Towards a Sustainable Palm Oil Industry

Environmental impacts of the palm oil industry, particularly in Indonesia, and how the industry can move towards sustainability

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Preface

Writing this thesis has been an educational and memorable experience, with many ups and downs, marking the end of our education.

Sustainability is a very relevant topic in today's climate, and it has been an interest of ours for years, especially after we started learning more about the issue through our education at the University of Agder. The controversy surrounding palm oil has been a topic of discussion among Norwegian businesses such as Nidar and Freia, which further piqued our interest in this specific topic. We therefore knew this was something we wished to incorporate into our master thesis.

Writing our thesis has demanded much time and effort. It is therefore extra important that the people that have been helping are recognised. We would first like to show our appreciation and gratitude to our supervisor Stein Olav Kristiansen, for meeting us both in person and on video-call, and for giving us plenty of great feedback. Thanks to Agung Audrajat, secretary to the Ambassador at the Embassy of the Republic of Indonesia, for helping us and giving us insight on issues in Indonesia. Lastly, we want to thank our family and friends for all their support and motivation.

Abstract

This thesis investigates the negative environmental impacts of the growing palm oil industry in Indonesia, and strives to find solutions to the difficult task of attaining sustainability. Throughout the thesis we aim at presenting information that relates to and provides useful insight into the palm oil industry and Indonesia, as well as surrounding elements that affect and are affected by the industry, and lastly provide insight into necessary steps going forward in order to achieve a sustainable industry.

We explore the evolution and findings of different environmental impact assessments. The three assessment tools, life cycle sustainability assessment, life cycle assessment, and total economic valuation, were investigated in an integrative case study. The results from the assessments are discussed in the context of relevant literature. The chosen life cycle sustainability assessment holistically evaluates the level of sustainability in the production process of crude palm oil. Through the study we discovered a crucial need for improvement in the environmental dimension. The life cycle assessment gives deeper insight into the crude palm oil production process and technologies for sustainable utilization of empty fruit bunches, where we found that composting was one of the most favourable technologies. The total economic valuation addresses the serious threat from deforestation, more specifically in Leuser National park on Sumatra. The effects on the economic value under deforestation versus conservation scenarios are investigated, and it was found that the conservation scenario has a higher total economic value than the deforestation scenario.

The thesis concludes that the biggest problem from an environmental point of view is the high rate of deforestation and clearing of peatlands, as it causes a number of other negative impacts, such as the high amount of GHG released during this process and distribution of biodiversity. We discovered a strong connection between environmental sustainability and economic sustainability, meaning that economists can play an important role when moving towards a sustainable palm oil industry in Indonesia. Lastly, sustainable drives such as consumer awareness, pressure from non-governmental organizations and certification were identified. Despite the available solutions, it was determined that the main issue holding the industry back from sustainability lies in the lack of motivation and poor implementation of these solutions due to financial barriers.

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Abbreviations

AMDAL – Analisis Menganai Dempak Lingkungan
CPO – Crude Palm Oil
EFB – Empty Fruit Bunches
EIA – Environmental Impact Assessment
FFB – Fresh Fruit Bunches
GHG – Greenhouse Gases
ISCC – International Sustainability and Carbon Certification
ISO – International Organization for Standardization
ISPO – Indonesian Sustainable Palm Oil
LCA – Life Cycle Assessment
LCC – Life Cycle Costing
LCI – Life Cycle Impact
LCSA – Life Cycle Sustainability Assessment
NDPE – No Deforestation, No Peatland Development, and No Exploitation
NGO – Nongovernmental Organization
NPV – Net Present Value
NSMD – Non-state Market Driven
NTFP – Non-Timber Forest Products
POME – Palm oil mill effluent
RSPO – Roundtable on Sustainable Palm Oil Certification
SEA – Strategic Environmental Assessment
TEV – Total Economic Value

Chapter 1: Introduction

The palm oil industry has been growing rapidly since the 1980's, with each following year seeing increased expansion and revenues, while the detrimental environmental consequences worsen accordingly. Indonesia has over the years become the largest producer of palm oil, and the demand is growing every year, especially in eastern Asia. The socioeconomic benefits of the palm oil industry are for the most part positive today, but questions have been raised about the long-term sustainability of the industry. We therefore aim to assess the current state of the palm oil industry in Indonesia and find clues as to how the industry can, and needs, to change in order to achieve that goal, perhaps before it is too late.

There are several components to achieving a sustainable industry that needs to be addressed. The starting point is the high rate of deforestation and clearing of peatlands undertaken to make way for the cultivation of oil palms. This land clearing is carried out by both large organizations with large plantations, as well as smallholders who can be either independent or part of smallholder schemes. These processes are found to be highly unsustainable and lead to a vast array of environmental impacts. The outcome could be irreversible loss of biodiversity and important ecological functions. The theoretical consequence of the business-as-usual scenario is that in the end, little to no vegetation will be able to grow where the plantations have been, and that includes oil palms. The degradation of soil caused by fertilizers and pesticides also increase the risk and detrimental effects of natural disasters such as floods, landslides, droughts, and changing river flow patterns. In the worst-case scenario, most of the natural flora and fauna spread throughout the Indonesian archipelago might be completely destroyed, or become an unrecognisable shadow of the thriving state it has existed in for thousands and thousands of years.

Indonesia is the largest producer of palm oil in the world, and together with Malaysia, which is the second largest, they produce between 85%-90% of all the palm oil produced in the world. These are also countries that are in the middle of developing as emerging economies and still have many citizens living under the poverty line. The palm oil industry - which is valued at around USD $100 billion and makes up 17% of the agricultural GDP of Indonesia - is therefore an important industry for the countries, both as nations and for the many stakeholders. Additionally, the industry outcompetes other oilseed competitors and alternative crops such as rice and rubber, by providing higher yields from the same area and is more labor intensive, which means it provides more jobs. Palm oil in itself is also a highly priced product that is used in a number of products – such as cosmetics, biofuels, food, and more - across the world, due to its favorable attributes. It is safe to say that the palm oil Industry is not going away anytime soon, but neither will the environmental impacts if nothing is done.

What we will discuss in this paper is therefore the current state of the industry and the environment in the tropical regions that make up the Indonesian archipelago, and what influences the industry. We will do so by providing an overview of the various stakeholders and other forces that govern the industry, going over the various environmental and economic costs and benefits, and by using three case studies to help shed light on and gain insight into what the industry needs to address in order to become more sustainable. The thesis mainly focuses on environmental impacts as well as the economic dimension. We will not be focusing on social effects of the palm oil industry, such as child and slave labour, unsafe working conditions, health risks, and culture.

Chapter 2: The palm oil industry and environmental impacts

The Palm Oil industry is important for Indonesia's economic development, but the industry's growth is also problematic as it causes numerous negative environmental impacts when expanding into rainforests and peatlands, such as loss of the natural rainforests and biodiversity. This chapter seeks to describe the palm oil industry, palm oil as a product as well as the negative environmental impacts of the industry.

2.1 The concept of sustainability

Sustainability is a central concept in this paper. It is therefore important to have a clear understanding of what the term entails. Many organizations and authors are using different definitions of the term sustainability, with some definitions being more popular than others.

Jennings & Zandbergen (1995, p. 1023) presents the argument that *"individual organizations cannot become sustainable*", and that "*Individual organizations simply contribute to the large system in which sustainability may or may not be achieved*". The Brundtland Commission report defines sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Emas, 2015, p. 1). Many companies follow this definition, while Frece & Harder (2018) argue that organizational sustainability should focus on organizational values instead of human needs. With that said, the Brundtland Commission's definition might not be suitable for corporate sustainability, but it does however address market policy makers.

Elkington (1999, 2018) takes the definition of sustainability a step further by explaining that there are three bottom-lines that the sustainability concept is built upon, which are people, profit, and planet. In other words, an organization or industry becomes sustainable by balancing these three elements. However, the three elements are unstable and constantly fluctuating.

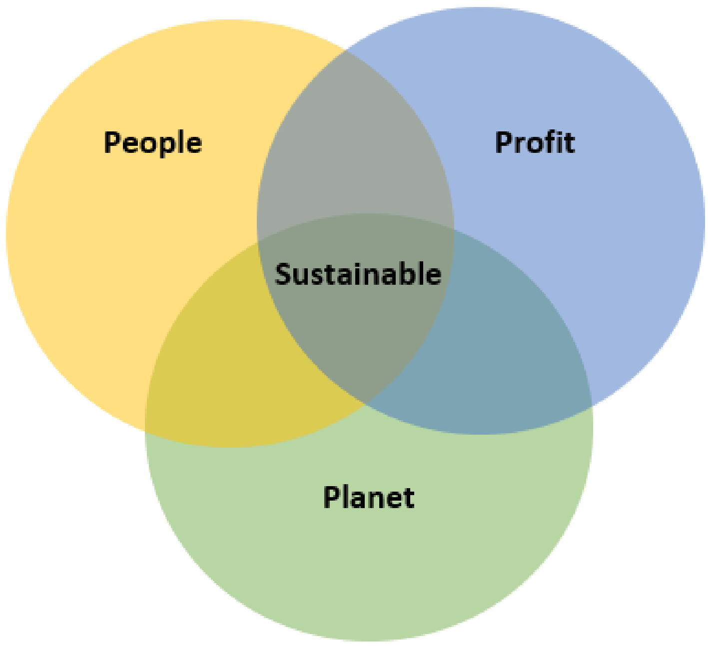

Figure 1: John Elkington's triple bottom line

As the figure above illustrates, the triple bottom line does not only concern sustainability in each individual element, but also how they are connected and dependent on each other.

Both the Elkington and Brundtland Commission definitions of sustainability can, by themself, be vague. Herman Daly created the following definition that will be useful in this case; "*A sustainable society needs to meet three conditions: its rates of use of renewable resources should not exceed their rates of regeneration; its rates of non-renewable resources should not exceed the rate at which sustainable renewable substitutes are developed; and its rates of pollution emission should not exceed the assimilative capacity of the environment*" (Elkington, 1999, p. 55).

In order to attain sustainable plantation practices, the plantation must balance and benefit the 3 Ps; profit, people, and planet (Basiron, 2007). This applies to any agricultural crop, including palm oil.

2.2 The palm oil industry

2.2.1 Palm oil

Palm oil is made from the pulp of fruit that grows on oil palm trees (D'Antone & Spencer, 2015). These trees grow naturally in some rainforests, however they are also being cultivated in plantations of varying scales. Palm oil has proved to be one of the most profitable uses of land in tropical regions. Production of palm oil is financially more attractive than substitutions such as rice and rubber, when considering agricultural land use, while being more labor intensive which means it provides more jobs per hectare (Bissonnette & De Koninck, 2015; SPOTT, 2016). Palm oil outcompetes its vegetable oil competitors with yields that are five to ten times higher, long shelf life, desirable health properties, and more versatility (Voora, Bermudez & Balino, 2019). Palm oil also has one of the lowest production costs, making it possible to request lower prices than competing vegetable oils (Carter, Finley, Fry, Jackson & Willis, 2007).

Palm oil is an important source of edible oil and is the world's most used vegetable oil, as it provides almost 30% of the world's edible vegetable oil (Corley, 2009: D'Antone & Spencer, 2015). Palm oil is used in various edible products and is likely to be found in bread, ice cream, chocolate, and margarine (Azhar, Saadun, Prideaux & Lindenmayer, 2017). Furthermore, palm oil is used in many products other than food - such as makeup, soap, cleaning detergent, and biofuel. Prior to the rapid development of demand for biofuel, as much as 17% of palm oil was used for non-edible purposes (Corley, 2009). The demand for non-edible purposes had increased to 20% in 2017 (Kushairi et al., 2018). The yearly demand for palm oil is estimated to double from 2009 to 2050, from 120 million tonnes to 240 million tonnes (Azhar et al., 2017). Approximately 80-90% of the global supply of palm oil is produced by Indonesia and Malaysia (Zahan & Kano, 2018).

2.2.2 The palm oil industry in Indonesia - A positive force

Indonesia's economy has been growing rapidly the last 20 years (World Bank, 2019). This is, among other reasons, due to the palm oil industry - which has become one of Indonesia's most important sources of economic growth, employment generation, rural poverty alleviation, and export earnings. The palm oil industry makes its main impact in three different ways. Firstly, crude palm oil (CPO) is used as a raw material in the domestic cooking oil industry. Secondly, it generates a large number of jobs for both plantation-workers and smallholder growers. And, lastly, it provides the government with revenues as the third most valuable export product in Indonesia. The industry contributes to the economy through output and value, while it provides employment through its agricultural sector that benefits farming communities in rural areas (Kasryno, 2015).

The following are the three forms of ownership of plantations in Indonesia: smallholders, private companies, and state-owned (Glastra, Wakker & Richert, 2002). Around 2 million smallholders cultivated palm oil according to a 2013 agricultural census. Additionally, another 7.8 million people were employed somewhere along the palm oil value chain through The Indonesia Palm Oil Association (GAPKI) and connected industries, as of 2018. The export value of this industry reached USD $23 billion in 2017 and contributed 17% of Indonesia's agricultural gross domestic product in 2014 (Purnomo et al., 2020).

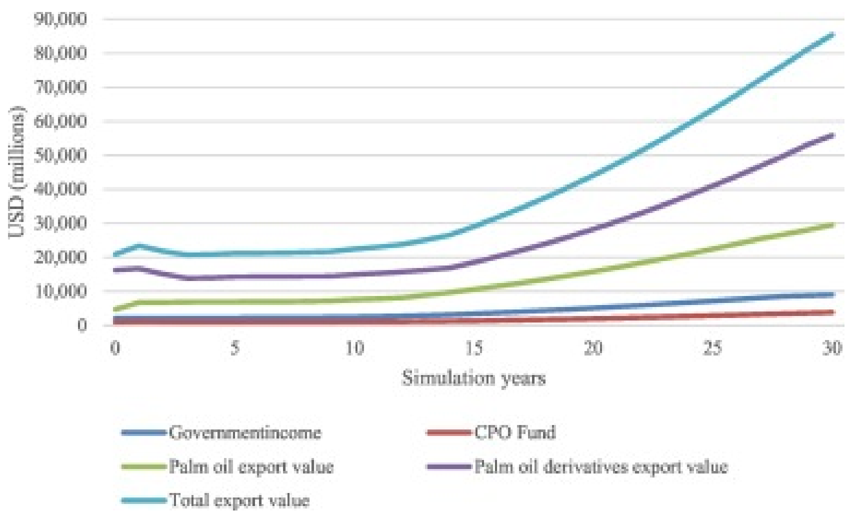

Figure 2: Export, government income, and CPO Fund (million USD). 32 year simulation, 2015 base year (Purnomo et al., 2020, p. 6).

A growing awareness of the health deficits of trans fats and the potential ban of products containing trans fats, has created room for palm oil to expand its market share as a substitute. Biodiesel made from palm oil has been banned from counting towards the 2030 reduced CO_2 emission goals in the EU. However, the largest consumer of palm oil is by far Asia, accounting for two thirds of global consumption (Voora et. al., 2019). The EU ban only accounts for a 1% financial loss of export, but it might set a dangerous precedent for the industry if other important importers such as Norway, the US, China, and India adopt the policy (Purnomo et al. 2020). This can however, potentially be combated with sustainable development in the industry.

There are some concerns about the actual impact that the palm oil industry has on Indonesia. While it seems clear that the economic impact is positive for the time being, there are questions being raised about the sustainability and social impact it carries. Findings indicate that poverty alleviation is unevenly distributed between villages based on "*biophysical locations and baseline socio economic conditions of nearby communities prior to oil palm developmen*t" (Santika, et al., 2019, p. 105). However, the dominant economic impact seems to be positive, especially for those living under the poverty line. Rural poverty in the Riau province for instance, decreased from 21% to 10%, between 2009 and 2013 (Shahputra & Zen, 2019).

The yields per unit of land that smallholders - who often are poor - are able to harvest, are typically much smaller when compared to large corporate plantations. Smallholders take up a considerable amount of the land area used for oil palms, estimated to take up around 50% of the total area. They fall behind the plantations for a number of reasons - which includes soil and weed cover management, canopy management, harvesting, pest and disease management, plant nutrition, and several other reason that relate to planting practices such as spacing and general treatment of the oil palms (Jelsma, Woittiez, Ollivier & Dharmawan, 2018). Palm oil remains a highly suitable product for smallholders, despite the difficulties that come with the cultivation of oil palms, and can provide a good living for many people with high returns to land, labor, and capital. Some scheme smallholders have even managed to outcompete the large plantations' yields by exploiting both smallholder and large plantation advantages, and by better sharing information and knowledge between themselves (Jelsma, Slingerland, Giller & Bijman, 2017).

2.3 Environmental impacts

2.3.1 Rainforests and biodiversity - Why they matter

The tropical rainforests that are found on the Indonesian archipelago are part of one of earth's largest biomes, also known as major life zones. These are part of the tropical rainforests found around the equator and are home to some of the oldest and most primitive major vegetation, as well as containing some of the most biodiverse fauna in the world (Smith, 1998). Indonesia's rainforests make up 10% of the world's tropical rainforests and 5.4% of the world's total forest areas, as of 2020 (Brearley et al., 2019: FAO & UNEP, 2020). Tropical rainforests covered 15% of global land area in 2013, and are the largest and most important carbon sinks above ground (Brearley et al., 2019).

Forests help supply water, provide livelihoods, mitigate climate change, and are essential for sustainable food production (FAO & UNEP, 2020). This dependency holds especially true for poor rural areas such as Indonesia, where studies have found a high reliance on forest resources, and smallholders account for 36% of the crude palm oil production (Kasryno, 2015; Gunawan et al., 2008). This relationship should be considered when addressing how to make a sustainable transition without negatively affecting the Indonesian population.

There exists undeniable evidence for the decline in biodiversity around the globe, and while it is hard to understand and predict the exact consequences of the loss of biodiversity, there are some general principles that are understood (NASA, w.y.). The rate of decline in biodiversity is exponential, which is made all the worse when taking into consideration that sustained biodiversity helps ecosystems operate normally and recover faster after shocks to the equilibrium (Moron, Sheppard & Lonsdale, 2014). Indonesia hosts the third largest selection of known tree species in the world with 5,263 out of 60,082. These trees do not exist in isolation and are part of an interconnected system consisting of plants, insects, animals, and fungi. Replanting forest does not bring back these other crucial species that are necessary for a healthy and thriving ecosystem, nor does it guarantee that conditions remain favorable to support the same three species after having cleared the area (FAO & UNEP, 2020).

Loss of biodiversity affects every aspect of how energy and nutrients contained within the plants, animals, and soil are produced and used, to how they are broken down as biomass to be recycled for use again (Moron et al., 2014). Loss of biodiversity also affects the distribution of the energy and nutrients throughout the ecosystem. How much individual species affect other species and the ecosystem as a whole can vary drastically, with certain species having little or no practical impact while others can be considered crucial species for proper ecological functioning. However, the loss of several less impactful species can have an additive effect and cause major disruptions to the natural equilibrium. The loss of one species can lead to either a decline or increase in several others, having a chaotic and unpredictable impact on the local environment, which again can stack up to affect the global ecosystem.

2.3.2 Deforestation

Deforestation means to convert forested areas to other purposes, which in this case is the conversion of rainforest for the purpose of creating palm oil plantations, and increased deforestation in Indonesia typically mirrors an increase in planted areas (Tan & Lee, 2009; Vijay, Pimm, Jenkins & Smith, 2016). Palm oil is a chief driver for deforestation in Indonesia alongside the timber industry (Austin, Schwantes, Gu & Kasibhatla, 2019). Kaimowitz and Angelsen has concluded from their research that "*deforestation tends to be greater when: forested lands are more accessible; agricultural and timber prices are higher, rural wages are lower, and there are more opportunities for long distance trade*" (Kaimowitz & Angelsen, 1998, p. 5), which applies to the palm oil industry in Indonesia.

Indonesia doubled the planted area for palm oil production in a decade, from 2003 to 2014 (Khatiwada et al., 2015). The peatland area used for plantations increased from 700,000ha in 2000 to 2,000,000ha in 2014 (Uda, Hein & Sumarga, 2017). The absolute rate of deforestation in Indonesia fluctuated between 0.71 million hectares and 1.78 million hectares annually between the years 1990 and 2005, making it one of the countries with the highest deforestation rates on the planet (Hansen et al., 2009). The Indonesian Ministry of Environment and Forestry released numbers in 2015 that unveiled that 24 million hectares of rainforest were lost in the 25 years between 1990 and 2015, which is comparable to the size of the United Kingdom (Greenpeace International, 2018). As a result, the Indonesian government publicly committed to reducing deforestation, but they have not been successful (Tacconi, Rodrigues & Maryudi, 2019).

Forestry regulations recommend developing palm oil plantations in areas that are unforested or on abandoned lands, instead of in forested areas. There was in 2016, 17 to 26 million hectares of available land suitable for palm oil plantations in Indonesia (Afriyanti, Kroeze & Saad, 2016). Yet, all major palm oil plantations have done the opposite and developed in forested areas and on disputed land (Setiono et al., 2015).

Logging and burning are the most common ways to clear out forests in order to make room for plantations in Indonesia (Austin et al., 2019). From the year 2002 to 2015 the average rate of active fires in plantations were 0.078 fire-detections per square kilometer per year (Austin et al., 2019; Carlson et al., 2018). These intentional fires have on many occasions caused accidental forest loss, as large fires are difficult to control (Carlson et al., 2018). In 2015 there were serious out of control fires in Indonesia's rainforests. The fire's daily greenhouse gas emissions frequently surpassed the daily emissions of the USA (Global Fire Emissions Database, 2015; Harris et al., 2015). Smoke haze from the fire impacted millions of lives and might have caused up to 100,000 premature deaths (Burrows, 2016). Fires started in relation to the palm oil industry were the main source of haze. The weather was extremely dry in this period, which could be the reason for the extreme amount of smoke.

The Indonesian state's policies have been facilitating the rapid development of palm oil plantations causing deforestation. The state's decentralisation of power, that came through Law No. 22/1999, opened the floor for corruption and competition, as well as making it possible for the local governments to grant plantation permits in an uncontrolled manner (Tacconi et al., 2019). Under the national forestry regulation from 2002, local governments are no longer allowed to issue these permits, yet many local governments proceed to do so (Setiono & Husein, 2015). For instance, in Central Kalimantan, which is a province of Indonesia, there have been issued hundreds of permits to plantations, without the central forest authority having issued formal land release, covering about four million hectares of forest in this area (Tacconi et al., 2019).

A significant amount of the deforestation in Indonesia is done illegally, but illegal deforestation is harder to detect than legal deforestation. Consequently, the tracing of climate change and achieving a sustainable industry is significantly more difficult because of illegal deforestation. Furthermore, illegal deforestation works as a driver for corruption in addition to robbing the government of revenues as well as natural resource bases. Deforestation also undermines and depletes livelihoods, and fuels social conflict (Hoare, 2015). Illegal deforestation occurs due to weak law enforcement and inadequate monitoring. Indonesia generally suffers from corruption, and the palm oil industry is no exception (Transparency International, 2020; Setiono et al., 2015). In fact, it has been shown by studies that bureaucrats, political parties, parliament members, army, and police have all been involved in illegal forest activities, either directly or indirectly (Tacconi et al., 2019). Furthermore, local governments as well as forestry and law enforcement officials, have been known to accept bribes in exchange for permits and other legal documents (Setiono et al., 2015).

Indonesia has not been successful in their commitment to reduce illegal deforestation. Brazil, on the contrary, has with forest law enforcement activities been successful in reducing deforestation significantly (Tacconi et al., 2019). At least they were successful until 2020, when the deforestation rate increased due to the encouragement of agriculture in the rainforest from the president, and a cut in the environment ministry's budget, according to BBC News (2020; 2021). The strategy they were successful with was largely based on timely remote sensing imaging which allowed them to identify and observe the illegal deforestation. Indonesia would likely benefit from assessing Brazil's forest law enforcement strategy and should consider how they could apply lessons from Brazil's experience to their own forest law enforcement.

2.3.3 CO2 emissions

Land use activities account for most of Indonesia's carbon emissions as a single source, with an expectation that it will contribute to more than 50% of the emissions through 2030. If this estimate holds true, then emissions from the Land Use, Land-Use Change and Forestry (LULUCF) sector, and peat land activities will contribute to 2.5% of the world's GHG emissions. It is also estimated that around 20% of palm oil plantations are located on peat land (Shahputra & Zen, 2019), which is concerning since there exists no doubt that peat land oxidation is the greatest single source contributor to CO_2 emissions per ha (Shahputra & Zen, 2019; Purnomo et al., 2020). Purnomo et al., estimates that the approximately 2.3Mha of oil palm plantations on peatlands emit more than 100M tons of CO_2e (CO_2 equivalent). Estimates indicate total yearly carbon emission from plantation related activities on peatland to be well over 400t C per ha in Southeast Asia (Uning et al., 2020; Uda et al., 2017). In total, palm oil plantations have been linked to a 2.5 gigaton loss in carbon stock in tropical peatlands since 1990 (Uning et al., 2020).

The release of GHG from the forests and peat lands occurs both at the point of destruction - by logging, draining, clearing, and fires - and over time as groundwater levels decrease and soil organic matter decomposes (Purnomo et al., 2020). Land clearing activities and peatland fires make up another 38% of CO_2 emissions, while the palm oil mill effluent (POME), which is highly pollutive, also produces a large quantity of GHG. Treatment of POME is an essential part of wastewater treatment plants, but is expensive and requires tests to determine the right treatment process based on the characteristics of the wastewater (Poh et al., 2010).

Chapter 3: Drivers of sustainability

This chapter provides relevant descriptions of potential driving forces pushing for sustainable change, such awareness in the industry, government regulation, certification, and policy.

3.1 Awareness in the industry

The topic of corporate social responsibility and consumer awareness of sustainability in the palm oil industry has increased since the end of the 20th century and has therefore become an increasingly important factor for palm oil producers (Hutabarat, Slingerland, Rietberg & Dries, 2018). Social media developed rapidly during this period, playing a huge role in the growth of consumer awareness (D'Antone & Spencer, 2015). This has created a 'cancel culture’, which essentially is a social media culture where boycotting a company or a person becomes a trend (Ng, 2020).

Consumer awareness challenges the palm oil industry. If sustainable palm oil does not become the new normal in the future, when awareness might have intensified, there is a probability that consumers will take the “palm oil-free” position and boycott palm oil as an ingredient (D'Antone & Spencer, 2015). Loss of reputation can therefore be seen as a cost and influence companies' cost-benefit analysis (Brandi et al., 2013).

Non-governmental organizations (NGOs), such as Greenpeace and World Wild Fund for Nature (WWF), play a huge role in spreading awareness about the palm oil industry through research, articles, and campaigns (Ivancic & Koh, 2016). An example of this is Greenpeace’s video ‘Rang-tan: the story of dirty palm oil’, which has over 40 million views on Youtube alone (Greenpeace, 2018). Nestle is an example of a brand that lost money and changed their supplier of palm oil because they did not want to be associated with illegal deforestation after Greenpeace initiated a boycott (Gong, Gao, Koh, Sutcliffe & Cullen, 2019; Brandi et al., 2013). Another brand that experienced scrutiny over their palm oil use is Cadbury, who was led to exclude palm oil from many of their products or only use sustainable palm oil, as well as issuing an apology (D'Antone & Spencer, 2015; Nzherald, 2009).

When switching suppliers, either reactionary or pre-emptively to expected criticism, companies look for plantations providing certified palm oil. Concerned stakeholders demanding sustainable palm oil have caused different voluntary certification schemes to surge (Hutabarat et al., 2018). With that said, Greenpeace has gone back and forth from supporting certain certification schemes and has accused certified palm oil of being a con, specifically addressing the Roundtable on Sustainable Palm Oil (RSPO) (Young, 2019). The RSPO responded to Greenpeace's claims by pointing to the fact that they have a strict set of criteria regarding deforestation, and further explained that these strict criteria are not something they can carry out alone and that it will take time (RSPO, 2021). Despite that reponse, the RSPO took Greenpeace's criticism seriously and steps have been taken to strengthen their commitment to transparency and accountability.

If consumers demand sustainable palm oil and are willing to bear the extra costs of certification and other measures to become sustainable, actors in the palm oil industry would profit from satisfying that demand (Gale, 1955). A study from 2019 on the impact of sustainability on consumers' willingness to pay, where coffee production was used as an example, found that striving for sustainability does not always pay off, while bad conduct tends to be punished (Lingnau, Fuchs & Beham, 2019).

3.2 Certification

Certification is a major topic when discussing the palm oil industry and has become increasingly important. There are many types of certification systems that cover different aspects of the palm oil industry. The main purpose of certification standards is to stimulate sustainable production of palm oil with limited negative environmental and social impacts (Hutabarat et al., 2018). Certification is usually supposed to give assurance that forest practices linked to palm oil are legal and sustainable. However, the real effects of certification and how well it really works to fight deforestation in Indonesia is unclear (Carlson et al., 2018). Although certification has shown signs of reducing illegal deforestation, the reduction has not been significant, and palm oil is still a huge driver of forest loss (Heilmayr, Carlson & Benedict, 2020).

3.2.1 Voluntary international standards

No deforestation, no peat development, and no exploitation (NDPE), is a policy that emerged in 2011 and became increasingly popular in 2013 (Efeca, 2020). The policy is meant to ensure sustainable palm oil and in many cases goes beyond both the legal and certification requirements. However, the scope of NDPE policies vary from company to company and palm oil produced under NDPE policy is not officially certified. The fact that NDPE policy is voluntary makes compliance hard to inspect, and transparency is therefore very important for attaining sustainability. To achieve transparency, NDPE uses an implementation reporting framework allowing the different parts of the palm oil supply chain to report progress of delivering on NDPE commitments. The system is not perfect, but there is capacity for improvement and it has the potential to become more robust in the future.

International NGOs and private organisations established the Roundtable on Sustainable Palm Oil (RSPO), which was briefly mentioned above, in 2004. The RSPO was established with the purpose of promoting sustainable production and trade of palm oil, and includes stakeholders concerned for the level of sustainability throughout the palm oil value chain (Pichler, 2013). The RSPO standards are based on the guidance of "People, Planet and Profit" and are referred to as some of the most important and advanced standards (Brandi et al., 2013). In 2012, the RSPO was responsible for certifying 12% of the world's palm oil, making it the largest certification scheme for palm oil, and various countries in Europe had the intention of only importing RSPO certified palm oil by the year 2020 (Hutabarat et al., 2018; Ivancic & Koh, 2016).

International Sustainability and Carbon Certification (ISCC) is a voluntary international standard under the European Union Renewable Energy Directive. It is one of the world's largest certification systems and focuses on sustainable production of biomass for biofuels (Brandi et al., 2013). The main criteria for ISCC concerns sustainability requirements for the production of biomass, requirements for greenhouse gas emission savings, and supply chain traceability and mass balance requirements.

3.2.2 Government regulation

In 2011, Indonesia established the national Indonesian Sustainable Palm Oil (ISPO) certification (Choiruzzad et al., 2021). This was taken as a sign that there was displeasure with the RSPO and the concept of non-governmental organizations, and raised questions about legitimacy of private companies creating policy meant to regulate the industry. The formation of the ISPO was done as a response to growing international criticism about the environmental and social impact of palm oil production. The already uncertain authority and status of voluntary international multi-stakeholder standards, have become even more questionable following the ISPO. Some are concerned that the government mostly seeks to present an outward front to combat criticism aimed at the more destructive and polluting parts of the industry. Government regulations that apply to private businesses can have both positive and negative effects on the industry and the environment depending on factors such as intent, formulation, implementation, enforcement, competing regulations, etc.

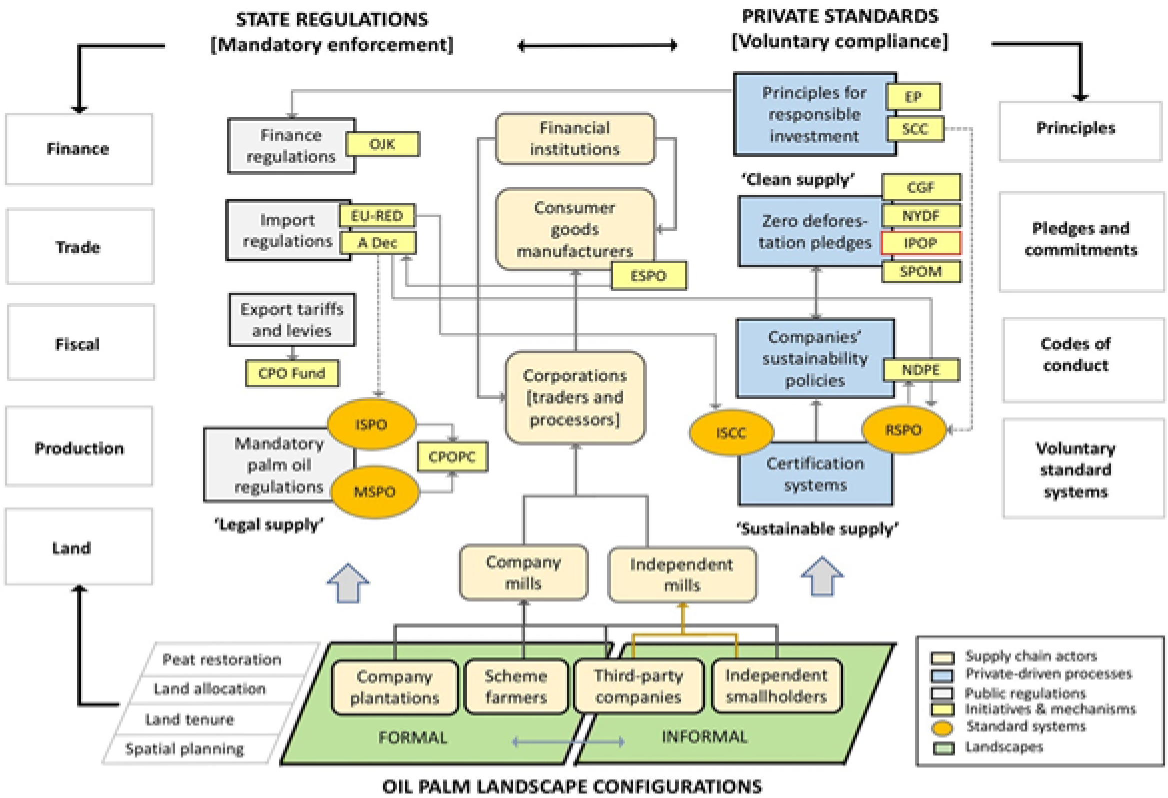

Figure 3: The complex landscape that governs the palm oil industry. (Pacheco et al. 2018, p. 574).

"*Palm Oil Plantations include all activities related to: managing natural and human resources, production facilities, tools and machinery, cultivation, harvesting, processing, and marketing of oil palm.*" (FAOLEX Database, 2020). This is what the ISPO aims at managing through its business system. The goal of the ISPO is to create a sustainable industry that does not cause further deforestation and drainage of peatlands, increase the acceptance and competitiveness of Indonesian palm oil plantations in the international market, as well as reducing the proliferated release of greenhouse gases throughout the industry's value chain. This means that both natural and human resources are included, the same goes for physical capital and marketing of palm oil (FAOLEX Database., 2020).

3.3 Effectiveness of certification and policy

There are a lot of discussions surrounding certification and policy as a tool to combat deforestation and whether it is effective or not (Carlson et al., 2018). The non-state market driven (NSMD) certifications that are usually pushed by NGOs are not enforced by law or the local government, meaning the certification provider or a third-party actor is required for follow-up. That also means that there are no inherent consequences for not acting in accordance with the certification's guidelines. This leaves little incentive for profit-maximizing firms to undertake expensive restructuring to conform to the certification (Auld & Cashore, 2013).

