits for the plantation amounted to 101,381.39 USD ha⁻¹ while the socioeconomical benefits of the Papua tropical forest were 108,229.42 USD ha⁻¹ for a 25 year return period. From these values, the average non discounted value of benefits for the plantation was 4,055.26 USD ha⁻¹ y⁻¹, while for the forest ecosystem services was 4,329.18 USD ha⁻¹ y⁻¹. The difference between benefits, for a 25 year cycle, was -6,848.03 USD ha⁻¹; therefore the benefits of the forest are higher than those of the plantation for a 25 year cycle. When subtracting discounted benefits a value of -34,722.75 USD ha⁻¹ for 25 years was obtained (Table 32).

Table 32: Summary of Financial Model Results.

Commercial oil palm plantation versus Tropical forest in Papua	Value (USD ha ⁻¹)
Commercial oil palm plantation:	
Profit - 25 years cycle and 3 % increase in revenue prices and costs	101,381.39
Average Yearly Profit - 3 % increase in revenue prices and costs	4,055.26
NPV of Profit with 10 % Discount Rate	24,782.78
Tropical forest:	
Benefits with 1 % increase in ecosystem service value	108,229.42
Average Yearly Profit - 1 % increase in ecosystem services value	4,329.18
NPV of Profit / Cost with 5 % Discount Rate	59,505.53
Subtraction:	
Profit Plantation - Benefits Tropical Forest, 25 years cycle	-6,848.06
Yearly Profit Plantation - Benefits Tropical Forest	-273.92
NPV of [Profit Plantation - Benefits Tropical Forest]	-34,722.75

3.3.2.5 Sensitivity Analysis Results

A sensitivity analysis for the socio-economic model was run, changing some of the critical variables.

Escalations: Firstly all the escalations (3% increase in revenue prices and costs of oil palm plantation, 1% increase in ecosystem services value) were removed. In this scenario profits from the plantation fell to 53,824.40 USD ha⁻¹ and the benefits from the forest to 94,886.05 USD ha⁻¹. The difference was -41,061.65 USD ha⁻¹. Average yearly benefits from the forest were 3,795.44 USD ha⁻¹ y⁻¹ and the profits from the plantation 2,153.00 USD ha⁻¹ y⁻¹.

Changes in commodity prices: the commodity market prices for crude palm oil and kernel oil were varied +/-10%. A 10 % increase in palm oil prices resulted in 116,743.18 USD ha⁻¹ plantation benefits over a 25 year cycle, a value very similar to the benefits of the forest ecosystem services in the baseline scenario (108,229.42 USD ha⁻¹). When the commodity palm oil prices were decreased by 10 %, the profits of the oil palm plantation dropped to 86,019.60 USD ha⁻¹, a value much lower than the value of the forest ecosystem services. Therefore, the sensitivity analysis for commodity prices showed that these variables can greatly change the results of the model.

Change of Yields: The range of yields (3.92 - 6.04 t ha⁻¹ y⁻¹ for Crude Palm Oil and 0.74-1.24 t ha⁻¹ y⁻¹ for Kernel oil) expected for the plantation (Andrianto et al., 2014), resulted in a range of values for the plantation profits from 80,478.08 to 151,257.17 USD ha⁻¹. These values highlighted that oil palm yields had a great impact on the results of the model.

Water Ecosystem Services: a variation in the value of the water ecosystem services benefits by +/- 10 % gave a value of the forest ecosystem services of 106,270.07-110,118.81 USD ha⁻¹. Therefore the sensitivity analysis showed that the variation in the water ecosystem benefits did not have a great impact on the model results.

Infinite period of forest ecosystem services: the value of social benefits of the forest was calculated for an infinite period. In case of maintaining the initial assumptions of 1 % escalation and 5 % discount rate for social services the infinite value of the plantation was 129,902 USD per ha compared to a 108,229 USD per ha value for the 25 year period. For a 3 % discount rate and no escalation a value of 162,246 USD per ha was obtained, for a 1 % discount rate a 486,740 USD per ha was obtained, in case no discount rate would be applied an infinite value of ecosystem services would be obtained.

3.3.2.6 Emissions Switching Values Results

The next analysis performed was to iterate the value of the CO₂ eq emissions in order to determine the switching value for which the value of emissions the value of the benefits of the plantation equaled that of the forest in the baseline scenario. It was found that at 22.36 USD per ton of CO₂ eq the model broke even and the plantation commercial benefits equaled the socioeconomical services of the climax tropical forest in our Papua case study.

3.3.2.7 Wealth Redistribution. Winners and Losers

Wealth redistribution from LUC from forest to oil palm was analyzed; not only is important to understand if this project is feasible, but also who is benefitting or losing from this conversion process. Forest ecosystem services and commercial plantation profits distribution without and with plasma scheme are shown in Figure 13. These results reveal that the benefits from the forest ecosystem services are mainly shared by the local population in the form of provisioning and regulatory services and by the global population in the form of carbon storage and CO₂ eq avoided emissions. After the transformation from forest to oil palm the profits change hands, passing mainly to the national level through the benefits of the oil palm plantation and taxes, and are redistributed to society.

Figure 13: Geographical distribution of Forest, Plantation and Plasma Scenarios. Profits Distribution by Category of Plantation and Plasma Scenarios.

Further analysis of how benefits change hands in this case study, in which the investor is a local Indonesian company, is given in Table 33. In case of a foreign investor, profits would be divided into a 43 % foreign profit and a 41 % national profit, for the non plasma scheme scenario. Therefore there is a clear change in hands of profits when a plantation is established on forested land. Profits from the local and global level are shifted to the national level, and to the foreign level in case of foreign investors. Biggest losers are local people and biggest winners are the plantation owners and the government of Indonesia through tax benefits.

Table 33: Winners and losers of the land use change. Summary table.

Profit/ (Cost) per area	USD ha ⁻¹			
Local - Loss of ecosystem services	-2,806.04	Biggest loser	65%	of losses is for local people
Local - Jobs and social benefits	250.81		5%	of profits
Local - Taxes	251.93		5%	
Regional - Loss of Ecosystem Services	-464.89	Loser	11%	of losses is for the region
Regional - Jobs	101.62		2%	of profits
Regional - Taxes	205.19		4%	
National - Company	2,400.90	Biggest winner	43%	of profits is for Indonesia, or other country investor
National – Jobs	516.97		9%	
National - Taxes	1,803.32		33%	of profits is for Indonesia, redistributed to Society
Global - All Humanity	-1,057.66	Big loser	24%	of losses is for humanity

Oil palm plantations generally have a positive effect over upstream and downstream industries in the region where they are established, in the medium and long term. The plantation of this case-study is located in a remote location. Based on information from the interviews conducted at the plantation and research during the site visit it could be observed that very few upstream industries were settled, limited basically to construction basic materials such as aggregates and sand; industries of other raw materials such as cement or fertilizers, needed for the plantation establishment were not located in the area and these materials have to be brought from other parts of Indonesia or imported. At present, there are no downstream industries able to process CPO to other final consumer products or biofuels. Therefore, the drag effect of the plantation the first years is estimated to be low. As the region develops the effect of oil palm plantations over other local industries shall increase. Further research is needed to estimate the drag effect of new established oil palm plantations in Papua.

An input output (I/O) model for palm oil industry in Papua can be found in Obidzinski et al. (2014). According to these authors, multiplying coefficients are in the range of 155 % on the province economy. Comparing the results of the forests ecosystem services to the plantation without any escalation the benefits from the plantation are 2,153.00 USD ha⁻¹ y⁻¹ and benefits from the forest ecosystem services are 3,795.44 USD ha⁻¹ y⁻¹, so the escenario of conserving the forest is still more beneficial, even when considering the I/O effect of the plantation on the provincial economy.

3.3.3 LUC Emissions Results

Following the approach described in section 2.5, LUC emissions from forest conversion to oil palm in Indonesia in 2014, represented about 7.00 % of total Indonesian emissions, 10.28 % of Indonesian LUC emissions, and 0.35 % of world emissions.

4 DISCUSSION

For the sake of clarity, and consistency with Chapter 3, the Discussion Chapter is organized into three consecutive sections in which the results of each step of the research are discussed.

4.1 SWOT Analysis for New Oil Palm Plantations in Indonesia

Based on the results of Chapter 3, a SWOT Matrix and Economic, Environmental and Social Targets (strategies) have been generated and are presented in this section.

4.1.1 SWOT Matrix

The SWOT matrix can be found in Table 7. The main characteristics of new oil plantation establishment are as follows:

4.1.1.1 Strengths

The establishment of new oil palm plantations in the eastern region of Papua can be a profitable business for investors willing to take the risks to establish new plantations in this region. The abundant land available suitable for oil plantation and the possibility to obtain large concessions attract investors. The climatology allows for good yields and good quality oil that can be sold competitively international markets. The oil palm industry is very well established in Indonesia, with many big players capable of making the required investments and with the technical know-how needed for establishment of big plantations. At the same time government regulations allow the local population to participate in the plantations as smallholders, 20 % of the plantation area is reserved for the local population.

4.1.1.2 Weaknesses

Papua is still an unstable political area; independent movements make the area still unstable. At the same time Papua is a remote region, with still limited access to supplies, making investment requirements higher. The local population lacks agricultural knowledge, and in certain cases opposes plantations' establishment, as they interfere with their traditional way of living and clear the forest that they depend on. Environmental issues that oil palm plantation establishment generates have created global controversy, and international agencies' monitoring of new plantations establishment makes the process more difficult.

4.1.1.3 Opportunities

The establishment of new plantations allows the development of rural and remote areas. Infrastructure creation allows access to education and health facilities to the local

population. Development of oil palm plantations brings economic development to the region. The commercial profits of plantations generate taxes that are paid at the local, regional and national levels, allowing wealth redistribution to the Indonesian society. New plantations generate jobs and allow for entrepreneurial opportunities through the plasma scheme. Crude Palm Oil can be converted to biodiesel, which is cleaner energy than conventional fossil fuel diesel and has the potential of reducing greenhouse emissions. At the same time biodiesel allows Indonesia to reduce oil imports, providing energy security for the country.

4.1.1.4 Threats

Clearing of forests for oil palm plantations and the associated loss of forest ecosystem services constitute the biggest threats to new oil palm plantation establishment. As natural habitats are destroyed the local population loses their way of living, which mainly depends on access to forest products. Local communities become displaced as forests disappear, generating conflicts between plantation companies and the local population. When land with high carbon storage, such as forests, is transformed into oil palm plantations, CO₂eq emissions due to land use change are released to the atmosphere. These emissions lead to climate change. Also, special attention shall be paid to the wealth redistribution during the establishment of the new plantations. Investors are making profits and the local population is assuming the losses when forest is cleared to establish oil palm plantations.