A remaining incentive for adopting certification is external pressure from NSMD forces, or as a pre-emptive measure against official and mandatory regulations such as the ISPO. In 2013, CEO of the company Wilmar International, Kuok Khoon Hong, shared their intentions of making sure their own plantations, and the companies they source from, would provide palm oil with no links to deforestation by committing to the NDPE policy (Wilmar International Limited, 2014). This was a huge development since Wilmar International is one of the world's biggest trading companies of palm oil, causing other major traders to follow suit (Greenpeace International, 2018).

In 2018 numbers showed that as much as 74% of the total refinery capacity in Indonesia is operated by traders with NDPE policies (Kuepper, Steinweg & Aidenvironment, 2018). With that said, deforestation has not slowed down even though the the conditions have been in place for the palm oil industry to normalize 'no deforestation', indicating that the brands and trading-companies announcing their NDPE policies, have failed to identify and eliminate sources of palm oil that have links to deforestation. This is partly due to the brands and trading-companies not having nor demanding consequence maps from their suppliers. This displays the difference between creating and planning policies versus implementing them effectively (Greenpeace International, 2018).

Certification and policy typically strive to eliminate fire associated deforestation in an effort to combat accidental forest loss, and in a large sample of plantations from 2009 to 2014, it was discovered that fire associated deforestation was less common in certified plantations (Carlson et al., 2018). With that said, it is still unclear if certification has a direct effect on the reduction of fire occurrences, or if this is connected to the fact that most of the certified plantations are those with little to no remaining natural forest.

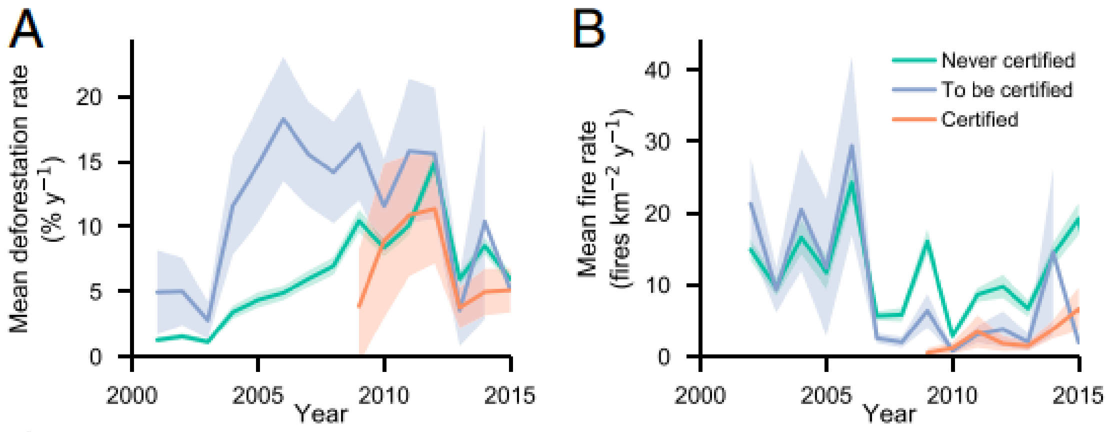

Figure 4: Mean deforestation rate and mean fire rate within Indonesia's palm oil plantations (Carlson et al., 2018, p. 3)

Figure 4 indicates that certification has a positive impact on deforestation and fire rates. However, the mean fire rate increased in the years following up to 2015. This could be due to the fact that more plantations are being certified, or the increase of fires in certified plantations could imply that certification has a causal effect on fire rates (Carlson et al., 2018).

3.3.1 Greenwashed certification and idealistic arguments

As mentioned, the impact that certification has had on sustainable production of palm oil is widely debated and various sources report a vast array of results. There will always be those who aim to take advantage of systems meant to promote positive change. This should be considered when determining the effectiveness of certification in regard to sustainability. A study by Carlson et al., (2017), found that certification had a significant effect on reducing deforestation through logging, by as much as 33%. However, certification was mostly acquired for the older plantations that had little remaining natural forest.

Certification can create a false image of sustainability in the industry, making consumers less aware, while making the producers richer through higher mark-ups from the perceived sustainable harvesting. This has been observed in the logging industry where timber with Forest Stewardship Council (FSC) certification can fetch 15-25% higher prices at auction. There have been several scandals in the logging industry where FSC loggers have carried out illegal logging and a Chinese company offered to put FSC labels on illegal wood for a higher markup (Conniff, 2018). This should in our opinion be considered as a likely outcome in the palm oil industry as well, unless countermeasures are put into place.

There exists a debate between idealists and those who favor more practical approaches to the environment and sustainability (Prasad & Elmes, 2005). A critique aimed at "green certification" is that the various certifications often lack concern for the practical, and become empty idealistic fronts. The palm oil industrys vital role in improving conditions in developing nations such as Indonesia creates implications when there is talk about slowing down growth. It is easy to state that the palm oil industry needs to change, but it is something else to say how it should change without negatively affecting the many lives that depend on the industry. There is also a debate around the very concept of splitting idealism and praxis. These often end up as two different sides and advocates might lean heavily to one side of the debate, but there might not be any reason to split these two into mutually exclusive parts (Newton, 2005).

3.4 Cost of certification

The certification process in Indonesia is long and costly. The costs related to certification can be divided into the following three; compliance costs, transaction costs, and opportunity costs (Lee, Rist, Obidzinski, Ghazoul & Koh, 2011). Each link in the supply chain has to comply with the standards of certification in order to receive certification, meaning that certification has to be financially attractive for each of these links in order for them to meet these requirements voluntarily. In addition, it also depends on sufficient demand and customers willingness to pay for sustainable palm oil (Hutabarat et al., 2018: Brandi et al., 2013). With that said, an increase in income and premium prices due to certification has been identified as potential financial benefits for smallholders (Rietberg & Slingerland, 2016). Certification also ensures that smallholders are not excluded from certain markets with sustainability standards (Brandi et al., 2013).

Certification standards carry more challenges for smallholders than large scale companies, and 5-10% of smallholders were in fact left out of certification projects in 2016 (Hutabarat et al., 2018). These barriers relates to costs, access to financial means, availability of legal documents, acquiring and improving knowledge, and skills - which are reflected in the fact that there were 2.3 million smallholders in Indonesia in 2015, and only 129,155 smallholders worldwide were RSPO certified that same year (Hutabarat et al., 2018). Without financial support smallholders generally lack the financial means to meet certification costs, especially the start-up costs (Brandi et al., 2013).

Based on an overview displayed by Kuit and Waarts, (2014), the annual cost of certification is between 0.61 and 2,604.69 EUR per farmer, while the upfront costs are between 18 and 403 EUR per farmer. Research from the year 2013 to 2015 shows that certified smallholders in Indonesia, compared to the circumstances prior to RSPO certification, generates up to 21% higher revenues from sales, but it also creates a loss of net income the first year of up to 8% per hectare (Hutabarat et al., 2018). The economic performance of palm oil smallholders with certification has to be improved in order to motivate other smallholders.

Chapter 4: Methodology

4.1 Problem statement and research questions

Research questions are more descriptive than hypotheses, and are often more suitable in social science. We strive to conclude explanations on our subject with the use of words and have therefore chosen a main problem statement. Since we are researching a wide subject matter, we have chosen three research questions to supplement the problem statement. The research questions guide the process and represent the specific information needed in order to answer the problem statement (Sekaran & Bougie, 2016). The purpose of the research questions is not mainly to find answers with double underlining, but rather to provide deeper insight and understanding.

Problem statement	Environmental impacts of the palm oil industry, particularly in Indonesia, and how the industry can move towards sustainability
Research question 1	What are the major negative environmental impacts of the current and expanding palm oil industry in Indonesia?
Research question 2	How can economists contribute by taking the environment into account when calculating profitability, and how can the negative environmental impacts be measured?
Research question 3	What are the most efficient drivers of sustainable action for the palm oil industry?

4.2 Research method

We wish to give insight to how the palm oil industry, particularly in Indonesia impacts the environment, how these impacts can be measured, and how the industry can move towards more sustainable practices. A research case study strategy is considered to be the appropriate research method in order to answer the research questions as well as the problem statement.

A case study should be done "*when you want to understand a real-world case and assume that such an understanding is likely to involve important contextual conditions pertinent to your case*" (Yin, 2018, p. 45). This method is well suited to describe, explain, give insight to, and create a deeper understanding of an issue. The following three types of research case studies can be defined: explanatory, descriptive, and exploratory (Yin, 2018). The appropriate form of case study in our research is the exploratory case study, as we are not only answering "how" and "why" questions, but also "what" questions, which are exploratory.

We have chosen three studies as the sources for our case study. Firstly, a study on life cycle sustainability assessment, conducted by Omrat, Sharaai & Hashim (2021), which evaluates the level of sustainability of crude palm oil production. Secondly, a study conducted by Chiew & Shimada (2013), which is a life cycle assessment of the energy consumption and environmental impact of various technologies for utilizing empty fruit bunches using different recycling options, and thirdly, a total economic valuation of the Leuser national park, conducted by Beukering, Cesat & Janssen (2003). The selection process as well as the relevance of these will be further explained in chapter 6.

4.3 Scope of the case study

Many publications have discussed specific environmental impacts of the palm oil industry. Our study has a new contribution by presenting and analysing relevant environmental impact assessment models, demonstrating how they measure environmental impacts differently, and then using the empirical data to answer the research questions as well as the problem statement. Each model is presented individually and provides different data fit to answer the research questions. The study does not seek to thoroughly investigate the social dimension, but rather focus on the environmental and economical dimensions since these are more relevant when answering the problem statement, although some social factors will be mentioned for context. The theory presented in chapter 5 will be used as tools when carrying out the case study in chapter 6.

4.4 Choice of data collection method

The case study method comprises a wide range of data collection tools. The opportunity to collect empirical material from various sources allows triangulation, which is a strength that case studies possess (Yin, 2018). Case studies may provide both qualitative and quantitative data for analysis and interpretation, however, we are primarily focusing on analysing qualitative data (Sekaran & Bougie, 2016). Our research is bibliographic, meaning that our information is gathered from published material. When collecting data for our general theory and specific cases, we perform two different literature reviews.

Literature reviews allow us to build our research on existing knowledge and provide readers with a clear overview of knowledge. "*Articles that review extant research in a domain can be incredibly useful to the scientific progress*" (Palmatier, Houston & Hulland, 2018, p. 5). Furthermore, literature reviews works as a tool to detect themes and theoretical perspectives (Snyder, 2019). There are many forms of literature reviews, but systematic review, semi-systematic review, and integrative review are three broad types.

A semi-systematic approach to the literature review best fits the first part of this study, which the case study is built upon, where we go through different environmental impact assessments, as it gives an overview of the topic as well as an overview of development over time (Snyder, 2019). The search can both be and not be systematic, and the analysis and evaluation can be both qualitative and quantitative, although this review type is most commonly followed by a qualitative analysis, as done in this thesis.

For the case study we used an integrative approach. An integrative review is similar to a semi-systematic review but the integrative approach usually has a different purpose, and is a review method that allows for a more comprehensive understanding of an issue by summarizing existing empirical literature (Broome, 1993). The purpose of an integrative review is to critique and synthesize literature and the search strategy is usually not systematic. In order to successfully conduct an integrative review, it should contribute with a new conceptual model or theory (Snyder, 2019).

Chapter 5: Literature review of environmental impact assessment

With the increasing environmental awareness, different theories, models, and empirical studies have surfaced in the last few decades. This literature review presents the evolution of environmental impact assessments, with focus on palm oil and tropical agriculture. As mentioned in chapter 4, the review makes us able to draw on existing knowledge, and allows us to detect themes, theoretical perspectives, and development over time (Palmatier et al., 2018: Snyder, 2019).

A semi-systematic review is useful in instances such as this when it is not possible to review every article that could be relevant to the study (Snyder, 2019). The selection process was done in four sections, firstly, by finding the most relevant headlines for tropical agriculture and environmental impact assessments. Secondly, by reading the abstracts of the most relevant headlines. Thirdly, by reading the full-texts of the articles with the most relevant abstracts. And lastly, by choosing the final sample. Criteria evaluated in the literature selection were: year of publication, relevance, if it was published by a credible source such as Earthscan or ScienceDirect, and language of the article. To elaborate, out of the literature evaluated, we chose the articles with most relevant information to help answer the problem statement. When several sources provided the same relevant data, we made a decision based on when the article was published and of which article best explained the concepts. The literature search was done in two databases: Google Scholar (Scholar.google.com) and Oria (Oria.no). These databases were searched using combinations of the following search words: strategic environmental assessment, environmental impact assessment, life cycle assessment, total economic valuation, SEA, EIA, LCA, TEV, evolution, development, palm oil, tropical agriculture, and tropical rainforests.

There were a number of sources explaining and confirming the same information about environmental impact assessment in general. Most of the sources focused on the positive aspects and few pointed out the negative. There was not much information specifically related to the evolution of environmental impact assessments in regard to tropical agriculture and palm oil. Out of the numerous sources we went through we picked a final sample of literature consisting of 12 sources from the period between the year 1980 and 2020, which was sufficient enough to shortly present the notable environmental impact assessments and create a foundation to build our case study on.

Final literature sample - Theory			
Title	**Author**	**Year**	**Method**
For whom do NGOs speak? Accountability and legitimacy in pursuit of just environmental impact assessment.	Lai, Jia Yen, & Hamilton, Alistair.	2020	Literature review and case study with content analysis, semi-structured interview, and group discussion.
The total economic value of forest ecosystem services in the tropical forests of Malaysia	Nitanan,K., Shuib, A., Sridar, R., Kunjuraman, V., Zaiton, S., & Herman, M.	2020	Total economic valuation of Malaysian rainforests.
Life Cycle Assessment - Theory and Practice	Hauschild, M., Rosenbaum, R., & Olsen, S.	2015	Overview of the theoretical and practical aspects of life cycle assessment.
Introduction to environmental impact assessment.	Glasson, J., & Therivel, R.	2013	Use of material from previous editions, drawing on findings of important reviews, and case studies.
The practice of strategic environmental assessment	Therivel, R., & Paridario, M. R	2013	Case studies, interviews, questionnaires, and drawing on important findings.
More than total economic value: How to combine economic valuation of biodiversity with ecological resilience	Admiraal, J., Wossink, A., Groot, W., & de Snoo, G	2013	Combining ecological resilience with total economic valuation in order to improve the environmental assessment of the latter.

Evaluation of the environmental impacts assessment (EIA) system in Lao PDR.	Wayakone, S., & Makoto, I.	2012	Review of literature and study of EIA legislation, administrative procedures, guidelines, and relevant documents.
Walking the sustainability assessment talk — Progressing the practice of environmental impact assessment (EIA).	Morrison-Saunders, Angus, & Retief, Francois	2012	Literature review.
Life cycle costing and externalities of palm oil biodiesel in Thailand	Silalertruksa, T., Bonnet, S., & Gheewala, S.	2011	Life cycle costing.
Strategic Environmental Assessment for sustainable expansion of palm oil biofuels in Brazilian north region.	de Carvalho, C. M.	2011	Literature study and environmental assessments.
Introduction to environmental impact assessment.	Glasson, J., Therivel, R, & Chadwi, A.	2005	Use of material from previous editions, drawing on findings of important reviews, and case studies.
Environmental Impact Assessment Review, About the Journal	Environmental Impact Assessment Review	1980	Review of existing literature.

5.1 Environmental impact assessment methods

We will be presenting the evolution of environmental impact assessment methods that focus on palm oil and tropical agriculture. The most common and relevant impact assessments for our analysis, focused on impacts on the environment, are environmental impact assessment

(EIA) - which the life cycle assessment (LCA) method is often used to conduct - and strategic environmental assessment (SEA) (Environmental impact assessment review, 1980).

5.1.1 Environmental impact assessment

Environmental impact assessment (EIA) was first introduced in the 1960s, and was formally established in 1969 in the United States (Glasson & Therivel, 2013). Over the last 50 years, EIA has grown and gained a family of assessment tools, called impact assessment (IA) or environmental assessment (EA). These focus on widening the scope, scale, and integration of assessments, consisting of social impact assessment, health impact assessment, risk impact assessment, strategic environmental assessment, traffic impact assessment, and more, as well as associated techniques such as life cycle assessment, multicriteria decision analysis, and cost benefit analysis (Environmental impact assessment review, 1980: Glasson & Therivel, 2013).

EIA is a tool to assess impacts of planned activity on the environment in advance, which allows for measures to be taken in order to avoid negative impacts (Glasson & Therivel, 2013). EIA therefore has the potential to deliver on sustainability expectations. The tool did not initially start out with sustainability as the underlying purpose, however, it has been extended in many cases to qualify as a sustainability assessment (Morrison-Saunders & Retief, 2012). EIA has not only received praise. It was in its early years described as issue driven and flexible, but have in later years been criticised for lacking these qualities and has in some cases only been used to "*tick the box with respect to procedural compliance*", instead of as a thorough quality control and analysis (Morrison-Saunders & Retief, 2012, p. 34).

With that said, the demand for EIA has been growing internationally. The Rio Declaration on Environment and Development, that took place in 1992, was an important factor in promoting EIA (Glasson & Therivel, 2013). The conference laid out an action plan for the international community on how to achieve sustainable development, including topics such as biodiversity and deforestation. The environmental impact assessment tool was employed in nearly all countries in the world in 2012, as 191 out of the 193 members of the United Nations had in one way or another committed to the application of EIA (Morrison-Saunders & Retief, 2012). In some developing countries EIA might be the only sustainability oriented tool employed.

Different variants of EIA with different criteria have surfaced over the years and the scope continues to widen and grow (Glasson & Therivel, 2013). Christopher Wood, for example, presented an EIA evaluation model in 1995, containing 14 core criteria. This model has been applied to many developing countries, including Indonesia, Malaysia, and Thailand (Wayakone & Makoto, 2012). There are factors affecting the implementation of EIA in developing countries and in tropical areas. For instance, data and models suitable for tropical areas sometimes differ from temperate areas, how countries perceive the significance of impacts vary, and technology and knowledge may also vary. The roughly charted figure nr 5, from 2005, demonstrates how the status of EIA can differ in different parts of the world. It also showcases that the parts of the world known to produce palm oil were not as evolved as North America and Western Europe in the mid 2000s, while the palm oil industry started to endure rapid development (Glasson et al., 2005).

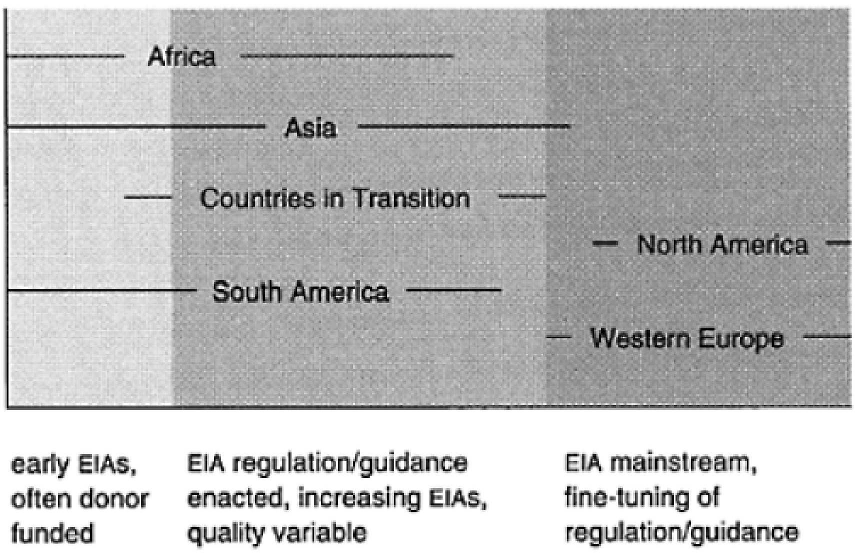

Figure 5: Status of EIA systems worldwide from 2005 (Glasson et al., 2005, p. 309)

With that said, EIA can be done in different ways, using different criteria, and is fit to analyse and evaluate many different environmental impacts. A relevant example is deforestation in tropical agriculture, specifically the palm oil industry, where EIA in that context is linked to forest governance through the granting of licenses (Lai & Hamilton, 2020). But EIA is not always effective. Benin, a country in West Africa, has lost significant areas covered with tropical rainforests due to the palm oil industry, although the country has had an EIA system since 1995 (Glasson et al., 2005). But the EIA practices at the time were impacted by lack of collaboration and communication between essential ministries, lack of public environmental awareness, and poverty, which contributed to the lack of effectiveness.

5.1.1.1 EIA development in Indonesia

NGOs have participated in Indonesia's EIA development since the 1970's as a response to the high deforestation rates, which is caused by, among others, the palm oil industry. Indonesia's EIA was first introduced in 1982, and is often referred to as Analisis Mengenai Dampak Lingkungan (AMDAL). Indonesia used Canada's EIA model as a blueprint for AMDAL. However, Indonesia has struggled to implement it in an effective way. An example of this is that the AMDAL commission has rejected different palm oil projects, but plantations have on many occasions received permits regardless (Lai & Hamilton, 2020).

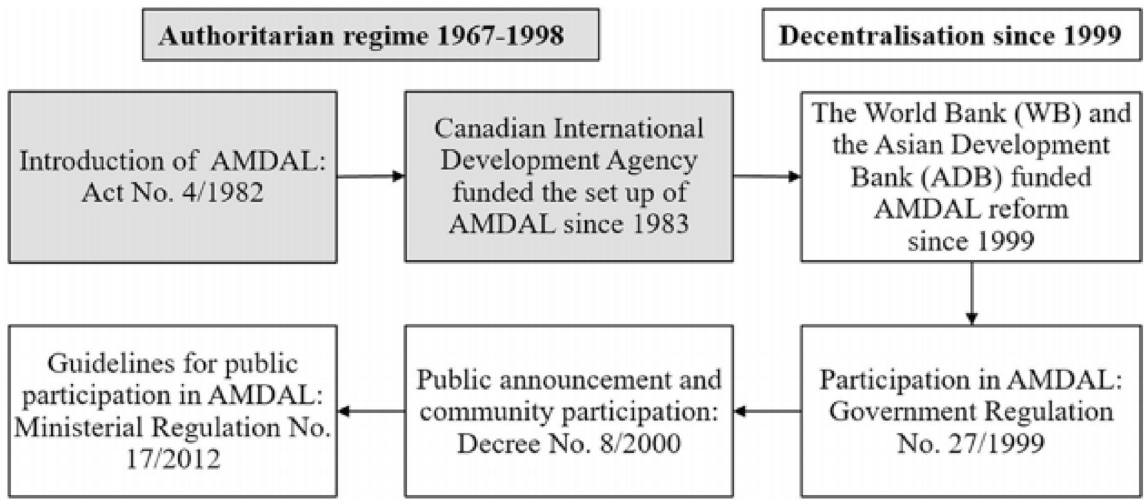

Figure 6: Development of AMDAL regulatory framework (Lai & Hamilton, 2020, p. 4)

5.1.2 Life cycle assessment

The term life cycle is a metaphor that is intended to communicate the importance of assessing the entirety of processes and steps involved in producing a product or service. The main reasoning behind using a LCA approach above others, is that it can identify and avoid situations where impact shifts between life cycle stages, where reduction in the impact in one process can come at the cost of increased impact in another. LCA was first developed in the 1960s in response to growing environmental degradation and the worry regarding limited resources. As a response to products having more complex systems and the expanding use of LCI (life cycle inventory) data and impact assessment methodologies, the first versions of

SimaPro and GaBi were developed, which are dedicated LCA software that is still widely used today with newer versions. Changes were also made over time in order to accommodate for a greater understanding of the interconnectivity between the environment and the social dimension, which led to even further development with newly emerging LCSA (life cycle sustainability assessment) studies that consider not only the environmental and social dimensions, but also the economic (Hauschild, Rosenbaum & Olsen, 2015). Below are some notable events in the life cycle of LCA methods.

In the case of palm oil, that typically means that it starts with the cultivation of oil palms and harvesting of fruit bunches, and finally, the production and shipment of the final product, CPO (crude palm oil) (Silalertruksa et al., 2011). It is more common to assess this as part of a broader study that focuses on one of the several products that are made using CPO, such as biofuel. For example, studies, one made by Silalertruksa et al., have found that certain blends of biodiesel are able to compete with petroleum diesel in cost when taking the environment into consideration, with ultimately comparable environmental impact. The reason why they end up being fairly comparable, and part of the reason why biofuel is somewhat mistakenly understood to be more sustainable than fossil fuels, is that the majority of the environmental impact from palm oil based biodiesel comes from the cultivation and harvesting of feedstock, while it is the combustion of petroleum diesel that causes the greatest impact. This difference in where the impact occurs during a products life cycle illustrates the need to consider the entire life cycle of a product or service, instead of focusing on specific steps or processes in the value chain.

LCA results are quantitative and can therefore be used to compare impacts on climate change between different processes and product systems, and this can also be useful for identifying the most critical impact variables (Hauschild et al., 2015). The results from LCAs are often initially complex as all emissions and resources are mapped with thousands of resource uses, and emissions being considered as part of the first step of the LCA. In the next step these variables are simplified into more manageable numbers and is done so by using mathematical cause/effect models to calculate the potential environmental impacts. The quantification done is based on science and uses measurements and proven casualties as its basis.

LCA can be used in quite a lot of ways and at many different levels of scope. It can be used to formulate, implement, evaluate, and present policy making and governmental decision making (Silalertruksa et al., 2011). Furthermore, it can be used in business at both corporate and product level to identify both internal and external hotspots and impacts. It is also used as part of non-state driven market forces and can influence the decision making of individuals. Put simply, it identifies impact categories and quantifies them, which in turn can be used to make better plans and strategies across various government, corporate, and societal levels.

5.1.3 Strategic environmental assessment

Many of the European Member States established SEA systems in the late 1980's. However, SEA was first introduced in the European Union in 2004, and is being used more frequently in many countries worldwide (Glasson et al., 2005). It was stated that the application of strategic environmental assessment (SEA) had grown quickly in 2013. Although few countries had established regulations of the assessment, several countries developed guidelines directing how an assessment as such should be implemented (Therivel & Paridario, 2013). Various definitions of SEA can be found, but a common definition is that SEA is "*a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest stage of decision making on par with economic and social considerations*" (Glasson et al., 2005, p. 358).

SEA has been referred to as an important tool when evaluating the environmental impacts, as well as land use change in regards to palm oil expansion - or other palm oil related plans, programs, or policies (PPPs)(de Carvalho, 2011). Usually, SEA is conducted before a potential EIA. SEA expands the operations from the EIA of projects to a strategic level. Furthermore, SEA provides informed recommendations and earlier strategic decisions (Glasson & Therivel, 2013). Simply put, SEA can be characterized as a form of EIA for PPP's (Glasson, Therivel & Chadwi, 2005).

When SEA emerged, the quality was limited, due to both lack of experience and appropriate techniques (Glasson et al., 2005). These problems have diminished over time, while others have emerged. Firstly, many PPPs are vague and unclear. Secondly, the policy process is dynamic in nature and issues are therefore likely to be redefined multiple times. Thirdly, since policy is a political process, there is the issue of decision-makers taking their own interests into account.

5.1.4 Total economic valuation

The total economic valuation (TEV) approach has become a popular method for assessing the value of nature. Its approach is based on estimating the total economic value that humans can extract from an ecosystem (Admiraal, Wossink, Groot & de Snoo, 2013). Put another way, the approach uses the monetary value of outputs of an ecosystem at a set point in time and does not focus on the state of the ecosystem. Some argue that this leaves the approach open to criticism as it concerns itself too much with the economic value for people and ignores the system in itself. This is not an invalid criticism when it comes to a purely environmental view of the approach and its application, when viewed in isolation as in without additional approaches such as LCA, but when the economic state of the ecosystem also plays a major role, the approach is quite a good one. This does not mean that it is incapable of considering the environment, but that it might do so in a more or less limited fashion.

Tangible resources such as timber, water and air purification, protection of the watershed, pollination, soil fertility renewal, protection of wildlife resources, tourism, and climate regulation can be valued using several different methods such as Direct Use Value (DUV), Indirect Use Value (IUV), and Non-Use value (NUV), which all contribute to the TEV (Nitanan et al., 2020). Biodiversity helps to protect ecosystems from state change and does therefore have economic value to humans as it helps to maintain ecological function, as well as being important for eco-tourism, as previously discussed (Admiraal et al., 2013).

Our assessment is that total economic valuation is a great tool for assessing the overall value of an ecosystem in terms of outputs and value to humans. There are certain concerns to how well it addresses concerns that relate to the long-term sustainability of the ecosystem it is attempting to evaluate. We believe that these concerns are in part addressed by the various factors that are considered in the TEV case study that is included later in this paper. Among these factors are the focus on eco-tourism, which fully depends on the maintenance of the ecological functions of the Leuser ecosystem, as well as how interconnected the ecosystem is between the various species and the overall quality of soil, air, and water.

Chapter 6: Case studies of environmental impact assessments

In this chapter we present an integrative review. The study has been conducted in a similar method as the semi-systematic review in the previous chapter, the difference is that the semi-systematic review was done to provide a wider theoretical background to build the integrative review on. The integrative review deep-dives into three cases, describing the palm oil industry through three different environmental impact assessments focusing on three different aspects of the industry, thus providing a wider and more comprehensive understanding of the industry and environmental impacts (Broome, 1993).

The transparency of how articles were selected and the integration of research is crucial. The selection process started out by doing a somewhat random search using different keywords related to palm oil and sustainability. As we read through various articles and research papers we found that most of the research done on the topic was done through life cycle studies, and the literature that we read often mentioned this, and stated that this was the most accepted method as of today. We then started to search more specifically for life cycle studies, but we soon discovered two things, there was a lack of studies that looked at the cultivation of oil palms and the production of CPO in isolation. Most of the studies we could find were aimed at the energy and/or biofuel sector. This held especially true for Indonesia, which very few studies used as a geographical location, while Malaysia, as the second largest palm oil producer, had many more studies based on its palm oil industry. During the entire process we started by finding articles that seemed relevant based on the headline, then we read the abstracts, and potentially introduction, to determine further relevance - and finally - we dived into the articles themselves to determine if it held essential information.

The main criteria we used when selecting cases was the geographical area, preferably Indonesia but tropical rainforest in the southern Asian basin were suitable substitutions. Furthermore, we evaluated topical relevance, the credibility of the publisher - such as ScienceDirect and Sustainability, age, approach, and how the material was presented. The literature search was done in two databases: Google Scholar (Scholar.google.com) and Oria (Oria.no). These databases were searched using combinations of the following search words: life cycle assessment, Indonesia, production cost analysis, LCC costing, total economic valuation, LCC, LCA, LCSA, TEV, palm oil, production, tropical agriculture, crude palm oil, palm oil cultivation.

We have chosen to use an LCSA study in order to highlight the need for consideration of the impacts of the palm oil industry in a holistic fashion. Our original intent was to complete this paper using various life cycle studies, but ultimately we could not find a suitable LCC study, which was important for the economic dimension included in this paper. This led us to search for another type of study we could use to assess the economic dimension, for which we chose the TEV of Leuser National Park in Sumatra, Indonesia, which we had used previously in the paper. We chose this as it provided insight into how economists can contribute in environmental matters, and because we found the TEV approach an interesting one that added to our paper by taking a different approach, especially by its implementation of three different use scenarios. By which we mean that instead of looking at the direct cost of impacts in isolation without regard for the overall value, it considered the cost of the impacts in relation to the overall value of the chosen geographical area, here the Leuser National Park.

LCSA is a rather newly developed approach to assessing environmental impacts. It is a much more holistic approach compared to LCA, LCI, or LCC studies, which allows for a broader and more complete picture of the full extent of the environmental impacts. The chosen study provided good insight into the social, economic, and environmental dimensions in a clear way, it also presented its data in a smart and creative fashion. The LCA study mainly deals with the waste material from the production of CPO, which seems somewhat neglected in many other studies, and with a life cycle approach we found this to be an important and interesting addition in order to round out the paper.

Final literature sample - Case			
	Case 1	**Case 2**	**Case 3**
Title	Visualization of the Sustainability Level of Crude Palm Oil	Current state and environmental impact assessment for utilizing oil palm	Economic valuation of the Leuser National Park on Sumatra, Indonesia

	Production: A Life Cycle Approach	empty fruit bunches for fuel, fiber and fertilizer - A case study of Malaysia	
Author	Omrat, N. Sharaai, A. H. & Hashim, A. H.	Chiew, Y. L & Shimada, S.	Beukering, P., Cesar, H. & Janssen, M.
Year	2021	2013	2003
Method	Life Cycle Sustainability Assessment.	Life Cycle Assessment.	Total Economic Valuation. Impact assessment.
Geographical area	Johor, Malaysia	Malaysia	Indonesia
Theme	A holistic approach utilizing several life cycle models as dimension in order to determine the environmental, economic, and social impact of crude palm oil production.	Analysis of the utilization of empty fruit bunches for fuel, fiber, and fertilizer and their respective environmental impact.	A total economic valuation of the Leuser Ecosystem under the three following scenarios: deforestation, conservation, and selective utilization.

6.1 Case 1: Life cycle sustainability assessment

In order to understand the environmental damage and the economic cost of producing crude palm oil (CPO), an LCSA model can be used. We chose a LCSA study by Omran, Sharaai & Hashim (2021) to draw information from, and want to make it clear that case 1 is built on this source. The study was designed to be a holistic approach and it combines life cycle costing (LCC), social life cycle assessment (S-LCA), and standardized life cycle assessment (LCA), into the life cycle sustainability assessment (LCSA). The focus of this paper is the environmental and economic impacts of the industry, but also how to move in a more sustainable direction, which is why a holistic approach, that here also includes the social impacts, fits well, as social impacts generally influence policy and regulation. The following section is an extraction of the data most relevant to our own thesis, with some descriptions of the methodology used for context and better understanding.

6.1.1 Methodology

The goal of the original LCSA study was *"to evaluate the level of sustainability of crude palm oil production in two selected palm oil mills in Johor Bahru/Malaysia*" (Omran et al., 2021, p. 3). The scope of the study was limited to harvesting and production of CPO, both at the palm oil plantation and at the mill where CPO is refined, where most of the impact occurs. 1 megatonne (MT) of CPO was used as the functional unit in the study. An overview of the life cycle of CPO can be found in the original case in appendix nr 1, figure 1.

A data collection sheet was used to gather data from the selected palm oil mills for the year 2019. The data were collected for the following items: consumption of water, fresh fruit bunch (FFB) crops yield, power consumption from turbines, chemical fertilizers and pesticides, consumption of energy, diesel and water for the mills processes, quantity of FFBs transported to the mills and the respective average distances, consumption of diesel, and waste production included in the crude palm oil production's life cycle.

6.1.1.2 LCSA scoring system

The three dimensions in the study – environmental, economic, and social - are assumed to have the same weight, but the indicators for these dimensions have different percentages of contribution to product sustainability. Inventory data from the dimensions were given scores from 0 to 4, with an additional differentiation between negative and positive indicators. A high score, closer to 4, indicates high positive scores and low negative scores, meaning an overall "better" score.

6.1.2 Results

6.1.2.1 Environmental dimension

The environmental impact that was found, through the Eco-Indicator 99 method, showed that the most significant environmental factors were from climate change, respiratory inorganics (substances which cause breathing difficulties), carcinogens (substances that promote cancer), land use, and fossil fuels, in both selected mills. The major contributor to the ecosystem quality impact category in the study was from FFB production at the plantations, under the land use subcategory. GHG emissions such as CO_2 and methane were identified as the main drivers for the climate change subcategory under the human health impact category. And lastly, fossil fuels make up most of the resource use impact category. This tells us that the impacts are quite substantial and varied and that it can be difficult to determine which impacts to address first.

Mill A had the highest environmental impact in all categories, details can be seen in appendix nr 1, table 2. The reason for this is that A has both a larger plantation mill and a higher capacity than B. This means that plantation mill A requires more use of fertilizers, pesticides, diesel, power, and water to produce the FFB that the mill processes, which then in turn, due to higher capacity, generates more waste such as shells, fibers, and empty fruit bunches. This naturally causes more gas emissions as well. We consider the reason behind these higher costs and impacts to be unclear in this case, despite the costs having been calculated based on a functional unit. We speculate that it could be a negative consequence caused by larger scale production, such as pesticides having an exponential effect on the environment, but we can not find anything conclusive.

6.1.2.2 Economic dimension

It was found that mill A had higher costs in every impact category, see appendix nr 1, table 3, except for initial investment cost, and in almost all subcategories. The supplementary material to the study shows that items such as a generator, transport, and machines was the reason behind the comparatively high initial investment cost for mill B. The higher costs for mill A is easily explained by the greater size of this plantation mill. It naturally requires more fuel, manpower, fertilizer, etc., to operate a larger mill with a greater capacity than that of mill B.

6.1.2.3 Social dimension

The social dimension was aimed at both the workers' satisfaction with their workplace, but also the local community as a whole and the mill's contribution to the community. For most of the subcategories the workers satisfaction was around 90% or higher and indicated that they were generally pleased, see appendix nr 1, table 4 for further details. Most of the workers were pleased with their tasks and their relationship to their manager, their wages, low discrimination and equal opportunity, and social security and benefits. The greatest source of displeasure was the mill's management of cultural and heritage conservation issues, where only 68% of respondents were satisfied. There was also a 79.5% positive response to the local communities' job opportunities.

6.1.3 Conclusion

The results of each dimension were scored and visualized through a graphical presentation of the life cycle sustainability assessment (LCSA) results, as seen in figure 7. The old triangle area, which represents the maximum score, comes out to 6.9, while the new triangle which reflects the sustainability score, only equals 3.9, or 56.5%, indicating a low sustainability score. The study concludes that CPO requires considerable work in order to become a sustainable product, but the authors also note that further applications of the method are necessary in order to fully assess its applicability. It was found that the production of CPO contributes to environmental damage primarily from respiratory inorganics, fossil fuel usage, and climate through land-use. The primary force behind the economic cost was the high initial investment cost. The social impact was dominated by accident and injury and social benefits. A detailed scoring card can be found in appendix nr 1, table 8.

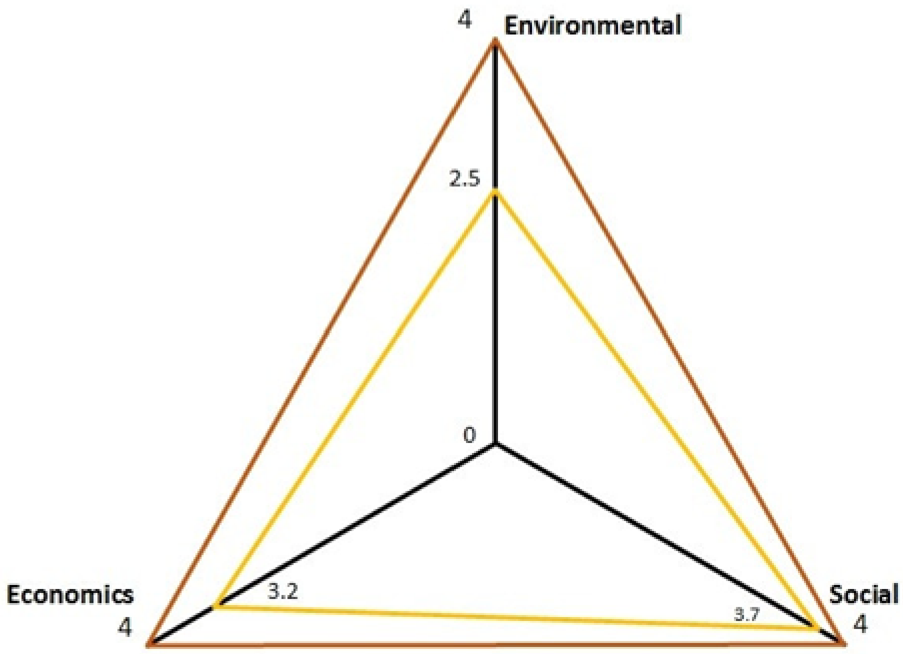

Figure 7: "*Graphical representation of life cycle sustainability assessment*" (Omran et al., 2021, p. 14)

6.2 Case 2: Life cycle assessment

We chose the Life Cycle Assessment (LCA) study by Chiew & Shimada (2012) as the source for case 2. Oil palm residue and the usage of it has been a matter of focus in Malaysia, leading much research on and development to emerge, and we take advantage of this as Malaysia can be used as a comparable country to Indonesia. The LCA study assesses the energy consumption and environmental impact of various technologies for utilizing the empty fruit bunches (EFB), using seven different options for the recycling of EFB left over from the production of CPO. The study therefore gives us insight into the production process and utilization of EFB as well as the land-use-effect. This will be useful when discussing the palm oil industries sustainability as well as alternative sustainable solutions, especially in reducing greenhouse gas emission.

6.2.1 Methodology

The seven treatment options are: "*ethanol production, methane recovery, briquette production, CHP plant (combined heat and power plant), composting, MDF (medium density fiberboard) production, and pulp and paper production*" (Chiew & Shimada, 2012, p. 110). The study considered the pre-treatment processes involved in every treatment option, and then the final disposal of the waste remaining after the processes. The advantages of the different environmental impacts were evaluated by looking at the allocation of avoided products within the systems for each technology. Lastly, a sensitivity analysis was performed using the Eco-indicator 99 method to determine the land-use effect.

The following impact categories were investigated further: acidification, ozone layer depletion, human toxicity, freshwater ecotoxicity, abiotic depletion, global warming, photochemical oxidation, marine ecotoxicity, terrestrial ecotoxicity, and eutrophication.

6.2.2 Results

6.2.2.1 Environmental impact assessment without allocation of avoided products

If there is no allocation of avoided products, then composting stands out as the most environmentally friendly treatment of EFB due to the fact that it has the lowest values in most of the impact categories. On the opposite side, pulp and paper production is the least environmentally friendly technology as it has the highest values by far in all of the impact categories, with eutrophication as an exception.

Depending on the intended use of the LCA, different treatment options might be considered as the more favorable choice. If we perceive global warming, acidification, and ozone layer depletion as the most crucial categories of impact, then an overall review suggests that the least to most detrimental impact on the environment, in order, comes from composting, followed by *"briquette production, MDF production, CHP plant, methane production, ethanol production, and pulp and paper production*" (Chiew & Shimada, 2012, p. 118). Composting only emits 22.2 kg CO_2e per tonne of EFB, which is less than a sixteenth of the 361.8 kg CO_2e emitted from pulp and paper production. Similarly, composting only emitted 0.07 kg SO_2e (sulfur dioxide equivalent) per tonne of EFB compared to the 1.38 kg SO_2e from pulp and paper production, which is almost twenty times less.

6.2.2.2 Environmental impact assessment with allocation of avoided products

The environmental impact of each method was also calculated by considering the allocation of avoided products. Under the allocation scenario, EFB provides no significant benefit in any of the impact categories when used as an alternative source of fiber in MDF production. Nonetheless, the CHP plant and methane recovery, when connected to the national power grid, is in fact favorable in almost all the impact categories. EFB used in composting also performs well all in all with benefits in five out of the eight impact categories.

The technologies such as CHP plant, ethanol production, briquette production and methane recovery, that convert EFB into biofuel, are to varying degrees favorable to the environment. CHP plant, composting, and methane recovery have high potential for reduced effect on global warming with reduced GHG emission of 218.6 kg, 176.5 kg, and 154.6 kg of CO_2e equivalent per tonne of EFB, respectively. Briquette production and ethanol production reduces GHG emissions by 44% and 25%, through allocation of avoided products. Yet, pulp and paper production and MDF production reduction is less than 1%, which is insignificant.

6.2.2.3 Normalization values

CHP plants had good performance and proved to have benefits greater than methane recovery in seven of the impact categories with normalized values, for which details can be found in appendix nr 2, table 5. Compared to CHP plants, methane recovery generally provides less benefits to the environment. CHP plants also perform better than composting by benefitting more impact categories since it has significant impacts in the three categories; abiotic depletion, marine aquatic ecotoxicity, and global warming. MDF production as well as pulp and paper production are less beneficial treatments due to the high levels of energy used in the process, the chemicals being used, and emission stemming from the waste treatment.

6.2.3 Sensitivity analysis of land-use-effect

It is assumed that land use will alter habitat size by threatening species with extinction when humans take over vast areas for agricultural purposes. When measuring the land-use-effect, we look at the disappearance of species. This is done with the unit of Potentially Disappeared Fraction of Species given per area per year.

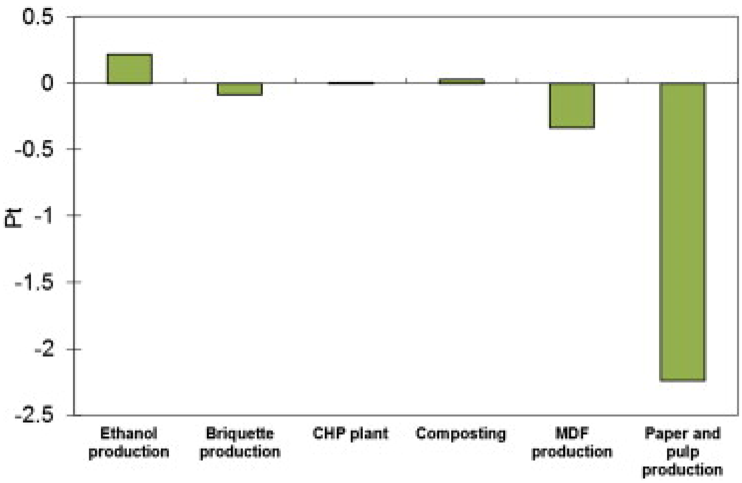

Figure 8: "*Land use impact of each technology in Ecoindicator 99*" (Chiew & Shimada, 2013, p. 120).

We can see the impact on land use in figure 8, when the implementation of the treatments convert the land into industrial areas. The benefits for pulp and paper production is clear when it comes to impact on land use at 2.2 Pt (40 PDF m^2yr), compared to the second highest which is MDF with a minor benefit of 0.3 Pt (6 PDF m^2yr). This is due to the difference in conversion rate from EFB. Although pulp and paper is beneficial in regard to the land-use-effect, it does not outweigh the fact that it is the least environmentally friendly option measured by the impact categories, in our opinion.

6.2.4 Conclusion

When evaluating which technology provides the lowest emission results - given the assumptions used in the LCA study, without considering allocation of products and by-products - composting came out as the winner, and biriquett was in second place, followed by "*MDF production, CHP plant, methane recovery, ethanol production, and lastly pulp and paper production*" (Chiew & Shimada, 2012, p. 118). The order is different when allocation of products and by-products are taken into account, as CHP plant have the least emission, next, in order, is "*methane recovery, composting, briquette production, ethanol production, MDF production, and pulp and paper production*" (Chiew & Shimada, 2012, p. 121). In both instances, pulp and paper production is the least favorable technology. While composting is in the top three most favorable technologies in both instances. Lastly, the MDF production as well as the pulp and paper production have an advantageous impact on land use.

6.3 Case 3: Economic valuation of the Leuser National Park

We chose the study on economic valuation of the Leuser National Park by Beukering, Cesar & Janssen (2003) as the source for case 3. Despite being protected by its status as an Indonesian national park, the Leuser National Park on Sumatra was, and is, under serious threat from deforestation. Ecological functions, that is the dynamic balance and natural processes, such as water purification, decomposition of wastes, etc, in the ecosystem – started to decline. The park was host to several animals which face probable extinction. Additionally, a great number of economic activities in and around the park were also affected. The study was conducted with a twofold objective to first was to use a systems dynamic model to find the total economic value (TEV) of the Leuser ecosystem. The second objective was to evaluate the effects on economic value under deforestation vs conservation scenarios.

The total economic valuation approach is an alternative approach when compared to the more widely used life cycle methods, when it comes to evaluating the environmental impact and economic costs and benefits of tropical rainforests. We found this to be a useful tool which provides a different view for how the impacts of land-clearing in regard to the palm oil industry can be measured. This alternative approach also provides further insight that can be used when answering how economists can contribute by taking the environment into consideration. The greatest advantage that we have found from the total economic valuation approach is that it provides a long-term estimate of the environmental impacts and their costs/benefits, in addition to not only considering the impacts that the palm oil industry has, but also the potential costs and benefits. The case is a bit old but we have previously provided data that supports the findings. Additionally, since we are more concerned with the approach and its applicability in the modern climate, the age of the study does not present itself as an issue.

6.3.1 Three scenarios

In the *deforestation scenario* it was assumed that both legal and illegal deforestation would continue along the trend at the time, as well as harvesting of non-timber forest products (NTFP). As a consequence, eco-tourism would not be developed and the international interest in investing in conservation and carbon sequestration funds would decrease. When this starts to affect the ecological functions, it affects the local community as well. This was also assumed to be the most likely scenario if everything was left as business-as-usual.

The *conservation scenario* assumed a complete halt of deforestation with maximum development of eco-tourism. International investment in conservation funds continues to be high, while investment in carbon sequestration increases.

Finally, the *selective use scenario* allows for logging of primary forest at a considerably reduced rate, with replanting of logged forest being compulsory. This would lead to less primary forest but the overall forest area remains constant, as it is replaced with secondary forest. Harvesting of NTFP will be actively developed but the decrease in levels of biodiversity will lead to a lesser degree of eco-tourism, due to less biodiversity, when compared with the conservation scenario. The same were expected to occur when it comes to investment in conservation and carbon sequestration, as well as the ecological functions such as water supply and flood prevention.

6.3.2 Methodology

A dynamic simulation model was used to evaluate the three scenarios – conservation, selective use, and deforestation – during 2000-2030. The period was chosen in order to provide sufficient time for the main environmental impacts to occur, and short enough to leave room for estimations on future development. They also identified the different types of benefits and how these were distributed between the various stakeholders, and their regional distribution. The choice to use TEV was made based on the stated assumption that most economists agree that the value of natural resources extends beyond only their direct financial value. Therefore, the value these resources have are considered in the broadest sense of the term.

6.3.3 Results

6.3.3.1 Total economic value

When applying the 4% discount rate, the calculated total economic value under each scenario were US $9.1 billion for the *conservation scenario*, US $7.0 billion for the *deforestation scenario*, and lastly US $9.5 billion for the *selective utilization scenario*. The annual net benefits can be seen in figure 9.

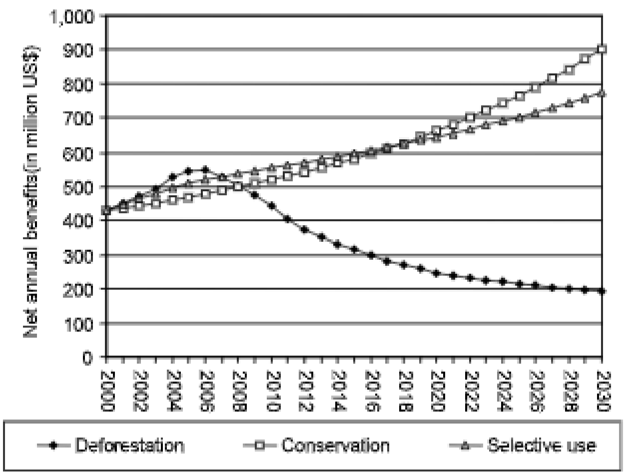

Figure 9: "*Net annual benefits over time of Leuser National Park*" (Beukering et al., 2003, p. 57).

Figure 9 shows that the conservation and selective use scenarios have far greater socio-economic benefits than the deforestation scenario after 10 years. The reason behind the initial benefit of deforestation comes from the large revenues from increased logging and harvesting, as well as the negative impacts of deforestation still being manageable. After the most lucrative forest has been cut down and only hard to reach forest is left, timber and NTFP becomes less attractive for logging companies. The declining ecological functions start to stack up over time, further reducing the benefits of the deforestation scenario. The opposite happens under the conservation scenario where better utilization of goods and services leads to greater benefits. Several sectors such as hydro-electricity, tourism, and agriculture also benefit from the rainforest functioning properly.

6.3.3.2 Benefit distribution

The Leuser Ecosystem provides many beneficial goods and services and these vary significantly between the three scenarios. The deforestation scenario notably loses out in all categories except for agriculture and timber, which is to be expected. For both the conservation and selective use scenarios we find the most important benefits come from water supply and flood prevention, and we also find that the selective use scenario greatly benefits from NFTP. There is also a geographical difference in distribution based on geographical characteristics, the size of the economy, and the level of dependency on the park - that we will not go further into here, but which can be found in the original study. See appendix nr 3, table 4 for details on the distribution.

6.3.3.3 Stakeholders

The group benefitting the most from the Leuser ecosystem is the local community and therefore their share will grow from the conservation scenario. It is the logging industry that benefits the most from the deforestation scenario, as expected, but even the wealthy stakeholders of both the logging and plantation industries are negatively affected to a certain degree in the long run under the deforestation scenario. They are directly dependent on the forests for their business and are therefore themselves affected by their own unsustainable practices which causes decline in ecological services. The local government benefits more in the short-run vs long-run from deforestation, due to declining taxes - and the international community benefits greatly from conservation through biodiversity and sequestration, which is important for developed countries.

The elite logging and plantation industry takes a much larger proportion of the total value when comparing the deforestation scenario with the conservation scenario, 23% vs 11%. The considerable power that these two interconnected industries have between them create extremely high barriers for realizing the conservation scenario. There is a conflict of interest between the logging and plantation industries, and the local and international communities.

6.3.4 Conclusion

The sensitivity analysis, which tested several crucial parameters, showed that the many necessary assumptions made did not impact the results fundamentally, and as such they hold. Total economic value is a proficient tool to assess the welfare changes that the various scenarios will have on the Leuser Ecosystem. Besides the various TEV for each scenario - US $9.1 billion for the *conservation scenario*, US $7.0 billion for the *deforestation scenario*, and lastly US $9.5 billion for the *selective utilization scenario* – the analysis also reveals that the benefits are spread fairly equally across the local regencies under the conservation scenario. Deforestation has the opposite effect, and it is reasonable to assume that this might cause conflict between the regions, while conservation can lessen that tension. Additionally, by supporting the underprivileged majority of society, conservation contributes to social and economic equality.

As a consequence of the strong economic and political power of the logging and plantation industries, destructive and unsustainable practices continue to ravage the Leuser Ecosystem. This leads to both the least economically favorable scenario to be the most likely one to occur, as well as preventing those who are already doomed to be the losers from being compensated fairly when deforestation continues, to have a chance to recover. The least preferable scenario both economically and for the environment, is the one most likely to continue.

Chapter 7: Analysis

In this chapter we will be discussing information and findings from the previous chapters and use it to answer our research questions. The first research question focuses on negative impacts on the environment, while the last two are oriented towards identifying sustainable solutions. The discussion and the research questions should form a foundation for answering the problem statement “Environmental impacts of the palm oil industry, particularly in Indonesia, and how the industry can move towards sustainability”.

7.1 What are the major negative environmental impacts of the current and expanding palm oil industry in Indonesia?

In trying to assess and understand the environmental damage of the palm oil industry in Indonesia, we analyse existing literature and research documented in the descriptive chapters as well as the LCSA case study. In the absence of literature and data from Indonesia, Malaysia was used as a comparable country.

7.1.1 Evaluation of the triple bottom line

To identify ways the palm oil industry can move towards sustainability, it is important to not only identify the major environmental impacts, but to also say a few words about the overall sustainability. However, we emphasize that the environmental dimension is the main focus.

The LCSA study identifies that the practises in the economic dimension at the plantations and mills are not optimal with today's standard. The social dimension from LCSA is quite good due to fair salaries, job satisfaction, equal opportunity, and safe and healthy living conditions. Meanwhile, culture and heritage and job opportunities in the local community drag the score down. With that said, if we look away from the LCSA study and on to a broader view, negative impact can be found in the social dimension. For example, the 2015 forest fires in Indonesia did not only contribute to climate change through GHG emission, it also had a detrimental impact on lives and caused an estimated 100,000 premature deaths.

The LCSA study concludes that the environmental factors with highest significance were from climate change, toxic substances, land use, and fossil fuels. The LCSA triangle helps us understand that there aren't just many different environmental impacts, which are discussed later, but the impacts are also significant. The LCA study found that current waste management practices are outdated and function poorly, having a large negative effect on both the environment and profits.

There are concerns in all three of the dimensions which reflect the concerns highlighted by the triple bottom line, reflecting a weak overall sustainability in the industry. With this insight it is clear that there is potential in all three dimensions.

7.1.2 Cause and implications of deforestation

Indonesia has one of the highest deforestation rates in the world, and we therefore seek to understand the reason for and consequences of the excessive deforestation activities.

The first and simplest answer to what we investigate is that the natural rainforest is being cleared out in order to make room for palm oil plantations. The natural forests are essential for the global climate and help mitigate climate change. The conversion of rainforests for the purpose of creating palm oil plantations is therefore a significant impact in itself, but it has also proven to trigger other consequences. It is also linked to climate change, forest fires, greenhouse gas emissions, and it is a threat to biodiversity and ecosystems, which are further discussed later. In the case of the Luser ecosystem, we see how long-term sustainability is not realistic with the current rates of deforestation. Given enough time, the extraction of resources for monetary gain will end up hurting not only the environment but the stakeholders motivated by money.

It is important to know not only what the environmental impacts are, but also what causes and drives them, in order to discover sustainable solutions. Accessible forested lands, higher prices for agriculture and timber, low rural wages, and opportunities for long distance trade are stimulators for deforestation. State policies facilitating development of palm oil plantations makes the matter worse. The power in granting plantation permits is decentralized, despite the fact that the local government no longer has formal power to issue permits. This was seen in Central Kalimantan, where hundreds of permits have been granted in spite of not having formal land release, and in many of the cases where formal land release has been given, there has been evidence of bribes. Corruption is a widespread problem in Indonesia, and as we see, the palm oil industry is no exception. Some environmental impacts would likely be present no matter how the industry operates, such as the release of GHG, but the impacts do not have to be major. However, all of the factors mentioned here drive deforestation and enable unsustainable practises, resulting in major impacts.

7.1.3 Impact on ecosystems

There is undeniable evidence of the decline in biodiversity, but what is the cause of these disruptions and what are the effects of it?

Through the LCSA study we discovered that a major contributing impact from the palm oil industry on the quality of the ecosystem was from fresh fruit bunch production at the plantations, in regard to land use and important factors such as deforestation and chemical usage in the production process. This is supported by the findings in the LCA case. When the natural rainforest is replaced with palm oil plantations it reduces the forest's plant diversity as well as diversity in animal species and habitat size. Considering that Indonesia holds one of the world's largest major life zones and contains some of the most biodiverse flora and fauna, the destruction of its rainforests is a critical problem.

The exact effect of and impact on the environment from biodiversity loss has been hard to pinpoint. What we have discovered is that biodiversity helps the ecosystem operate normally and recover faster after shocks to the equilibrium, and is therefore very important. When the loss of enough minor species starts to stack up, the effects become visible. The mix of species is complex and simply replanting forest does not bring back the loss of crucial species necessary for a healthy ecosystem. When one species is lost, it can lead to a decline or increase in several others, causing a chaotic and unpredictable impact on the local environment which can stack up and lead to a negative effect on the global ecosystem, and should clearly be avoided.

7.1.4 Greenhouse gas emission and climate change

The main drivers for climate change in relation to the palm oil industry are, according to the LCSA study, the destruction of the natural forests and GHG emissions, especially CO_2 and methane. These gases come from deforestation, destruction of peatlands, and production of fresh fruit bunches.

The LCSA study showcases, by comparing two plantations of two different sizes, what elements in the production process cause environmental damage and how much the scale of the production matters. It was discovered that larger plantations with higher capacity use more fertilizers, pesticides, diesel, power, and water to produce fresh fruit bunches, creating a larger amount of waste such as shells, fibers, and empty fruit bunches. This naturally causes them to have higher gas emissions in the production process. But before the production of palm oil starts, the plantations require a space to carry out the production process. This is when deforestation or destruction of peatlands occur.

Burning is a common method for clearing out forests and emits large amounts of GHG. Forstestburning involves large fires that are challenging to control, especially when the weather is dry. Intentional fires have therefore, on many occasions, caused accidental forest loss and emitted significant amounts of GHG. The fact that the daily emissions of GHG from forest fires was comparable with the daily emissions of the USA in 2015, emphasizes how damaging deforestation is, especially when done by burning.

With the production of fresh fruit bunches and burning as a method for deforestation discussed, the most significant GHG emitter must be investigated, namely peatland destruction. Peatland oxidation is the greatest single source contributing to CO_2 emissions per ha and an estimated 20% of palm oil plantations are located on peatlands. It should therefore come as no shock that palm oil plantations on peatlands are responsible for more than 100M tons of CO_2e (CO_2 equivalent) emissions. The 2.5 gigaton loss in carbon stock in tropical peatlands since 1990 is highly problematic. Peatland areas used for plantations increased from 700,000 ha to 2,000,000 ha in the 14 years from 2000 till 2014. These numbers do not only indicate major negative environmental impacts, but it also indicates future growth, based on the past growth, implying worse impacts in the future.

7.1.5 Conclusion

We discovered that there is a crucial need for the reduction of major environmental impacts and that all the environmental impacts discussed are linked. Firstly, destruction of peatlands and removal of the natural forest means the removal of a natural system that helps mitigate climate change, as well as creating additional negative effects to the climate and the environment, through GHG emission, especially through CO_2 and methane. Secondly, the effect on the quality of the ecosystem mitigated from production of fresh fruit bunches, through land use and chemicals that reduce forest's plant and animal diversity jeopardise some of the most biodiverse flora and fauna in the world, and hinders the ecosystems from operating normally.

In conclusion, the major negative environmental impacts are destruction of peatlands and the natural rainforests, resulting in loss of biodiversity, disruption of important ecosystems and ecological functions, degradation of soil, and significant amounts of GHG emissions. Accordingly, deforestation, destruction of peatlands, and GHG emissions needs to be reduced to lessen the environmental impact on climate change, biodiversity, and ecosystems.

7.2 How can economists contribute by taking the environment into account when calculating profitability, and how can the negative environmental impacts be measured?

It is well known that money plays an important role in most aspects of modern society, and the palm oil industry is no exception, nor is how businesses manage resources and interact with the environment. It does therefore seem like a necessity to be able to put monetary values on environmental impacts and create more digestible representations of these numbers, than those often found in existing research papers. This will make them easier to understand and use when creating governmental or industry policies and regulations. We have chosen studies that attempt to do this by using life cycle approaches in order to determine a monetary value that can be used to evaluate the extent of these impacts. Additionally, we used a study that estimates the total economic value of an Indonesian national park, and how different logging and deforestation practices will affect this value over time. It is not only the cost of environmental impacts that needs to be considered. Producing crude palm oil (CPO) does of course have costs associated with it, and these need to be considered together with the environmental costs before we can see the entire picture and compare palm oil and palm oil derivatives, to other products. According to the SEA method, the three sustainability dimensions that we have included, should be considered as equally important. Another way of phrasing it is that these three should preferably be addressed together.

When discussing the necessary steps for the palm oil industry to become sustainable, there is no denying the important role that costs and profits play. Neither the locals of Indonesia nor the greater palm oil industry is likely to take any meaningful action towards sustainability as long as there are greater profits to be made by doing business-as-usual. When economists are able to present economic arguments for why the various industry actors should focus on more sustainable practices, that is when we are likely to see meaningful change. It is important that these figures are presented in ways that are easy to understand, and that underlines that, while it might be more costly in the short run, investments in environmental sustainability will equal greater profits in the future, and for a longer time period. Investing in alternative waste management is an example of how economists can demonstrate that high initial investment in equipment and systems can lead to higher economic return in the future, while also taking the environment into account. Tropical rainforests have great economic potential, but the resources are finite, and sustainability is essential. Environmentally sustainable forestry practices can lead to greater profits in the long run and be more economically sustainable as well, while identifying the economic value of rainforests can help in making better plans and regulatory policies.

7.2.1 The role of environmental impact assessments

One of the primary uses of impact assessments today, is assessing the impact of activities on the environment prior to the start of the activity. This means that the approach lends itself well when attempting to predict the potential outcome of any given activity that will affect the environment. Many environmental impacts are not immediately apparent and might manifest at a later time, or in some cases after an activity has concluded. Therefore, simply being content with seeing how things go or monitoring the state of the environment along the way, is not enough. While EIA has been part of Indonesian system for a long time, the implementation has been poor. This is stated in the literature by Lei & Hamilton, and our findings have been similar. The primary advantage of utilizing EIA studies in this thesis is that despite there being somewhat limited data to draw from, this approach is still the most used approach which provides us with more data. In addition, we found it to be the most extensive type of study providing a lot of relevant information that relates to our research questions.

The lack of EIA articles, especially life cycle studies focused on Indonesia, indicates to us that there is a lack of transparency and research in the Indonesian palm oil industry. Also of note, is that several of the studies done on the environmental impact of palm oil cultivation and CPO production struggled with finding willing participants among the various plantation and mill owners, and when they did, the number of plantations and mills were limited. This, first of all, indicates an unwillingness to cooperate and reveal potential weaknesses in the sustainability of their processes, but it also limits studies to a degree when they are forced to work with smaller sample sizes. This does not invalidate the existing literature, but there is clearly a need for more transparency and there is still a lot of work to be done when it comes to further research, and in regard to both inventing and implementing better sustainable practices in the Indonesian palm oil industry.

By using EIA and taking environmental concerns into consideration, we become better at understanding the environmental losses that are associated with the loss of primitive primary forest and biodiversity, and can uncover how replanting is not an equal substitution. These losses can be seen in the evaluation of the total economic value of the Leuser ecosystem, and having empirical data on this can help with avoiding or limiting potential irreversible losses in biodiversity. As stated, this loss directly affects important ecological functions and services such as carbon storing, flood prevention, soil quality, etc. We cannot predict or know all the various connections that exist in these ecosystems, meaning we cannot simply plant new trees and assume that everything will go back to normal. Even if we did know, many natural processes can easily be irreversibly damaged, and would in the best of cases take many years to restore. Making plans that take the environment into consideration have become an absolute necessity for creating a sustainable world, which we all know is becoming a more and more critical concern for humanity. EIA is an effective way to do this, especially as the empirical data is expanded upon and more research is being done.

7.2.2 Measuring environmental impacts

Since the palm oil industry plays such a large role in the Indonesian economy it affects quite a large number of people. The industry has been directly connected to a considerable reduction in poverty in certain regions in Indonesia as well as decreasing the inequality of development. As it is the poor that relies the most on natural resources and they are also the ones most impacted when they are being destroyed by the unsustainable practices that the palm oil industry deploys. It is also important to understand the full value of the natural resources that remain to the world, from both an environmental and economic perspective. We can use this understanding to better protect the poor and those that rely on these resources the most, and incentivize those who hold power but have few or no concerns beyond economic gains. This effect on the poor does not appear to be the case when considering today's literature, given the high LCSA social score, but could be expected to appear in future literature as the environmental impacts become more evident.

There are many different ways that environmental impacts can be measured, but in general the two overarching approaches is to look at either how our actions affect the “quality” of the environment, or how our actions affect the economic value that we can extract from the environment. These two concepts are of course tightly interwoven with each other as we explained above since the value we can extract can vary greatly depending on how we treat the world around us and how natural processes are affected. But not every environmental aspect is something we want to, or should, extract economic value out of, nor necessarily something we *can* extract value from. Protected forests and peatlands still carry immense value through their ecological functions when they store carbon, produce oxygen, provide protection from natural disasters, host and nurture biodiversity, etc.

Various sources provide different estimates for how much the palm oil industry in Indonesia contributes to the environmental impact on the world. It is understandably hard to quantify and estimate the many potential effects of an entire industry, especially when not all the various environmental impacts can be quantified and have to be viewed qualitatively; But, the better we understand these impacts the more we can do to limit them. By tracking the movement of the palm oil industry and comparing the effects on areas that are vs are not affected by the industry, we can better predict what will happen in the future, and we can better understand why and how these impacts occur. These impacts can also be predicted more accurately by using various models and simulations based on empirical data.

7.2.2.1 Life cycle costing

The LCC (life cycle costing) approach taken in the LCSA study considers the actual costs of producing the baseline product made from palm oil, CPO. Supported by previous literature on the subject of the production cost of CPO, they found that the most costly part of producing CPO is by far the cost of FFB (fresh fruit bunches), which makes up 80%-90% of the cost. This is important since we are not only concerned with the environmental sustainability of the industry, but also the economic sustainability. The life cycle approach tells us that both ends of a product's life cycle matters, and everything in between, so both the price of feedstock and how the waste products are managed, affect the overall cost of producing CPO.

7.2.2.2 Total economic value

A different approach can be seen in the TEV (total economic value) of the Leuser ecosystem. Here the approach is aimed at determining the value of the Sumatran forest, which is being destroyed, and it is found that there is actually greater value to be collected from being less destructive and removing less resources from the forest. When this is taken together with the fact that there are many areas that are not covered with primary forest, or forest of any kind, that are suitable for palm oil plantations, we can clearly see that there are better options for how we use the land areas that already are available to us.

By comparing different scenarios and viewing them through the lens of their economic value the study manages to not only quantify many of the various resources that are contained inside the forest, but they also present it in an easy-to-understand way that can resonate with both decision makers and everyday people. This is something we believe is crucial when it comes to the palm oil industry, since NGOs and similar NSMD stakeholders play an important role in trying to make the industry more sustainable, and many of those involved might not be trained researchers or economists that can understand complicated papers or what might seem like obscure values for the environmental impacts.

7.2.3 How economists can contribute to sustainability

Smallholders make up a considerable part of the cultivation of palm oil but have smaller profit margins than large plantations, and often compensate for less effective land use by increasing the overall area they grow oil palms on. That means that more of the environment gets destroyed because the smallholders cannot earn the same amount as large plantations from the same amount of land area. This is caused by a lack of information and training in proper cultivation and harvesting techniques. We also know that handling waste material and wastewater is expensive and complicated processes for the CPO production mills. Implementing better technology could potentially cut costs and reduce GHG and respiratory inorganic emissions, which could benefit both the palm oil industry and the local stakeholders. The mill owners save money, obviously, but part of that money could also be put towards educating smallholders, which would in return mean lower costs for fresh fruit bunches as it would enable smallholders to make better use of their land and cultivate it more efficiently.

While the conservation scenario described in the TEV case is the one that is most sustainable for the environment in isolation, we cannot afford to ignore the influence money has in such matters. Therefore, the selective use scenario explained in the TEV of the Leuser ecosystem case seems like a much more likely scenario in the real world. In addition, it was found to be the most lucrative scenario among the three, slightly more so than the conservation scenario and by far more lucrative than following the old rate of deforestation. Palm oil producers could stop destroying the forests in order to make room for their plantations because these can be established in less critical places, at the same time they could be investing in industries that benefit from lessening the deforestation rate, such as tourism, hydropower, and NTFP (non-timber forest product) harvesting. This would fulfill all the three sustainability dimensions. The social impact comes into play with how the palm oil industry helps alleviate poverty and inequality, and since those most affected by the declining health of the environment are the poor, especially the locals that directly depend on the Indonesian rainforests.

The TEV study is able to identify several important factors that come into play when one wants to promote sustainability, and especially when attempting to identify the correct approach to reach said goal. How the various benefits and detriments are distributed can be used to appeal to various stakeholders in more efficient ways when we know what affects each stakeholder, and how significantly it does so. This is an important factor considering how resource scarcity is a common cause of conflict. It also helps to identify how critical the various impacts are, and where we should turn our focus in order to address the most immediate problems. We can use this information to identify both how much damage the different impacts do in regard to the environment, the economy, and society – and we can use this information as a part of estimating the costs associated with taking sustainable actions.