4.1.2 SWOT Targets

Economic, environmental and social targets, which allow us to develop the strategy to establish sustainable oil palm in Papua, have been developed from the SWOT analysis. Economic, Environmental and Social aspects of the establishment of new oil palm plantations are discussed below:

4.1.2.1 Economic Targets

The Economic Targets are summarized in Table 34. The general discussion on these targets is given next.

S-O Targets: plantations shall create jobs to promote local development. Creation of jobs is of critical importance and utilizing the local population will greatly reduce the costs of plantations' establishment and operation. Training programs are required to allow locals to work at the plantations. Also, investors shall take advantage of the plasma scheme; financing shall be made available from private and public sources. Taxes obtained from plantations shall be used to redistribute plantation benefits.

Indonesia can improve its trade balance and to ease its dependence on fossil fuels by promotion of sustainable palm oil biodiesel.

W-O Targets: the oil palm industry brings the opportunity to improve local infrastructures and develop remote Papuan regions. Creation of infrastructures brings further investment opportunities by reducing transportation costs for products' import and export. The plasma scheme gives investors a very good opportunity to train the local population in oil palm cultivation techniques, improving regional skills and reducing costs. Improved health facilities have the potential to improve the community's life expectancy (Bloom et al., 2004). The establishment of education programs has the potential to improve GDP (Hanushek and Wobmann, 2007).

S-T Targets: Indonesian palm oil companies know-how shall be utilized to include the local population in the oil palm business through jobs and plasma scheme opportunities. In order to have the local population support the plantations they shall have an active role in the business. Additionally, profits obtained by investors shall be shared with the local population; establishment of health and education facilities is required.

W-T Targets shall include the development of infrastructures that help improve plantation profitability by reduction of logistics costs. Local population shall be included in the business.

4.1.2.2 Environmental Targets

The Environmental Targets are summarized in Table 35. The general discussion on these targets is given next.

S-O Targets: the good climatic conditions and fertility of Papua soils allow for production of great quantities of Crude Palm Oil that can be processed to biofuels. The environmental opportunities include the production of cleaner energy and reduction of greenhouse gas emissions. Additionally, correctly managed palm oil plantations allow for energy security improvement, without hurting the environment. Land with low carbon storage shall be chosen for conversion.

W-O Targets: the renewable energy potential of this industry shall be utilized. Emissions from land use change shall be avoided during the transformation phase and emissions reduction potential shall be utilized by using biodiesel instead of fossil fuel diesel. Utilization of Marginal land is a way to decrease emissions from Land Use Change.

International accepted standards for emissions calculation shall be adopted. The value of ecosystems services shall be preserved. Transformation of high value ecosystems such as forests shall be shifted to lower value ecosystems such as marginal land.

Improvement of harvesting techniques has the potential to increase the yields and reduce the required plantation area, thus decreasing emissions due to land use change.

S-T Targets: oil palm plantations have the potential of reducing greenhouse gas emissions if established in the right places. New oil palm plantations shall take advantage of renewable energy potential, and shall be established in a sustainable way, acceptable by all stakeholders.

Planting bioenergy in marginal land is a good way to produce bioenergy, retaining better land for food crops and presenting a good opportunity for poor farmers (Liu et al., 2011). Another way to reduce land requirements is to improve agricultural techniques (Pauli et al., 2014).

W-T Targets: in order to avoid environmental threats clear sustainable regulations shall be put in place by the Indonesian Government. Sustainable management plans shall be established. Economic and environmental criteria shall be developed. The value of ecosystem services shall be included in the analysis of new plantations' feasibility. Also, the emission balance for the new plantations shall be analyzed and high carbon sink areas protected from transformation. Certification process of oil palm projects shall be required, the issuing certification agencies shall be independent, and accepted by the international community.

4.1.2.3 Social Targets

The Social Targets are summarized in Table 36. The general discussion on these targets is given next.

S-O Targets: development of rural areas is of critical importance; this development can be accomplished by the development of the plasma scheme. Allowing the local population to participate in plantation as smallholder investors makes them feel part of the project and allows integration of the community into the new investment. Development of infrastructures around the plantation allows improvement of the local population wellbeing.

W-O Targets: transmigration programs and development of oil palm plantations brings population from other areas to oil palm plantation areas in Papua. By integrating local and transmigrant population, a more diverse and open society can happen, opening isolated areas. Learning programs from the companies and the local government shall be established to train the local population and allow them to become palm oil entrepreneurs.

S-T Targets: a socialization process is required to avoid social conflicts with the local population. Sharing of profits through job generation, plasma scheme and infrastructure creation are required to engage in a smooth establishment process.

W-T Targets: local population engagement is required, and a mutual beneficial agreement is required to allow for a smooth transition. Plantations shall provide social infrastructures such as health and safety, in order to compensate for the land taken for the plantation.

Table 34: SWOT economic targets for new plantation establishment in Papua.

Internal Analysis for Economic Aspects		
	STRENGTHS (S)	WEAKNESSES (W)
	S1. Business opportunity	W2. High costs due to remote location
	S4. Competitive Price	
	S5. Climate adequate for Palm Oil	
	S6. Corporate know-how	
OPPORTUNITIES (O)	<u>S-O Targets</u>	<u>W-O Targets</u>
O2. Wealth redistribution through Taxes	Create jobs through establishment of plantations, train the local people on oil palm cultivation	Investment in infrastructures through taxes allows to reduce cost due to remoteness
O4. Increase in GDP	Taxes to be used to improve country's wellbeing	Plasma scheme to be used to improve local population oil palm business know-how
O7. Entrepreneurship (plasma scheme)	Promote economic development of rural areas adaptable to oil palm plantation	
	Allow for Indonesia's growth	
	Allow population to set up their own plantations	
THREATS (T)	<u>S-T Targets</u>	<u>W-T Targets</u>
T8. Wealth redistribution (Winners and Losers)	Use know-how from plantations to include local population into the plantation profits, through jobs and plasma scheme	Improve infrastructures, improve profitability
	Redistribute wealth through creation of infrastructures, such as health, education and social facilities	Train local population, include in the business

Table 35: SWOT environmental targets for new plantation establishment in Papua.

Internal Analysis for Environmental Aspects		
	STRENGTHS (S)	WEAKNESSES (W)
	S2. Abundant Available Land.	W5. International Community Monitoring
	S3. Clean Energy Generation	
	S5. Climate Adequate for Palm Oil	
OPPORTUNITIES (O)	<u>S-O Targets</u>	<u>W-O Targets</u>
O3. Alternative Source of Energy	Utilize the renewable energy to reduce emissions	Use the renewable energy potential, in a sustainable way acceptable by all stakeholders
O9. Energy Security	Improve Indonesian energy security without harming the environment, land with low emissions and still suitable can be used for new plantations	
O10. Biodiesel Emissions Savings		
THREATS (T)	<u>S-T Targets</u>	<u>W-T Targets</u>
T1. Deforestation	Allow conversion process to be sustainable, use land that does not increase emission due to LUC	Develop sustainable laws, land management plans and independent certification processes
T2. Loss of Ecosystem services	Use of Marginal Land	
T3. Loss of Natural Habitats	Improve agricultural practices	
T6. Global CO ₂ eq Emissions		
T7. Climate Change		
T9. Fires		

Table 36: SWOT social targets for new plantation establishment in Papua.

Internal Analysis for Social Aspects		
	STRENGTHS (S)	WEAKNESSES (W)
	S7. Investment in the Region	W1. Unstable area due to Politics W3. Local Population Oil Palm Cultivation Know-how W4. Population Opposition to plantations
OPPORTUNITIES (O)	<u>S-O Targets</u>	<u>W-O Targets</u>
O1. Job Creation	Development of rural areas by establishment of plasma scheme	Take advantage of transmigration programs and learning programs to train the population on harvesting techniques
O5. Development of Rural Areas	Develop infrastructures that improve local population's wellbeing	A more open society shall allow remote areas to open and become more diverse
O6. More open society		
O7. Entrepreneurship (plasma scheme)		
O8. Improved Infrastructures		
THREATS (T)	<u>S-T Targets</u>	<u>W-T Targets</u>
T4. Displacement of Local Population	Allow plasma scheme to include the local population into the establishment process	Engage local population, make them part of the plantation
T5. Conflicts and Riots	Job creation to avoid social conflicts Socialization process	Develop infrastructures, health and education facilities Share benefits

4.2 Emissions and Feasibility of New Oil Palm Plantations in Indonesia

Several improvements in the current practices to produce palm oil and its derived biofuels were proposed. There are several ways to improve the process of production and refining that can lead to a more efficient process and reduced emissions, each of these improved practices are now discussed.

4.2.1 Improved Agricultural Practices

Improvement of agricultural practices has the potential to improve oil palm yields. FAO (2010), gives certain recommendations on the agricultural practices to be applied on plantations. Selection of the site, density selection, tilling, fertilizing and weeding techniques is required to achieve high plantation yield.

According to Casson et al. (2014), aboveground average carbon stocks of $90 \text{ t CO}_{2\text{eq}} \text{ ha}^{-1}$ are reported in Jambi province. This value is about 50 % higher than the value of 60 t ha^{-1} given by the European Commission (2010), for the calculation of land use change emissions. Therefore, yield improvement has a high potential for emissions reduction of newly established plantations.

Yield has also influence on biofuels' emissions savings. According to Garraín et al. (2014), GHG emissions of Hydro-generated Biodiesel (HBD) are higher than for fossil fuel diesel in the well to tank scenario, due to the emissions in the farming stage, 90 % of these emissions coming from agricultural practices. Improvement in fertilizers, reduction of fallow periods, efficiency of water use, reduction of tillage and burning operations can reduce emissions from agricultural practices.

Increasing plantations' yield can allow a reduction of palm oil's emissions due to the change of the use of the land. Higher yields allow higher carbon storage and therefore lower emissions due to new plantation establishment. Our calculations show that improving agricultural practices that allow a raise in oil palm carbon storage from 60 t ha^{-1} to 90 t ha^{-1} , would reduce the yearly emissions from land use change in Indonesia from 168.5 to 99.8 Mt $\text{CO}_{2\text{eq}}$. Improving the yield of plantations would also allow reduction on the plantation required area, reducing the need to convert new areas, and improving the economic feasibility of plantations.

4.2.2 Genetic Breeding

According to Barcelos et al. (2015), the global average CPO yield of 3.5 t ha^{-1} should be raised to 11-18 t ha^{-1} . An increase in yield potential generates benefits in terms of emissions reduction by land use change as well as increased profitability of the crop.

In terms of emissions an improvement of the average palm oil yield to 11 tons per ha could allow emissions yearly change from 168.5 Mt $\text{CO}_{2\text{eq}}$ to 143.2 Mt $\text{CO}_{2\text{eq}}$,

corresponding to a 13 % reduction of land use change emissions compared to the baseline emission scenario based in current practices. It would also allow a reduction of 59 % of the current area needed for oil palm plantations.

In terms of economic investment returns the IRR would increase from 38.48 % to 74.0 %.

4.2.3 Avoidance of Fire

According to FAO (2019), emissions consist of methane, nitrous oxide, and carbon dioxide of forest land cover classes 'Humid and Tropical Forest' and 'Other Forests' and from combustion of organic soils.

Glauber and Gunawan (2016) estimated that 2.6 Mha were burnt in 2015 in Indonesia; a big part of the burning was due to draining of peat and was largely driven by oil palm plantations.

Our model considers the emissions due to fire by assuming that 20 % of peat forests are subject to fire during the conversion Process. An increase of CO₂eq from 168.51 to 176.59 Mt per year occurs under this hypothesis. Measures to avoid fire practices for plantation establishment as well as avoidance of plantation in peat soil would greatly reduce emissions cost by fire.

4.2.4 Improved Soil Management

According to Pirker et al. (2016) oil palm is not very demanding in physical or chemical soil properties. Improving soil practices to avoid soil degradation by improved agricultural practices has the potential to reduce LUC emissions to 112.24 Mt CO₂eq y⁻¹. This reduction represents a decrease of 33 % from the baseline scenario.

4.2.5 Avoid Plantation in Peat

Peat lands are concentrated in southeast Asia; Indonesia holds 16.7 Mha of the total world known peatlands area of 21.7 Mha (Pirker et al., 2016). According to Miettinen et al. (2016), the great majority of the remaining forest areas in the study area had been selectively logged, with only 6 % of peatlands showing no signs of human influence.

According to the results of our study avoiding plantation in Peat would reduce yearly emissions from oil palm land use change 168.5 Mt CO₂eq to 143.8 Mt CO₂eq. This is a 15 % reduction over the total oil palm land use change that could be achieved by just avoiding plantations in Peat.

4.2.6 Use of Marginal Lands

According to Simeh (2005), there is no more prime land in Malaysia for palm oil; marginal lands such as deep peat, steep and tin tailings imply higher costs. High profitability of oil palm and low availability of prime land has overlooked the need for soil optimality. Based on the article from Paramanathan (2013), there are a number of marginal soil types in the tropics, they are soils on steep terrain, soils on dry regions, highly weathered soils, lateritic soils and acid sulfate soils, organic soils and soils after specific land use change.

Our economic model shows that differences in internal rate of return of the project occur when modifying the initial establishment costs from a fertile mineral soil to marginal soils, such as deep peat, steep land and tin tailings. In the case of peat soils and steep lands the IRR is reduced from 39 to 31 and 28 % respectively, still these values allow profitability and a return above Indonesian interest rates. In the last 5 years average short term interest rates in Indonesia have been between 5.00 and 7.50 % (Trading Economics, 2019a) while the 10 year bond has been between 6.01 and 8.72 % (Trading Economics, 2019b). In the case of Tin Tailings IRR of 18 % the soil condition greatly jeopardizes the project feasibility although it is still reasonably feasible.

This difference in investment returns would require subsidies to companies planting in marginal lands so the difference in earnings from planting sustainably is compensated. Profitability of oil palm is high and can still be achieved when planting in marginal lands. Therefore, options such as planting in forested land should totally be discontinued and moved to other type of original land uses. Achieving profitability and preserving ecosystem services should be made compatible.

4.2.7 Avoided Deforestation

According to Ministry of Environment and Forestry Republic of Indonesia (2018), by the end of 2017, 750,123 ha of land had been released from the Forest Area to communities through land subjected to agrarian reform (TORA program), with another 1,630,421 ha to be released by the end of 2018 and of 1,754,222 ha by the end of 2019. To facilitate the implementation of its social forestry program, the Indonesian Government intends to allocate a total of 12.7 Mha of state forest for management by local communities.

According to Suwandi (2017), about 554,084 ha were converted from to oil palm on average from 2008 to 2017. Based on the proportion of forested area released for new oil palm plantations given by Ministry of Environment and Forestry (2018), about 58 %, or 242,857 ha were released annually for oil palm plantations. Based on Casson et al. (2014), 140,191 ha per year of mineral forest and 102,747 ha per year of peat land forest were converted to oil palm plantations. These results obtained in our study were slightly higher than those of Austin et al. (2017), who stated that oil palm plantations expansion occurred at an average rate of 450,000 ha y^{-1} , and 117,000 ha deforestation per year from 2010-2015. Most of this loss occurred in secondary rather than primary

forest. For our emissions calculations forest was estimated to be primary when converted to oil palm, as degrading might have happened in the previous years but the emissions shall be accounted from its original condition until it is converted to oil palm.

Avoiding plantations in forested area, either in mineral soil or peat, was found to be the most advantageous scenario based on the emissions saving potential results. Avoiding plantations in forest would allow CO₂eq of newly established oil palm plantations land use emissions to be reduced from 168.51 to -7.82 million tons per year. These results assume that the plantations in forested land are redistributed proportionally to the rest of soil categories. Alternatively, these plantations could be shifted to low stock soil categories such as bare soil that have negative emissions due to land use change, in this case even higher emissions savings could be achieved. Therefore, avoiding deforestation is the most important scenario to be analyzed. In terms of emissions reduction avoiding deforestation is the most important measure to be implemented.

Another way to reduce emissions and act as a carbon sink to avoid climate change is to allow degraded or logged forest to regenerate to their original condition. According to the European Commission (2010), Tropical Forest holds 230 t C ha⁻¹ while degraded forest holds 45 t C ha⁻¹ (10-30 % canopy cover), therefore allowing forests to regenerate would allow a fixation of 185 t C ha⁻¹, equivalent to emissions savings of 678.3 t CO₂eq ha⁻¹. According to Poorter et al. (2016), the capacity of secondary forest to regenerate is 3.05 t C ha⁻¹ y⁻¹, therefore during one plantation cycle (25 years) the secondary forest could reach a vegetation value of 121.25 t C ha⁻¹. This is higher than the carbon vegetation value for oil palm plantations of 60 t C ha⁻¹, stated by European Commission (2010).

4.2.8 Feasibility due to the use of Palm as Biofuel

4.2.8.1 Emissions Reduction Potential

Compared to petroleum diesel, biodiesel contributes less smoke opaqueness, lower levels of CO, SO₂, lower volatile organic compounds (VOCs), Particulate Matters (PM), aldehyde emissions and polyaromatic hydrocarbons. Atadashi et al. (2011), explains that biofuels offer advantages such as sustainability, biodegradability, lower GHG, regional and agricultural development, and fuel security supply.

According to Sonthalia and Kumar (2019), hydro-processing of oil is a newer technology involving lower production cost and utilization of existing infrastructures and flexibility in the use of feedstock. HVO can effectively reduce NO_x, PM, HC, CO. Average reduction emissions with 100% HVO were estimated at 10%, 30 %, 29 % and 39 % for NO_x, PM, CO and HC respectively. According to Nilavunesan et al. (2016), hydro processing is one of the routes to produce biodiesel. Second generation, green diesel technology produces a green diesel very close to mineral diesel, meeting ASTM D975. Kiatkittipong et al. (2013) demonstrates the initiated use of relevant refining palm oil for bio-hydrogenated diesel production. Triglycerides and fatty acids are converted to straight chain alkanes ranging

from n-C15 to n-C18 known as middles distillates which are suitable to be used as diesel fuel. Straight chains alkanes have a cetane number above 98.

4.2.8.2 Selection of Biofuels

Based on the results of our study, biodiesel calculated savings without methane recovery were $4.33 \text{ t CO}_2 \text{ ha}^{-1} \text{ y}^{-1}$, with methane recovery savings increase to $6.90 \text{ t CO}_2 \text{ ha}^{-1} \text{ y}^{-1}$. For HVO calculated savings without methane recovery are $4.96 \text{ t CO}_2 \text{ ha}^{-1} \text{ y}^{-1}$ and with methane recovery $7.74 \text{ t CO}_2 \text{ ha}^{-1} \text{ y}^{-1}$. Shifting of the whole current production of biodiesel to HVO would allow important savings in emissions.

The current palm oil derived biofuel produced in Indonesia is biodiesel. According to (Rahmanulloh, 2018), production of biodiesel in Indonesia was 3.416 billion liters in 2017, about 12 % of diesel consumption.

HVO is still in a feasibility stage, according to Reuters (2019a), Pertamina (Indonesian National Petroleum Company) just signed an agreement to cooperate for existing refineries conversion to process HVO from oil palm biodiesel.

4.2.8.3 Processing of POME to methane

According to Lam and Lee (2011), POME is a highly polluting wastewater with high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) which can cause severe pollution of water resources. POME was identified as a potential source to generate renewable bioenergy such as biomethane and biohydrogen through anaerobic digestion.

According to Idris et al. (2018), POME was evaluated and found to be a potential medium in microalgae cultivation. *Chlorella* UMACCC 283 produced in 5 % POME showed big potential as biodiesel feedstock, contributing to the reduction of nutrients such as PO_4 , NO_2 and COD. Lam and Lee (2011) stated that POME contains high level of organic matters and thus, adoption of anaerobic digestion is required to convert wastes to biogas (biomethane), and further aerobic processing of the treated effluent was conducted in order to meet the required discharge standards. Biogas refining and storage system can be installed at palm oil mills as a long term investment; this biogas can be later converted to compressed natural gas. Norfadilah et al. (2016), has studied the potential for Bio-hydrogen production from palm oil mill effluent (POME), which seems to be another promising opportunity to eliminate POME and increase the emissions reduction potential of biofuels derived from palm oil.

Casson et al. (2014) quantified operating costs of 3–4 US cents per kilowatt-hour of electricity produced, and 10 years to recover the investment costs for the methane digester producing electricity for internal use. According to the Indonesia Palm Oil Mill Board, only about 10% of mills were equipped with biogas power plants.

The European Parliament and the Council of the European Union (2018), states savings of CO₂ emissions of biodiesel compared to diesel of 51 % with methane capture system and 32 % without methane capture system. In Indonesia about 10 % of biodiesel plants have methane recovery system (Cahyat, 2013) and therefore 32 % emissions savings was used as a basis for this study. Savings of CO₂ emissions of HVO compared to diesel are 53 % with methane capture system and 34 % without methane capture system.

Based on the results of our study, biodiesel calculated savings without methane recovery were 4.33 t CO₂eq ha⁻¹ y⁻¹, with methane recovery savings increase to 6.90 t CO₂eq ha⁻¹ y⁻¹. For HVO calculated savings without methane recovery were 4.96 t CO₂eq ha⁻¹ y⁻¹, with methane recovery 7.74 t CO₂eq ha⁻¹ y⁻¹. Therefore 2.57 t CO₂eq ha⁻¹ y⁻¹ could be saved by installing methane capture in biodiesel plants and 2.77 t CO₂eq ha⁻¹ y⁻¹ could be saved by installing methane capture system in HVO plants.