7.2.4 Conclusion

We find that there is a strong connection between economic and environmental sustainability in the palm oil industry, since the economic dimension depends on ecological functions, such as hydrology, soil quality, etc. We also see that biodiversity is important for the tourism industry which depends on biodiversity and critically endangered species in order to attract tourists. There are also the indirect costs that can affect any industry that relies on infrastructure, through the destruction of roads, railways, etc., caused by degradation of natural elements - trees, hills, etc. - that protects man-made infrastructure. All of these are in various ways connected to the deforestation that in large part is being driven by the palm oil industry.

Economists can therefore play an important role in moving the palm oil industry in Indonesia towards a more sustainable future. Firstly, by using tools such as the various EIA methods, economists can identify the most critical areas affected by environmental impacts, and what these impacts are. This should be done according to the SEA approach. Secondly, they can convert the environmental impacts, both positive and negative, into monetary values that can be both easier to understand for the layman as well as appeal more to certain stakeholders, especially industry stakeholders. Thirdly, they can determine the value of natural resources, and how best to use these in sustainable ways that will benefit both the environment and the stakeholders. Fourthly, they can assist in identifying the various costs associated with converting to more sustainable practices and determine the potential profit and savings the palm oil industry can achieve by making these changes. Fifthly, they can help to bridge the gap between idealism and praxis. And finally, all of the contributions listed above can be used to make better policies and strategies that incorporate the environment in a way that benefits both the economic and environmental stakeholders.

7.3 What are the most efficient drivers of sustainable action for the palm oil industry?

We have identified what the major negative environmental impacts are, including measurements and costs, and how economists can play an important role in moving the palm oil industry towards sustainable action, and have in that regard discussed different environmental impact assessments. When answering the last research question; “What are the most efficient drivers of sustainable action among palm oil businesses?”, we will first be discussing different solutions for sustainability, and secondly, the forces driving the industry towards sustainable action. The topics in this part of the discussion include recycling, certification and policy, government regulations, consumer awareness, and pressure from NGOs.

7.3.1 Sustainable solutions

To move towards sustainability means to move towards "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Barison, 2007, p. 293). This is attained through balanced plantation and production practices that benefit the planet, people, and profit. But what is causing the industry to operate in unsustainable ways generating negative environmental impacts? We discovered earlier in the analysis that deforestation and destruction of peatlands created major negative environmental impacts, such as climate change and disruption of biodiversity and ecosystems. The discovered contributors to deforestation and peatland destructions were, in short summary, weak law enforcement, corruption, decentralization of power, accessible forested lands, higher prices for agriculture and timber, low rural wages, and opportunities for long distance trade. These are therefore examples of what is keeping the industry from sustainable practises and of what should be improved. However, there are limitations to what can be done realistically, at least in the near future.

7.3.1.1 Reducing GHG emission through recycling

We identified in the LCA study that the production process and utilization of empty fruit bunches left over from the CPO production have a great impact. Finding sustainable solutions for recycling of the empty fruit bunches means finding solutions for a more sustainable palm oil industry. We specifically look at options for reducing GHG emissions, which is a major negative environmental impact of the industry.

Without allocation of avoided products, composting was, out of the seven treatment options, an excellent option for recycling, as it had low impact in most of the categories and only emits 22.2 kg CO_2e, per tonne of EFB without allocation of alternative products. To put that into perspective, the emission is only 1/16 of the emission from pulp and paper production. With allocation, CHP plant was the best option as it reduces the GHG emission with 218.6 kg per tonne of EFB. Palm oil producers should evaluate which alternative fits best for them based on their level of allocation of avoided products. With that said, we should determine an option that works well both with and without allocation of avoided products. The technologies that had high potential in both instances were composting and briquette production. On the other side, Pulp and paper production was the least favorable technology in both instances, and therefore appears to be inadequate, although it has a positive effect on land-use and contributes more to the reduction of habitat size compared to the other treatment options. However, other factors should also be considered since the LCA study did not include machinery, infrastructure, emissions from the palm oil mill, or palm oil plantations.

7.3.1.2 Reducing deforestation and peatland destruction

The next subject of discussion is reduction of deforestation and peatland destruction, mainly through monitoring, certification, and policy. We know that illegal deforestation occurs due to weak law enforcement and inadequate monitoring. Indonesia's weak law enforcement should be considered for improvement as it helped Brazil a great deal in reducing deforestation. The reasoning behind Brazil's temporary success lay in their monitoring strategy, allowing them to observe illegal deforestation and then making forested lands less accessible. This could however be a challenge for Indonesia due to their decentralized power and corruption. But the government did commit to reducing deforestation in 2019, thus reduction of the deforestation rate may still appear. The biggest barrier for this change to occur is the active opposition from the elite industry, as we discovered in the TEV case.

Policy and certification is a topic of interest when discussing the major negative environmental impacts of the palm oil industry and might work where law enforcement does not. Certification is supposed to stimulate sustainable production of palm oil and assure stakeholders that the palm oil was produced in a sustainable manner.

7.3.1.2.1 Certification and reduction of negative environmental impacts

Now we will be discussing how effective certification and policy is and has been at reducing negative environmental impacts. In the last part of the discussion, we consider if certification can push the industry towards sustainability.

There is a clear difference between creating and planning certification systems and policies versus implementing them efficiently. The real effects of certification and how well it really works to fight deforestation in Indonesia is unclear. Various European countries had the intention of only importing RSPO certified palm oil, RSPO has certified 12% of the world's palm oil, and 74% of the refinery capacity in Indonesia operates with NDPE policies. Despite these numbers, the deforestation rate is still high. This indicates that policies and certification systems have failed to identify and eliminate sources of palm oil that have links to deforestation. This might be a consequence due to the lack of required information to determine whether their suppliers are compliant with the policies and certification systems.

RSPO has stated that they have very strict sustainability standards and it can therefore be challenging and time consuming to implement them in an effective way, and we have identified a need for increased transparency and accountability from the plantations. Perhaps this is an issue with some or all of the policies and certification schemes, explaining to some extent the lack of efficiency. ISCC emphasizes transparency and supply chain traceability in their certification scheme, which might be a reason for them being one of the world's largest certification systems. ISCC has GHG emission savings as one of their main criteria, which is important in minimising major negative environmental impacts. But the effectiveness of ISCC is uncertain.

Government regulation is complex and its effectiveness in the industry and on the environment very much depends on intent, formulation, implementation, enforcement, and competing regulations. Government regulations might have higher potential than voluntary standards. However, transparency is important in both instances, but compliance is harder to attain in voluntary systems. Furthermore, since the non-state market driven certifications chems are voulatary, and it is the certification provider or third party actors responsibility to follow up, there are no inherent consequences of not complying with all of the guidelines in place, which would likely have a negative effect on compliance and effectiveness.

A normal standard for certification schemes to implement is the ban of fire as a deforestation method in order to avoid accidental and excessive forest loss. It is however unclear if certification has a direct effect on deforestation. Figure 4 in chapter 3 showcases a decrease in the mean deforestation and forest fire rate. At the same time fire rates have increased in certified plantations in the last years, but not as much as in the plantations that have never been certified where the mean fire rate increased drastically. This could be due to certification systems being uneffective, more plantations obtaining certification, dry weather, or all three. Nonetheless, the graph suggests that certification does assist in reducing deforestation and forest fires compared to non-certified plantations.

Certification systems and forestry regulations recommend developing palm oil plantations in unforested areas or on abandoned mineral land instead of destroying forested areas and peatlands, as a solution to deforestation. This option should be considered as there was 17 to 26 million ha of available land in Indonesia in 2016 declared as suitable for palm oil plantations. Still, palm oil plantations are not utilizing the available land and continue to destroy the natural forests. The reason for plantations not using available land could be due to transportation costs and accessibility.

Regardless of the positive effects certification may or may not have, we should discuss the possible negative effects as well. In a country troubled by corruption, there will likely be those who exploit the system, regardless of the fact that it was put in place to promote positive change. This is where the concept of greenwashing is relevant. It is mostly older plantations gaining certification, more specifically those plantations that do not have any natural forest left to destroy. Certification in regard to deforestation does therefore say little about the plantations sustainability in that context. Certification does not have much use without enforcement and follow-up, and can actually be damaging by painting a false picture of the degree of sustainability.

7.3.1.3 Conclusion

First, a major negative environmental impact identified was GHG emission. Composting and briquette production proved to be a sustainable way of managing empty fruit bunches left over from the production process that emits little GHG, and should be considered. Solutions discussed for reducing deforestation and peatland destruction were firstly improvement of forest law enforcement and monitoring, as Brazil did.

Moving on to a subject in a seemingly better position to improve and be implemented, namely certification and policy, which might work where law enforcement does not. It is understood that the impact certification has on sustainable production is unclear, due to the fact that it is widely debated and that various sources report quite different results. It should be noted that policy and certification systems do have some positive effects and potential, although the effects and reduction of deforestation has not been substantial. Certification has the potential to reduce deforestation and peatland destruction if palm oil plantations complied with their recommendation to grow palm oil on available mineral land instead of in forested areas.

We do not know how the industry would look without certification systems and we can't deny that setting rules, boundaries, and following up on these could generate results. It is clear that improvements and adjustments are needed, especially in regard to enforcement and transparency. Holding actors in the industry accountable by demanding transparency through consequence maps from palm oil suppliers and generally improving transparency systems, such as what is being done in the NDPE policy scheme, would be possible improvements.

7.3.2 Drivers for sustainable action

Now that we have discovered some possible sustainable actions and how they can reduce negative impacts on the environment, we need to discuss the drivers for these actions. Various drivers can be identified, such as awareness of unethical practises and certification.

7.3.2.1 Awareness challenges the industry

Awareness has many different positive impacts regarding sustainability, which has to be discussed from two perspectives, consumer awareness and awareness from other stakeholders, such as NGOs and the government. These actors are important, as it is clear that the palm oil industry will not move towards sustainability on its own initiative. With the increasing environmental awareness over the last few decades, several empirical studies and models such as EIA have emerged, providing knowledge and further enhancing awareness. In this regard, AMDAL has been one of the positive developments in Indonesia, caused by awareness.

Consumer awareness has been a powerful force with the rise of social media and the development of cancel culture. Consumers can through this force challenge industries and companies, including the palm oil industry. This has an effect on the reputation of palm oil, which may lead people to boycott palm oil through social media trends. Loss of reputation is hard to recover from, and should therefore be taken seriously by actors in the industry. If palm oil is cancelled or boycotted by consumers, and companies using palm oil as an ingredient in their products switch to other plant oils, it will have a significant effect on the industry as well as Indonesia's economy. Loss of reputation can therefore be detrimental and can be seen as a cost, and it will influence companies cost-benefit analysis.

If consumers demand sustainable palm oil and are willing to bear the extra costs of producing a sustainable product, actors would in theory profit from satisfying the demand. Consumers are generally willing to pay a premium for sustainable products, likewise willingness to pay generally decreases with unethical behaviour. Hence, palm oil producers might not increase their profits by moving towards sustainability, however, they would prevent loss of profits by preventing loss of reputation and customers.

We conclude that the effect of consumer awareness can be significant, but who encourages consumer awareness in the palm oil industry? This brings us to our next point, namely NGOs. Different NGOs have been criticizing the palm oil industry for a long time and spread awareness to consumers through large informative campaigns which appeal to consumers' emotions. Greenpeace's viral Rang-tan video heavily incorporated pathos into the video to convey the message in a compelling and memorable fashion. By spreading awareness, these NGOs put pressure on actors in the industry. However, the change has to be accomplished in the supply chain, which is not something that can be done by consumers and NGOs alone. With that said, some change has and can arguably be achieved. Greenpeace's boycott of Nestle, which forced them to apologize and take sustainable actions, showcases the power of NGOs and consumers through boycotts.

7.3.2.2 How effective is certification as a driver towards sustainability?

The greatest argument for adopting certification is external pressure and mandatory regulations. The demand for sustainable palm oil and pressure from consumers and NGOs has led various certification schemes to emerge, such as RSPO which was created as a reaction to NGO campaigns, and includes concerned stakeholders throughout the value chain. Although the effectiveness of certification is unclear, we can still discuss how certification works as a driver towards sustainability. The concept of certification schemes are important as they are supposed to provide information to consumers and companies on which suppliers have sustainable practises, as well as holding them accountable.

The increase in voluntary certification schemes and demand for certified palm oil forces the industry towards sustainability. Companies can simply be cancelled if they do not use certified products, which Cadbury and Nestle are examples of. The two companies issuing apologies and changing their behaviour was a shift towards sustainability in itself, but it also strengthened consumer awareness and pressure on the industry, by putting pressure on companies using palm oil in their procuts, which in turn puts pressure on palm oil producers.

Wilmar used the concept of sustainable palm oil to build their reputation. The CEO responded to criticism and then used it as an opportunity to promote sustainable palm oil and create a trend of companies integrating NDPE policies into their supply chain. The CEO argued that it was possible to produce palm oil while still protecting the forests and contributing to development in palm oil growing regions, including Indonesia. Since Wilmar is one of the world's biggest trade companies, it impacted many other major trading companies to implement the same policy. Although the success was limited, it still demonstrates how actors in the industry can move the industry towards sustainability. When more and more companies switch to certified palm oil, as a reaction to criticism or to avoid ending up with a loss of reputation, such as with Nestle and Cadbury, it will likely send a message to the palm oil supply chain, including the plantations. Palm oil suppliers, like any other business, strive to generate profit and will therefore strive to satisfy their customers. Ergo, there exists pressure from consumers, NGOs, and certification schemes affecting the industry.

But certification may also hinder the drive towards sustainable action. Indonesia's government formed ISPO as a response to international criticism. The establishment of ISPO could also be due to displeasure with NGOs creating certification and policy ment to regulate the industry. However, corruption in Indonesia drove the palm oil industry towards expansion, which was a reason for the rise of NGOs in the first place. Competition in the market of certification schemes may be seen as a positive component. However, ISPO has on one side led some to question the authority of voluntary international standards, and on the other side made some concerned that the government seeks to present an outward front to combat criticism without implementing sustainable action. This can be reflected in AMDAL which has had some effect, but has still not been implemented in an effective way.

Greenwashing through certification and the government's promises of change without real sustainable implementation or follow up, can actually damage the push for sustainability, as it gives a false impression of sustainability, tricking consumers and making them less aware. This might lead consumers to believe that further action is unnecessary or not as crucial. Consequently, there are relevant NGOs investigating the different certification systemes and sharing information with the public. Greenpeace has on several occasions accused RSPO of questionable behaviour, forcing them to improve.

Some companies eliminate palm oil from their products entirely, regardless of certification, in fear of scrutiny. This affects the palm oil industry which is vital for improving conditions in Indonesia, and there is a concern that certification and its strict standards can dismantle plantations, especially smallholder plantations, and slow down growth. The practicality of certification in changing the industry without negatively affecting the lives that depend on it is hard to determine. There is a risk of hurting the economic growth in Indonesia through the palm oil industry by moving towards sustainability too fast, but also by moving towards sustainability too slow.

There is the positive aspect, where certification has high potential when implemented effectively with the intention of reducing negative environmental impacts without halting Indonesia's growth. Then there is the negative aspect, where certification is not always implemented effectively, thus creating a false image of sustainability. Furthermore, there is valid concern regarding the practicality of certification. Hence, we see that there are forces in respect to certification pushing and halting the drive towards sustainable change.

7.3.2.3 Challenges in reaching sustainability due to certification costs

Costs and barriers related to certification is arguably a factor as to why certification has some negative consequences. Given the assumption that certification has potential for reducing negative environmental impacts, and that the potential of certification is greater than the negative considerations, discussing the costs of certification is highly relevant when deciding if it is halting the shift towards sustainability.

We concluded that consumers are usually willing to pay a premium for sustainable and certified products, but there needs to be a sufficient demand and their willingness to pay has to exceed the costs related to certification. Each link in the supply chain has to comply with the certification standards, meaning that certification needs to be financially attractive for each of these links in order for them to voluntarily meet the sustainable standards. We have found that premium prices of certification is a potential financial benefit as it has been shown to generate up to 21% higher revenues from sales, and that it also provides opportunities in different markets. At the same time, certification has also been shown to create loss of net income up to 8% per hectare the first year. Indicating that certification is usually not financially attractive in the start-up phase.

Furthermore, it is more challenging for smallholders than large scale companies to achieve certification as they dont have the same means to meet the start-up costs of certification or other costs related to certification. Overcoming barriers regarding costs, access to financial means, availability of legal documents, and acquiring and improving knowledge and skills, can be challenging for many companies and especially smallholders. This halts the drive towards sustainable action, since smallholders in Indonesia produce over one third of the palm oil. To become certified, the links in the supply chain need motivation and financial means to overcome the initial loss in net income.

These high start-up costs and many barriers could certainly be a factor as to why certification standards are not met or implemented effectively. If smallholders had motivation and assistance in the start-up phase, the negative aspects regarding poor implementation, creating a false sustainable image, and issues regarding practicality, would be reduced.

7.3.2.4 Conclusion

It is clear that awareness from consumers, NGOs, and the government is important and has a positive effect through pressure, especially since it is clear that the palm oil industry will not move towards sustainability on its own initiative. Although, there are limits to what their influence can do in the short run.

Certification has potential when implemented effectively with the intention of reducing negative environmental impact without halting Indonesia's growth. There are forces in regard to certification pushing and halting the drive towards sustainable change. Certification seems to have higher potential for positive impact than negative impacts on reducing negative environmental impacts and increasing sustainability in the industry in the long run. The greatest argument for links in the supply chain to adopt certification is external pressure and mandatory regulations. The increase in voluntary certification schemes, demand for certified palm oil, and companies switching to certified palm oil, forces the industry towards sustainability. Actors in the Indonesian palm oil industry might not increase their profits by moving towards sustainability, however, they would prevent loss of profits by preventing loss of reputation and customers. Lastly, we emphasize that certification has not shown significant results, but it has the potential of preventing poor implementation, creating a false image of sustainability, and issues regarding practicality, if the start-up phase and barriers were more manageable, especially for smallholders.

Chapter 8: Conclusion

We have through the thesis aimed at presenting information that relates to and provides useful insight into the palm oil industry and Indonesia, and the surrounding elements that both affect and are affected by the industry. Our goal has been to assess the current state of the industry and to provide further elaboration on the impact it has on the environment. Additionally, we wanted to provide insight into what we consider as the necessary steps going forward in order to achieve a sustainable industry in accordance with the triple bottom line, that can support both the environment and the various stakeholders.

Firstly, we have found that the biggest problem from an environmental point of view, is the high rate of deforestation and clearing of peatlands in order to make room for palm oil plantations, and the high amounts of GHG released during this process as well as during the production of CPO. Clearing of forests, especially primary forest, and peatlands, causes a series of negative impacts that include GHG emissions, degradation of soil and its many consequential impacts, loss of biodiversity, release of respiratory inorganics, and loss of natural protection against natural disasters.

Secondly, there is a strong connection between environmental and economic sustainability, especially in poor countries and regions. This means that economists can play important roles when moving towards a sustainable palm oil industry in Indonesia. They contribute by quantifying environmental data and converting it to monetary values which is easier to understand for many stakeholders, and are more interesting for some. They also contribute by further detailing the most critical environmental impacts and identifying processes that can reduce costs and negative environmental impacts. Economists can therefore contribute to all the steps required for attaining sustainability. They can do so by providing models and estimates of values and environmental impacts that should be used for evaluating plans, strategies, and policies that relate, in any way, to the environment. And finally, they can contribute by evaluating the actual results when such plans have already been put into motion or have concluded, generating empirical data which can be applied to future projects.

Finally, various sustainable solutions were identified in the discussion, but the main issue lies in the lack of motivation and poor implementation of sustainable solutions, stemming from financial barriers and concern of slowing down the economic growth. Certification was a considerable topic of discussion and we concluded that certification has potential when implemented effectively with the intention of reducing negative environmental impacts without halting Indonesia's growth. The increased awareness in the industry, specifically from consumers and NGOs, as well as an increase in the number and size of certification schemes, are identified as the main forces with the highest potential for moving the industry towards sustainable action.

In assessing and applying the three different case studies LCSA, LCA, and TEV - and using the results from all three in our discussion and conclusion - we have contributed with a new conceptual model. To further explain, we have, instead of going in depth on one EIA, provided a wider and more comprehensive understanding on different environmental impact issues in the palm oil industry and in Indonesia, which is something we have not found in our literature search. This method provides a holistic conclusion based on more holistic research.

8.1 The path forward for the Indonesian palm oil industry

The way forward as we see it, has to start with the stakeholders that are furthest away, the consumers and NGOs. Both the government and the industry leaders have shown themselves to be unwilling and incapable of making meaningful sustainable changes, while the smallholders and plantation workers cannot afford, nor have the knowledge required to become more environmentally sustainable, despite it being more profitable and economically sustainable in the long run.

When consumers and NGOs demand sustainable palm oil and boycott palm oil products, the producers will have to follow suit, and will be forced to implement more sustainable cultivation and production processes. For this to work however, there needs to be better oversight and enforcement of sustainable certification schemes. At the same time, the government is strongly incentivised to support this change with policy, regulations, and stronger enforcement of said changes. The government should also offer training for smallholders, who are important for the national economy, so that they can use the land area they occupy more effectively, reducing unnecessary land-clearing.

This change needs to be based on empirical data and address the most critical areas first, which is deforestation of primary forest and clearing of peatland, as well as outdated and poor production processes and waste management, which causes high emissions of GHG, destruction of soil and hydrology, and harmful particles. There are both economic and environmental advantages to implementing sustainable practices such as better waste management and waste-water treatment which will pay off over time, despite some high initial costs, so these should be implemented where possible, especially in the private and government owned plantations who are more likely to have sufficient capital to do so.

Literature list:

Admiraal, J., Wossink, A., Groot, W. & de Snoo, G. (2013). More than total economic value: How to combine economic valuation of biodiversity with ecological resilience. *Ecological Economics*, 89, 115-122. https://doi.org/10.1016/j.ecolecon.2013.02.009

Afriyanti, D., Kroeze, C. & Saad, A. (2016). Indonesia palm oil production without deforestation and peat conversion by 2050. *Science of the Total Environment*, 557, 562-570. https://doi.org/10.1016/j.scitotenv.2016.03.032

Auld, G. Cashore, B. (2013). Mixed Signals: NGO Campaigns and Non-state Market Driven (NSMD) Governance in an Export-Oriented Country. *University of Toronto Press*, volume 39, 143-156. https://www.jstor.org/stable/23594777?seq=1#metadata_info_tab_contents

Austin, K. G., Schwantes, A., Gu, Y. & Kasibhatla, P. S. (2019). What causes deforestation in Indonesia? *Environmental Research Letters*, 14(2). 10.1088/1748-9326/aaf6db

Azhar, B., Saadun, N., Prideaux, M. & Lindenmayer, D. B. (2017). The global palm oil sector must change to save biodiversity and improve food security in the tropics. *Journal of environmental management*, 203, 457-466. http://dx.doi.org/10.1016/j.jenvman.2017.08.021

Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science and Technology*, 109(4), 289-295. http://dx.doi.org/10.1002/ejlt.200600223

BBC News. (2020, November. 30). Brazil's Amazon: Deforestation 'surges to 12-year high'. *BBC*. Accessed 23. May from https://www.bbc.com/news/world-latin-america-55130304. Accessed 23. May

BBC News. (2021, May. 7). Brazil's Amazon: Deforestation rises ahead of dry season. *BBC*. Accessed 23. May from https://www.bbc.com/news/world-latin-america-57017271

Beukering, P. Cesar, H. Janssen, M. (2003). Economic valuation of the Leuser National Park on Sumatra, Indonesia. *Ecological Economics*, 2003, 44(1), 43-62. https://doi.org/10.1016/S0921-8009(02)00224-0

Bissonnette, J-F. & De Koninck, R. (2015). Large Plantations versus Smallholding in Southeast Asia: Historical and Contemporary Trends. *BRICS Initiatives for Critical Agrarian Studies (BICAS)*. https://www.iss.nl/sites/corporate/files/CMCP_12-_Bissonnette_and_De_Koninck.pdf

Brandi, C., Cabani, T., Hosang, C., Schirmbeck, S., Westermann, L. & Wiese, H. (2013). Sustainability certification in the Indonesian palm oil sector: benefits and challenges for smallholders. *The German Development Institute*.

Brearley, F., Adinugroho, W., Càmara-Leret, R., Krisnawati, H., Ledo, A., Qie, L., Smith, T., Aini, F., Garnier, F., Lestari, N., Mansun, M., Murdjoko, A., Oktarita, S., Soraya, E., Tata, H., Tiryana, T., Trethowan, L., Wheeler, C., Abdullah, M., … Webb, C. (2019). Opportunities and challenges for an Indonesian forest monitoring network. *Annals of Forest Science*, 76(54). https://doi.org/10.1007/s13595-019-0840-0

Broome M.E. (1993). Integrative literature reviews for the development of concepts. *In Concept Development in Nursing,* 2nd edn, W.B. Saunders Co., Philadelphia, PA, pp. 231–250.

Budhi G., Kazuhiko, T., Atsushi, T. & Oekan S. Abdoellah. (2004) Community Dependency on Forest Resources in West Java. *Indonesia, Journal of Sustainable Forestry*, 18:4, 29-46. https://doi.org/10.1300/J091v18n04_02

Burrows, L. (2016). Smoke from 2015 Indonesian fires may have caused 100,000 premature deaths. *Harvard School of Engineering.* https://www.seas.harvard.edu/news/2016/09/smoke-2015-indonesian-fires-may-have-caused-100000-premature-deaths

Carlson, K., Heilmayr, R., Gibbs, H., Noojipady, P., Burns, D., Morton, D., Walker, N., Paoli. G. & Kremen, C. (2017). Effect of oil palm sustainability certification on deforestation and fire in Indonesia. *PNAS*. https://doi.org/10.1073/pnas.1704728114

Carlson, K. M., Heilmayr, R., Gibbs, H. K., Noojipady, P., Burns, D. N., Morton, D. C., ... & Kremen, C. (2018). Effect of oil palm sustainability certification on deforestation and fire in Indonesia. *Proceedings of the National Academy of Sciences*, *115*(1), 121-126. https://doi.org/10.1073/pnas.1704728114

Carter, C., Finley, W., Fry, J., Jackson, D., & Willis, L. (2007). Palm oil markets and future supply. *European Journal of Lipid Science and Technology*, *109*(4), 307-314. https://doi.org/10.1002/ejlt.200600256

Chiew, Y & Shimada, S. (2013). Current state and environmental impact assessment for utilizing oil palm empty fruit bunches for fuel, fiber and fertilizer - A case study of Malaysia. *Biomass and Bioenergy*, vol 51, 2013, p. 109-124. https://doi.org/10.1016/j.biombioe.2013.01.012

Choiruzzad, S. Tyson, A. & Varkkey, H. (2021) The ambiguities of Indonesian Sustainable Palm Oil certification: internal incoherence, governance rescaling and state transformation. *Asia Eur J*. https://doi.org/10.1007/s10308-020-00593-0

Conniff, R. (2018). Greenwashed Timber: How Sustainable Forest Certification Has Failed. *Yale School of the Environment*. Accessed 23. March 2021 from https://e360.yale.edu/features/greenwashed-timber-how-sustainable-forest-certification-has-failed

Corley, R. H. V. (2009). How much palm oil do we need? *Environmental Science & Policy*, *12*(2), 134-139. https://doi.org/10.1016/j.envsci.2008.10.011

D'Antone, S., & Spencer, R. (2015). Organising for sustainable palm oil consumption: A market-based approach. *Consumption Markets & Culture*, *18*(1), 55-71. https://doi.org/10.1080/10253866.2014.899217

de Carvalho, C. M. (2011). Strategic Environmental Assessment for sustainable expansion of palm oil biofuels in Brazilian north region. *Energy & environment*, *22*(5), 565-572.

Efeca. (2020, March). Palm Oil Sustainability: NDPE. (Info Briefing #5 Part 4). https://www.efeca.com/wp-content/uploads/2020/03/Certification-Scheme-NDPE-Infobriefing-5-Part-4-Final.pdf

Elkington, J. (1999). *Cannibals with forks: the triple bottom line of 21st century business*. Oxford: Capestone Publishing Ltd.

Elkington, J. (2018). 25 years ago I coined the phrase “triple bottom line.” Here’s why it’s time to rethink it. *Harvard Business Review*, 25, 2-5. https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it

Emas, R. (2015). The concept of sustainable development: definition and defining principles. *Florida International University*.

Kuit, M., & Waarts, Y. (2014). Small-Scale Farmers, Certification Schemes and Private Standards: Is There a Business Case? *Technical Centre for Agricultural Rural Cooperation ACP-EU (CTA)*. https://edepot.wur.nl/336063

Environmental impact assessment review. (1980). *Elsevier Science Inc*, 1(2), 101-218. https://www.sciencedirect.com/journal/environmental-impact-assessment-review/vol/1/issue/2

FAEOLEX Database. (2020). Regulation of the R.I. No. 44 of 2020 on the Certification System for Sustainable Palm Oil Plantation in Indonesia. *FAEOLEX*. http://www.fao.org/faolex/results/details/en/c/LEX-FAOC195054/

FAO and UNEP. (2020). The State of the World’s Forests 2020. Forests, biodiversity and people. *FAO*. https://doi.org/10.4060/ca8642en

Frecè, J. T., & Harder, D. L. (2018). Organisations beyond Brundtland: a definition of corporate sustainability based on corporate values. *Journal of Sustainable Development*, 11(5), 184-193. https://doi.org/10.5539/jsd.v11n5p184

Gale, D. (1955). The law of supply and demand. *Mathematica scandinavica*, 155-169. https://www.globalfiredata.org/regional.html#indonesia

Glasson, J., & Therivel, R. (2013). *Introduction to environmental impact assessment*. (4th ed.). Routledge.

Glasson, J., Therivel, R, & Chadwi, A. (2005). *Introduction to environmental impact assessment.* (3rd ed.). Routledge.

Glastra, R., Wakker, E., & Richert, W. (2002). Oil palm plantations and deforestation in Indonesia. What role do Europe and Germany play *WWF*. https://www.brandeis.edu/investigate/slavery/docs/palm/oil-palm-plantations-deforestation-indonesia-role-of-europe-and-germany.pdf

Gong, M., Gao, Y., Koh, L., Sutcliffe, C. & Cullen, J. (2019). The role of customer awareness in promoting firm sustainability and sustainable supply chain management. *International*

Journal of Production Economics, *217*, 88-96. https://doi.org/10.1016/J.IJPE.2019.01.033

Greenpeace international. (2018, September). *Final countdown: Now or never to reform the palm oil industry*. https://www.greenpeace.org/static/planet4-international-stateless/2018/10/6d4a29ea-greenpeace_finalcountdown_lowres.pdf

Greenpeace. (2018, 6. November). *Rang-tan: la historia del bebé orangután y el aceite de palma*

Hansen, M.C., Stehman, S.V., Potapov, P.V., Arunarwati, B., Stolle, F. & Pittman, K. (2009). Quantifying changes in the rates of forest clearing in Indonesia from 1990 to 2005 using remotely sensed data sets. *Environmental Research Letters*, 4, 1-12. https://iopscience.iop.org/article/10.1088/1748-9326/4/3/034001/pdf

Harris, N., Minnemayer, S., Stolle, F. & Payne, O. (2015, 16. November). Indonesia's Fire Outbreaks Producing More Daily Emissions than Entire US Economy. *World Resources Institute.* https://www.wri.org/blog/2015/10/indonesia-s-fire-outbreaks-producing-more-daily-emissions-entire-us-economy

Hauschild, M., Rosenbaum, R. & Olsen, S. (2015). Life Cycle Assessment - Theory and Practice. *Springer International Publishing*. https://link.springer.com/content/pdf/10.1007/978-3-319-56475-3.pdf

Jelsma, I., Slingerland, M., Giller, K., & Bijman, J. (2017). Collective action in a smallholder oil palm production system in Indonesia: The key to sustainable and inclusive smallholder palm oil? *Journal of Rural Studies*, 54, 198-210. https://doi.org/10.1016/j.jrurstud.2017.06.005

Heilmayr, R., Carlson, K. M. & Benedict, J. J. (2020). Deforestation spillovers from oil palm sustainability certification. *Environmental Research Letters*, *15*(7), 075002. https://ui.adsabs.harvard.edu/link_gateway/2020ERL....15g5002H/doi:10.1088/1748-9326/ab7f0c

Hoare, A. (2015). Tackling illegal logging and the related trade. *What progress and where next*, 79. https://www.youtube.com/watch?v=-6jxnzyDTIc&ab_channel=GreenpeaceEspa%C3%B1a

Hutabarat, S., Slingerland, M., Rietberg, P. & Dries, L. (2018). Costs and benefits of certification of independent oil palm smallholders in Indonesia. *International Food and Agribusiness Management Review*, *21*(1030-2018-3328), 681-700. https://doi.org/10.22434/IFAMR2016.0162

International Financial Reporting Standards. (2021). *IAS 24 Related Party Disclosures*. https://www.ifrs.org/issued-standards/list-of-standards/ias-24-related-party-disclosures/

ISCC. (2020, 19. March). *Responding to the coronavirus pandemic (COVID-19)*. https://www.iscc-system.org/responding-to-the-coronavirus-covid-19-pandemic/

Ivancic, H. & Koh, L. P. (2016). Evolution of sustainable palm oil policy in Southeast Asia. *Cogent Environmental Science*, *2*(1), 1195032. https://doi.org/10.1080/23311843.2016.1195032

Jelsma, I., Woittiez, L., Ollivier, J., & Dharmawan, A. (2018). Do wealthy farmers implement better agricultural practices? An assessment of implementation of Good Agricultural Practices among different types of independent oil palm smallholders in Riau, Indonesia. *Agricultural Systems*, 170, 63-76. https://doi.org/10.1016/j.agsy.2018.11.004

Jennings, P. D., & Zandbergen, P. A. (1995). Ecologically sustainable organizations: An institutional approach. *Academy of management review*, *20*(4), 1015-1052. https://doi.org/10.2307/258964

Kaimowitz, D., & Angelsen, A. (1998). Economic models of tropical deforestation: a review. https://doi.org/10.17528/cifor/000341

Kasryno, F. (2015). Consulting Study 15: The economic impacts of palm oil in Indonesia. https://www.simedarbyplantation.com/sites/default/files/sustainability/high-carbon-stock/consulting-reports/socio-economic/hcs-consulting-report-15-the-economic-impacts-of-palm-oil-in-indonesia.pdf

Khatiwada, D., Palmén, C. & Silveira, S. (2021). Evaluating the palm oil demand in Indonesia: production trends, yields, and emerging issues. *Biofuels*, *12*(2), 135-147. https://doi.org/10.1080/17597269.2018.1461520

Kuepper, B., Steinweg, P. T. & Aidenvironemnt. (2018). Shadow Companies Present Palm Oil Investor Risks and Undermine NDPE Efforts. *Chain Reaction Research.* 1-14. https://chainreactionresearch.com/report/shadow-companies-present-palm-oil-investor-risks-and-undermine-ndpe-efforts/

Kushairi, A., Loh, S. K., Azman, I., Hishamuddin, E., Ong-Abdullah, M., Izuddin, Z. B. M. N., ... & Parveez, G. K. A. (2018). Oil palm economic performance in Malaysia and R&D progress in 2017. *J. Oil Palm Res*, *30*(2), 163-195. https://doi.org/10.21894/jopr.2018.0030

Lai, Jia Yen, & Hamilton, Alistair. (2020). For whom do NGOs speak? Accountability and legitimacy in pursuit of just environmental impact assessment. Environmental Impact Assessment Review, 82, 106374. https://doi.org/10.1016/j.eiar.2020.106374

Lee, J. S. H., Rist, L., Obidzinski, K., Ghazoul, J. & Koh, L. P. (2011). No farmer left behind in sustainable biofuel production. *Biological conservation*, *144*(10), 2512-2516. https://doi.org/10.1016/j.biocon.2011.07.006

Lingnau, V., Fuchs, F. & Beham, F. (2019). The impact of sustainability in coffee production on consumers' willingness to pay–new evidence from the field of ethical consumption. *Journal of Management Control*, *30*(1), 65-93. 10.1007/s00187-019-00276-x

Moron, S. Sheppard A. & Lonsdale, M. (2014) Biodiversity. *CISIRO Publishing*. https://www.publish.csiro.au/ebook/download/pdf/6967

Morrison-Saunders, Angus, & Retief, Francois. (2012). Walking the sustainability assessment talk — Progressing the practice of environmental impact assessment (EIA*). Environmental Impact Assessment Review*, 36(Complete), 34–41. https://doi.org/10.1016/j.eiar.2012.04.001

NASA. (w.y). *Climate Change: How Do We Know?* Accessed 5. April 2021 from https://climate.nasa.gov/evidence/

Newton, T. (2005). Practical Idealism: An Oxymoron? *Journal of Management Studies*, 42, issue 4, 896-884, 2004. https://doi.org/10.1111/j.1467-6486.2005.00522.x

Ng, E. (2020). No grand pronouncements here...: Reflections on cancel culture and digital media participation. *Television & New Media*, 21(6), 621-627. https://doi.org/10.1177%2F1527476420918828

Nitanan,K., Shuib, A., Sridar, R., Kunjuraman, V., Zaiton, S. & Herman, M. (2020) The total economic value of forest ecosystem services in the tropical forests of Malaysia. *International Forestry Review*. 22(4), 485-503. https://www.ingentaconnect.com/contentone/cfa/ifr/2020/00000022/00000004/art00005?crawler=true&mimetype=application/pdf

Nzherald. (2009, 17. August). Cadbury caves - no more palm oil in its chocolate. https://www.nzherald.co.nz/business/cadbury-caves-no-more-palm-oil-in-its-chocolate/LFYVI2YYVUAAY3Q2RMWKUNASPY/

Omran, N. Sharaai, A. & Hashim, A. (2021). Visualization of the Sustainability Level of Crude Palm Oil Production: A Life Cycle Approach. *Sustainability*, 13(4):1607. https://doi.org/10.3390/su13041607

Pacheco, P. Schoneveld, G. Dermawan, A. Komarudin, H. & Djama, M. (2018). Governing sustainable palm oil supply: Disconnects, complementarities, and antagonism between state regulations and private standards. *Regulations & Governance*, 14(3), 568-598. https://doi.org/10.1111/rego.12220

Palmatier, R. W., Houston, M. B., & Hulland, J. (2018). Review articles: Purpose, process, and structure. 1-5.