Rahayu et al. (2015) handbook explains that methane capture plants that generate biogas were feasible through carbon credit incentive from the Clean Development Mechanism. Prices of carbon credits have fallen from 12 to 0.5 USD per ton of offset CO₂ since 2011. Despite this fact 36 companies registered their biogas production at CPO mills in 2012 and 10 of them have successfully received Certified Emissions Reductions (CERs). POME recovery constitutes a business opportunity for companies that can utilize POME waste to produce electricity to be used at their facilities or sent to the grid and sold to Perusahaan Listrik Negara - Indonesian Electric National company (PLN).

4.2.8.4 Relationship between Land Use Change Emissions and Biofuel Emission Savings

In the baseline scenario the ratio between emissions due to land use change and the savings using biodiesel without methane recovery are 71.2; this relationship goes down to 44.7 in case of assuming methane recovery is installed in all Indonesian refineries. For HVO the ratio between land use change emissions and potential savings is 62.1 and 39.9 for the scenarios without and with methane recovery. This means that the ratio between land use change emissions and savings in emissions using biofuel can be reduced to about half in case of using HVO produced with methane recovery instead of the current practice of producing biodiesel without methane recovery.

The baseline scenario still has a big emission deficit due to land use change. Improved yield scenarios, by improved agricultural practices and genetic breeding, have the potential to reduce land use change emissions. For improved agricultural practices, an improvement occurs and the relationship between land use change emissions and biodiesel potential savings is 41.3 and 25.9 for the scenarios without and with methane recovery, and 36.1 and 23.1 for HVO in the scenarios without and with methane recovery.

Scenario 5 implies avoiding plantations on peat soils, plantations are assumed to be shifted to the same original land use but in mineral soil. In this scenario the relationship between land use change emissions and biodiesel potential savings is 59.9 and 37.6 for the scenarios without and with methane recovery, and 52.3 and 33.5 for HVO in the scenarios without and with methane recovery.

Scenario 6 assumes no deforestation is allowed, and the plantations established in forested land are redistributed proportionally to the rest of the original land uses. In this scenario emissions due to land use change are negative, calculated average emission savings per ha were 14.1 t CO₂eq. If the savings due to biodiesel for a 25 year plantation cycle are added, emissions savings were 122.3 and 186.6 t CO₂eq ha⁻¹ in the without and with methane recovery scenarios. Equivalent HVO production plantation cycle emissions savings were 138.2 and 207.5 t CO₂eq ha⁻¹ in the without and with methane recovery scenarios.

4.2.8.5 Current Indonesian Policies

Rahmanulloh (2018) discusses regarding that Indonesian's Government mandate for Biodiesel mix for transportation, electricity and industry in 2020 is 30%. Financial support mechanism takes money from the export levy to put it into the subsidy of biodiesel. Import duty for biodiesel was 5%. The transportation sector accounts for 90 % of biodiesel consumed. The effective blending rate of PLN is 8-12%. In July 2018, the price of diesel was 5,150 and for biodiesel 7,949 IDR per liter. Required subsidy disbursements of funds for the 20 % blend are only happening in transport and electricity.

According to Casson et al. (2014), Indonesia has only been able to successfully develop biodiesel from palm oil since the government initiated investment in biofuels in 2006, being the sixth largest producer of biodiesel in the world. Consumption of CPO to produce biodiesel increased to around 7% in 2012.

In addition to the Indonesian biodiesel 20 % blending rule for all refined diesel since September 2019, the electric company PLN will have to fuel all remaining diesel power plants with biodiesel in the period of two years (Jakarta Post, 2019a).

Reuters (2019b) has stated the strategy of Indonesia to convert old diesel refineries to biofuel plants. As stated by BioRefineries Blog (2019) pioneer projects to produce fatty alcohol biofuel from Kernel Palm Oil have been started in Indonesia. Hydrotreatment to produced diesel fuel of blended CPO and fossil raw materials has been tested at Dumai Refinery (Jugem, 2019).

4.2.8.6 European Policies

The European Parliament and the Council of the European Union (2018) targets that 32 % of the consumed energy by 2030 shall be from renewable sources. Biofuels from food crops shall not be higher than 7% for the transport and railway sectors. For the

calculation of renewable energy consumption and the minimum country quota, the proportion of biofuels from food crops for which an expansion in lands with high carbon stock is being observed, will not be higher than the use on 2019 from 31st December 2023 up to the end of 2030, when the use of this biofuel shall be 0 %. As per our calculation in sub-section 3.2.4.1.4 palm oil derived biodiesel and HVO from Indonesian fall under high carbon risk and shall be phased out by 2030 according to The European Parliament and the Council of the European Union (2018). The increase on carbon sequestration from new oil palm plantations depends on the original land use. Four soil categories have been identified as being carbon sinks when establishment new oil plantations, these original land uses are: bare soil, intensive agriculture, upland shrub/grasslands and swamp shrub/grasslands.

As per The European Parliament and the Council of the European Union (2018), regulation, typical values for CO₂eq emissions savings from palm oil biodiesel and HVO without methane capture are 32 % and 34 % respectively. These savings do not include the change in emissions using the land; when change in the use of the soil occurs. These savings are added for these soil categories arriving (please refer to sub-section 3.2.4.1.1) to total savings of 97 %, 88 %, 88 % and 56 % for biodiesel fuel and 94 %, 86 %, 86 % and 56 % for HVO for the bare soil, intensive agriculture, upland shrub/grasslands and swamp shrub/grasslands soil categories.

According to The European Parliament and the Council of the European Union (2018) in order to comply with the renewable energy regulations and comply with each country's renewable energy % commitment emissions reductions of biofuels in the transport sector shall be at least 65 %, for plants established after January 1st, 2021. Biofuels coming from agricultural biomass shall not come from lands that after January 2008 have had a biodiversity rich condition, such as forested land, peat soils, biodiversity rich shrublands/grasslands or any other lands with high biodiversity.

As per this new directive, calculation for Biofuels emissions shall include the change in the use of the land. Without considering land use change none of the biofuels produced from palm oil comply with the emissions reduction requirement of 65 %. Soil categories with high carbon stock would be unfeasible in terms of emissions. Low stock soil categories: bare soil, intensive agriculture, upland shrub/grasslands comply with the 65 % emissions reduction requirement. The two first soil categories would comply also with the requirement of avoiding biofuels produced from raw materials coming from biodiversity rich lands, and therefore oil palm being planted in low carbon soil categories of bare soil and intensive agriculture would be feasible as per the requirement of The European Parliament and the Council of the European Union (2018) regulation, both in terms of emissions reduction and biodiversity preservation. All other soil categories considered in this study would not be acceptable for producing biofuels under The European Parliament and the Council of the European Union (2018) regulation.

Therefore, oil palm plantations can bring benefits if they are established in the right places, these benefits come from the emissions savings from the establishment process as well as the savings from biofuels use. Also, economic benefits are generated by the establishment of new oil plantations in soils with low carbon reserves and without high biodiversity value. Programs that can allow traceability of palm oil origin and that promote the establishment of oil palm plantations in bare or marginal soils are required. These types of programs would pull the demand for sustainable products. The difficulty to implement these programs is high as to guarantee the traceability of palm oil or its derived biofuels is difficult. Probably, for this reason, the European Union prefers to avoid the problem and phase out the use of oil palm biofuels. This regulation could bring other commercial problems and will most probably not affect significantly new plantation establishment process in Indonesia. Finding solutions for sustainable practices would probably be a better option in the long run.

The European Parliament (2017) stated that 73 % of global deforestation is due to agricultural clearing and 40 % is due to conversion of land to monocultural oil palm plantations. Also nearly half (49 %) of all recent tropical deforestation is due to clearing due to overseas demand for commodities, including palm oil.

European Union (2019), explained that the government of Indonesia imposes export tariffs for CPO that force in certain cases CPO producers to sell their product to biodiesel producers in Indonesia for less than adequate remuneration, also subsidies by direct transfer of funds and not collected taxes or export financing and guarantees. Due to these reasons the European Union has imposed import tariffs to Indonesian palm oil biodiesel in the range of 8 to 18 %, depending of the benefits received by each company.

Lingga (2019), stated that the audit conducted by the Indonesian Government Supreme Audit Agency found out that most concessions in Sumatra and Kalimantan had issues regarding the right of cultivation, establishment in forested or peat lands and involvement of small holders. According to that author emissions savings from palm oil biofuel would not count starting on 2020 and the EU aims to stop all palm oil imports by 2030.

4.2.8.7 Economic Feasibility for Indonesian Biodiesel

The results showed the cost of biodiesel in Europe produced with Indonesian CPO amounts to 0.649 euros and the biodiesel cost in Indonesia would be 8,301.74 IDR. These costs do not consider any savings in emissions.

According to CNMC (2019), in the period from January 2018 to February 2019 the cost of diesel has been between 0.401 and 0.565 euros per liter and the cost of biodiesel between 0.574 and 0.661 euros per liter (not including taxes). Our calculated cost for biodiesel in Europe coming from Indonesia was in the higher end of this cost range. The difference between the price of diesel and biodiesel during this period has been

between 0.13 and 0.17 euros per liter. According to AOP (2019) the cost of diesel in Spain in August 2019 was 0.622 euros per liter including wholesale price, distribution cost and profit margins, amounting 51 % of the selling price. In August 2019 the taxes in Spain amounted to 0.59 euros per liter, or 49 % of the total selling price of 1.212 euros per liter. In Europe, in the last 10 years the diesel fuel consumer prices have been within the 1.072 and 1.533 Euros per liter (European Environmental Agency, 2019).

For Indonesian biodiesel to be competitive, the cost of diesel would have to be at the same or lower level than the diesel cost of fossil fuel diesel price. This price is directly correlated to the cost of oil. Biodiesel has more chances to be competitive when the price of oil increases.

The cost of emissions savings from biodiesel compared to fossil fuel diesel accounts for 0.028 USD L⁻¹ for refining without methane recovery and 0.044 USD L⁻¹ with methane emissions recovery, based on a price of CO₂eq emissions of 30.4 USD per ton (Luckow et al., 2016). In order to promote the use of biodiesel and take advantage of its emissions savings the European governments can subsidize the cost difference between fossil fuel diesel and biodiesel. The subsidy for the emission saving cost could be justifiable and could be done by maintaining the selling the price and reducing the tax portion of the diesel selling price. The rest of the price difference between diesel and biodiesel would need additional subsidy from the government or an increase in price of blended diesel mix. Therefore, European policymakers can increase taxes to allow a higher blending biodiesel rate. This type of incentive occurred in Spain with a 0 % tax rate for biofuels as per regulations Spanish Government (2002) and The Council of the European Union (2003), this situation went on until the end of 2012 and was discontinued later due to the financial crisis.

In Indonesia the price of diesel is subsidized. The government pays the difference between the total cost of transportation fuels and the selling price. According to Jakarta Post (2019b) the subsidy of B30 biofuel would be lowered to 1500 IDR by 2020 with a quota of 15.31 million kiloliter. According to Global Petrol Prices (2019) the price of diesel in Indonesia in September 2019 was 12,100 IDR and government subsidies 2000 IDR per liter (Gabungan Industri Kendaraan Bermotor Indonesia (Gaikindo), 2019). The maximum feasible price for B30 fuel at that time would be 10,100 IDR. The cost of production of diesel fuel with 30 % biodiesel blending biofuel rate would need to be below this threshold.

Maulia and P Prem (2019) analyzed the situation of Indonesian oil palm industry and the reduction of exports caused by tariffs imposed by the EU and India. The leading importer of Indonesia's CPO was India with 61.21 % of the total volume, followed by the Netherlands (9.39 %) and Malaysia (6.63 %) (statista.com, 2018).

Indonesian president has brought up the possibility to increase the blend of biodiesel up to 50 % by the end of 2020, to compensate for the loss of exports. The requirements for subsidy would need to be higher or a raise in the price of fuel would be needed to meet this target.

Biofuel GHG emissions typical reduction values using the methodology from The European Parliament and the Council of the European Union (2018) do not account for the emissions generated due to land use change; in this study they were added to the calculation for each soil category, as recommended by this Directive, in order to assess the environmental feasibility of Indonesian oil palm biodiesel.

4.2.8.8 Indirect Land Use Change (ILUC)

The Directive European Commission (2019a) aims to address the ILUC issue, for determining the high ILUC risk feedstock and for certifying biofuels with low ILUC-risk. This Directive states that the existence of ILUC emissions has to be recognized. Certified low risk biofuels should be exempted from the production limits. In order to certify biofuels as low ILUC risk they shall comply with article 29 of The European Parliament and the Council of the European Union (2018), that states that support for renewable energy projects shall be given to those financially viable.

According to the European Commission (2019a) the increase in demand of food and cereals needs to come from intensification or expansion into nonagricultural lands, there is a risk of expansion into high carbon lands such as forests or peats. This expansion can invalidate the emissions savings from biofuels, as they can be planted in lands that can be used for food production. For this reason, all biofuels shall be cataloged according to their potential risk of expansion into high carbon stock land and only those with low risk shall be utilized for biofuels.

The European Commission (2019a) Directive establishes a formula to calculate the risk of indirect land use change; this formula calculates the risk of expansion into high carbon stock land. In sub-section 3.2.4.1.4 the results of ILUC risk expansion into high carbon land are shown. Results of our study based on the estimated forested and wetlands converted yearly into oil palm plantations showed that 42.48 % of the palm oil expansion in Indonesia took place on land with high C stock. Results shall be below 10 % in order to consider a certain crop to be low ILUC risk.

As per the European Commission (2019a), the use of biofuels produced from food crops in lands with high carbon stock, will be limited in 2021 to use values of 2019 and starting in 2023 their production will be reduced gradually to 0% in 2030. Therefore, as per the calculations of this study, Indonesian oil palm industry is considered high ILUC risk and the use of oil palm biofuels will be discontinued in Europe from 2030. Avoiding plantations establishment in forested and other high carbon storage lands, would make the risk of oil palm plantations be reduced to acceptable levels, and consideration for the use as a biofuel could be reconsidered.

4.3 Feasibility of a New Oil Palm Plantation in Papua, Indonesia

4.3.1 Oil Palm LUC Facts

Plantation companies are seeking land for oil palm in Papua, as there is abundant and cheaper land very suitable for oil palm, due to abundant rain and high temperatures

throughout the year (Prentice and Hope, 2005). If the palm oil companies are the ones making the profit and the local population receiving the problems and environmental cost due to the loss of ecosystem services then it could be argued that companies should compensate the local population. In the macroeconomic scale, consequences of deforestation are global, therefore, international monitoring and coaching as well as aid could be required to reverse deforestation practices.

Most of Indonesian Papua population still lives in rural areas and is dependent on the forests, as plantations are settled the people lose their traditional way to sustain themselves and they lack the education to re-convert to other occupations. Villages in Jayapura, are ruled by local leaders, and by local landlords who have rights over the local land. Their interests sometimes differ from those of the rest of the population. In our case study, landlords negotiated the conditions of the plantation and the benefits for the local population that include the plasma scheme.

The law in Indonesia supports conversion of forested land into other uses. According to the Government of Indonesia (2010), conversion of convertible forest into other uses is allowed as long as in river areas there is still 30 % forest area remaining. Beehler and Marshall (2007) predicted that by the end of the 21st century no lowland forests will remain in Papua. These forests constitute the end of the virgin primary forests left in Indonesia. Indonesia accounts for about 12 % of world total plant species (Hanafi et al., 2013).

Corporations look for land that can be converted into very big plantations; they require huge extensions of land without geographical separation at the lowest possible price. Oil palm requires a lot of rain and high temperatures but is not very demanding for specific soil types (Pauli et al., 2014). Forests and peat land are suitable for oil palm plantation, but other available and suitable land types can be used instead.

Environmental and customary rights and the right of indigenous communities are considered in Indonesian law (Government of the Republic of Indonesia, 2009), but the fact is that not holding an ownership title over the land makes the local community have a weak position in front of the big palm oil corporations. In this work, during the site visit, human rights violation was not seen. Although many of the villagers opposed the plantation, they were in agreement with the status quo, as long as they were given a share of the profits from the plantation. They are trading the access to forest products, water and wellbeing provided by the forest, for social benefits, jobs or entrepreneurial opportunities at the oil palm plantation. In order for the population to accept the plantation, these new obtained benefits should be higher than the losses due to forest removal.

As the local indigenous population is very poor and not well educated, it is not difficult for corporations to settle agreements that give locals access to a better life, in exchange

for the forest ecosystem services they enjoy. In our case study, the company had made an effort to employ local population and develop the plasma scheme. Environmentally, clearing had been conducted progressively and by mechanical means, but the fact of removing tropical forest was difficult to accept.

The period considered for the economic model both for the plantation and the forest was 25 years, corresponding to one plantation cycle, it is critical to analyze what could happen after the plantation cycle is finished. Oil palm plantations do not degrade the soil in excess, if a correct management with manure is conducted probably degradation would not occur and the plantation could be re-planted for a second cycle. Another options would be cultivation of other crops or even change to other type of land uses such as housing or industry. In any case it is not expected that the land that is still fertile would be abandoned. The use after the first oil palm plantation cycle would need to be compared to the forest, the use of the ecosystem services needs to be considered for an infinite period. The forest ecosystem services are even higher than those of the plantation when an infinite period for ecosystem services is considered, and the value is higher the lower is the discount rate that could be considered close to zero, in order to have a higher incentive to preserve the forest.

In view of the foregoing, it seems of particular importance the application of the concept of Social Cost of Carbon (SC-CO₂); this is an economic metric intended to provide a comprehensive estimate of the net damages, the monetized value of the net impacts from the global climate change that results from the increase in CO₂ emissions. According to estimates by the Global Change Interagency Working Group of the US Global Change Research Program (USGCRP) the SC-CO₂ in the year 2020 for a 3 % discount rate would be 42 USD t⁻¹, emissions in 2007 USD (National Academies of Sciences Engineering and Medicine, 2017).

4.3.2 Checking of Feasibility

First Check – Quantitative Analysis (Economics and Emissions)

Economic feasibility assesment of each project should be required. The benefits obtained from the original land type scenario shall be compared to the economic benefits rendered by the plantation. The change of forest to oil palm in this case study was found not economically feasible since the benefits of forest ecosystem services were higher than the ones of oil palm in most scenarios; i.e. conversion should not have been allowed.

Emissions of the original scenario should be compared to the emissions of the oil palm plantation. If the emissions of the oil palm plantation were found to be below the ones of the original scenario, the plantation in that particular location would be feasible. In case palm oil is used to produce biofuels, savings in emissions of the produced biodiesel shall be quantified, considering biodiesel production and land use change. If emissions

from land use change are above zero the recommendation should be that the project is not approved; another land with less carbon stock shall be chosen instead. In general land with a C stock higher than oil palm ($60-70 \text{ t C ha}^{-1}$) should not be considered.

Total carbon stocks (above and below-ground biomass) of tropical forests in Malaysia were estimated in a wider range ($4-384 \text{ t C ha}^{-1}$) than for oil palm plantations ($2-60 \text{ t C ha}^{-1}$) (Kho and Jepsen, 2015). As a reference, the vegetation values assumed by the European Commission (2010) for oil palm and tropical rain forest in insular Asia are 60 and 230 t C ha^{-1} . For tropical forest a loss of 623.3 tons of $\text{CO}_2 \text{ eq}$ per ha ($\leftrightarrow 170 \text{ t C ha}^{-1}$) has been calculated in this work, assuming that the condition of the soil remains the same; if soil carbon stock is considered (mineral soil), about 153.72 tons of $\text{CO}_2 \text{ eq}$ per ha have to be added up. In case of peat soil forest the loss would attain 832.75 tons of $\text{CO}_2 \text{ eq}$ per ha. The amount of $\text{CO}_2 \text{ eq}$ saved by biodiesel without methane recovery was estimated at 4.33 t ha^{-1} (32 % savings above diesel produced from fossil fuel) as per The European Parliament and the Council of the European Union (2018), which means that for land use change from tropical forest to oil palm in mineral soil 144 years would be required to recover the emissions from LUC by the use of the biodiesel without methane recovery; for conversion of peat soil forest to oil palm, 192 years would be required. These long recovery periods make LUC from tropical forest to oil palm unfeasible.

Second Check – Qualitative analysis; benefits and losses from LUC

For each project site both positive and negative effects of the oil palm plantation should be analyzed. In the present case study, the negative Impacts were loss of provisioning services, food, medicine, fuel, and timber from the forests. Loss of social services such as spiritual, wellbeing, meditation and a place for learning and teaching their kids. Also loss of regulating services, pollution of water courses, erosion, $\text{CO}_2 \text{ eq}$ emissions. The positive impacts were jobs creation, entrepreneurship opportunities, infrastructure creation, regional growth, profits for the Indonesian society in the form of taxes, access to health, creation of small businesses, some upstream business generation for construction materials, a more diverse society with the arrival of workers from other parts of Indonesia.

4.3.3 Incentives and Compensation Plan

The decision making process from land use change is discussed in this sub-section, and applied to our case study in Jayapura. The general decision making graph can be seen in Figure 14.