Pichler, M. (2013). "People, planet & profit": consumer-oriented hegemony and power relations in palm oil and agrofuel certification. *The Journal of Environment & Development*, *22*(4), 370-390. https://doi.org/10.1177%2F1070496513502967

Poh, P. Yong, Wei-Jin. & Chong, F. (2010) Palm Oil Mill Effluent (POME) Characteristics in High Crop Season and the Applicability of High-Rate Anaerobic Bioreactors for the Treatment of POME. *ACS Publications*. https://pubs.acs.org/doi/10.1021/ie101486

Prasad, P. Elmes, M. (2005). In the Name of the Practical: Unearthing the Hegemony of Pragmatics in the Discourse of Environmental Management*. *Journal of Management Studies*, 42(4). 845-867. https://doi.org/10.1111/j.1467-6486.2005.00521.x

Purnomo, H. Okarda, B. Dermawan, A. Ilham, Q. Pacheco, P. Nurfatriani, F. & Suhendang, E. (2020). Reconciling oil palm economic development and environmental conservation in Indonesia: A value chain dynamic approach. *Forest Policy and Economics*, 111, 102089.

https://doi.org/10.1016/j.forpol.2020.102089

Rietberg, P. & M. Slingerland. (2016. May.). Cost and benefits of certification for independent smallholders. A science for policy paper for the RSPO. *Wageningen University*. http://tinyurl.com/y93585xp

RSPO. (2020, 25. August). *RSPO Certification Audits during COVID-19 Crisis*. https://rspo.org/news-and-events/covid-19/rspo-certification-audits-during-covid19-crisis

RSPO. (2021, 10. March). *RSPO Responds to Greenpeace report on certification*. https://www.rspo.org/news-and-events/news/rspo-responds-to-greenpeace-report-on-certification

Santika, T. Wilson, K. A. Budiharta, S. Law, E. A. Poh, T. Ancrenaz, M. Struebig, M. Meijaard, E. (2019). Does oil pam help alleviate poverty? A Multidimensional counterfactual assessment of oil palm development in Indonesia. *World Development*, 120, 105-117. https://www.sciencedirect.com/science/article/pii/S0305750X1930097X

Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. (7th ed.). John Wiley & Sons.

Setiono, B. & Husein, Y. (2005). Fighting forest crime and promoting prudent banking for sustainable forest management. *Centre for International Forestry Research (CIFOR)*, 44.

Shahputra, M. A. & Zen, Z. (2019) Positive and Negative Impact of Oil Palm Expansion in Indonesia and the Prospect to Achieve Sustainable Palm Oil. *International Conference on Agriculture, Environment, and Food Security, IOP publishing*. https://iopscience.iop.org/article/10.1088/1755-1315/122/1/012008/pdf

Silalertruksa, T. Bonnet, S. & Gheewala, S. (2011). Life cycle costing and externalities of palm oil biodiesel in Thailand. *J. Clean. Prod.* 28, 225–232. https://doi.org/10.1016/j.jclepro.2011.07.022

Smith, J. (1998, revised and updated 2008). Tropical rainforest. Accessed 02. March 2021. https://www.britannica.com/science/tropical-rainforest

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039

SPOTT. (2016, 25. November). *Economic Impacts*. Accessed 04. March 2021 from https://www.spott.org/palm-oil-resource-archive/impacts/economic/#:~:text=Indonesia%20exported%2016.4%20million%20tonnes,to%20rural%20income%20in%20Indonesia.&text=The%20industry%20directly%20and%20indirectly,over%201.7%20million%20in%20Indonesia

Tacconi, L., Obidzinski, K. & Agung, F. (2004). Learning lessons to promote forest certification and control illegal logging in Indonesia. *CIFOR*. https://doi.org/10.17528/cifor/001588

Tacconi, L., Rodrigues, R. J. & Maryudi, A. (2019). Law enforcement and deforestation: Lessons for Indonesia from Brazil. *Forest policy and economics*, *108*, 101943.

https://doi.org/10.1016/j.forpol.2019.05.029

Tan, K. T., Lee, K. T., Mohamed, A. R., & Bhatia, S. (2009). Palm oil: addressing issues and towards sustainable development. *Renewable and sustainable energy reviews*, 13(2), 420-427. https://www.simedarbyplantation.com/sites/default/files/sustainability/high-carbon-stock/consulting-reports/socio-economic/hcs-consulting-report-15-the-economic-impacts-of-palm-oil-in-indonesia.pdf

Therivel, R. & Paridario, M. R. (2013). *The practice of strategic environmental assessment*. Routledge.

Transparency international. (2020). *Corruption Perceptions Index*. Accessed 10. March 2021 from https://www.transparency.org/en/cpi/2020/index/idn

Uda, S. Hein, L. & Sumarga, E. (2017). Towards sustainable management of Indonesian tropical peatlands. *Wetlands Ecol Manage,* 25, 683–701. https://doi.org/10.1007/s11273-017-9544-0

Uning, R. Latif, M. Othman, M. Junen, L. Hanif, N. Nadzir, M. Maulud, K. Jaafar, W. Said, N. Ahamad, F. & Takriff, M. (2020). A Review of Southeast Asian Oil Palm and Its CO_2 Fluxes. *Sustainability*, *12*(12), 5077. http://dx.doi.org/10.3390/su12125077

Vijay, V., Pimm, S. L., Jenkins, C. N. & Smith, S. J. (2016). The impacts of oil palm on recent deforestation and biodiversity loss. *PloS one*, *11*(7), e0159668. https://doi.org/10.1371/journal.pone.0159668

Voora, V. Larrea, C. Bermudez, S. & Balino, S. (2019). Global Market Report: Palm Oil. *The International Institute for Sustainable Development, Sustainable Commodities Marketplace Series*. https://www.iisd.org/system/files/publications/ssi-global-market-report-palm-oil.pdf?q=sites/default/files/publications/ssi-global-market-report-palm-oil.pdf

Wayakone, S. & Makoto, I. (2012). Evaluation of the environmental impacts assessment (EIA) system in Lao PDR. *Journal of Environmental Protection*, *3*(12), 1655-1670.

Wilmar International Limited. (2014). Annual report 2013: Gaining Strength in Adversity. *Wilmar International Limited.* https://www.wilmar-international.com/wp-content/uploads/2014/04/Wilmar-Annual-Report-2013-Final.pdf

World Commission on Environment and Development. (1987). Our common future. Oxford; New York: Oxford University Press.

Worldbank. (2019). *GDP (current US$) Indonesia*. Accessed 26. March 2021 from https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=ID

Yin, R. K. (2018). *Case study research: Design and methods* (6th ed.). Thousand Oaks, CA: Sage.

Young, N. (2019, 6. November). *5 problems with 'sustainable' palm oil*. Greenpeace. https://www.greenpeace.org/aotearoa/story/5-problems-with-sustainable-palm-oil/

Zahan, K. A. & Kano, M. (2018). Biodiesel production from palm oil, its by-products, and mill effluent: a review. *Energies*, *11*(8), 2132. https://doi.org/10.3390/en11082132

Appendix

Appendix 1: Case 1: Life cycle sustainability assessment

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Review

A Review of Southeast Asian Oil Palm and Its CO_2 Fluxes

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Received: 17 May 2020; Accepted: 15 June 2020; Published: 22 June 2020

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Abstract: Palm oil production is a key industry in tropical regions, driven by the demand for affordable vegetable oil. Palm oil production has been increasing by 9% every year, mostly due to expanding biofuel markets. However, the oil palm industry has been associated with key environmental issues, such as deforestation, peatland exploitation and biomass burning that release carbon dioxide (CO_2) into the atmosphere, leading to climate change. This review therefore aims to discuss the characteristics of oil palm plantations and their impacts, especially CO_2 emissions in the Southeast Asian region. The tropical climate and soil in Southeast Asian countries, such as Malaysia and Indonesia, are very suitable for growing oil palm trees. However, due to the scarcity of available plantation areas deforestation occurs, especially in peat swamp areas. Total carbon losses from both biomass and peat due to the conversion of tropical virgin peat swamp forest into oil palm plantations are estimated to be around 427.2 ± 90.7 t C ha^{-1} and 17.1 ± 3.6 t C ha^{-1} $year^{-1}$, respectively. Even though measured CO_2 fluxes have shown that overall, oil palm plantation CO_2 emissions are about one to two times higher than other major crops, the ability of oil palms to absorb CO_2 (a net of 64 tons of CO_2 per hectare each year) and produce around 18 tons of oxygen per hectare per year is one of the main advantages of this crop. Since the oil palm industry plays a crucial role in the socio-economic development of Southeast Asian countries, sustainable and environmentally friendly practices would provide economic benefits while minimizing environmental impacts. A comprehensive review of all existing oil plantation procedures is needed to ensure that this high yielding crop has highly competitive environmental benefits.

Keywords: palm oil; tropical area; carbon emission; CO_2; flux

Sustainability 2020, 12, 5077; doi:10.3390/su12125077

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1. Introduction

laeis guineensis, or oil palm, is a tree in the palm family (Arecaceae) that is cultivated as the most important source of oilseed today [1–3]. Oil palm trees are found only in the tropical forest ecosystem and grow in the range of 10° north and south of the equator. This tree species can grow in areas where the other tree species cannot grow well [4]. With average yields in major producing countries ranging between three and four mesocarps (palm) oil ha^{-1} $year^{-1}$, the oil palm is regarded as the most productive oil crop on the market [2]. Global palm oil production is increasing by around 9% per year and the oil is used in various kinds of products. Two of the biggest markets for palm oil are China and India [5–7].

Oil palm plantations have been associated with deforestation in many tropical regions [8–10] and affect the biodiversity of tropical forests [11]. Oil palm plantations support much fewer species than other tree crops [12,13]. In terms of global palm oil production, Indonesia and Malaysia are the largest producers, with the capacity to produce ≈43 million t $year^{-1}$, accounting for 87% of all palm oil. From 1990, Indonesia and Malaysia had a total oil palm harvested area of 6.5 million ha. However, between the years 1990 and 2010, more than 10% of the total deforestation in Indonesia and Malaysia was due to oil palm, even when assuming that only half of the oil palm expansion caused forest loss [14].

Other than deforestation, oil palm plantations have also been associated with carbon emissions and climate change [15,16]. Oil palm plantations have been associated with a 2.5 Gigaton Carbon (Gt C) loss in carbon stock in tropical peatlands since 1990 [17], and in many cases oil palm plantations have been linked to the loss of carbon stored within peatland areas [18–21]. Total carbon losses from biomass and peat of 427.2 ± 90.7 t C ha^{-1} and 17.1 ± 3.6 t C ha^{-1} $year^{-1}$, respectively, due to the conversion of natural tropical peat swamp forest to oil palm plantations, were recorded over the past 25 years. The amount of total carbon loss from peat is around 63% of the total carbon loss, demonstrating that it is essential that mitigation measures are developed to preserve tropical peat swamps from land conversion, which will, in turn, reduce the greenhouse gas load [22].

Since palm oil is important as a cheap source of vegetable oil, this study aims to discuss the characteristics of oil palm plantations and the surrounding environment. The associations of oil palm plantations with carbon dioxide (CO_2) fluxes are also presented, particularly those from the Southeast Asian region. A systematic review method based on relevant literature regarding oil palm plantations from various sources was used in this study. Peer-reviewed literature was identified and scrutinized for information, and data relating to oil palm plantations in tropical regions were summarized.

2. Oil Palm Characteristics and Its Environment

2.1. The Oil Palm Crop

The oil palm tree is a single-stemmed plant [7]. The woody stem carries a single terminal growing point, from which leaves appear at regular intervals in a double spiral [23]. According to Johnson [24], general oil palm leaves are branched into leaflets joined to a central leaf axis (the rachis) and often feature a feather. Palms bearing such foliage are often recognized simply as feather palms. An oil palm leaf can reach up to 5 m in length. Each leaf supports a single inflorescence, which can be either male or female [25]. Oil palms bear both functionally male and female flowers on the same tree in an alternating cycle to minimize the chances of self-pollination [26].

An oil palm tree begins to bear fruit 3–4 years after planting. The fruits are in bunches, encompassing the oily pericarp, shell and kernel, which contains 45–55% of edible oil [7,27,28]. The weight of each fruit bunch is approximately 15–30 kg and can reach up to 50 kg [29,30]. The harvested product is a fruit bunch comprising between 1500 and 2000 fruitlets [25]. The products of the fresh fruit bunch include crude palm oil, which is extracted from the orange-yellow mesocarp, while palm kernel oil is usually extracted from the white kernel [25,29].

2.2. Climate

Geographically, the oil palm flourishes best in lowland regions in the tropical rainforest [30,31]. The oil palm is planted in a wide range of latitudes on each continent, roughly 10° north and south of the equator. This distribution is due to how the global oceanic and atmospheric currents affect the climate, as well as the presence and relative position of large landmasses that can greatly alter the temperature and rainfall [32].

In general, the equatorial belt offers suitable cultivation environments for oil palm, because it provides a suitable amount of sunshine, high temperatures, and wet and humid conditions with a high rainfall rate [33,34]. Specifically, there are five important climatic conditions for oil palm cultivation as proposed by Goh [35] (Table 1). Ultimately, to achieve the best yield from oil palms, the oil palms need minimum climatic requirements, such as adequate sunshine and solar radiation of 16–17 MJ m^{-2} day^{-1}, annual rainfall of 2000–2500 mm, low vapor pressure deficit and temperatures of a mean maximum in the range of 29–33 °C and a mean minimum in the range 22–24 °C.

Table 1. Proposed classification of climatic properties in relation to the suitability for oil palm.

Climatic Element	Highly Suitable	Suitable	Moderately Suitable	Currently Unsuitable	Permanently Unsuitable
Annual rainfall (mm $year^{-1}$)	2000–2500	2500–3000 1700–2000	3000–4000 1400–1700	4000–5000 1100–1400	>5000 <1100
Duration of dry season (month)	0	1	2–4	5–6	>6
Mean annual temperature	26–29	29–32 23–26	32–34 20–23	34–36 17–20	>36 <20
Daily solar radiation (MJ m^{-2})	16–17	17–19 14–16	19–21 11–14	21–23 8–11	>23 <8
Wind (m s^{-1})	<10	10–15	15–25	25–40	>40

Source: Goh [36].

The oil palm industry plays a crucial role in the socio-economic development of Malaysia [36]. The oil palm yield critically depends on climatic factors [37,38]. Hence, local microclimate changes due to altering land-use, topography, soil properties, etc. and regional changes forced by large-scale global changes are expected to impose significant impacts on the palm oil industry in the coming decades. Therefore, assessing these impacts requires information at both the regional and local scales.

From a large-scale perspective, the El Niño-Southern Oscillation phenomenon (ENSO) is known to influence palm oil production months after its peak. Both warm and cold events negatively impact oil palm production. In the short term (a few months) the warm event, or El Niño, is associated with prolonged dry spells that may lead to bunch failure and floral abortion in oil palm trees [39]. In the longer term of 1–2 years, the production of oil palm is commonly disrupted due to sex differentiation. On the other hand, La Niña, which brings about more rainfall in the country, often disrupts harvesting and logistics management. In addition, La Niña also induces poor pollination and fruit-sets [40].

There is a lack of comprehensive studies on how climate change impacts oil palm production and yield and the underlying socioeconomics. Most studies have focused on a broader scale perspective and discussed the climate suitability instead of focusing on the yield, which is likely determined by the complex interplay between broad climatic factors and local-scale biotic and abiotic interactions. For instance, Paterson et al. [41], using the results from Global Climate Models (GMCs) and a niche model via a stepwise approach, argued that climate change is expected to reduce the area with suitable climates for oil palm plantations over the maritime continent. Studies linking oil palm to ENSO and its implications for short-term forecasts are numerous [42,43]. However, there is a lack of studies discussing the implications of ENSO variability in the future warmer climate and how this is linked to local environmental changes that may affect oil palm cultivation in the future. The hypothesis is that the warmer climate is expected to enlarge the variance of natural climate variability and bring about stronger El Niño and La Niña events [44]. This alteration is expected to impact the regional circulation over Southeast Asian regions, and this impact will be cascaded down to the local scale. The assessment of climate change impacts at a specific plantation thus requires relevant information at both large and plantation scales.

2.3. Soil Classification and Characteristics

The tropical soils used for the cultivation of oil palms have been classified based on the United States Department of Agriculture (USDA) Soil Taxonomy system [45]. There are four types of common soils found: ultisols, oxisols, histosols and mollisols. The types of soil differ between regions in the equatorial tropics. For example, ultisols, oxisols and histosols are generally available in Southeast Asia. In Africa, the soil types oxisols, ultisols and mollisols are commonly found, while in America, oxisols and ultisols are the common soils [25].

Soil characteristics are crucial for oil palm cultivation because they are contributing factors to oil palm production levels [25]. There are two systems available that assess the suitability of soils for growing oil palm. The first system is by Olivin [46,47], who suggested a systematic method for assessing soils for oil palm. The system grades the soils based on soil texture, the quantity of gravel and stones, drainage, and chemical composition, i.e., pH, organic matter and exchangeable cations. In general, Olivin [46,47] defined a good soil as one with little gravel, a texture of soil that allows reasonable drainage, and soil that manages to retain plenty of exchangeable cations and contains a good amount of organic matter.

The second system is that of Paramananthan [48], which provides a detailed set of suitability criteria for the cultivation of oil palm. The system is intended for Southeast Asia, but would probably be relevant in all similar climates [49]. Several important characteristics have been determined by the system, and one is that land with a slope of more than 20° is considered unsuitable, because planting on steep slopes is prone to erosion and can cause problems, e.g., difficulty in harvesting and degradation of the average quality of the soil for the planted oil palm trees [50,51]. In addition, the system selects land that is neither insufficiently or excessively drained, nor prone to flooding. In terms of soil physical criteria, the soil structure needs to be stable and able to provide excellent stable drainage. Additionally, Paramananthan [52] identified and discussed the number of soil types that are generally unsuitable for palms and in which oil palm cannot thrive. They are soils in dry regions, highly weathered soils, soils on steep terrain, lateritic soils, acid sulphate soils, saline soils, sandy soils and organic soils.

3. The Oil Palm and Climate Change Factors

3.1. Deforestation

Forests play important roles in the global ecosystem, where they absorb CO_2 by photosynthesis, which is then released by autotrophic respiration [53]. Forest areas are also known to be carbon pools that trap carbon content in the soil and sub-surface for thousands of years. Any changes or modification to forest areas, as well as forest fires, contribute to carbon emissions. As reported by van Der Werf et al. [54], it has been estimated that between 1997 and 2009 there were carbon emissions of 2.0 Pg C year^{-1} with important contributions from Africa (52%), South America (5%), Equatorial Asia (10%), the boreal region (9%) and Australia (7%). Figure 1 shows the benchmark map of carbon stored in the earth's tropical forests for over 2.5 million ha of forest area and 75 countries, as reported by NASA [55].

Deforestation is usually defined as the loss of forest cover through the conversion of the land to another land-use [56,57]. Factors that contribute to carbon emissions from deforestation include the high profits that come with international trade, which in turn mean losses of unsustainable production are most noticeable at local levels [58–60]. Large amounts of forest areas have been cleared for food crops and also plantations [61]. Global policy changes and the increased demand for biofuels in the transport and energy sectors are also contributing factors [58]. Moreover, deforestation in Southeast Asia is also linked with the logging of tropical timber for economic development [62]. Estimations on deforestation rates were 17–127% for oil palm, 44–129% for timber and 3.1–11.1% for logging in

Indonesia [63]. It is been estimated that an area of 3.5×10^6 ha was burned in east Kalimantan between 1982–1983, which then happened again in 1994 [64]. A study by Yong [65] found that there was a 0.54% deforestation rate in Malaysia with an annual average tree cover loss of 2%. Major drivers of deforestation in Malaysia are commercial loggers, commercial oil palm and other tree planters, infrastructure developers and governmental agencies that are reducing areas of forest land [65].

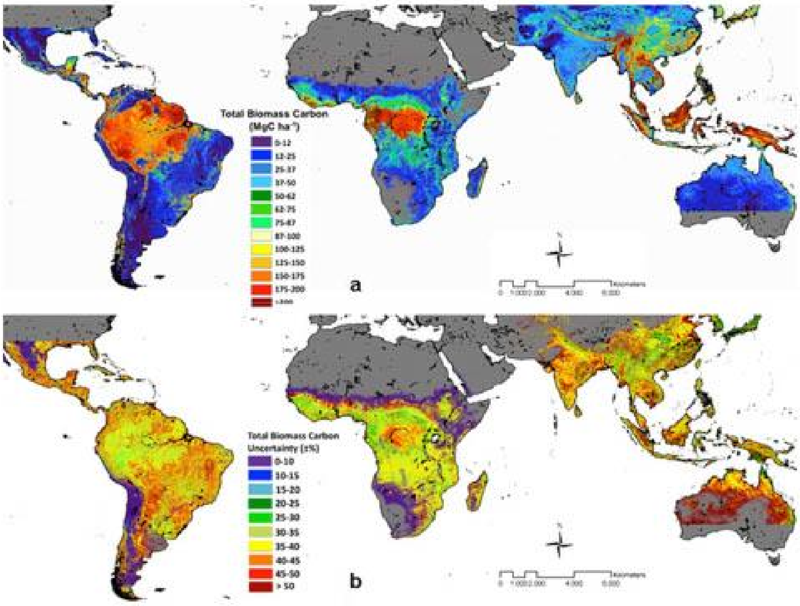

Figure 1. Map of (a) total biomass carbon; (b) total biomass carbon uncertainty. Source: NASA [55].

Deforestation can also have economic and health impacts, and impacts on the environment, flora and fauna of an area. As reported by Wolf [62], deforestation can significantly affect soil erosion, flooding and climate change; it can cause agricultural losses, and wildlife and indigenous peoples are also impacted. A study by Chua, Chua and Wang [64] also revealed that the 1997–1998 deforestation and forest fires in Southeast Asia led to the Nipah virus outbreak, and the deforestation was then exacerbated by drought driven by the ENSO event. Another environmental impact was suggested to be the daily temperature in terms of reduced daytime temperatures and increases in boundary layer clouds. This also had the consequence of rising albedo, transpiration and latent heat loss [66]. Deforestation was suggested to influence the regional climate, elevate local temperatures, cause a decline in precipitation and limit soil moisture, thus increasing climate variability and causing drought [67]. The role of a state or country in preserving forests can support environmental sustainability. The Sabah state government, through the Sabah Structure Plan 2033, has committed to preserving the permanent forest reserve based on the priority conservation area. The state of Sabah also retains forest areas as the largest land-use areas in 2033 with 66.71% of the total area of Sabah (Town and Regional Planning Department of Sabah, Kota Kinabalu, Sabah, 2016). The Sabah Structure Plan 2033 is a legal document that focuses on the prioritization of the conservation of forests [68].

3.2. *Peatland Areas*

Peatland plays a significant role as a carbon pool and is an important component of the carbon soil–atmospheric exchange process [69]. In Southeast Asia only, forested peatland stores at least

42,000 million metric tons (Mt) of soil carbon [70]. According to Yoshino et al. [71], the total area of peat swamps in Southeast Asia was estimated to be 25 million ha, with 43.1% in Papua, Indonesia, 22.5% in Sumatera, 22% in Kalimantan, and other areas in Peninsular Malaysia, Thailand and Malaysian Borneo. When peatland areas are developed for agriculture, the peat soil in these swamp forests tends to decay and release huge stores of carbon into the atmosphere [69,72].

The natural ecosystem of peatland is usually wet, where un-drained peat consists of 10% plant matter and 90% water, making these areas waterlogged where ponding of rainwater on peat surfaces occurs [70,73]. However, due to economic pressures, peatland areas are being deforested, drained and often burned for agricultural purposes, such as oil palm and pulpwood plantations [70]. Drained peatlands, such as in Sumatra and Kalimantan, are susceptible to fires where drought has intensified the flammability of the peat, and fires are widely used to clear the land, degrade re-growing vegetation and maintain the land for growing crops [72]. Fires in peatland areas are not easy to extinguish and often burn for a long period. Moreover, anthropogenic activity with the use of fires by people to clear and convert the land to agricultural areas, particularly for oil palm plantations, contributes to uncontrolled burning, which in turn damages large areas of peatland [74]. It is estimated that the peat swamp forest in Sumatra has declined by about 4% over the last two decades due to timber activities, plantations and fires [67,75].

There are five flux components of peatland, including net CO_2 uptake by vegetation, CO_2 emissions from disturbed peatland, CO_2 emissions and other emissions from fires, exports of dissolved and particulate organic carbon and emissions of methane [70]. A study by Othman and Latif [76] found that 1 hour of peat combustion releases 13.850–20.610 $\mu g\ m^{-3}$ of CO, and concluded that peat soil fires produce various amounts of air pollutants and significantly affect atmospheric chemical reactions.

3.3. Biomass Burning

Biomass burning, particularly of agricultural waste, is a major source of aerosol [77]. Certain areas in the world face severe haze episodes due to biomass burning of wheat straw, peatland soil, agricultural waste and forest areas. Biomass burning has also been performed with the aid of fire for land clearing. As reported by Yokelson et al. [78] and Langmann et al. [79], biomass composition plays a significant role in the combustion process, where during the first phase of burning the biomass fuel undergoes thermal degradation and water and volatiles are released. The second phase is pyrolysis, which includes cracking of the carbon chain fuel molecules. Then, several complex mixtures are released and formed during the distillation and pyrolysis process that forms flaming combustion. Shouldering combustion then occurs when the oxygen supply is limited and exothermic reactions take place, which are gas–solid reactions between oxygen and carbon, which then produce high levels of CO_2. Moreover, intense biomass burning episodes, for example in the year 2015, can also be enhanced by dry weather related to the occurrence of strong El Niño conditions [80].

Biomass burning is related to smoke haze and this recurring environmental problem in Southeast Asia affects regional air quality [81,82]. Biomass burning is also a top contributor to particulate pollution in Southeast Asia. Almost every year, fires from biomass burning in Sumatra and Borneo during the dry season, particularly between September to October, contributed to PM_{10} concentrations above 150 $\mu g\ m^{-3}$ at multiple locations in the southern region of Southeast Asia [81]. Another impact of the burning of garden and agricultural residue, especially in suburban areas, is an additional source of anhydro sugars and other organic compounds to aerosol [83].

Emissions from biomass burning have been estimated, particularly targeting carbon emissions. Among the key parameters in estimating fire emissions and biomass burning are the burned area, the fuel load, the combustion factor and the emission factor [84,85]. Estimated Greenhouse Gases (GHGs) and carbon emissions from fires, particularly including non-forest, Acacia species, forest and peat soil fires in Central Sumatra in the year 2013 were calculated by Gaveau et al. [67], where 172 ± 59 Tg CO_2-eq of GHGs were released during the period of 18–24 June. These fire emissions were 26% of the average annual carbon emissions from tropical Asia between 2003 and 2008. A study by Shi et al. [86] on carbon emissions from biomass burning in Southeast Asia for the period 2001–2010 used different types of satellite data. The study found that more than 60,000 km^2 $year^{-1}$ was burned in areas predominantly concentrated in Myanmar, northern Thailand, eastern Cambodia and northern Laos, while the Biosphere Model Integrating Eco-physiological and Mechanistic Approaches using Satellite (BEAMS/MCD45A-Peat) data analysis determined that 210.7 Tg C was released from 2001 to 2010 with the largest contributor being Indonesia. Emission inventories of non-agricultural open fires from 2000 to 2009 in Asia was performed by Song et al. [85], who determined that annual emissions for CO_2 and CO were 83 and 6.1 Tg $year^{-1}$, respectively. They also suggested that burning emissions originated from forest areas because of the large biomass density.

4. Oil Palm and Gas Emissions

GHGs from oil palm areas are expected to influence climate change and air quality. Previous studies have shown that common biogenic GHGs can be both emitted naturally and absorbed by oil palm trees. In terms of GHG absorption, CO_2 is always the focus in relation to land-use changes relating to oil palm areas. According to Henson [87], a hectare of oil palm trees can absorb a net amount of 64 tons of CO_2 each year and produces around 18 tons of oxygen, which is higher than a forest's net absorption (42.4 t ha^{-1} $year^{-1}$).

Recently, a study by Nadzir et al. [88] revealed that the emissions of isoprene (C_5H_8), CO_2, and surface ozone (O_3) from oil palm plantation areas in the state of Pahang, Peninsular Malaysia, were significantly high due to meteorological factors such as temperature. The study observed high mixing ratios of isoprene during the day and low mixing ratios at night, which is consistent with many previous studies [89–92]. The maximum daytime peak values observed were ~25 ppb, while the lowest values were measured during the night with mixing ratios of ~0.5 ppb for isoprene. Surface O_3 was observed to have the same pattern where high mixing ratios were measured during the daytime (~60 ppb). CO_2, on the other hand, showed a diurnal pattern with high mixing ratios during the night compared to the daytime.

In addition to climate change issues, air quality problems can also be linked to oil palm land-use changes. Biogenic GHGs, also known as BVOCs (Biogenic Volatile Organic Compounds), such as isoprene (C_5H_8), can be released from oil palm trees. BVOCs contribute to about 90% of all VOCs in the atmosphere [93]. Isoprene and other BVOCs are linked to the production of surface O_3 in the presence of nitrogen oxide (NO_x) [94], which contributes to climate change and poor air quality. Surface O_3 is a widespread air quality problem if present in high concentrations with present-day levels of NO_x as well as biogenic and anthropogenic VOC emissions [95,96]. NO_x can be emitted from industrial and city areas near oil palm plantations depending on the prevailing wind. According to Nadzir et al. [97], the three major NO_x sources responsible for increased NO_x over oil palm plantation areas are all linked to agro-industrial activities, such as vehicle exhaust, palm oil plant combustion, and substantial soil nitrogen fertilization for plantations.

4.1. Emissions of CO_2

Oil palm plantations and related activities have been associated with climate change, where CO_2 is the main key driver. The main pathways where oil palm-related CO_2 is released into the atmosphere are through deforestation, peatland exploitation and biomass burning, as well as the oil palm plantations themselves [98]. This section, however, will only focus on CO_2 emissions from oil palm plantations on peat soil and related aspects as there is growing concern regarding the magnitude of CO_2 losses from one of the earth's natural carbon storage areas [99,100]. Better constraints on oil palm CO_2 have been addressed through common field CO_2 emission measurements on plantation soil (peat), while there is limited information on emissions from the drain, trunk, and leaf of the oil palm tree. Indonesia and Malaysia have been the main target areas of CO_2 emissions measurements, as they aim to dedicate millions of metric tons of palm oil to meet global demand in producing biofuels [101].

Oil palm plantations on peat soil in Indonesia have been estimated to have CO_2 emissions ranging between 12 and 95 t C ha^{-1} year^{-1} (Table 2). While most of the measurements were located in Sumatra, Indonesia, the highest CO_2 emission was recorded in Jambi and Riau (95 t C ha^{-1} year^{-1}) [102]. The lowest CO_2 emissions, however, were also recorded in Jambi (10 t C ha^{-1} year^{-1}) [103], which could imply high spatial variability of emissions from peat soil. In Malaysia, CO_2 emissions were estimated between 7 and 79 t C ha^{-1} year^{-1} (Table 2). The highest Malaysian peat soil CO_2 emissions were recorded in Selangor at 79 and 65 t C ha^{-1} year^{-1} in the years 2000 and 2006, respectively [104]. The lowest CO_2 emission was recorded in Sarawak (7 t C ha^{-1} year^{-1}), which also has the largest area of oil palm plantation on peat soil in Malaysia [105]. Comparisons between Indonesia and Malaysia's CO_2 emissions show that both countries, as main palm oil producers globally, have a comparable magnitude of emissions, which could be due to similar peat soils as well as oil palm tree characteristics.

Table 2. Peat soil CO_2 emissions from previously reported studies.

Country	Area	Year	Emissions (t C ha^{-1} year^{-1})	Reference
Indonesia	Jambi and Riau	2007–2010	95	Hooijer et al. [102]
	Jambi	2010–2011	13	Marwanto and Agus [106]
	Jambi	2011–2012	10	Dariah et al. [103]
	Riau	2011–2012	18	Husnain et al. [107]
	Riau	2016–2017	12	Marwanto et al. [108]
Malaysia	Selangor	2000	79	Matysek et al. [104]
	Sarawak	2002–2003	17	Melling et al. [109]
	Sarawak	2002–2003	41	Melling et al. [110]
	Sarawak	2003	7	Matysek et al. [104]
	Selangor	2006	65	Matysek et al. [104]

Extensive measurements on oil palm CO_2 emissions, such as from the root, trunk, drain and also above the canopy are essential to better understand the role of oil palm on global scale carbon emissions (Table 3). Oil palm root CO_2 emissions were estimated at 19 t C ha^{-1} year^{-1} in Aceh Barat, Indonesia [111], while a separate study in Sarawak, Malaysia showed the average trunk, drain and soil CO_2 emission was 24 t C ha^{-1} year^{-1} [112]. Comparisons between the two studies on CO_2 emissions suggest the oil palm tree root could release a huge portion of the high CO_2 emissions. On the contrary, a large area of oil palm plantation in Sabah, Malaysia recorded an average CO_2 uptake of 82 t C ha^{-1} year^{-1} above the oil palm canopy, higher than an intact forest (32 t C ha^{-1} year^{-1}) [113]. The high rates of carbon uptake of oil palm mean it is theoretically possible to achieve carbon neutrality for biofuels, in the long term replacing fossil fuels [114,115]. Based on the above argument, the overall emission and absorption of oil palm plantations with factors that influence these exchanges in tropical regions are presented in Figure 2.

Table 3. Oil palm plantations related CO_2 emissions.

Country	Area	Year	Emissions (t C ha^{-1} year^{-1})	Reference
Indonesia	Aceh Barat	2008	19 (Root)	Agus et al. [111]
Malaysia	Sabah	2008	82 (Above canopy-uptake)	Fowler et al. [113]
	Sarawak	2015–2017	24 (Trunk, drain, soil)	Manning et al. [112]

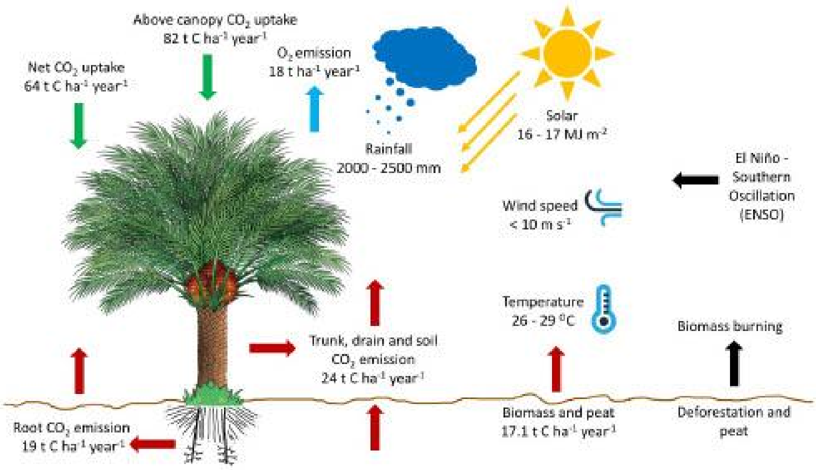

Figure 2. Emission and absorption of oil palm plantations with factors that influence these exchanges in tropical regions.

4.2. Comparison Studies on Oil Palm CO_2 with Other Crops

In this section, the focus on CO_2 flux has not been expanded upon in detail for other crops besides oil palm. The challenge in comparing emissions between different crops lies in the fact that not only do the soil types, rainfall and temperatures vary, but agricultural practices such as tillage, liming of soil and addition of nitrogen fertilizer can also influence CO_2 emissions [116–121]. In some cases, plantations such as rubber plantations have been shown to have a lower CO_2 flux compared to a natural forest [122]. Any useful comparison of emissions between different crops will require careful consideration of both the natural properties of the soil and agricultural practices in specific regions.

Table 4 shows some of the CO_2 emissions from different crops as well as intact forest. The CO_2 fluxes in these studies show that, overall, oil palm plantation CO_2 emissions are about one to two magnitudes higher compared to other crops, such as barley, corn and rubber. Corn appears to have the lowest emissions at 0.4 t C ha^{-1} $year^{-1}$. Based on these values alone, it would seem that CO_2 flux is highest in oil palm plantations. However, as mentioned in the earlier paragraph, various factors can affect the flux in the soil, as even oil palm flux has a range between 7 and 95 t C ha^{-1} $year^{-1}$, as shown in emissions studies in Malaysia and Indonesia (Table 2). The intact forest CO_2 flux recorded by Zhao et al. [122] is higher than that of oil palm recorded in a study by Matysek et al. [104]. Additionally, crop yields per hectare should be an important consideration, as total flux may be offset for crops with high yields, such oil palm, which has a potential yield that generally exceeds 8 t oil ha^{-1} $year^{-1}$ [25].

Table 4. CO_2 emissions from different crops.

Plant	Type	Time Measured (Location)	Emissions (t C ha^{-1} $year^{-1}$)	Reference
Barley	Soil	November 1998 to October 2000, over non-irrigated barley (Central Spain)	0.63	Sánchez et al. [123]
Corn	Soil	Based on agricultural inputs detailed by Frye and Blevins (1997) and Ismail et al. (1994), Blevins et al. (1983). (Kentucky, USA)	0.4	West and Marland [119]
Rubber Intact Forest	Soil	January and March 2016 (China)	5.7 9.5	Zhao et al. [122]

5. Conclusions

Overwhelming global demand for affordable vegetable oil has driven the fast expansion of oil palm plantations, especially in the Southeast Asian region. This expansion has led to many disastrous environmental issues, such as the destruction of natural carbon storage. The utilization of peatland and deforestation for oil palm plantations has been identified as the main challenge to controlling natural carbon emissions to the atmosphere. Previous estimation studies show that oil palm carbon and CO_2 emissions are a magnitude higher compared to other crops (e.g., barley, corn, rubber). Natural climate variability, such as El Niño and La Niña events, is expected to influence oil palm plantations at both large and small scales, and the change in this variability under warmer climates is expected to influence the palm oil yield. The ability of oil palms to absorb CO_2 (a net of 64 tons of CO_2 per hectare each year) and produce around 18 tons of oxygen is an advantage of this type of plantation.

To further reduce oil palm-related natural carbon emissions, a number of key processes can be implemented. For instance, curbing biomass burning, reducing the exploitation of peatland or swamp areas for plantation and replacing fossil fuels with biofuels to power plantation and production activities can achieve sustainable oil palm. The sustainability of plantation expansions can be achieved through a comprehensive review of all existing plantations to ensure that they align with existing sustainability criteria.

Author Contributions: Conceptualization, R.U. and M.T.L.; formal analysis, R.U.; investigation, R.U. and M.T.L.; writing—original draft preparation, R.U., M.T.L., M.O., L.J., N.M.H., M.S.M.N., K.N.A.M., W.S.W.M.J., N.F.S.S., F.A. and M.S.T.; writing—review and editing, R.U., M.T.L., M.O., L.J., N.M.H., M.S.M.N., K.N.A.M., W.S.W.M.J., N.F.S.S., F.A. and M.S.T.; supervision, M.T.L. and M.S.T.; project administration, M.T.L. and M.S.T.; funding acquisition, M.T.L. and M.S.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Malaysian Ministry of Higher Education, grant number KK-2019-014.

Acknowledgments: We would like to thank the Malaysian Ministry of Higher Education for funding this study through the KK-2019-014 research grant. We would also like to thank Rose Norman for proofreading this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Singh, R.; Ong-Abdullah, M.; Low, E.T.L.; Manaf, M.A.A.; Rosli, R.; Nookiah, R.; Ooi, L.C.L.; Ooi, S.E.; Chan, K.L.; Halim, M.A.; et al. Oil palm genome sequence reveals divergence of interfertile species in Old and New worlds. *Nature* **2013**, *500*, 335–339. [CrossRef] [PubMed]
2. Wahid, M.B.; Abdullah, S.N.A.; Henson, I.E. Oil palm—Achievements and potential. *Plant Prod. Sci.* **2005**, *8*, 288–297. [CrossRef]
3. Ibragimov, A.; Sidique, S.F.; Tey, Y.S. Productivity for sustainable growth in Malaysian oil palm production: A system dynamics modeling approach. *J. Clean. Prod.* **2019**, *213*, 1051–1062. [CrossRef]
4. Pasiecznik, N. *Elaeis guineensis (African oil palm)*; CAB International: Wallingford, UK, 2013.
5. Wilcove, D.S.; Koh, L.P. Addressing the threats to biodiversity from oil-palm agriculture. *Biodivers. Conserv.* **2010**, *19*, 999–1007. [CrossRef]
6. Fitzherbert, E.B.; Struebig, M.J.; Morel, A.; Danielsen, F.; Brühl, C.A.; Donald, P.F.; Phalan, B. How will oil palm expansion affect biodiversity? *Trends Ecol. Evol.* **2008**, *23*, 538–545. [CrossRef]
7. Edem, D. Palm oil: Biochemical, physiological, nutritional, hematological and toxicological aspects: A review. *Plant Foods Hum. Nutr.* **2002**, *57*, 319–341. [CrossRef]
8. Toulec, T.; Lhota, S.; Soumarová, H.; Putera, A.K.S.; Kustiawan, W. Shrimp farms, fire or palm oil? Changing causes of proboscis monkey habitat loss. *Glob. Ecol. Conserv.* **2020**, *21*, e00863. [CrossRef]
9. Margono, B.A.; Potapov, P.V.; Turubanova, S.; Stolle, F.; Hansen, M.C. Primary forest cover loss in Indonesia over 2000–2012. *Nat. Clim. Chang.* **2014**, *4*, 730–735. [CrossRef]
10. Gaveau, D.L.A.; Sloan, S.; Molidena, E.; Yaen, H.; Sheil, D.; Abram, N.K.; Ancrenaz, M.; Nasi, R.; Quinones, M.; Wielaard, N.; et al. Four Decades of Forest Persistence, Clearance and Logging on Borneo. *PLoS ONE* **2014**, *9*, e101654. [CrossRef]

11. Padfield, R.; Hansen, S.; Davies, Z.G.; Ehrensperger, A.; Slade, E.M.; Evers, S.; Papargyropoulou, E.; Bessou, C.; Abdullah, N.; Page, S.; et al. Co-producing a Research Agenda for Sustainable Palm Oil. *Front. For. Glob. Chang.* **2019**, *2*, 13. [CrossRef]
12. Luskin, M.S.; Potts, M.D. Microclimate and habitat heterogeneity through the oil palm lifecycle. *Basic Appl. Ecol.* **2011**, *12*, 540–551. [CrossRef]
13. Fayle, T.M.; Turner, E.C.; Snaddon, J.L.; Chey, V.K.; Chung, A.Y.C.; Eggleton, P.; Foster, W.A. Oil palm expansion into rain forest greatly reduces ant biodiversity in canopy, epiphytes and leaf-litter. *Basic Appl. Ecol.* **2010**, *11*, 337–345. [CrossRef]
14. Koh, L.P.; Miettinen, J.; Liew, S.C.; Ghazoul, J. Remotely sensed evidence of tropical peatland conversion to oil palm. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 5127–5132. [CrossRef] [PubMed]
15. Carlson, K.M.; Curran, L.M.; Ratnasari, D.; Pittman, A.M.; Soares-Filho, B.S.; Asner, G.P.; Trigg, S.N.; Gaveau, D.A.; Lawrence, D.; Rodrigues, H.O. Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 7559–7564. [CrossRef] [PubMed]
16. Lee, J.S.H.; Abood, S.; Ghazoul, J.; Barus, B.; Obidzinski, K.; Koh, L.P. Environmental impacts of large-scale oil palm enterprises exceed that of smallholdings in Indonesia. *Conserv. Lett.* **2014**, *7*, 25–33. [CrossRef]
17. Miettinen, J.; Hooijer, A.; Vernimmen, R.; Liew, S.C.; Page, S.E. From carbon sink to carbon source: Extensive peat oxidation in insular Southeast Asia since 1990. *Environ. Res. Lett.* **2017**, *12*, 024014. [CrossRef]
18. Jaenicke, J.; Rieley, J.O.; Mott, C.; Kimman, P.; Siegert, F. Determination of the amount of carbon stored in Indonesian peatlands. *Geoderma* **2008**, *147*, 151–158. [CrossRef]
19. Yule, C.M. Loss of biodiversity and ecosystem functioning in Indo-Malayan peat swamp forests. *Biodivers. Conserv.* **2010**, *19*, 393–409. [CrossRef]
20. Murdiyarso, D.; Lilleskov, E.; Kolka, R. Tropical peatlands under siege: The need for evidence-based policies and strategies. *Mitig. Adapt. Strateg. Glob. Chang.* **2019**, *24*, 493–505. [CrossRef]
21. Austin, K.G.; Kasibhatla, P.S.; Urban, D.L.; Stolle, F.; Vincent, J. Reconciling oil palm expansion and climate change mitigation in Kalimantan, Indonesia. *PLoS ONE* **2015**, *10*, e0127963. [CrossRef]
22. Hergoualc'H, K.; Verchot, L.V. Stocks and fluxes of carbon associated with land use change in Southeast Asian tropical peatlands: A review. *Glob. Biogeochem. Cycles* **2011**, *25*, 789–807. [CrossRef]
23. Rees, A. The apical organization and phyllotaxis of the oil palm. *Ann. Bot.* **1964**, *28*, 57–69. [CrossRef]
24. Johnson, D. Tropical palms. non-wood forest products 10/Rev. 1. In *Rome: Food and Agriculture*; Organization of the United Nations (FAO): Rome, Italy, 2011.
25. Woittiez, L.S.; van Wijk, M.T.; Slingerland, M.; van Noordwijk, M.; Giller, K.E. Yield gaps in oil palm: A quantitative review of contributing factors. *Eur. J. Agron.* **2017**, *83*, 57–77. [CrossRef]
26. Adam, H.; Collin, M.; Richaud, F.; Beulé, T.; Cros, D.; Omoré, A.; Nodichao, L.; Nouy, B.; Tregear, J.W. Environmental regulation of sex determination in oil palm: Current knowledge and insights from other species. *Ann. Bot.* **2011**, *108*, 1529–1537. [CrossRef] [PubMed]
27. Sumathi, S.; Chai, S.; Mohamed, A. Utilization of oil palm as a source of renewable energy in Malaysia. *Renew. Sustain. Energy Rev.* **2008**, *12*, 2404–2421. [CrossRef]
28. Langeveld, H.; Dixon, J.; van Keulen, H. Oil palm biodiesel in the Far East. In *Biofuel Cropping Systems*; Routledge: London, UK, 2014; pp. 178–193.
29. Zwart, R. Opportunities and challenges in the development of a viable Malaysian palm oil biomass industry. *J. Oil Palm Environ. Health (JOPEH)* **2013**, *4*, 41–46.
30. Henson, I.E. A Brief History of the Oil Palm. In *Palm Oil*; Lai, O.-M., Tan, C.-P., Akoh, C.C., Eds.; AOCS Press: Champaign, IL, USA, 2012; pp. 1–29.
31. Duke, J. *Elaeis guineensis Jacq*; Purdue University: West Lafayette, IN, USA, 1983.
32. Ollagnier, M.; Ochs, R.; Martin, G. The manuring of the oil palm in the world. *Manuring Oil Palm World.* **1970**, *36*, 3–63.
33. Chuah, T.; Wan Azlina, A.; Robiah, Y.; Omar, R. Biomass as the renewable energy sources in Malaysia: An overview. *Int. J. Green Energy* **2006**, *3*, 323–346. [CrossRef]
34. Yusoff, S. Renewable energy from palm oil–innovation on effective utilization of waste. *J. Clean. Prod.* **2006**, *14*, 87–93. [CrossRef]
35. Goh, K. Climatic requirements of the oil palm for high yields. In *Managing Oil Palm for High Yields: Agronomic Principles*; Goh, K.J., Ed.; Malaysian Society of Soil Science/Param Agric: Surveys, Malaysia, 2000; pp. 1–17.

36. Liew, W.L.; Kassim, M.A.; Muda, K.; Loh, S.K.; Affam, A.C. Conventional methods and emerging wastewater polishing technologies for palm oil mill effluent treatment: A review. *J. Environ. Manag.* **2015**, *149*, 222–235. [CrossRef]
37. Ong, H.T. System approach to the climatology of oil palm. I. Identification of rainfall and dry spell aspects. *Oleagineux* **1982**, *37*, 93–101.
38. Corley, R.H.V. Oil palm yield components and yield cycles. *Malays. Int. Agric. Oil Palm Conf. Paper* **2012**, *9*, 116–129.
39. Oettli, P.; Behera, S.K.; Yamagata, T. Climate Based Predictability of Oil Palm Tree Yield in Malaysia. *Sci. Rep.* **2018**, *8*, 2271. [CrossRef] [PubMed]
40. Kamil, N.N.; Omar, S.F. The Impact of El Nino and La Nina on Malaysian Oil Palm Industry. *Oil Palm Bulettin* **2017**, *74*, 1–6.
41. Paterson, R.R.M.; Kumar, L.; Taylor, S.; Lima, N. Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia. *Sci. Rep.* **2015**, *5*, 14457. [CrossRef]
42. Shanmuganathan, S.; Narayanan, A.; Mohamed, M.; Ibrahim, R.; Khalid, H. A Hybrid Approach to Modelling the Climate Change Effects on Malaysia's Oil Palm Yield at the Regional Scale. In *Recent Advances on Soft Computing and Data Mining. Advances in Intelligent Systems and Computing*; Springer: Cham, Switzerland, 2014.
43. Keong, Y.K.; Keng, W.M. Statistical Modeling of Weather-based Yield Forecasting for Young Mature Oil Palm. *APCBEE Procedia* **2012**, *4*, 58–65. [CrossRef]
44. Stevenson, S.L. Significant changes to ENSO strength and impacts in the twenty-first century: Results from CMIP5. *Geophys. Res. Lett.* **2012**, *39*, L17703. [CrossRef]
45. Soil Survey Staff. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys*; US Government Printing Office: Washington, DC, USA, 1975.
46. Olivin, J. Étude pour la localisation d'un bloc industriel de palmiers à huile. *Oléagineux* **1968**, *23*, 499–504.
47. Olivin, J. Study for the siting of a commercial oil palm plantation. *Oleagineux (France)* **1986**, *41*, 175–182.
48. Paramananthan, S. Soil requirements of oil palm for high yields. In *Managing Oil Palm for High Yields: Agronomic Principles*; Malaysian Society of Soil Science and Param Agricultural: Kuala Lumpur, Malaysia, 2000; pp. 18–38.
49. Corley, R.H.V.; Tinker, P.B.H. *The Oil Palm*; Wiley: Hoboken, NJ, USA, 2008.
50. Gobin, A.; Campling, P.; Deckers, J.A.; Poesen, J.; Feyen, J. Soil erosion assessment at the Udi-Nsukka Cuesta (southeastern Nigeria). *Land Degrad. Dev.* **1999**, *10*, 141–160. [CrossRef]
51. Hamdan, J.; Burnham, C.; Ruhana, B. Degradation effect of slope terracing on soil quality for Elaeis guineensis Jacq.(oil palm) cultivation. *Land Degrad. Dev.* **2000**, *11*, 181–193. [CrossRef]
52. Paramananthan, S. Managing marginal soils for sustainable growth of oil palms in the tropics. *J. Oil Palm Environ. Health (JOPEH)* **2013**, *4*, 1–16. [CrossRef]
53. Schrier-Uijl, A.P.; Silvius, M.; Parish, F.; Lim, K.H.; Rosediana, S.; Anshari, G. *Environmental and Social Impacts of Oil Palm Cultivation on Tropical Peat—A Scientific Review*; RSPO (Roundtable on Sustainable Palm Oil): Kuala Lumpur, Malaysia, 2013.
54. van Der Werf, G.R.; Randerson, J.T.; Giglio, L.; Collatz, G.J.; Mu, M.; Kasibhatla, P.S.; Morton, D.C.; Defries, R.S.; Jin, Y.; van Leeuwen, T.T. Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmos. Chem. Phys.* **2010**, *10*, 11707–11735. [CrossRef]
55. NASA. Carbon Stored in Earth's Tropical Forest. Available online: https://www.nasa.gov/topics/earth/features/earth20110531-i.html (accessed on 25 December 2019).
56. Jaafar, W.S.W.M.; Maulud, K.N.A.; Kamarulzaman, A.M.M.; Raihan, A.; Sah, S.M.; Ahmad, A.; Saad, S.N.M.; Azmi, A.T.M.; Syukri, N.K.A.J.; Khan, W.R. The Influence of Deforestation on Land Surface Temperature—A Case Study of Perak and Kedah, Malaysia. *Forests* **2020**, *11*, 670. [CrossRef]
57. Kamlun, K.U.; Goh, M.H.; Teo, S.; Tsuyuki, S.; Phua, M.-H. Monitoring of deforestation and fragmentation in Sarawak, Malaysia between 1990 and 2009 using landsat and SPOT images. *J. For. Sci.* **2012**, *28*, 152–157. [CrossRef]
58. Hooijer, A.; Silvius, M.; Wosten, H.; Page, S. *PEAT-CO2, Assessment of CO_2 Emissions from Drained Peatlands in SE Asia*; Delft Hydraulics Report: Delft, The Netherlands, 2006.
59. van Beukering, P.; Schaafsma, M.; Davis, O.; Oskolokaite, I. *The Economic alue of Petland Resources within the Central Kalimantan Peatland Project in Indonesia: Perceptions of Local Communities*; Institute for Environmental Studies: Amsterdam, The Netehrlands, 2008.

60. Wetland International. *Assessment on Peatlands, Biodiversity and Climate Change*; Wetland International: Kuala Lumpur, Malaysia, 2007.
61. Tyson, A.; Varkkey, H.; Choiruzzad, S.A.B. Deconstructing the Palm Oil Industry Narrative in Indonesia: Evidence from Riau Province. *Contemp. Southeast Asia* **2018**, *40*, 422–448. [CrossRef]
62. Wolf, H.A. Deforestation in Cambodia and Malaysia: The case for an international legal solution. *Pac. Rim Law Policy J.* **1996**, *5*, 431–432.
63. Busch, J.; Ferretti-Gallon, K.; Engelmann, J.; Wright, M.; Austin, K.G.; Stolle, F.; Turubanova, S.; Potapov, P.V.; Margono, B.; Hansen, M.C.; et al. Reductions in emissions from deforestation from Indonesia's moratorium on new oil palm, timber, and logging concessions. *Proc. Natl. Acad. Sci. USA* **2015**, *112*, 1328–1333. [CrossRef]
64. Chua, K.B.; Chua, B.H.; Wang, C.W. Anthropogenic deforestation, El Nino and the emergence of Nipah virus in Malaysia. *Malays. J. Pathol.* **2002**, *24*, 15–21.
65. Yong, C. *Deforestation Drivers and Human Rights in Malaysia: A National Overview and Two Sub-Regional Case Studies*; Forest Peoples Programme: Moreton-in-Marsh, UK, 2014.
66. IPCC. *Climate Change and Water*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2009.
67. Gaveau, D.L.A.; Salim, M.A.; Hergoualc'h, K.; Locatelli, B.; Sloan, S.; Wooster, M.; Marlier, M.E.; Molidena, E.; Yaen, H.; DeFries, R.; et al. Major atmospheric emissions from peat fires in Southeast Asia during non-drought years: Evidence from the 2013 Sumatran fires. *Sci. Rep.* **2014**, *4*, 1–7. [CrossRef]
68. Sloan, S.; Campbell, M.J.; Alamgir, M.; Lechner, A.M.; Engert, J.; Laurance, W.F. Trans-national conservation and infrastructure development in the Heart of Borneo. *PLoS ONE* **2019**, *14*, e0221947. [CrossRef]
69. Page, S.E.; Rieley, J.O.; Banks, C.J. Global and regional importance of the tropical peatland carbon pool. *Glob. Chang. Biol.* **2011**, *17*, 798–818. [CrossRef]
70. Hooijer, A.; Page, S.; Canadell, J.G.; Silvius, M.; Kwadijk, J.; Wösten, H.; Jauhiainen, J. Current and future CO_2 emissions from drained peatlands in Southeast Asia. *Biogeosciences* **2010**, *7*, 1505–1514. [CrossRef]
71. Yoshino, K.; Ishida, T.; Nagano, T.; Setiawan, Y. Landcover pattern analysis of tropical peat swamp lands in Southeast Asia. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2010**, *38*, 941–946.
72. Huijnen, V.; Wooster, M.J.; Kaiser, J.W.; Gaveau, D.L.A.; Flemming, J.; Parrington, M.; Inness, A.; Murdiyarso, D.; Main, B.; Van Weele, M. Fire carbon emissions over maritime southeast Asia in 2015 largest since 1997. *Sci. Rep.* **2016**, *6*, 1–8. [CrossRef]
73. Kløve, B.; Sveistrup, T.E.; Hauge, A. Leaching of nutrients and emission of greenhouse gases from peatland cultivation at Bodin, Northern Norway. *Geoderma* **2010**, *154*, 219–232. [CrossRef]
74. Kusumaningtyas, S.D.A.; Aldrian, E. Impact of the June 2013 Riau province Sumatera smoke haze event on regional air pollution. *Environ. Res. Lett.* **2016**, *11*, 075007. [CrossRef]
75. Miettinen, J.; Shi, C.; Liew, S.C. Two decades of destruction in Southeast Asia's peat swamp forests. *Front. Ecol. Environ.* **2011**, *10*, 124–128. [CrossRef]
76. Othman, M.; Latif, M.T. Dust and gas emissions from small-scale peat combustion. *Aerosol Air Qual. Res.* **2013**, *13*, 1045–1105. [CrossRef]
77. Ram, K.; Sarin, M.M.; Sudheer, A.K.; Rengarajan, R. Carbonaceous and secondary inorganic aerosols during wintertime fog and haze over urban sites in the Indo-Gangetic plain. *Aerosol Air Qual. Res.* **2012**, *12*, 359–370. [CrossRef]
78. Yokelson, R.J.; Griffith, D.W.T.; Ward, D.E. Open-path fourier transform infrared studies of large-scale laboratory biomass fires. *J. Geophys. Res.* **1996**, *101*, 21067–21080. [CrossRef]
79. Langmann, B.; Duncan, B.; Textor, C.; Trentmann, J.; Vanderwerf, G. Vegetation fire emissions and their impact on air pollution and climate. *Atmos. Environ.* **2009**, *43*, 107–116. [CrossRef]
80. Mead, M.I.; Castruccio, S.; Nadzir, M.S.M.; Dominick, D.; Thota, A.; Crippa, P. Impact of the 2015 wildfires on Malaysian air quality and exposure: A comparative study of observed and modeled data. *Environ. Res. Lett.* **2018**, *13*, 1–9. [CrossRef]
81. Hyer, E.J.; Chew, B.N. Aerosol transport model evaluation of an extreme smoke episode in Southeast Asia. *Atmos. Environ.* **2010**, *44*, 1422–1427. [CrossRef]
82. Varkkey, H.; Poh Onn, L. The Haze Problem in Southeast Asia: Palm Oil and Patronage. *J. Southeast Asian Econ.* **2017**, *34*, 573–575. [CrossRef]
83. Pegas, P.N.; Nunes, T.; Alves, C.A.; Silva, J.R.; Vieira, S.L.A.; Caseiro, A.; Pio, C.A. Indoor and outdoor characterisation of organic and inorganic compounds in city centre and suburban elementary schools of Aveiro, Portugal. *Atmos. Environ.* **2012**, *55*, 80–89. [CrossRef]

84. Seiler, W.; Crutzen, J.P. Estimates of the gross and net fluxes of carbon between the biospere and the atmosphere from biomass burning. *Clim. Change* **1980**, *2*, 207–247. [CrossRef]
85. Song, Y.; Chang, D.; Liu, B.; Miao, W.; Zhu, L.; Zhang, Y. A new emission inventory for nonagricultural open fires in Asia from 2000 to 2009. *Environ. Res. Lett.* **2010**, *5*, 1–6. [CrossRef]
86. Shi, Y.; Sasai, T.; Yamaguchi, Y. Spatio-temporal evaluation of carbon emissions from biomass burning in Southeast Asia during the period 2001–2010. *Ecol. Model.* **2014**, *272*, 98–115. [CrossRef]
87. Henson, I.E. Notes on oil palm productivity. IV. Carbon dioxide gradients and fluxes and evapotranspiration, above and below the canopy. *J. Oil Palm Res.* **1999**, *11*, 33–40.
88. Nadzir, M.S.M.; Ooi, C.G.; Harris, N.R.P.; Ashworth, K.; Bolas, C.; Bran, S.H.; Macatangay, R.; Jaafar, W.S.W.M.; Yusup, Y.; Latif, M.T.; et al. Driving factors for isoprene-surface ozone chemistry over an oil palm plantation in Malaysia. *Environ. Int.* **2020**, submitted.
89. Holzinger, R.; Sanhueza, E.; von Kuhlmann, R.; Kleiss, B.; Donoso, L.; Crutzen, P.J. Diurnal cycles and seasonal variation of isoprene and its oxidation products in the tropical savanna atmosphere. *Glob. Biogeochem. Cycles* **2002**, *16*, 1074. [CrossRef]
90. Biesenthal, T.A.; Bottenheim, J.W.; Shepson, P.B.; Brickell, P.C. The chemistry of biogenic hydrocarbons at a rural site in eastern Canada. *J. Geophys. Res. Atmos.* **1998**, *103*, 25487–25498. [CrossRef]
91. Goldan, P.D.; Kuster, W.C.; Fehsenfeld, F.C.; Montzka, S.A. Hydrocarbon measurements in the southeastern United States: The Rural Oxidants in the Southern Environment (ROSE) Program 1990. *J. Geophys. Res. Atmos.* **1995**, *100*, 25945–25963. [CrossRef]
92. Montzka, S.A.; Trainer, M.; Goldan, P.D.; Kuster, W.C.; Fehsenfeld, F.C. Isoprene and its oxidation products, methyl vinyl ketone and methacrolein, in the rural troposphere. *J. Geophys. Res. Atmos.* **1993**, *98*, 1101–1111. [CrossRef]
93. Guenther, A.; Karl, T.; Harley, P.; Wiedinmyer, C.; Palmer, P.I.; Geron, C. Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature). *Atmos. Chem. Phys.* **2006**, *6*, 3181–3210. [CrossRef]
94. Wennberg, P.O.; Bates, K.H.; Crounse, J.D.; Dodson, L.G.; McVay, R.C.; Mertens, L.A.; Nguyen, T.B.; Praske, E.; Schwantes, R.H.; Smarte, M.D.; et al. Gas-Phase Reactions of Isoprene and Its Major Oxidation Products. *Chem. Rev.* **2018**, *118*, 3337–3390. [CrossRef]
95. Ahamad, F.; Latif, M.T.; Tang, R.; Juneng, L.; Dominick, D.; Juahir, H. Variation of surface ozone exceedance around Klang Valley, Malaysia. *Atmos. Res.* **2014**, *139*, 116–127. [CrossRef]
96. Latif, M.T.; Huey, L.S.; Juneng, L. Variations of surface ozone concentration across the Klang Valley, Malaysia. *Atmos. Environ.* **2012**, *61*, 434–445. [CrossRef]
97. Nadzir, M.S.M.; Ashfold, M.J.; Khan, M.F.; Robinson, A.D.; Bolas, C.; Latif, M.T.; Wallis, B.M.; Mead, M.I.; Hamid, H.H.A.; Harris, N.R.P.; et al. Spatial-temporal variations in surface ozone over Ushuaia and the Antarctic region: Observations from in situ measurements, satellite data, and global models. *Environ. Sci. Pollut. Res. Int.* **2018**, *25*, 2194–2210. [CrossRef]
98. Khatun, R.; Reza, M.I.H.; Moniruzzaman, M.; Yaakob, Z. Sustainable oil palm industry: The possibilities. *Renew. Sustain. Energy Rev.* **2017**, *76*, 608–619. [CrossRef]
99. Wijedasa, L.S.; Jauhiainen, J.; Könönen, M.; Lampela, M.; Vasander, H.; Leblanc, M.-C.; Evers, S.; Smith, T.E.L.; Yule, C.M.; Varkkey, H.; et al. Denial of long-term issues with agriculture on tropical peatlands will have devastating consequences. *Glob. Chang. Biol.* **2017**, *23*, 977–982. [CrossRef]
100. Evers, S.; Yule, C.M.; Padfield, R.; O'Reilly, P.; Varkkey, H. Keep wetlands wet: The myth of sustainable development of tropical peatlands – implications for policies and management. *Glob. Chang. Biol.* **2017**, *23*, 534–549. [CrossRef]
101. Carter, C.; Finley, W.; Fry, J.; Jackson, D.; Willis, L. Palm oil markets and future supply. *Eur. J. Lipid Sci. Technol.* **2007**, *109*, 307–314. [CrossRef]
102. Hooijer, A.; Page, S.; Jauhiainen, J.; Lee, W.A.; Lu, X.X.; Idris, A.; Anshari, G. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* **2012**, *9*, 1053–1071. [CrossRef]
103. Dariah, A.; Marwanto, S.; Agus, F. Root- and peat-based CO_2 emissions from oil palm plantations. *Mitig. Adapt. Strateg. Glob. Chang.* **2014**, *19*, 831–843. [CrossRef]
104. Matysek, M.; Evers, S.; Samuel, M.K.; Sjogersten, S. High heterotrophic CO_2 emissions from a Malaysian oil palm plantations during dry-season. *Wetl. Ecol. Manag.* **2017**, *26*, 415–424. [CrossRef]

105. Melling, L.; Chaddy, A.; Goh, K.J.; Hatano, R. Soil CO_2 Fluxes from Different Ages of Oil Palm in Tropical Peatland of Sarawak, Malaysia as Influenced by Environmental and Soil Properties. *Acta Hortic.* **2013**, *982*, 25–35. [CrossRef]
106. Marwanto, S.; Agus, F. Is CO_2 flux from oil palm plantations on peatland controlled by soil moisture and/or soil and air temperatures? *Mitig. Adapt. Strateg. Glob. Chang.* **2013**, *19*, 809–819. [CrossRef]
107. Husnain, H.; Wigena, I.G.P.; Dariah, A.; Marwanto, S.; Setyanto, P.; Agus, F. CO_2 emissions from tropical drained peat in Sumatra, Indonesia. *Mitig. Adapt. Strateg. Glob. Chang.* **2014**, *19*, 845–862. [CrossRef]
108. Marwanto, S.; Sabiham, S.; Funakawa, S. Importance of CO_2 production in subsoil layers of drained tropical peatland under mature oil palm plantation. *Soil Tillage Res.* **2019**, *186*, 206–213. [CrossRef]
109. Melling, L.; Hatano, R.; Goh, K.J. Soil CO2 flux from three ecosystems in tropical peatland of Sarawak, Malaysia. *Tellus B Chem. Phys. Meteorol.* **2005**, *57*, 1–11. [CrossRef]
110. Melling, L.; Goh, K.J.; Beauvais, C.; Hatano, R. Carbon Flow and Budget in Young Mature Oil Palm Agroecosystem on Deep Tropical Peat. *Planter* **2008**, *84*, 21.
111. Agus, F.; Wahyunti, A.D.; Setyanto, P.; Subiksa, I.G.M.; Runtunuwu, E.; Susanti, E.; Supriatna, W. Carbon Budget and Management Strategies for Conserving Carbon in Peatland: Case Study in Kubu Raya and Pontianak Districts, West Kalimantan, Indonesia. In *Proceeding of International Workshop on Evaluation and Sustainable Management of Soil Carbon Sequestration in Asian Countries*; Indonesian Soil Research Institute: Bogor, Indonesia, 2010.
112. Manning, F.C.; Kho, L.K.; Hill, T.C.; Cornulier, T.; Teh, Y.A. Carbon Emissions From Oil Palm Plantations on Peat Soil. *Front. For. Glob. Chang.* **2019**, *2*, 37. [CrossRef]
113. Fowler, D.; Nemitz, E.; Misztal, P.; Di Marco, C.; Skiba, U.; Ryder, J.; Helfter, C.; Cape, J.N.; Owen, S.; Dorsey, J.; et al. Effects of land use on surface-atmosphere exchanges of trace gases and energy in Borneo: Comparing fluxes over oil palm plantations and a rainforest. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **2011**, *366*, 3196–3209. [CrossRef]
114. Meijaard, E.; Sherman, J.; Ancrenaz, M.; Wich, S.A.; Santika, T.; Voigt, M. Orangutan populations are certainly not increasing in the wild. *Curr. Biol.* **2018**, *28*, R1241–R1242. [CrossRef]
115. Sharvini, S.R.; Noor, Z.Z.; Chong, C.S.; Stringer, L.C.; Glew, D. Energy generation from palm oil mill effluent: A life cycle assessment of two biogas technologies. *Energy* **2020**, *191*, 116513. [CrossRef]
116. Xiao, D.; Ye, Y.; Xiao, S.; Zhang, W.; He, X.; Wang, K. Effects of tillage on CO_2 fluxes in a typical karst calcareous soil. *Geoderma* **2019**, *337*, 191–201. [CrossRef]
117. Pareja-Sánchez, E.; Cantero-Martínez, C.; Álvaro-Fuentes, J.; Plaza-Bonilla, D. Tillage and nitrogen fertilization in irrigated maize: Key practices to reduce soil CO_2 and CH_4 emissions. *Soil Tillage Res.* **2019**, *191*, 29–36. [CrossRef]
118. Wilson, H.M.; Al-Kaisi, M.M. Crop rotation and nitrogen fertilization effect on soil CO_2 emissions in central Iowa. *Appl. Soil Ecol.* **2008**, *39*, 264–270. [CrossRef]
119. West, T.O.; Marland, G. Net carbon flux from agriculture: Carbon emissions, carbon sequestration, crop yield, and land-use change. *Biogeochemistry* **2003**, *63*, 73–83. [CrossRef]
120. Bernoux, M.; Volkoff, B.; Carvalho, M.d.C.S.; Cerri, C.C. CO_2 emissions from liming of agricultural soils in Brazil. *Glob. Biogeochem. Cycles* **2003**, *17*, 1049. [CrossRef]
121. Ball, B.C.; Scott, A.; Parker, J.P. Field N_2O, CO_2 and CH_4 fluxes in relation to tillage, compaction and soil quality in Scotland. *Soil Tillage Res.* **1999**, *53*, 29–39. [CrossRef]
122. Zhao, Y.-L.; Goldberg, S.D.; Xu, J.-C.; Harrison, R.D. Spatial and seasonal variation in soil respiration along a slope in a rubber plantation and a natural forest in Xishuangbanna, Southwest China. *J. Mt. Sci.* **2018**, *15*, 695–707. [CrossRef]
123. Sánchez, M.L.; Ozores, M.I.; López, M.J.; Colle, R.; De Torre, B.; García, M.A.; Pérez, I. Soil CO_2 fluxes beneath barley on the central Spanish plateau. *Agric. For. Meteorol.* **2003**, *118*, 85–95. [CrossRef]

Source: Omran, N. Sharaai, A. & Hashim, A. (2021). Visualization of the Sustainability Level of Crude Palm Oil Production: A Life Cycle Approach. Sustainability, 13(4):1607. https://doi.org/10.3390/su13041607

Appendix 2: Case 2: Life cycle assessment

BIOMASS AND BIOENERGY 51 (2013) 109–124

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Current state and environmental impact assessment for utilizing oil palm empty fruit bunches for fuel, fiber and fertilizer – A case study of Malaysia

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ARTICLE INFO

Article history:
Received 21 July 2012
Received in revised form
20 December 2012
Accepted 13 January 2013
Available online 19 February 2013

Keywords:
Life cycle assessment
Oil palm biomass
Recycling
Environmental impact
Elaeis guineensis

ABSTRACT

This paper describes the trend of utilizing oil palm residue, i.e. the empty fruit bunches (EFB) left after extraction of the palm oil, using a case study of Malaysia, which is one of the world's major palm oil producers, and discusses the environmental performance of recycling technologies being developed in Malaysia for fuel, fiber, and fertilizer. Seven technologies are analyzed: ethanol production, methane recovery, briquette production, biofuel for combined heat and power (CHP) plants, composting, medium density fiberboard (MDF) production, and pulp and paper production. The life cycle assessment (LCA) method is used to discuss the environmental impacts of these technologies for adding value to this biomass. Sensitivity analyses are conducted to determine the land use effects for the various technologies utilizing EFB and to estimate the energy generation potential of raw EFB in CHP plants and methane production. Among the technologies for energy production, CHP plants have the best performance if the electricity generated is connected to the national grid, with superior benefits in the majority of impact categories compared to briquette, methane, and ethanol production. Overall, we find that methane recovery and composting are more environmentally friendly than other technologies, as measured by reduction of greenhouse gas emissions. Pulp and paper, and MDF production are favorable technologies for land use impacts; however, they have intense primary energy requirements, chemical use in the processes, and emissions from their waste treatment systems. Our results provide information for decision makers when planning for sustainable use of oil palm biomass.