Figure 14: Decision Making Feasibility Graph.

After the project feasibility check, a compensation plan for each case should be established in order to comply with the principle of fairness. The concept is that, when a project is proved to be feasible and it is undertaken, winners should compensate losers. For instance, compensation for locals includes plasma, jobs, infrastructures, health and education. A survey shall be conducted, in order to identify the demands of the local population. If benefits of the new plantation are above the losses, the land use change is feasible, this scenario will occur with degraded lands or lands with low value of ecosystem services (Figure 15).

Figure 15: Decision Making (Feasibility) Graph, before decision about LUC is taken, in feasible scenario.

If the project is unfeasible it should be discontinued, and compensation channeled in order to conduct it in a feasible way. This is the scenario applicable to our case study. The decision making process for this scenario can be seen in Figure 16 below:

Figure 16: Decision Making (Feasibility) Graph, before decision about LUC is taken in non-feasible scenario.

Another scenario is when land use change has been already conducted without doing a feasibility check (Figure 17), benefits are higher than losses. Losers from the process shall be compensated.

Figure 17: Decision Making (Feasibility) Graph, after decision about LUC is taken in feasible scenario.

In case losses are higher than benefits further plantation expansion in case of having been planned, shall be halted. The already transformed area of the plantation should be kept as it cannot longer be reversed. Avoiding further expansion can be achieved by having the correct legislation and to be implemented firmly. Also winners such as land owners and investors shall be given compensation, an alternative to make a profit shall be made available to them. Other sustainable forest use, that can generate profits to land owners, shall be considered. Logging shall not be done at a higher rate than the capacity of the forest to regenerate. Plantation investors shall be given access to land suitable for palm oil plantation at a fair price. This strategy is explained below in Figure 18.

Figure 18: Decision Making (Feasibility) Graph, after decision about LUC is taken in non-feasible scenario.

In our case study about 5,000 ha have been transformed, the other 23,000 ha have not yet been cleared or transformed. Based in our financial model, the benefits from the plantation are lower than those from the lost ecosystem services from the forest and therefore the land use change should be reversed. This methodology is summarized in Figure 19.

Figure 19: Decision Making (Feasibility) Graph, case study graph, before conversion.

In our case study the plantation has been established and a very small amount of money has been paid to land owners to take over the land. Benefits obtained from the land are higher than the land cost for the investor, but owners are not being compensated for the benefits obtained from the local population. Legislation that does not allow conversion when benefits from the plantation are below the benefits from the forest is required. Spatial plans identifying lands without high ecologic value and mechanisms to transfer these lands at a fair price to palm oil investors are required. This strategy is explained in Figure 20 below.

Figure 20: Decision Making (Feasibility) Graph, case study after conversion.

4.3.4 Regulatory Measures

One of the most important measures to avoid the loss of biodiversity as well as deforestation from land use change from forests and high biodiversity land to agricultural uses, particularly oil palm plantations, is to establish a land management plan for each region, and to identify the right places to plant oil palm, not only from the point of view of economics and crop requirements but also for environment protection, including carbon storage. According to Pacheco et al. (2011), seven biofuel sustainability standards (UE-RED, RTFO, RSB, RTRS, RSPO, FSC and SAN) have been developed. These certification agencies issue sustainability certificates based on their own criteria. They lack consensus on mitigation of impacts of indirect land use change. A standardized checking and monitoring system should be established through an independent agency. Certification shall be complemented by other mechanisms as effective land use planning.

4.3.5 Recommendations

At the time the field work was conducted the plantation under study was only about 5,000 ha but it was expected to expand to a planned size of 28,000 ha. According to the results of this study, the first recommendation would be that the rest of the area granted for the plantation was not converted to oil palm. Another suitable land should be searched and a way to compensate the company for the price difference should be

proposed. Oil palm plantations might be feasible in other areas that are not forested. Identification of areas without a high ecological and economic value would be required.

Survey results showed that the local population demanded the plantation company to share the profits with the local population; this could be achieved by giving them fair jobs and by giving them access to the plasma scheme. Training the local population into the oil palm cultivation techniques is of critical importance. Development is important for the region. Oil palm plantations should provide the local population with access to infrastructures, health and education. Access to electricity and potable water is very important for the local population. Other recommendations for improvement from the local population are to avoid deforestation, fair land purchase, compensation for loss of forest ecosystem services and construction of downstream industries. Another issue that needs improvement is community involvement in the process of negotiation and decision making as they are the ones that suffer the consequences of the loss of forest and the access to the provisioning services they depend on for a living.

The plantation is not bringing the problems in itself, and it has been demonstrated to generate value. The problem is not to establish an oil palm plantation but to do it in forested land, due to loss of many ecosystem services in a local and global level. Other available lands could be used instead. Spatial plans and compensation programs are required to establish oil palm plantation in the right places.

5 CONCLUSIONS

Oil palm new plantation establishment in the region of Papua has the potential to bring many benefits to indigenous communities and to generate development and GDP growth for Indonesia. At the same time there are threats such as deforestation and loss of ecosystem services that need to be addressed. Conducting new plantation establishments in a sustainable way would allow the oil palm industry to improve current practices and achieve international acceptance. Palm Oil brings advantages to the Indonesian society, but generates very high emissions due to land use change that cannot be offset by its use as biofuel. About 168 Mt CO₂eq are emitted per year in Indonesia due to the establishments of new oil palm plantations, mainly in forested land. Indirect land use risk of expansion into high carbon land is very high, with an estimated value of 42.48 %.

The most important measure to be taken is to stop drastically cultivation in current forests or peat lands. Not necessarily the level of production needs to be maintained or reduced but production growth has to be achieved without invading new lands of high biodiversity and high carbon storage. Some of the mechanisms to reduce deforestation are coming from improvement of agricultural techniques; relevant literature show that oil palm plantations production yields can be increased by improving the plantation's management. Genetic modification is seen as another potential way to increase the yield of oil palm plantations. Oil palm can be established in marginal lands without substantial increase in the establishment costs and still within profitable conditions for investors.

Biofuels produced for palm oil, such as biodiesel and HVO generate emissions savings compared to standard fossil fuel diesel. Their emission savings potential needs to be utilized. HVO improves emission savings compared to diesel and can be blended in higher rates; this technology shall be established in Indonesia in the mid-term. Processing POME effluent increases emission savings, it constitutes a good business opportunity as it can be transformed into biogas to generate electricity. New Biofuel Technologies shall be developed to improve palm oil biofuel benefits.

The results of this study show that biofuels coming from low stock carbon soil categories including: bare soil, intensive agriculture, upland shrub/grasslands comply with the emissions reduction requirement from the European Union biofuel sustainability regulations. In addition, the two first soil categories comply with the requirement of avoiding biodiversity rich land plantations. Oil Palm being planted in low carbon soil categories of bare soil and intensive agriculture would be feasible to produce biofuels.

Cooperation of the Indonesian Government to improve current practices and improve palm oil production sustainability is required. Halting production does not seem as an

option, so cooperating towards cleaner production seems like the most reasonable option. Current certification programs do not avoid new establishments in forested or peat land. New concessions shall be strictly monitored by international agencies in cooperation with the Indonesian Government. The solution shall come from legislation and subsidies to compensate from the higher costs of sustainable practices shall be put in place.

As long as palm oil traceability cannot be guaranteed, drastic measures as the one imposing a ban on oil palm biofuels by the EU will keep happening as legislators and stakeholders cannot be in control. Transparency is required by palm oil production countries. Certified palm oil is more expensive and requires subsidies, the EU has the opportunity to establish certification programs in cooperation with Indonesia and pay for the premium required to produce sustainably.

Palm Oil product mix has to be communicated to society, product classification based on environmental advantages is required. Labeling for the different types of biofuels according to their savings in emissions could help promote the understanding and generate demand for the different products. The palm oil products are seen as commodities and therefore no price differentiation for products complying with environmental regulations is perceived by the population. Products such as HVO with biogas production from POME coming from sustainable plantations could be differentiated to pull the demand for this type of products. Traceability of products from the plantation, up to the refining process is required for appropriate labeling and commercialization as well as for fair subsidy distribution, and inclusion on biofuel quotas.

A combination of some of these policies, such as combining avoided deforestation, use of new technology biofuels and improved agricultural practices can generate significant emission savings and make oil palm plantations very sustainable in terms of emissions savings when palm oil is used to generate fossil fuels. Halting deforestation is the most crucial measure to be adopted by the Indonesian oil palm industry.

Economic and social effects generated by newly established oil palm plantations need to be analyzed. Economic benefits of lost biosystems being replaced by oil palm shall be compared to the benefits generated from the plantation in order to have a clearer picture of consequences of plantations' establishment. According to the results of our case study, the conversion from primary forest to oil palm at our plantation was considered not feasible as benefits from the forest ecosystem services were higher than the commercial and social benefits of the plantation. Another suitable land should be searched. Oil palm plantations might be feasible in other areas that are not forested. Identification of areas without a high ecological and economic value would be required.

The plantation is not bringing the problems in itself, and it has been demonstrated to generate value. The problem is not to establish oil palm plantations but to do it in non-

suitable land uses such as forested land, due to loss of many ecosystem services in a local and global level. Other available land categories could be used instead. Spatial plans and compensation programs are required to establish oil palm plantation in the right places.

Results of this work showed that the benefits from Primary Forest Ecosystem Services for our case study in Papua-Indonesia are above the ones of palm oil; therefore, the land use change was considered non-feasible from an economic point of view. Emissions due to land use change represented 623.3 tons of CO₂ eq per ha following methodologies developed for the case that palm oil was used for biodiesel; it was estimated that 144 years would be needed to recover the emissions from forest conversion.

Oil palm plantations generate value through the creation of jobs, entrepreneurship opportunities through the plasma scheme, creation of upstream and downstream industries and creation of infrastructures. Plantations, when established, should also bring additional benefits to the population such as access to health, education and profit sharing. Establishment of oil palm plantations in forested land has many negative consequences, due to loss of ecosystem services in a local and global level. Forests are very important for local people; they are their source of income, inspiration, freedom as well as leisure. Forests allow local population to live in a simple way. The plantation can bring economic benefits, but the loss of the forest cannot be replaced.

In the process of conversion from primary forest to oil palm benefits are changing hands. Commercial plantations are feasible businesses; about 80 % of the benefits from the oil palm plantation are shared by the investors and the Indonesian Government. The local population captures about 14 % of the benefits in the form of health, education, infrastructures, plasma entrepreneurship opportunities and local jobs. About 24 % of the losses are lost at a global level mainly due to CO₂eq emissions from the loss of forest carbon storage, loss of existence value and genetic material. The balance should be shifted towards the local population. Plantation companies should include social and environmental targets plantation strategic plans. These plans shall be approved at the feasibility stage.