1. Introduction

Malaysia is one of the top producers of palm oil in the world, with a total area of 50,000 km² of oil palm plantations. A total of 423 palm oil mills are operating in Malaysia. In 2011, a total of about 92.9 million tonnes of fresh fruit bunches (FFB) were harvested and processed in the palm oil mills, resulting in the generation of about 44 million tonnes of solid oil palm residues and 62 million tonnes of palm oil mill effluent during the palm oil extraction. The solid oil palm residue is a biomass consisting of, by wet weight, 23.8 million tonnes (54%) of empty fruit bunch (EFB), 13.2 million tonnes (30%) of shell, and 7.9 million tonnes (18%) of fiber [1].

The palm oil industry accounts for the largest biomass production in Malaysia, and since the 1960s, all palm oil mills have depended on their own biomass for fuel, using mainly the shells and fibers. However, the empty fruit bunches have not

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http://dx.doi.org/10.1016/j.biombioe.2013.01.012

been optimally used, because they are wet, bulky, and voluminous, which are unfavorable properties for transportation and handling; instead, they have been left by the millers to rot at the palm mill and plantation. Palm oil mill effluent (POME) also represents the largest potential for biomass energy utilization in the country, but this resource is readily available and in need of an efficient and effective means of utilization [2]. Studies have reported that only about 30% of palm oil mills in Malaysia are involved in recycling activities for EFB and POME [3]. In order to improve the environmental performance of palm oil production, the industry must start being concerned with using all resources from the oil palm in an optimal way, while at the same time minimizing the environmental impact of the recycling systems in or outside of the mill.

Several different technologies have been developed and are now available in the market for effective use of oil palm residue, especially EFB as main feedstock. However, most of the palm oil millers do not have a directive for choosing which technology to invest in to solve the issue of EFB disposal [3]; therefore, they continue to practice the old disposal method. This situation also creates difficulties for third party investors in recycling technologies who need to acquire EFB for their feedstock. Indeed, palm oil millers must become acquainted with many recycling technology options and learn how best to utilize the EFB, for fuel, fiber or fertilizer. They must weigh the benefits and drawbacks of the products, by-products or energy that are generated. Policy makers should provide information about the technologies and establish guidelines to help millers reduce the environmental impact and boost the growth of the recycling industry, in order to bring optimal benefits to the millers and the nation.

A few studies have been carried out to evaluate the environmental impacts of palm oil production, which include conventional recycling methods in palm oil mills [4–6]. For this study, the development of recycling technology options available in the market for effective use of EFB, as well as policy initiatives promoting these new technologies have been reviewed. The aim was to develop a basis data set to evaluate the environmental impact of these technologies using the life cycle assessment (LCA) method. This study will show how LCA can be useful for the evaluation of technologies used for processing the EFB and the conditions under which some EFB utilization chains can be made environmentally sustainable, using the results from studies conducted in the recent past. Sensitivity analyses were conducted to determine the land use effect of every technology and to compare the energy generation potential for the raw EFB use in CHP plants with methane recovery. A life cycle based comparison of different technologies for utilizing EFB is useful for making decisions for recycling technology options and for providing information about effective and economical combinations of different conversion systems. The results provide a benchmark for continuing improvement of environmental performance and can aid in the creation of a road map for sustainable utilization of EFB.

2. Methods

In this study, seven different technologies are considered – four using EFB as biofuel and three using EFB as material: 1) Ethanol production, 2) Methane recovery, 3) Briquette production, 4) CHP plant, 5) Composting, 6) MDF production, 7) Pulp and paper production. The life cycle assessment approach was used to discuss the energy consumption and the overall environmental impact of different technologies for utilizing EFB. The analysis considered the pre-treatment, processes involved in every technology, and final disposal of the wastes that remain after the process. The benefits of the various environmental impacts are also evaluated by considering the allocation of avoided products within the system boundaries for each technology.

3. Current status of recycling technology options

To make use of EFB biomass, many new technologies have been developed at local research institutes such as the Palm Oil Research Institute of Malaysia (PORIM), Malaysian Palm Oil Board (MPOB), and Forest Research Institute Malaysia (FRIM), in collaboration with local universities. These recycling technologies described below convert EFB to biofuel and value-added products.

3.1. *Ethanol production*

In 2006, the Malaysian National Biofuel Policy was launched by the government to reduce fuel consumption, especially in the transportation and industry sectors, by promoting palm oil as the main commodity for biofuel production, with the added benefit of stabilizing palm oil prices. However, the high price of crude palm oil, controversy over palm oil for food versus fuel, and the issue of sustainable biofuel production have discouraged utilization of palm oil for biofuel production [7]. EFB is regarded as an excellent feedstock for the production of biofuels due to its abundant supply, year-round availability, and because unlike palm oil, it is not used as food and feed. The process of converting EFB to ethanol is more complex than current ethanol production from corn or sugarcane, because the complex cellulose–hemicellulose–lignin structure needs to be broken up before fermentation can begin. Consequently the technology is not yet used on a commercial scale. Researchers are finding the most effective and low-cost enzymes for the pre-treatment and organisms for the fermentation process.

A test done by BioCentrum at Denmark's Technical University estimated that 1 tonne dry EFB is able to produce 0.39 m^3 of ethanol using a new process (wet explosion) for pre-treatment [8]. Other techniques, however, have proven to be less efficient. Piarpuzán et al. [9] demonstrated a method of ethanol production from EFB using alkaline pre-treatment and enzymatic hydrolysis approach, which yielded ethanol at only 0.067 $m^3\ t^{-1}$ of dry EFB. Millati et al. [10] also using dilute sulphuric acid pre-treatment, achieved a yield of 0.112 $m^3\ t^{-1}$ of dry EFB. Yano et al. [11] developed new yeast strains, and utilized milling pre-treatment, with enzyme hydrolysis, resulting ethanol yield 0.13 $m^3\ t^{-1}$ of dry EFB.

On 28, Dec 2010, Sime Darby Plantation Sdn. Bhd. began collaborating with Mitsui Engineering and Ship building Co. Ltd. (MES) of Japan to construct and operate the first bio-ethanol demonstration plant which will convert oil palm EFB into ethanol. The plant will have a raw EFB processing capacity of 1.25 t d^{-1} and use hydrothermal pre-treatment and enzymatic hydrolysis technology. The pilot plant will collect operational data and confirm the technical feasibility of commercial-scale production of ethanol from EFB [12].

3.2. Methane recovery

There has been little commercial interest in using EFB for methane recovery in the market due to its lignocellulosic composition. Currently, there is a local company which is using the juice from pressed EFB mixed with POME for methane production. Using anaerobic digestion technology for capturing biogas in a palm oil mill with 30 tonnes of FFB per hour, the company is able to produce 11,200 m^3 d^{-1} of biogas with 62.5% of methane [13].

However, raw EFB have a high potential to produce methane in the form of biogas, because they are biodegradable and have high moisture content. Paepatung et al. [14] estimated that the maximum specific methane production rate for EFB with ratio of inoculum to substrate of 3:1 and at mesophilic condition (310 K) is 0.0135 m^3 d^{-1}, which is relatively low and the final potential yield of methane from EFB (for 90 days of retention) is 0.37 m^3 kg^{-1} of Volatile Solid (VS). However, Nieves's experiment [16] performed at thermophilic condition (328 K), inoculum and substrate ration 2:1, for retention of 7 days and 30 days, the methane yield is 0.13–0.202 m^3 kg^{-1} of VS. O-Thong [17] also reported that in thermophilic conditions, inoculum and substrate ration 4:1, for 45 days of retention, the highest of methane yield of EFB is 0.202 m^3 kg^{-1} of VS at initial organic load of 20 kg m^{-3}.

Experiments have verified that EFB are a suitable substrate for co-digestion with POME, with optimal conditions for the daily maximum specific biogas production of 0.0574 m^3 kg^{-1} Chemical Oxygen Demand (COD), the methane yield is predicted to be 25.6% [18].

Studies have been carried out to improve the biogas yield from EFB through pre-treatment EFB with NaOH, which can obtained methane yield of 0.404 m^3 kg^{-1} of VS [16]. The combination of hydrothermal treatment with NaOH pre-soaking EFB and co-digestion with POME method obtained methane yield of 0.392 m^3 kg^{-1} of VS [15,17].

3.3. Briquette production

Due to the limited local demand for heat and energy, the Malaysian palm oil industry has developed a new business opportunity in transporting oil palm residue (shell, EFB) to overseas locations such as the Netherlands and Japan to use in boiler in power plants [19,20]. To improve the potential of EFB, vendors transform them into briquette form, which allows for easier transportation and higher quality combustion due to lowered moisture content and increased calorific value. In 2008, MPOB demonstrated that EFB can be converted into briquette form with different compositions of oil palm residue and sawdust [21]. Currently, Global Green Synergy, a local company, provides a model for briquette production, by pressing dry EFB fiber into cylinders of diameter 9.5 cm and length 30 cm, which have moisture content less than 10% and calorific value of 18 MJ kg^{-1} [22].

In November 2009, the Japanese ITOCHU Corporation and the world's largest palm oil producer, Felda Palm Industries Sdn. Bhd., formed a joint venture company, FNI Biofuel Sdn. Bhd., to produce solid fuel from EFB. The target annual production of the solid fuel is 24,000 tonnes, to be exported to Japan and consumed by Tokyo Electric Power Company beginning in 2012. Ultimately, the company plans to raise the annual production of the solid fuel to 120,000 tonnes per year [23].

3.4. Combined heat and power plant

In 2001, the Malaysian government announced renewable energy as the "5th fuel" in its Fuel Diversification Policy. In conjunction with this policy, the Small Renewable Energy Power Program (SREP) was launched in May 2001 by the Ministry of Energy, Water and Communication to encourage utilization of agriculture waste, such as oil palm residue, rice straw, and wood chips, for power generation and electricity generated from these resources is eligible to be connected to the national grid with a limitation of 10 MW. Pusat Tenaga Malaysia (PTM) (now Malaysia Green Technology Corporation) was entrusted with implementing the Biomass Power Generation and Co-generation in the Malaysian Palm Oil Industry (BioGen project) by the Government of Malaysia, with additional support from the United Nation Development Programme (UNDP) and the Global Environment Facility (GEF). This project aims to reduce the growth rate of greenhouse gas emissions from fossil fuel fired combustion processes and seeks to make use of the unutilized biomass by increasing power generating capacity using cogeneration technology. This led to the first demonstration of a 13 MW combined heat and power (CHP) plant using EFB as its main fuel in Bahau, Negeri Sembilan [24].

At the same time, the European Commission (EC) and the Association of South-East Asian Nations (ASEAN) cooperated to form the EC-ASEAN COGEN Programmes to promote European cogeneration technology in ASEAN countries. One of the projects undertaken in this program was the TSH Biomass Power Plant in Sabah with a capacity of 14 MW: 10 MW to sell to the national grid and 4 MW for their own plant use. Such biomass cogeneration projects also qualify for carbon credits under the Clean Development Mechanism (CDM) project of the Kyoto Protocol implemented by the United Nations Framework Convention on Climate Change (UNFCCC). All of these policies have attracted many investments; according to the PTM and UNFCCC, a total of 18 CHP plants using EFB as fuel are registered under SREP, CDM, and COGEN, with power plant scales ranging from 1 to 14 MW, yielding a total installed capacity of 145 MW [25,26]. Some of them are installed at the palm oil mill and some are independent power plants connected to the grid.

However, not all of them have successfully started production, for example only 3 CHP plants are reported in operation under the SREP program [27]. CDM reports on these CHP projects indicate that they are having major issues with the preparation of the fuel (EFB) for the power plants. It is difficult for plant owners to establish a consistent supply chain for the feedstock of their CHP plants, and the high moisture content and bulkiness of EFB makes it difficult to transport and leads to poor combustion. To mitigate these difficulties, pre-treatment by shredding and drying is important for converting EFB into a better fuel for the boiler, and a policy is required to control the local biomass supply to develop a sustainable system of using EFB for power generation [28,29].

3.5. *Composting*

Composting is one of the conventional recycling methods. Since the government has banned the uncontrolled incineration of biomass (mainly EFB) under the Environment Quality Act in 1974, the mills are now obliged to find alternative means of utilizing the EFB. Palm oil mills with plantations can use their EFB for mulching and soil conditioning, or fertilizer to conserve soil moisture and to reduce the soil temperature. However, using EFB for mulching has a few limitations, most notably transportation costs; therefore, agronomists in Malaysia have suggested composting, which can reduce the EFB 50%~75% by volume and can be used as fertilizer in the oil palm plantation, or for other end uses such as landscaping, golf courses, and horticulture.

To produce high quality compost in a short period of time, different heaping conditions, mechanical aeration frequency, and additives such as chicken manure, POME, and liquid fermentation wastes from food processing industry have been investigated [30]. Only the POME and liquid fermentation wastes from food processing additive are commonly used due to their ample supply. These studies reported that the C/N ratio of the compost from EFB ranges from 12 to 15 [31,32].

Currently, there are two types of composting plant in Malaysia: closed system and open system. For an open system, which most of the mills are practicing, the incoming EFB is shredded into fiber using hammer mill machinery that is interfaced to the palm oil mill. The shredded EFB are then moved to composting plants where they are strip laid on flat to gently sloping well-drained terrain. POME is sprayed onto the compost piles. Some millers mix boiler ash, kernel shells and

Table 1 – Reference process flows of technologies considered.

Technology options	Reference flow
Ethanol production	[Pre-treatment (Shredding + Washing)] → [Saccharification] → [Fermentation] → [Distillation] → [Wastewater treatment] *Replacement of gasoline.
Methane recovery	[EFB handling] → [Shredding] → [Mixing with temperature 328 K] → [Methane collection] → [Wastewater treatment] *Replacement of electricity generated supply to national grid.
Briquette production	[EFB handling] → [Shredding] → [Dehydration] → [Briquetting] *Replacement of hardcoal used in the power plant's boiler.
CHP plant for electricity generation	[Pre-treatment (Shredding + Drying)] → [Combustion] → [Ash disposal] *Replacement of electricity generated supply to national grid. *Ash as potassium fertilizer.
Composting	[Pretreatment (Shredding)] → [Windrowing] → [Turning for aeration (1-3 times/week)] → [Spraying POME and adding microbes] → [Sampling] → [Bagging] → [Wastewater treatment] *Replacement for chemical fertilizer.
MDF production	[Pre-treatment (Shredding)] → [Mechanical pulping] → [Drying] → [Blending fibers with resin and wax] → [Forming] → [Pressing] → [Sanding] → [Wastewater treatment] *Replacement for hardwood and residue wood.
Pulp and paper Production	[Pre-treatment (Shredding)] → [Chemical pulping] → [Bleaching] → [Refining] → [Paper making] → [Wastewater treatment] *Replacement for fiber that extracted from hardwood.

Note: * Replacement of resource

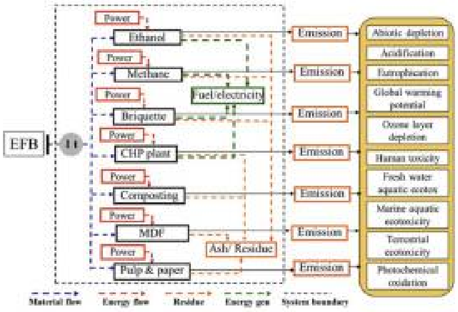

Fig. 1 – System boundary of the technology options for utilizing EFB.

fibers into the compost piles. The piles are periodically turned (1–3 times per week) by the use of a moving mechanical device on tracks to promote uniform aeration and to control the temperatures in the composting process. To make the compost biologically active, cultured soiled microorganisms and beneficial fungus are added to the compost piles about 1–2 weeks prior to maturity. Finally, mineral fertilizers are also added a few weeks before maturity to enrich the compost's nutritional value for end use. It takes 2–3 months for compost to be matured, and the matured compost is packed and transported to the oil palm plantation for application by a mechanical spreader.

In an open system, there is emission from composting EFB process. The CO_2 emission from EFB compost is considered greenhouse gas (GHG) neutral. However, there are CH_4 and N_2O emissions during the composting of EFB, and these amounts are rather small [54]. Composting is considered to be a carbon trading project because of the large contribution of avoided CH_4 emission from palm oil mill effluent (POME) and EFB decaying in landfills. Currently six projects are registered under the CDM project [26]. The major palm oil companies in Malaysia such as Felda and Sime Darby are interested in this technology. Felda is currently operating four composting plants at their mills in Maokil, Trolak, Jengka and Sampadi. Another two in Kalabakan, Sabah and Jeranga, Terrengganu are still being planned [33]. Sime Darby has planned the construction of 23 composting plants, seven of which have already been commissioned [34].

3.6. *Medium density fiberboard production*

Currently, the MDF industry in Malaysia has 14 plants with a total annual installed capacity of 2.9 h m^3. Malaysian exports of MDF amounted to 1.2 h m^3, with a value of about USD 400 million in 2008 [35]. In the 1990s, most of the MDF plants in Malaysia depended on the supply of rubberwood as their feedstock. With the declining supply of rubberwood, the Malaysian MDF industry can no longer rely entirely on rubberwood material. The industry started to use *Acacia mangium* and mixed hardwood in order to sustain their operations in future [36]. However, due to the high costs of these materials, palm biomass such as oil palm trunk, fronds, and EFB are being promoted as fiber sources to mix together with rubberwood in the manufacture of MDF.

Research results have shown that MDF from EFB is compatible with the properties of MDF from rubberwood. To industrialize MDF production from EFB, MPOB built a pilot MDF plant to simulate an industry plant, to promote EFB use as part of the raw material for MDF production [37]. EFB is shredded into fiber and blended with formaldehyde, then pressed with hot press at a temperature of about 413 K. MDF from EFB has a density of 400–800 kg m^{-3}, and it has great absorption properties compared to wood-based MDF [50]. To improve the quality of EFB for MDF production, current research continues investigating the optimal ratio of EFB to be mixed with rubberwood, pre-treatment of the EFB fiber to remove its residual oil, and understanding the mechanical and physical properties of MDF from EFB [38,39].

Agro-Bio Fibre Sdn Bhd began its operations in 1998 as a pioneer manufacturer of MDF from EFB. This technology was jointly developed with the FRIM [40]. Another example, Tian Siang Trading Sdn. Bhd. is operating an MDF plant with a capacity of 50 m^3 d^{-1}, but this product is currently only being sold to local buyers in Malaysia. An export market has not been established due to low volume of production and little awareness of this new product in overseas markets [41].

3.7. *Pulp and paper production*

Malaysia's pulp, paper, and paper board industry relies heavily on imports – not only of the final products, but also for the raw materials for local plants. Progress towards self-sufficiency in this sector is slow due to the typically small production capacities of Malaysian paper mills, which are not more than 300 kt y^{-1} [42].

Increasing paper production in a self-sufficient way requires identifying local sources of fiber. This new demand has led to the planning of more forest plantation projects. However, competition for land use from other industries, such as oil palm plantations, has restrained the plan. In an attempt to improve self-sufficiency and reverse the trend of net import in this sector, the Malaysian government has made investments of USD 15 million for promoting oil palm residue as fiber source for pulp and paper production, making it a priority in the industrial master plan (IMP2 and IMP3) for research and development [43,44].

FRIM has been a leader in developing new technologies for the production of pulp and paper from EFB. They and others have investigated the suitability of EFB for paper and pulp making with different pulping processes (mechanical, semi-chemical, chemical, and hybrid), bleaching processes (conventional chlorination, total free chlorine, elemental chlorine free), and by blending with softwood pulp [45–50]. EFB has been found to be a good raw material, and EFB pulp can be manufactured into various paper grades.

Based on the technology developed by FRIM, in 2008, the world's first palm oil-based pulp and paper mill was established in Kunak Town, Tawau Region in Sabah [51]. ECOFUTURE Berhad and SEA Pacific Paper Technology Engineering Sdn. Bhd are both new companies that convert EFB pulp into

Table 2 – Inputs and output from production fuel from EFB.

	Unit	Ethanol (1 kg)	Methane gas (1 m^3)	Briquette (1000 kg)	Electricity, CHP plant (1 MW h)
Inputs					
Transformation, to industrial area	m^2	0.0016[a]	–	0.012[g]	0.011[i]
Material					
EFB	kg	10.6[b]	12.6[e]	3000.0[h]	2310.0[j]
Water tap	m^3	0.64[c]	50.6[e]	–	0.33[c]
Lubricating oil	kg	–	–	–	0.014[c]
Ammonia	kg	–	–	–	3.47E–05[c]
Sulphuric acid	kg	0.14[d]	–	–	–
Sodium chloride	kg	–	–	–	0.017[c]
Lime	kg	0.097[d]	–	–	–
Energy					
Electricity	kW h	0.38[d]	0.05[c]	138.13[h]	230.00[j]
Steam	kg	5.1[d]	–	–	–
Diesel	kg	–	–	0.5[h]	–
Heat	MJ	–	6.4[f]	0.63[c]	–
Outputs					
Compost	kg	–	12.6[k]	–	–
Debris	kg	–	–	0.001[k]	0.013[c]
Effluent	m^3	0.6[k]	50.6[k]	–	0.003[c]
Disposal oil	kg	–	–	–	0.014[c]
Ash to landfill	kg	–	–	–	10.0[j]
Emission					
Heat, waste[l]	MJ	1.4	0.2	519.7	828.0
CH_4	kg	–	0.002[c]	–	–
H_2S	kg	–	0.001[c]	–	–
CO_2	kg	–	1.3[c]	0.5[c]	416.0[c]
CO	kg	–	–	0.1[c]	0.029[c]
NO	kg	–	–	–	0.19[c]
NOx	kg	–	–	0.01[c]	–
$NH_{3\ (odor)}$	kg	–	0.003[c]	–	–
N_2O	kg	–	0.0008[c]	–	0.093[c]
Particulates < 10 μm	kg	–	–	0.12[c]	–
Particulates (2.5 μm)	kg	–	–	–	0.021[c]

a Estimation from ethanol plant area of 835 m^2 and ethanol production 0.1 m^3 d^{-1} for 15 years [55].
b Estimation from 1.25 t of EFB producing 0.15 m^3 of ethanol [12].
c Ecoinvent database [56].
d Ref. [57].
e Estimation based on ratio of EFB to inoculum is 1:4 [17].
f Assumes that 125.4 MJ of heat is needed for heating up each cubic meter of water in the process.
g Briquette production plant of 1620 m^2 and annual briquette production 18,000 t for 7 years [22].
h Data obtained from Global Green Synergy Sdn. Bhd [22].
i CHP plant area of 12,100 m^2 and electricity production 40,300 MW for operation of 8000 h annually over 21 years [58].
j Data obtained from Sunquest Sdn. Bhd. (Juay HH, personal communication, July 2010) and reference from the project's CDM PDD [58].
k Estimated from mass balance.
l Estimated from electricity and fuel consumption and energy balance. Gross calorific value of diesel is 44.800 kJ kg^{-1}.

different by-product such as medium paper, container, and wrapping paper [52].

4. Life cycle assessment

Life cycle assessment is one of the principal decision support tools for assessing the flow dynamics of resources. LCA can give insight into the environmental burdens per functional unit (kg t^{-1}) of EFB processed, assuming EFB's moisture content is 65%. The inflow and outflow data, emissions, and resource recovery through electricity from the system or resources which can be replaced with EFB were considered. Fig. 1 shows the system boundary and Table 1 shows the reference process flows of the technology options for utilizing EFB.

The life cycle impact assessment was performed with SimaPro (version 7.0) software [53], adopting the CML 2 baseline (2000) method. Ten different impact categories were evaluated: abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, human toxicity, fresh water ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation. The characterization of every category is defined as in Eq. (1) and each impact category is explained in detail in the Guidance of CML [54]. The normalized indicator result category is defined as the indicator result category divided by the

Table 3 – Inputs and output from production fertilizer and fiber from EFB.

	Unit	Compost (1000 kg)	MDF (1 m^3)	Paper (1000 kg)
Inputs				
Transformation, to industrial area	m^2	0.05[a]	0.0007[e]	0.01[j]
Material				
EFB	kg	2600[a]	10,000[e]	5140[k]
POME	m^3	5.5[a]	–	–
Water tap	m^3	–	1.4[f]	91.8[k]
Aluminium sulphate	kg	–	4.4[c]	–
Paraffin wax	kg	–	6.5[g]	–
Urea formaldehyde resin	kg	–	65.0[g]	–
Kaolin	kg	–	–	172[c]
(Limestone, Quicklime)	kg	–	–	(172, 5) [c]
Sulphuric acid	kg	–	–	16[c]
Magnesium sulphate	kg	–	–	2.3[c]
Sodium chlorate	kg	–	–	14[c]
Sodium hydroxide	kg	–	–	21[c]
(CO_2, N, O_2) liquid	kg	–	–	(1.1, 1.2, 12.9)[c]
Sulfur dioxide	kg	–	–	1.1[c]
Energy				
Electricity	kW h	20.7[a]	414.7[h]	1350[l]
Diesel	kg	1.6[a]	0.9[h]	–
Fuel	MJ	–	9188 (logs & wood chips)[h]	16,740 (Natural gas) [l]
Output				
Solid waste	kg	–	–	1.2[b]
Debris	kg	–	2.2[f]	33[b]
Effluent	m^3	–	0.8[c]	32.4[k]
Leachate	m^3	0.054[a]	–	–
Ash	kg	–	1.9[f]	–
Emission				
Heat, waste[m]	MJ	160.5[b]	10,721.2	21,600.0
$CH_{4,\ biogenic}$	kg	0.2[c]	–	–
($CO_{2,\ fossil}$, $CO_{2,\ biogenic}$)	kg	(64, –)[c]	–	(1440, 370) [c]
(CO_{fossil}, $CO_{biogenic}$)	kg	(20.8, –)[c]	–	(7.0, 0.6) [c]
NO_x	kg	0.0005[c]	–	1.7[c]
(SO_2, NO_2, HCl)	kg	–	–	(0.5, 2.0, 0.02) [c]
NH_3	kg	0.01[c]	–	0.02[c]
Elements (C, N, P, K, Ca, Fe, S, Mg)	kg	(28.0, 2.2, 1.3, 2.8, 0.7, 1.1, 0.9)[d]	–	(–, 0.1, 0.01, 0.3, 0.1, 0.02, –, 0.02) [c]
Heavy metal (Mn, Zn, Cu, Cr, Pb, Cd)	kg	(0.02, 0.009, 0.007, 0.009, 0.004, 0.004)[d]	–	(0.002, 0.003, –, –, –, –) [c]
Formaldehyde	kg	–	0.06[i]	–
Particulates, <2.5 μm	kg	–	–	0.7[c]
Absorbable organic halogen	kg	–	–	0.1[c]
(BOD, COD)	kg	–	–	(1.2, 13.0) [c]

a Average data from three composting plants [59,60].
b Heat release from compost during the process is estimated 146.2 MJ t^{-1}, and heat release from EFB is 14.3 MJ t^{-1} (see Section 4.2).
c Ecoinvent database [56].
d EFB compost content of nutrients and heavy metals at 60 days is taken from a pilot plant [32].
e 23 million tonnes of EFB produced 2.3 m^3 of MDF [61], and assuming that MDF plant area is 16,000 m^2 for 2.3 h m^3 of MDF for 10 years [62].
f Ref. [63].
g ~1% of paraffin wax [63] and ~10% of resin content [39,63].
h Wood chips and logs used for process heat and diesel use for equipment [63].
i Estimated from production each kilogram of fiberboard needs 0.09 g of formaldehyde and MDF density of 650 kg m^{-3}.
j Estimated from pulp and paper plant of 20,000 m^2 for production ~100 t d^{-1} of EFB pulp for 15 years.
k Estimated 35,000 t of pulp produced from 180,000 t of EFB, water consumption 8800 m^3 d^{-1}, and effluent emission 3100 m^3 d^{-1} [64].
l Total electricity and steam consumption for pulping, bleaching, refining, paper machine, and other processes [65]. Natural gas as main fuel for generating steam and the enthalpy steam is estimated as 2.7 GJ kg^{-1}.
m Estimated from electricity and fuel consumption and energy balance. Gross calorific value of diesel is 44,800 kJ kg^{-1}.

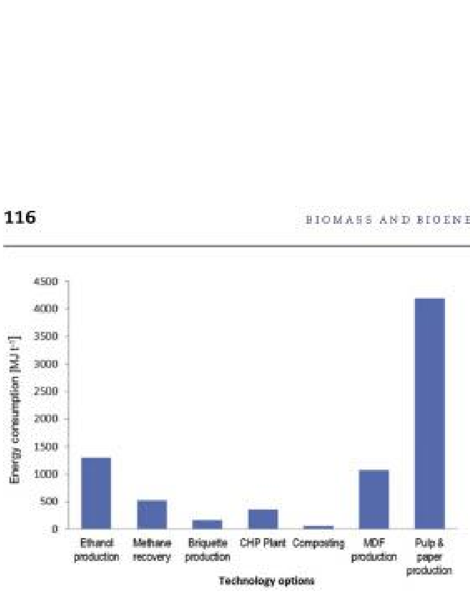

Fig. 2 – Energy consumption of each technology for processing one tonne of EFB.

indicator result category reference. This indicator indicates the relative significance of the various environmental impacts of the LCA system according to the geographical area. The characterized results are divided by their respective normalized values and multiplied by assigned weights that give the relative importance of the particular impact category. The World, 1990, was selected as the normalization value for our analyses.

$$\text{Indicator result}_{\text{category}} = \sum_i m_i \times \text{Characterisation factor}_{\text{category},i} \quad (1)$$

where i is the type of intervention (substance of emission) and m_i is magnitude.

4.1. *Life cycle inventory analysis*

A life cycle inventory for the LCA model has been established based on data collected from existing plants, interviews of employees in major palm oil companies and stakeholders involved with the technologies in Malaysia, review of selected literature, and Ecoinvent databases. The input and output for processes considered for each of these technologies are shown in Table 2 and Table 3.

4.2. *Assumptions*

Electricity consumption in all processes of every technology is taken from the average of Malaysian national electricity production: 59% natural gas, 30% coal, 2% diesel oil, 2% fuel oil and 7% hydro of energy input [66]. Machinery and infrastructure of all technologies are not included and only input materials flows, such as fossil fuels and electricity consumption are considered. Emission from the palm oil mill and oil palm plantation are not included in this study. Assuming that the ambient temperature is 303–308 K, compost temperature

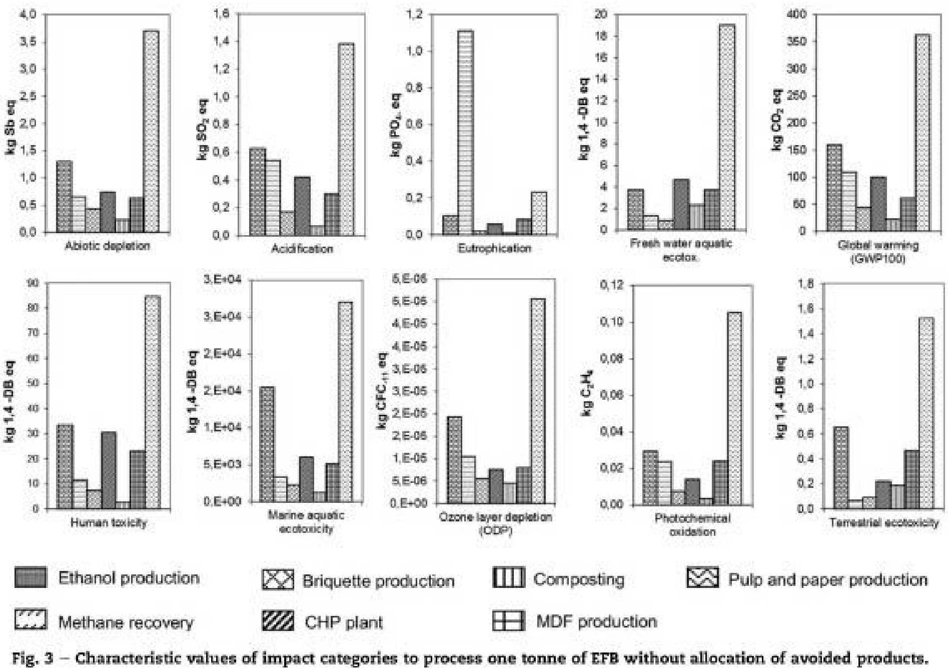

Fig. 3 – Characteristic values of impact categories to process one tonne of EFB without allocation of avoided products.