Economic, environmental and social feasibility check should be required for each new oil palm project. Feasible projects' investors shall compensate local population losing access to ecosystem services, and non-feasible projects shall be funded to be conducted in a feasible way. Other available lands could be used instead. Spatial plans and compensation programs shall be required to establish oil palm plantation in the right places. Above all, further research is required to determine the accurate values of the different ecosystem services in Papua; knowing the value would become an incentive for preservation.

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7 APPENDICES

7.1 APPENDIX 1: MAP OF INDONESIA, MAP OF PAPUA PROVINCE AND PLANTATION DETAIL MAP

Map of Indonesia

Map obtained from: CIFOR PAPUA ATLAS. Website: <https://atlas.cifor.org/papua/#en>

Plantation Location Map

Map obtained from: CIFOR PAPUA ATLAS. Website: <https://atlas.cifor.org/papua/#en>

Plantation Detail Map

Map obtained from: CIFOR PAPUA ATLAS. Website: <https://atlas.cifor.org/papua/#en>

7.2 APPENDIX 2: LAND USE CHANGE EMISSIONS DUE TO CARBON STOCK CHANGES FROM THE DIFFERENT SOIL CATEGORIES TO OIL PALM PLANTATIONS

Forest to Oil Palm Escenario:

Forest in mineral soil Jayapura more than 30 % canopy	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	N/A
F_I	N/A
$SOC = SOC_{ST} \times F_{LU}$	86 t C/ha
C_{VEG}	230 t C/ha
$CS_R = SOC + C_{VEG}$	316 t C/ha

Palm Oil Plantation Jayapura - perennial crops, no tillage, low input	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 ton C/ha
F_{LU}	1
F_{MG}	1
F_I	1
SOC	86 t C/ha
C_{VEG}	60 t C/ha
$CS_R = SOC + C_{VEG}$	146 t C/ha

CS_R 316 t C/ha

CS_A 146 t C/ha

$CS_R - CS_A$ 170.0 t C/ha

$CS_R - CS_A$ 623.3 t CO₂eq/ha

Grassland to Oil Palm Escenario:

Grassland	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	86.0 t C/ha
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
C_{VEG}	8.1 t C/ha
$CS_R = SOC + C_{VEG}$	94.1 t C/ha

Oil Palm Plantation Jayapura - perennial crops, no tillage, low input	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
SOC	86 t C/ha
C_{VEG}	60 t C/ha
$CS_R = SOC + C_{VEG}$	146 t C/ha

CS_R	94.1 t C/ha
CS_A	146 t C/ha
$CS_R - CS_A$	-51.9 t C/ha
$CS_R - CS_A$	-190.3 t CO ₂ eq/ha

Agroforest to Oil Palm Escenario:

AGROFOREST -	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
SOC	86 t C/ha
C_{VEG} -AGROFOREST	83.56 t C/ha

Oil Palm Plantation Jayapura - perennial crops, no tillage, low input	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
SOC	86 t C/ha
C_{VEG}	60 t C/ha
$CS_R = SOC + C_{VEG}$	146 t C/ha

CS_R	180.1 t C/ha
CS_A	146 t C/ha
$CS_R - CS_A$	34.0 t C/ha
$CS_R - CS_A$	124.8 t CO ₂ eq/ha

Intensive Agriculture to Oil Palm Escenario:

Cropland	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	86.0 t C/ha
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
C_{VEG}	8.1 t C/ha
$CS_R = SOC + C_{VEG}$	94.1 t C/ha

Oil Palm Plantation Jayapura - perennial crops, no tillage, low input	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
SOC	86 t C/ha
C_{VEG}	60 t C/ha
$CS_R = SOC + C_{VEG}$	146 t C/ha

CS_R	94.1 t C/ha
CS_A	146 t C/ha
$CS_R - CS_A$	-51.9 t C/ha
$CS_R - CS_A$	-190.3 t CO ₂ eq/ha

Bare Soil to Oil Palm Escenario:

Bare Soil	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	86.0 t C/ha
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
C_{VEG}	0 t C/ha
$CS_R = SOC + C_{VEG}$	86.0 t C/ha

Oil Palm Plantation Jayapura - perennial crops, no tillage, low input	
$CS_R = SOC + C_{VEG}$	
$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I$	
SOC_{ST}	86 t C/ha
F_{LU}	1
F_{MG}	1
F_I	1
SOC	86 t C/ha
C_{VEG}	60 t C/ha
$CS_R = SOC + C_{VEG}$	146 t C/ha

CS_R	86.0 t C/ha
CS_A	146 t C/ha
$CS_R - CS_A$	-60 t C/ha
$CS_R - CS_A$	-220.0 t CO ₂ eq/ha

Peat Forest to Oil Palm Escenario:

Original Scenario - Drained Forest Change to Drained Oil Palm					
Above Carbon Change	t C/ha	t CO ₂ eq/ha			
CVEG Natural forest	230	841.8			
CVEG – Oil Palm	60	219.6			
Soil Peat Drained	t CO ₂ eq/ha y	t CO ₂ eq/ha y	t CO ₂ eq/ha		
Degraded Forest	5.3	5.3	106		
Oil Palm	11	11	220		
	kg CH ₄ /ha y	t CO ₂ eq/ha y	kg CH ₄ /ha	t CO ₂ eq/ha	
Degraded Forest	2.5	0.0525	50	1.05	
Oil Palm	0	0	0	0	
	kg NO ₂ /ha y	t CO ₂ eq/ha y	kg NO ₂ /ha	t CO ₂ eq/ha	
Degraded Forest	2.8	0.868	56	17.36	
Oil Palm	1.2	0.372	24	7.44	
		5.1515			
Fire - if forest burnt to plant Oil Palm					
Emissions (tons CO ₂ eq/ha)	393.59	t CO ₂ eq/ha			
Emissions vegetation above ground	622.2	t CO ₂ eq/ha			
ORIGINAL SCENARIO - FOREST	124.41	t CO ₂ eq/ha			
NEW SCENARIO OIL PALM	227.44	t CO ₂ eq/ha			
Increase in Emissions change to palm oil in drained peat	103.03	t CO ₂ eq/ha a			
TOTAL EMISSION CHANGE	725.23	t CO ₂ eq/ha a			
TOTAL EMISSION CHANGE	832.75	t CO ₂ eq/ha			
TOTAL EMISSION CHANGE INCLUDING FIRE	1226.35	t CO ₂ eq/ha			

Peat Shrub/Grasland to Oil Palm Escenario:

Above Carbon Change	t C/ha	t CO ₂ eq/ha		
CVEG Grassland	8	29.28		
CVEG – Oil Palm	60	219.6		
Soil Peat Drained	t CO ₂ /ha y	t CO ₂ eq/ha y	t CO ₂ /ha	
GRASSLAND	9.6	9.6	192	
Oil Palm	11	11	220	
	kg CH ₄ /ha y	t CO ₂ eq/ha y	kg CH ₄ /ha	t CO ₂ eq/ha
GRASSLAND	7	0.147	140	2.94
Oil Palm	0	0	0	0
	kg NO ₂ /ha y	t CO ₂ eq/ha y	kg NO ₂ /ha	t CO ₂ eq/ha
GRASSLAND	5	1.55	100	31.00
Oil Palm	1.2	0.372	24	7.44
		0.075		
Fire - if forest burnt to plant Oil Palm				
Emissions CO ₂ eq (t / ha)	393.595	t CO ₂ eq/ha		
Emissions from Change in vegetation above ground	-190.32	t CO ₂ eq/ha		
ORIGINAL SCENARIO - GRASSLAND	225.94	t CO ₂ eq/ha		
NEW SCENARIO OIL PALM	227.44	t CO ₂ eq/ha		
Increase in Emissions from change to oil palm in drained peat	1.50	t CO ₂ eq/ha		
TOTAL EMISSION CHANGE	-188.82	t CO ₂ eq/ha		
TOTAL EMISSION CHANGE INCLUDING FIRE	204.78	t CO ₂ eq/ha		
TOTAL EMISSION CHANGE	-81.30	t CO ₂ eq/ha		
TOTAL EMISSION CHANGE INCLUDING FIRE	312.30	t CO ₂ eq/ha		

7.3 APPENDIX 3: SURVEY (ENGLISH LANGUAGE)

SURVEY - PHD IN ENERGY ENVIRONMENTAL SCIENCES/ TECHNICAL UNIVERSITY OF MADRID

SOCIOECONOMICAL IMPACTS OF PALM OIL PLANTATIONS ON FORESTED AREA IN PAPUA

1. Have there been any palm oil plantations established recently: Yes ☐ No ☐

2. When was this plantation established? Year.....

3. Was the plantation established on:

Forest Land ☐ Shrub Land ☐ Cultivated Land ☐ Grassland ☐ Marginal Land ☐

4. Was the establishment smooth: Yes ☐ No ☐ Not Sure ☐

5. Was compensation for land and wood paid to landowners: Yes ☐ No ☐ Not Sure ☐

6. Was land allocated to local communities: Yes ☐ No ☐ Not Sure ☐

Was a 20 % of the plantation area allocated to the communities as required by law:

Yes ☐ No ☐ Not Sure ☐

7. What is your perception of palm oil plantations: Good ☐ Bad ☐ Neutral ☐

8. Please rate your perception of palm oil plantations: Best 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 ☐ Worse

9. What is your relationship with the palm oil plantations in this area:

None ☐ Suffer Negative Effects ☐ Benefit from positive effects ☐

Work at the plantation ☐ Smallholder Owner ☐

10. What are the positive effects that you have experienced from the palm oil plantations:

Better Infrastructures ☐ Access to education ☐ Access to jobs ☐ Access to healthcare ☐ Access to Potable Water ☐ Higher community wellbeing ☐ Access to Electricity ☐ Improved Transportation ☐ More diverse/open society ☐

Please explain your thoughts:

.....

11. In terms of employment did the palm oil plantation hire:

Local People ☐ Java/transmigrant people ☐ Both local and Transmigrant ☐ Not Sure ☐

12. Question for employees of the plantation, small land holders or related industries/services:

In terms of income, how much income do you generate derived from palm oil plantations?

< 500,000 IDR ☐

Between 500,000 and 1,000,000 IDR ☐

Between 1,000,000 and 2,000,000 IDR ☐

Between 2,000,000 and 10,000,000 IDR ☐

More than 10,000,000 IDR ☐

13. Has your purchasing power increased due to palm oil plantation establishment: Yes ☐ No ☐

14. Are you able to save some money at the end of the month due to palm oil plantation establishment:
Yes ☐ No ☐

15. If you answered Forest Land/Shrub Land please specify what are the negative effects that you have experienced from the palm oil plantations planted on forested land:

Water Pollution ☐ Air Pollution ☐ Increase Erosion ☐ Decrease in Tourism ☐
Deforestation ☐ Human Rights Violation ☐ Land Grabbing ☐ Fire ☐ Decrease in Food
☐ Decrease in Wood ☐ Decrease in other forest products ☐
Lost of Flora and Fauna ☐ Increase in Pests ☐ Loss of access to land for farming ☐
Loss of access to forest products ☐

Please explain your thoughts:

.....

16. Do you depend on Forest for making a living? Yes ☐ No ☐

17. How important is the forest for you: More imp: 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 ☐ Less Imp.

18. If answered yes to question 14 please estate which of the following forest ecosystem services do you depend on:

Wood ☐ Medicine ☐ Food ☐ Fibre ☐

19. Please specify which products you obtain from the forest.....

20. How much economic value do these services represent per month?

< 500,000 IDR ☐

Between 500,000 and 1,000,000 IDR ☐

Between 1,000,000 and 2,000,000 IDR ☐

More than 2,000,000 IDR ☐

21. What of the following forest services are important for you and your family:

Tourism ☐ Spiritual Wellbeing ☐ Leisure ☐ Hunting ☐ Fishing ☐

22. If answer yes please explain which ones are more important for you

.....

23. How you value their importance (either qualitatively or quantitatively):

.....

24. How much economic value do these services represent per month?

< 500,000 IDR ☐

Between 500,000 and 1,000,000 IDR ☐

Between 1,000,000 and 2,000,000 IDR ☐

More than 2,000,000 IDR ☐

25. If you answered cultivated land in question 3 is cultivated area:

What type of crop was harvested in this area?

26. Was your family dependent of this crop? Yes ☐ No ☐

27. If answer yes to the previous question please state the value you obtained from this crop?

< 500,000 IDR ☐

Between 500,000 and 1,000,000 IDR ☐

Between 1,000,000 and 2,000,000 IDR ☐

Between 2,000,000 and 10,000,000 IDR ☐

More than 10,000,000 IDR ☐

28. What other services have been lost when changing from cultivated land to palm oil plantation?

Water Pollution ☐ Air Pollution ☐ Increase Erosion ☐ Decrease in Tourism ☐

Deforestation ☐ Human Rights Violation ☐ Land Grabbing ☐ Fire ☐ Decrease in Food

☐ Decrease in Wood ☐ Lost of Flora and Fauna ☐ Increase in Pests ☐

Loss of access to land for farming ☐

Please explain your thoughts:

.....

If you answered grassland area in question 3 is cultivated area:

29. Was livestock affected by this change of land use change? Yes ☐ No ☐

30. If answered yes to the previous question please specify what type of cattle was displaced.

.....

31. Was your family dependent on livestock raising? Yes ☐ No ☐

32. If answer yes to the previous question please state the value was obtained from raising livestock?

< 500,000 IDR ☐

Between 500,000 and 1,000,000 IDR ☐

Between 1,000,000 and 2,000,000 IDR ☐

Between 2,000,000 and 10,000,000 IDR ☐

More than 10,000,000 IDR ☐

33. What other services have been lost when changing from grassland to palm oil plantation?

Water Pollution ☐ Air Pollution ☐ Increase Erosion ☐ Decrease in Tourism ☐

Deforestation ☐ Human Rights Violation ☐ Land Grabbing ☐ Fire ☐ Decrease in Food

☐ Lost of Flora and Fauna ☐ Increase in Pests ☐

Loss of access to land for livestock raising ☐

Please explain your thoughts:

.....

34. What improvements would you recommend when plantations are established:

Fair Land Purchase ☐ Sharing of Profits with the community ☐

More Jobs/hire local people ☐ Avoid Fire ☐ Avoid Deforestation ☐ Plant in other area

Improved Infrastructures ☐ Access To health ☐ Access to education ☐

Compensation for lost forest services ☐ Develop Downstream Industries in the area

Not Sure ☐

Please explain your thoughts:

.....

35. Data of Respondents:

Name (optional):

Gender: Male ☐ Female ☐

Age: 10-20 years ☐ 21-30 years ☐ 31-40 years ☐ 41-55 years ☐ 56-65 years ☐

More than 65 years ☐

Original City:

Occupation before plantation:

Occupation after plantation:

Income (optional):

☐ < 500,000 IDR/Month

☐ Between 1,000,000 IDR/Month and < 1,000,000 IDR/Month

☐ Between 2,000,000 IDR/Month and 3,000,000 IDR/Month

☐ > 3,000,000 IDR/Month

7.4 APPENDIX 4: PICTURES DURING THE SITE VISIT

JAYAPURA PLANTATION

PLANTATION'S INFRASTRUCTURES

SOCIETY

INFRASTRUCTURES

TOURISM

FOREST

All pictures have been taken by the author of this document. ©P.J.Acosta

7.5 APPENDIX 5: FOREST ECOSYSTEM SERVICES BENEFITS CALCULATIONS

Provisioning Services for the local population:

Average Value of Tangible Services	24,000,000.00 IDR	Results from survey
Average Value of Non Tangible Services	12,000,000.00 IDR	Results from survey
IDR/person and year	36,000,000.00 IDR	Results from survey
IDR/USD	13,400	March 2016
USD/person and year	\$2,686.57	From survey
GDP PER CAPITA PPP (INTERNATIONAL USD)) INDONESIA	\$11,057.60	World Bank World Development Indicators, (The World Bank, 2015)
PAPUA GDP PER CAPITA (2010)	30,979,000.00 IDR	Knoema (2010)
PAPUA GDP PER CAPITA (2010)	\$2,311.87	Knoema (2010)
FACTOR	4.78	
Adjusted Value of Provisioning Services	12,849.79	USD/person and year in PPP International USD
Area Jayapura	1,115,715.00	Knoema (2010)
Area Plantation	28,000.00	Based on survey data
Percentage of total area	2.5%	
People living close to the plantation	3,456.83	Average from Jayapura (similar to survey data)
USD/ha y value lost of ecosystem services	<u>\$1,586.41</u>	

TANGIBLE PROVISIONING SERVICES	66.67%	From survey results the tangible provisioning services
Weight Distribution	Weight	
Wood	45%	Distribution by importance
Medicine	10%	Distribution by importance
Food	35%	Distribution by importance
Fibre	10%	Distribution by importance

Value of Ecosystem services	USD/(ha and year)
Wood	\$475.92
Medicine	\$105.76
Food	\$370.16
Fibre	\$105.76
TOTAL	\$1,057.61

NON TANGIBLE	33.33%	From survey results the non tangible services
	USD/(ha and year)	
Value of Ecosystem services	<u>\$528.80</u>	

Ecotourism and Recreation:

Tourism Ecosystem Services	6	Flights per day
	1,080	Person per day
	394,200	Person per year
	1,000	USD per person
	394,200,000	Total expenditures
	20%	% of tourists from total passengers
	\$78,840,000.00	Total expenditure tourism per year
Area Jayapura	1,115,715	Ha
Area Plantation	28,000	Ha
	2.51%	Percentage of total area
Tourism assigned to plantation	\$1,978,569.80	
	<u>\$70.66</u>	USD per ha and year

Water Ecosystem Services. Provision and Regulating Ecosystem Services

The value of water ecosystem services has been calculated, as follows:

The georeferenced image of the plantation was exported to Autocad; areas of the categories (ecosystems): inland wetlands, river/waterflows, coastal wetlands and tropical forest of the plantation concession were calculated by drawing the areas in the Autocad drawing and using the calculate area function of the program. The values for the water supply and regulating services of each ecosystem were taken from the article by de Groot et al. (2012).

Due to the location of the plantation it is believed that the value of the regulating services that the forest and the wetlands related to the meandering rivers both inland and at the coastline is very high, both from the point of view of the water quality, as well as with respect to sedimentation. Ecosystems are modified by the plantation; therefore their original regulating properties are lost. Below we can see the table with the site specific calculations for the water ecosystem services at the plantation.

Water Provisioning Services

	Area (m ²)	Area (ha)	Value (USD)	Value (USD/ha)
Inland Wetland	5,799,079.20	579.91	\$2,366,024,313.60	\$ 408.00
	7,030,800.00	703.08	\$2,868,566,400.00	\$ 408.00
River	3,866,052.80	386.61	\$6,989,823,462.40	\$ 1,808.00
	2,812,320.00	281.23	\$5,084,674,560.00	\$ 1,808.00
Coastal Wetland	3,659,500.00	366.0	\$4,453,611,500.00	\$ 1,217.00
Tropical Forest	263,510,620.80	26351.1	\$7,114,786,761.60	\$ 27.00
Total	286,678,372.80	28667.8	\$28,877,486,997.60	<u>\$ 100.73</u>

Water Regulating service

	Area (m ²)	Area (ha)	Value (USD)	Value (USD/ha)
Inland Wetland	5,799,079.20	579.91	\$32,509,637,995.20	\$ 5,606.00
	7,030,800.00	703.08	\$39,414,664,800.00	\$ 5,606.00
Tropical Forest	263,510,620.80	26351.06	\$90,120,632,313.60	\$ 342.00
Total	276,340,500.00	27634.05	\$162,044,935,108.80	<u>\$ 586.40</u>

It is believed that these values are site-specific and that no double counting has been incurred, but uncertainty on the precision for the calculations of the ecosystem areas still exist, therefore sensitivity with a +/- 10% range of calculated values was run.

Provision of genetic material

The medicine industry value is calculated. Medicine Industry data is summarized in the table below, has been obtained from Hanafi et al. (2013):

	Modern Medicines	Herbal Medicines	Contribution Herbal Medicine
Year	US \$ (billion)	US \$ (billion)	%
2003	17	2	10.5
2005	21.3	2.9	12
2010	37.3	7.2	16

Based on this data the following calculations are performed to arrive to the medicine value per ha.

Total Value Medicine in Indonesia	\$44,500,000,000	Calculated from table above
Indonesian Land (ha)	181,157,000	World Bank (2020)
Value of medicine per ha	245.64	USD/ha
The economic value of biodiversity	<u>65.5</u>	12.5 % for modern medicine assumed based on Pearce and Moran (1994)
Add effect of Indonesian genetic material to international drugs		
Total Global Pharmaceutical Value	\$1,034,700,000,000	statista.com (2020)
% of plants of Indonesia over all	12%	Hanafi et al. (2013)
Royalties	12.50%	Pearce and Moran (1994)
Value total market by Indonesian genetic material	\$15,520,500,000.00	USD
Value total market by Indonesian genetic material per ha	<u>85.67</u>	USD/ha
Total Medicine Value	<u>151.16</u>	USD/ha
Rent Capture from Royalties in Indonesia	0.55	The mid range value from the range of Pearce and Moran (1994): 0.1-1.0 was taken.
Total Medicine Value Captured in Indonesia	<u>112.603</u>	USD/ha