Table 4 – Assumptions and estimation of allocation products and by-products.

Technology	Assumptions	Equivalence	Reference
Ethanol production	Energy content of gasoline = 46 MJ kg^{-1} Energy content of ethanol = 31 MJ kg^{-1}	1 kg of ethanol ⇔ 0.67 kg of gasoline	[67]
Methane recovery	Gas engine electricity generation efficiency = 40% LHV methane gas = 35.8 MJ m^{-3}	1 m^3 of methane gas ⇔ 3.98 kW h of national electricity	[13,68]
Briquette production	Calorific value of EFB briquette = 18 MJ kg^{-1} Average energy content of hardcoal (bituminous) = 29.6 MJ kg^{-1}	1 t of briquette ⇔ 0.61 t of hardcoal (bituminous)	[22,69]
CHP plant	Every MW h of electricity generated from CHP is transmitted to national grid with efficiency of 88%. EFB contains 1% of ash that has high content of potassium, which can be used for chemical fertilizer.	1 MW h of electricity (CHP plant) ⇔ 880 kW h of national electricity 1 t of EFB ⇔ 0.01 t of potassium (ash).	[29]
Composting	EFB compost has nutrient content of 2.2% N, 1.28% P, and 2.79% K. Assuming that chemical nitrogen fertilizer contains 46% of N, phosphate fertilizer contains 46%–54% of P_2O_5, and potash fertilizer contains 60% of K_2O.	1 t EFB compost ⇔ chemical fertilizer (47.8 kg of N fertilizer, 25.6 kg of P fertilizer, and 46.5 kg of K fertilizer) Note: Crop uptake efficiency is not included.	[32,70]
MDF production	–	1 t EFB ⇔ 0.86 m^3 industrial hardwood and 0.22 m^3 of residue wood.	[56]
Pulp and paper production	–	1 t EFB ⇔ 2.8 m^3 industrial hardwood	[56]

is 323–335 K, and the specific heat capacity of air 1.175 kJ kg^{-1} K^{-1}, the heat released from decomposition of EFB during composting is estimated to be 37.6 MJ t^{-1}.

4.3. *Data quality requirements*

Due to different levels of maturity of the technologies in the Malaysian market, we were able to collect complete material and energy inputs for only briquette production, CHP plants, and composting plants. However, we were able to use data and estimates from a case study for ethanol production. Several studies have been conducted for methane production from EFB, with results varying based on experimental conditions. The median values of methane yield data [17] were used to estimate inputs for this study; other values are discussed in Section 5.3.2. For pulp and paper and MDF plants, we were able to utilize some studies on energy, and we relied on the ecoinvent database for the remaining inputs.

5. Results and discussion

According to the survey and literature reviewed, the technologies are estimated to produce the following products from a tonne of EFB:

- Ethanol plant: 94.7 kg of ethanol (0.12 m^3 of ethanol);
- Methane recovery: 79.0 m^3 of methane;
- Briquette plant: 0.33 t of briquette;
- CHP plant: 0.43 MW h of electricity;
- Composting plant: 0.4 t of compost;
- MDF plant: 0.1 m^3 of MDF;
- Pulp and paper plant: 0.2 t of pulp and paper;

5.1. *Energy consumption of the technology*

Energy consumption for all the processes considered for the technologies are shown in Fig. 2 (see. Table 1 for processes involved). Pulp and paper production consumes the most energy – about 4.2 GJ to process a tonne of EFB – among all the technologies, followed by ethanol production for about 1.3 GJ and MDF production for 1.07 GJ. This is because all these technologies involve processes that require machinery that uses a large amount of electricity and heat. These technologies also necessitate spending energy on proper EFB pretreatment, such as shredding, washing, and drying processes, to convert EFB into clean fiber for raw material. Based on our estimation, composting consumes less energy than the others because it only involves the use of small machinery and vehicles. The energy consumption for methane recovery, CHP plant, and briquette are 520 MJ, 360 MJ and 166 MJ respectively.

5.2. *Environmental impact assessment*

5.2.1. *Without allocation of avoided products*

Fig. 3 shows the comparative results of characteristic values of impact categories for all technologies without allocation of avoided products. Composting is the most environmentally

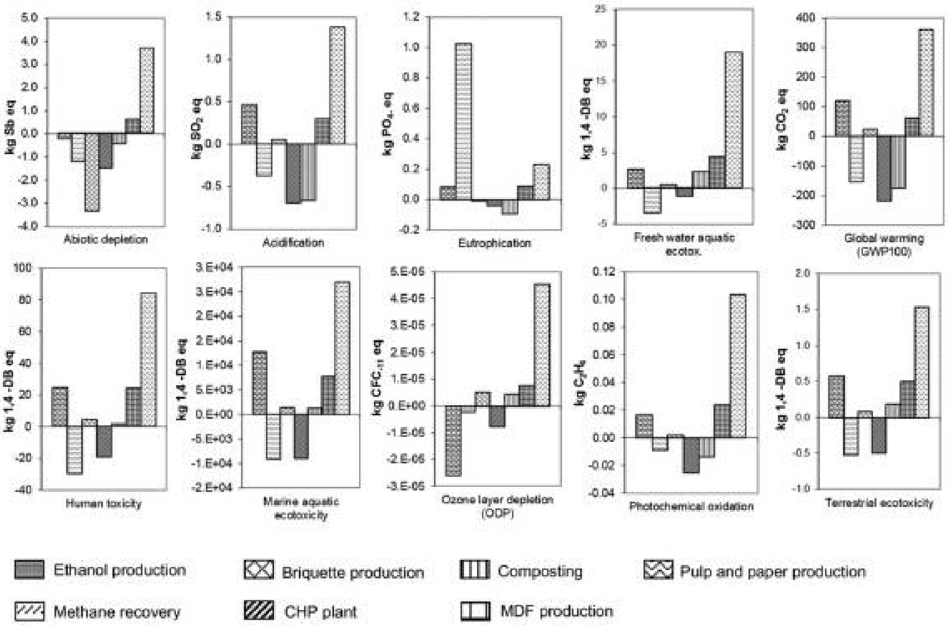

Fig. 4 – Characteristics of impacts categories for different technologies with allocation of utilizing one tonne of EFB.

friendly technology, as it has the lowest value for almost all impact categories, except fresh water aquatic ecotoxicity and terrestrial ecotoxicity, for which the briquette production and methane recovery perform best. Methane recovery from EFB has an especially high impact on eutrophication compared to the other recycling technologies.

Conversely, pulp and paper production is not a favorable technology, as it has the highest values for all impact categories, except for eutrophication, where it is lower than methane recovery. MDF production has higher values compared with CHP plants in the impact categories of eutrophication, ozone depletion, terrestrial ecotoxicity, and photochemical oxidation. For the biofuel technologies, briquette production has a lower impact than methane recovery, CHP plants, and ethanol production for all impact categories, except terrestrial ecotoxicity, which, methane recovery has the lowest impact. Ethanol production has a relatively high impact compared to CHP plants for all impact categories, except fresh water aquatic ecotoxicity, where CHP plants have a higher impact due to ash emission.

If global warming, acidification, and ozone layer depletion are considered as the most important impact categories for decision making, then overall, our results show that composting has the least impact on the environment, followed by briquette production, MDF production, CHP plant, methane production, ethanol production, and pulp and paper production. For the impact category of global warming, pulp and paper production has the highest impact, emitting 361.8 kg CO_2 equivalent, and next is ethanol production at 159.6 kg CO_2 equivalent, methane recovery 108.6 kg CO_2 equivalent, CHP plant 100.0 kg CO_2 equivalent, MDF production 61.2 kg CO_2 equivalent, briquette production 43.7 kg CO_2 equivalent and composting is 22.2 kg CO_2 equivalent. However, for the acidification and ozone layer depletion categories, MDF production has less impact on the environment than CHP plants. For acidification, the pulp and paper emitted 1.38 kg SO_2 equivalent, and followed by ethanol production 0.63 kg SO_2 equivalent, methane recovery 0.54 kg SO_2 equivalent, CHP plant 0.42 kg SO_2 equivalent, MDF production 0.30 kg SO_2 equivalent, briquette production 0.17 kg SO_2 equivalent and composting 0.07 kg SO_2 equivalent.

5.2.2. *With allocation of avoided products*

The impact of allocation of avoided products if EFB is used for biofuels or biomaterial was investigated based on the assumptions and estimation as shown in Table 4. Results for characteristics of the different technologies for utilizing EFB by allocation of avoided products in the model are shown in Fig. 4.

EFB used as an alternative fiber source in MDF production and pulp and paper production does not provide a significant benefit in any impact categories. The CHP plant, however, is a favorable technology for all impact categories if the electricity generated is connected to the national grid. Next is

Table 5 – Normalization values of impact categories to process one tonne of EFB without and with allocation of avoided products [×1.0 E−12].

Impact categories	Ethanol production		Methane recovery		Briquette production		CHP plant		Composting		MDF production		Paper and pulp production	
	W/O	W	W/O	W	W/O	W	W/O	W	W/O	W	W/O	W	W/O	W
Abiotic depletion	8.2	−1.4	4.1	−7.6	2.7	−21.2	4.7	−9.5	1.4	−2.8	3.9	3.9	23.4	23.3
Acidification	1.9	1.4	1.7	−1.2	0.5	0.2	1.3	−2.1	0.2	−2.1	0.9	0.9	4.3	4.3
Eutrophication	0.8	0.6	8.4	7.7	0.1	−0.1	0.4	−0.3	0.1	−0.7	0.6	0.7	1.8	1.7
Global warming (GWP100)	3.6	2.7	2.5	−3.5	1.0	0.6	2.3	−5.0	0.5	−4.0	1.4	1.4	8.2	8.2
Ozone layer depletion (ODP)	0.017	−0.023	0.009	−0.002	0.005	0.005	0.01	−0.01	0.004	0.004	0.01	0.01	0.04	0.04
Human toxicity	0.6	0.4	0.2	−0.5	0.1	0.1	0.5	−0.3	0.04	0.03	0.4	0.4	1.4	1.4
Fresh water aquatic ecotox.	1.8	1.3	0.6	−1.7	0.4	0.2	2.2	−0.6	1.1	1.1	1.8	2.1	9.2	9.2
Marine aquatic ecotoxicity	20.4	16.9	4.4	−12.1	3.0	1.8	8.0	−11.9	1.6	1.6	6.7	10.3	35.6	35.6
Terrestrial ecotoxicity	2.5	2.2	0.3	−2.0	0.4	0.3	0.8	−1.9	0.7	0.7	1.8	1.9	5.8	5.8
Photochemical oxidation	0.3	0.2	0.2	−0.1	0.1	0.02	0.1	−0.2	0.03	−0.1	0.2	0.2	1.0	1.0

W/O: Without allocation; W: With allocation.

methane recovery, which is also favorable technology for all impact categories, except it has significant impacts in eutrophication. Composting has benefits in abiotic depletion, acidification, eutrophication, global warming and photochemical oxidation if EFB is used. Briquette production used for replacement of fuel in the power plant's boiler has positive environmental impacts on abiotic depletion and eutrophication; ethanol production for replacement of gasoline has a positive environmental impact on ozone layer depletion. Briquette and ethanol production are not favorable in other impact categories like acidification, global warming, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation. However, the emission from combustion of EFB briquette is not included in this analysis.

The technologies that convert EFB into biofuel, such as CHP plant, briquette production, ethanol production, and methane recovery are favorable to the environment, especially in the impact category of abiotic depletion. For global warming potential, the CHP plant can reduce greenhouse gases of 218.6 kg CO_2 equivalent; composting and methane recovery are 176.5 kg CO_2 equivalent and 154.6 kg CO_2 equivalent, respectively. By allocation of avoided products, greenhouse gas emissions for briquette and ethanol are reduced by 44% and 25%, respectively. However, pulp and paper production and MDF production give no significant reduction (less than 1%).

5.2.3. *Normalization*

Table 5 shows the normalization values of all impact categories for every technology to process one tonne of EFB

Table 6 – Emission of substances to air and water for impact category of marine aquatic ecotoxicity [kg 1, 4-DB eq].

Substance	Compartment	Ethanol production	Methane recovery	Briquette production	CHP plant	Composting	MDF production	Paper and pulp production
Hydrogen fluoride	Air	241	149	231	499	45	236	1490
Metals, unspecified	Air	142	10	183	396	33	166	1027
Nickel	Air	857	53	118	281	35	251	1300
Selenium	Air	96	37	3	3	3	20	597
Vanadium	Air	9782	290	75	74	85	1508	7844
Barium	Water	1975	799	1437	2735	563	1457	7664
Beryllium	Water	740	956	24	24	27	250	1329
Cobalt	Water	132	44	2	340	2	98	181
Copper, ion	Water	82	9	19	205	4	53	1784
Nickel, ion	Water	214	72	155	869	32	292	2522
Selenium	Water	358	154	4	4	5	34	154
Vanadium, ion	Water	503	525	10	438	11	358	657

Table 7 – Emission of substances to air for impact category of global warming [kg CO_2 eq].

Substance	Ethanol production	Methane recovery	Briquette production	CHP plant	Composting	MDF production	Paper and pulp production
Carbon dioxide	37.1	1.9	35.6	77.3	6.5	32.4	200.4
Carbon dioxide, fossil	113.3	65.1	4.9	4.7	13.5	22.9	123.9
Dinitrogen monoxide	0.4	19.0	0.1	12.0	0.1	1.1	4.0
Methane	2.1	0.1	2.5	5.4	0.4	2.3	13.9
Methane, biogenic	1.1	18.8	0	0	1.2	0.7	1.3
Methane, fossil	5.5	3.4	0.5	0.5	0.6	1.7	15.7

without allocation of avoided products. All of the technologies give a significant environmental impact in the category of marine aquatic ecotoxicity and a minor impact in the categories of abiotic depletion, global warming and fresh water aquatic ecotoxicity, terrestrial ecotoxicity, acidification, and eutrophication.

CHP plants perform well, showing greater benefits than methane recovery in several impact categories: abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, and photochemical oxidation; methane recovery only fares noticeably better for fresh water aquatic ecotoxicity and human ecotoxicity. CHP plants also benefit more impact categories than composting because it has significant impacts in the marine aquatic ecotoxicity, abiotic depletion, and global warming. However, using ethanol production from EFB in the transportation sector does not contribute a significant impact to ozone layer depletion. Ethanol and briquette production are only able to make contributions to abiotic depletion. In general, methane recovery gives lower benefits to the environment compared to CHP plant, especially to the category of eutrophication. Further processing, such as use of the digestate for fertilizer, could potentially alter the environmental impacts of methane recovery, however this is beyond the system boundary of this study.

Pulp and paper production and MDF production are still considered unfavorable technologies because the energy used in the process, chemicals used, and emission from the waste treatment in the processes are comparably high compared to impact categories of marine aquatic ecotoxicity, abiotic depletion, and global warming potential.

5.2.4. *Inventory analysis of compounds*

Table 6 and Table 7 show the inventory analysis of the impact categories of marine aquatic ecotoxicity and global warming potential with a 0.5% cutoff. The results in Table 6 show vanadium, barium, nickel ion, beryllium, and vanadium ion are the main pollutants emitted through waste and waste water treatment from methane, MDF, ethanol, and pulp and paper production. For the impact category of global warming, CO_2, N_2O, CH_4 emission from the process and CO_2, CO, and CH_4 emission from utilizing fossil fuel are the main sources [see Table 7]. Ethanol production, methane recovery, and composting have higher CO_2 emission from utilizing fossil fuel than CO_2 emission from the process. Meanwhile, the CO_2 emission from briquette production, CHP plant, MDF production, and pulp and paper production, are higher than CO_2 emission from fossil fuel.

5.3. *Sensitivity analysis*

5.3.1. *Land use effect*

In the CML methodology, the impact of land use change is not considered. In this case, pulp and paper and MDF production may not be evaluated completely because, for example, if EFB is used for making pulp and paper, it will reduce deforestation and land use for fiber tree plantation. Therefore, Ecoindicator 99 is selected for evaluating the land use effects of these recycling technologies. In Ecoindicator 99, the land use effect quantifies land occupation and land transformation. The assumption is that the land use will effect a change in habitat size when mankind occupies large areas for urban and agricultural purposes, by threatening many species with extinction. The effects of land use by man-made systems are measured by the disappearance of species with the unit of Potentially Disappeared Fraction of Species (PDF, given per area per year), and different types of land-use will have different effects. However, methane recovery is not included due to a lack of data from actual plants.

Fig. 5 shows the impact on land use when implementation of these technologies transforms the land to industrial area given by the method of Ecoindicator 99. Using EFB for pulp and paper production benefits the impact category of land use at 2.2 Pt (40 PDF m^2 yr), and MDF production and briquette production have a minor benefit of 0.3 Pt (6 PDF m^2 yr) and 0.1 Pt (2 PDF m^2 yr) to the land use respectively. This is because the conversion rate from EFB to paper and MDF are different. For MDF production, EFB only contributes to the minor substitution of fiber supply, while EFB used in pulp and paper can

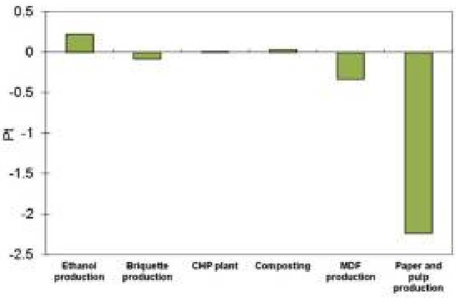

Fig. 5 – Land use impact of each technology in Ecoindicator 99.

avoid transformation of land for fiber tree plantations. The minor land use benefit for briquette production is due to avoided land use for mining hardcoal. Other technologies have no significant impact on land use change, except that ethanol production has a minor impact of 0.2 Pt (4 PDF m^2 yr) to the land use. This is because of the land area used for ethanol production is relatively large compared to other technologies.

5.3.2. *Electricity generation potential of raw EFB*
Assuming that the raw EFB has 65% moisture content, the electricity generation potential of a tonne of raw EFB is 968 MJ when used as fuel for a CHP plant with electricity efficiency of 22%. However, raw EFB has an electricity generation potential of 516–1715 MJ t^{-1} if the methane generated is subsequently used to produce electricity (see Appendix 1). Methane recovery from EFB is a viable technology for energy recovery based on the experimental data. However, the methane yield of EFB also can vary significantly depending on the quality of EFB and the biogas plant configuration, such as the reactor type and operating conditions.

6. Conclusion

Research and development of technologies for utilization of oil palm residue are well established in Malaysia. The use of this biomass as a raw material for bioenergy and biomaterial is encouraged by the need for a secure energy supply, a reduction of greenhouse gas emissions, and for achieving self-sufficiency in the fiber industry. However, a sustainable system for commercializing the various developed technologies is yet to be studied.

The energy consumption and environmental impact of each technology for utilizing EFB have been evaluated by the use of life cycle assessment. Based on the assumptions and the data sources applied to this LCA study, the following conclusions are drawn:

- The technology that has the least emission is composting, followed by briquette production, MDF production, CHP plant, methane recovery, ethanol production, and pulp and paper production. However, when allocation of products and by-products are considered, the most favorable technology is CHP plant, followed by methane recovery, composting, briquette production, ethanol production, MDF production, and pulp and paper production.
- The sensitivity analysis shows that utilizing raw EFB for electricity generation can generate relatively high energy compared to CHP plant, and the pulp and paper and MDF production also have a beneficial impact on land use.

Acknowledgments

The authors would like to thank Sime Darby, Felda Holdings, Sunquest Power Plant, and Global Green Synergy for providing data in this study and for their supportive cooperation. The authors also like to thank Prof. Mohd Tusirin Hj Mohd Nor and Prof. Håkan Jönsson for valuable advice, and William Klemm for proof reading.

Appendix 1. Electricity generation potential of raw EFB

These calculations estimate the electricity generation potential of raw EFB used for fuel in CHP plants or used for methane gas production. We assume that raw EFB has 65% moisture content and standard temperature and pressure.

(1)Fuel for CHP plant

Lower calorific value of raw EFB = 4.4 GJ t^{-1} of EFB [29]
Electricity generation efficiency of CHP plant = 22%

Electricity generation potential of raw EFB = 4.4 GJ t^{-1} of EFB × 0.22 = 968 MJ t^{-1}

(2)Methane gas production

Electricity generation efficiency of gas engine = 40 % [13]
Energy potential of methane gas = 35.8 MJ m^{-3} [68]
Theoretical estimation of methane potential (MP) of raw EFB is 0.422 m^3 kg^{-1} of VS [15, 17]. However, at thermophilic condition,

a) Experimental estimation MP of raw EFB (low value) = 0.13–0.202 m^3 kg^{-1} of VS [16]

Methane gas potential (1 t of raw EFB) = (1000 kg of EFB × 35 % of dry EFB × 79.2% of VS) × 0.13 = 36.0 m^3

Electricity generation potential of raw EFB = 36.0 m^3 × 35.8 MJ m^{-3} × 0.40 = 516 MJ t^{-1}

Methane gas potential (1 t of raw EFB) = (1000 kg of EFB × 35 % of dry EFB × 79.2 % of VS) × 0.202 = 56.0 m^3

Electricity generation potential of raw EFB = 56.0 m^3 × 35.8 MJ m^{-3} × 0.40 = 802 MJ t^{-1}

b) Experimental estimation MP of raw EFB (medium value) = 0.153–0.202 m^3 kg^{-1} of VS [17]

Methane gas potential (1 t of raw EFB) = (1000 kg of EFB × 39.2% of VS) × 0.153 = 60.0 m^3

Electricity generation potential of raw EFB = 60.0 m^3 × 35.8 MJ m^{-3} × 0.40 = 859 MJ t^{-1}

Methane gas potential (1 t of raw EFB) = (1000 kg of EFB × 39.2% of VS) × 0.202 = 79.1 m^3

Electricity generation potential of raw EFB = 79.1 m^3 × 35.8 MJ m^{-3} × 0.40 = 1133 MJ t^{-1}

At mesophilic condition, 90 days of retention c) Experimental estimation MP of raw EFB (high value) = 0.37 m^3 kg^{-1} of VS [14]

$T = 273.15$ K, $P = 101.325$ kg m^{-1} s^{-2}, $R = 8.314$ J mol^{-1} K^{-1}

Methane gas potential (1 t of raw EFB) = (350 kg of EFB x 92.5 % of VS) x 0.37 x 101.325/(8.314 x 273.15) = 5.345 mol kg^{-1}

Electricity generation potential of raw EFB = 5.345 mol kg^{-1} × 802.35 kJ mol^{-1} × 40% = 1715 MJ t^{-1}

Summary:

Reference	Methane yield [m^3 kg^{-1} of VS]	Methane yield [m^3 t^{-1} of raw EFB]	Electricity generation potential [MJ t^{-1} of raw EFB]
Nieves [16]	0.130–0.202	36–56	516–802
O-Thong [17]	0.153–0.202	60–79	859–1133
Paepatung [14]	0.370[a]	(120)	1715 (1715)

[a]If value was in standard temperature and pressure the methane yield and electricity generation potential are the value in brackets.

Based on the experimental results using batch assays, the energy potential of one tonne raw EFB without pretreatment or co-digestion other material is 516–1133 MJ, and the yield depends on the number of retention days and initial organic loading rate. The energy potential of the raw EFB can be increased up to 1715 MJ with retention of more than 90 days.

REFERENCES

[1] Malaysian Palm Oil Board [Internet]. Statistics. Area and sectoral status. Kelana Jaya: Economics & Industry Development Division. Available from: http://bepi.mpob.gov.my/; 2011 [accessed June 2011].
[2] Chow MC, Mohd Basri W, Chan KW. Availability and potential of biomass resources from the Malaysian palm oil industry for generating renewable energy. Oil Palm Bull 2008;56:23–8.
[3] Roslan A, Mohammad Fairuz K, Ahmad Borhan AN, Mohd Arif S. A study on the Malaysian oil palm biomass sector – supply and perception of palm oil millers. Oil Palm Ind Econ J 2011;11(1):28–41.
[4] Vijaya S, Ma AN, Choo YM, Nik Meriam NS. Life cycle inventory of the production of crude palm oil – a gate to gate case study of 12 palm oil mills. J Oil Palm Res 2008;20(1):484–94.
[5] Vijaya S, Ma AN, Choo YM. Capturing biogas: a means to reduce greenhouse gas emissions for the production of crude palm oil. Am J Geosci 2010;1(1):1–6.
[6] Stichnothe H, Schuchardt F. Comparison of different treatment options for palm oil production waste on a life cycle basis. Int J Life Cycle Ass 2010;15(9):907–15.
[7] Nagarajan M. Biofuel policy and development in Malaysia. Development of oils, fats and sago industries division [Internet]. Ministry of Plantation Industries and Commodities Malaysia. Available from: http://istic-unesco.org/meetingdoc/Biofuel%20Policy%20and%20Development%20in%20Malaysia.pdf; 22 June 2009 [accessed May 2011].
[8] BioCentrum-DTU, Denmark's Technical University. Ethanol potential for empty fruit bunches pre-treated by wet-explosion. Report prepared under Malaysian. Danish Environmental Cooperation Programme, Renewable Energy and Energy Efficiency Component; 2008.
[9] Piarpuzán D, Quintero JA, Cardona CA. Empty fruit bunches from oil palm as a potential raw material for fuel ethanol production. Biomass Bioenerg 2011;35(3):1130–7.
[10] Millati R, Wikandari R, Trihandayani ET, Cahyanto MN, Taherzadeh MJ, Niklasson C. Ethanol from oil palm empty fruit bunch via dillute-acid hydrolysis and fermentation by *Mucor indicus* and *Saccharomyces cerevisiae*. Agric J 2011;6(2):54–9. http://dx.doi.org/10.3923/aj.2011.54.59.
[11] Yano S, Murakami K, Sawayama S, Imou K, Yokohama S. Ethanol production from oil palm empty fruit bunches in Southeast Asian countries considering xylose utilization. J Jpn Inst Energy 2009;88(10):923–6.
[12] The Bioenergy site com [Internet]. Sime Darby Plantation to build ethanol plant. Available from: http://www.thebioenergysite.com/news/7839/sime-darby-plantation-to-build-ethanol-plant; 6 January 2011 [accessed January 2011].
[13] Novaviro Technology Sdn. Bhd. [Internet]. Specifications of Novaviro-KS anaerobic digester technology and scope of KS anaerobic digester system. Available from: http://novaviro.com.my/ [accessed 10 December 2011].
[14] Paepatung N, Nopharatana A, Songkasiri W. Methane potential of biological solid materials and agricultural wastes. As J Energy Env 2009;10(01):19–27.
[15] Fang C. Biogas production from food-processing industrial wastes by anaerobic digestion [PhD Thesis]. Kongens Lyngby: Technical University of Denmark; December 2010.
[16] Nieves DN, Karimi K, Horváth IS. Improvement of biogas production from oil palm empty fruit bunches (OPEFB). Ind Crops Prod 2011;34(1):1097–101.
[17] O-Thong S, Boe K, Angelidaki I. Thermophilic anaerobic co-digestion of oil palm empty fruit bunches with palm oil mill effluent for efficient biogas production. Appl Energy 2012;93:648–54.
[18] Saleh AF, Kamarudin E, Yaacob AB, Yussof AW, Abdullah MA. Optimization of biomethane production by anaerobic digestion of palm oil mill effluent using response surface methodology. Asia Pac J Chem Eng 2012;7(3):353–60.
[19] Damen K, Faaij A. A greenhouse gas balance of two existing international biomass import chains the case of residue co-firing in a pulverised coal-fired power plant in the Netherlands. Mitig Adapt Strateg Glob Chang 2006;11(5–6):1023–50.
[20] Asia Biomass Energy Cooperation Promotion Office [Internet]. Import of EFB (Empty Fruit Bunch) of palm is swelling. Available from: http://www.asiabiomass.jp/english/topics/1001_03.html [accessed January 2011].
[21] Nasrin AB, Ma AN, Choo YM, Mohamad S, Rohaya MH, Azali A, et al. Oil palm biomass as potential substitution raw materials for commercial biomass briquettes production. Am J Appl Sci 2008;5(3):179–83.
[22] Global Green Synergy Sdn. Bhd. Proposal on setting up an 18000 MT annual capacity briquetting plant [pamphlet]. Kuala Lumpur: Global Green Synergy Sdn. Bhd; 2010.
[23] ITOCHU Corporation [Internet]. Biomass fuel production project in Malaysia. Available from: http://www.itochu.co.jp/en/news/2009/091124.html [accessed March 2011].
[24] United Nations Development Programme (UNDP). Malaysia generating renewable energy from palm oil waste [Internet]. Kuala Lumpur: UNDP. p. 11, 24 &25. Available from: http://www.undp.org.my/uploads/Renewable_Energy_Palm_oil_wastes.pdf; August 2007 [accessed August 2009].

http://www.dnv.com/focus/climate_change/Upload/CDM_PDD_Lahad_Datu_rev2.4.pdf; 2007 [accessed August 2009].
[61] Hanim A. Agro-Bio banks on technology [Internet]. Malaysia: The Star. Availabe from:, http://biz.thestar.com.my/news/story.asp?file=/2009/4/24/business/3757628&sec=business; 24 April 2009 [accessed June 2011].
[62] Wikimapia [Internet]. Agro Bio Fibre Sdn. Bhd.'s plant area. Available from: http://wikimapia.org/5719926/ms/Agro-Bio-Fibre-Sdn-Bhd [accessed June 2011].
[63] Wilson JB. Life cycle inventory of medium density fiberboard in terms of resources, emissions, energy and carbon. Wood Fiber Sci 2010;42(1):107–24.
[64] Validation report, Report no: 2008-9208Avoided emissions from biomass wastes through use as feed stock in pulp and paper Kunak, Sabah production [Internet]. Available from:, http://cdm.unfccc.int/filestorage/L/B/N/LBNXGZ1F8UJ0KRVAPCW3MQ6YO72IE4/4611%20FVR.pdf?t=alB8bTdiNmx1fDCSUUTm0V8cKjAF8bl6zahD; 2008 [accessed May 2011].
[65] United Nations Industrial Development Organization (UNIDO), The Energy Conservation Center (ECC), Japan. Handy manual paper and pulp industry. Output of a seminar on energy conservation in paper and pulp industry, 1993, Bangkok, Thailand and Manila, Philippines. Vienna: UNIDO; 1993. p. 3.
[66] Mohd Ghazali NA. Coal demand outlook in Malaysia. Energy input in power stations, 2005. Ministry of energy, water and communications (MEWC). Proceedings of Clean Coal as a Sustainable Energy Development Strategy; 6–8 February 2007; Hanoi, Vietnam. Session 1. p. 9.
[67] Coley D. Energy and climate change – creating a sustainable future. West Sussex: John Wiley & Sons Ltd; 2008. p. 549.
[68] Perry RH, Green DW. Perry's chemical engineers' handbook. 7th ed. McGraw Hill; 1997.
[69] Mc Veigh JC. Energy around the world – an introduction to energy studies, global resources, needs, utilization. Oxford: Pergamon Press; 1984. p. 71.
[70] Origin Fertilisers (UK) Limited [Internet]. Product list. Available from: http://www.originfertilisers.co.uk/product_list [assessed 12 December 2012].

[25] United Nation Framework Conventional for Climate Change (UNFCCC) [Internet]. CDM projects. Available from: http://cdm.unfccc.int/ [accessed August 2009].
[26] Damiri NA. List of SREP projects [online]. Pusat Tenaga Malaysia: Malaysia Energy Center. Email to Chiew YL; 12 August 2009 [accessed 13.12.12].
[27] Department of Energy Management and Industry Development, Energy Commission of Malaysia. Electricity supply industry in Malaysia – performance and statistical information 2010. Putrajaya: Suruhanjaya Tenaga (Energy Commission of Malaysia); 2012. p. 65.
[28] Malaysian Palm Oil Council (MPOC) [Internet]. POIC head calls for biomass policy. Available from: http://archive.mpoc.org.my/POIC_Head_Calls_for_Biomass_Policy.aspx; 19 January 2010 [accessed January 2010].
[29] Chiew YL, Iwata T, Shimada S. System analysis for effective utilisation of palm oil waste as energy resource. Biomass Bioenerg 2011;35(7):2925–35.
[30] Damanhuri MA. Hands-on experience in the production of empty fruit bunches (EFB) compost. Paper presented at the CETDEM Malaysian Organic Farming Seminar. Petaling Jaya, Selangor, Malaysia; 1998.
[31] Oviasogie PO, Aisueni NO, Brown GE. Oil palm composted biomass: a review of the preparation, utilization, handling, and storage. Afr J Agric Res 2010;5(13):1553–71.
[32] Baharuddin AS, Wakisaka M, Shirai Y, Abd-Aziz S, Abdul Rahman NA, Hassan MA. Co-composting of empty fruit bunches and partially treated palm oil mill effluents in pilot scale. Int J Agric Res 2009;4(2):69–78.
[33] Felda Holdings Bhd. [Internet]. Available from: http://www.feldaholdings.com/content.php?h=2055&lang=EN [accessed July 2010].
[34] Hanim A. Sime Darby aims to intensify R&D efforts [Internet]. Malaysia: The Star. Available from: http://biz.thestar.com.my/news/story.asp?file=/2011/3/29/business/8368509&sec=business; 29 March 2011 [accessed April 2011].
[35] Ministry of Plantation Industries and Commodities Malaysia. National timber industry policy 2009–2020 [Internet]. Kuala Lumpur: National Library of Malaysia. p. 8. Available from: http://www.mtib.gov.my/natip/Natip3.pdf; 2009 [accessed December 2012].
[36] Forestry Department. Wood processing – oil palm fiber as an alternative raw material [Internet]. Foundation Agricultural Organization (FAO) Corporate Document Repository. Available from: http://www.fao.org/docrep/w7715e/w7715e08.htm [accessed June 2011].
[37] Mohamad H, Anis M, Ridzuan R, Ropandi M, Kamaruddin H, Astimar A, et al. MDF from oil palm biomass. MPOB information series, MPOB TT No. 168; 2002.
[38] Ridzuan R, Shaler S, Mohd Ariff J. Properties of medium density fibreboard from oil palm empty fruit bunch fibre. J Oil Palm Res 2002;14(2):34–40.
[39] Abdul Khalil HPS, Nur Firdaus MY, Jawaid M, Anis M, Ridzuan R, Mohamed AR. Development and material properties of new hybrid medium density fiberboard from empty fruit bunch and rubberwood. Mater Des. 2010;31(9):4229–36.
[40] Agro-Bio fiber Sdn. Bhd. [Internet]. Available from: http://www.asiagiant.com/agrobio/ [accessed June 2011].
[41] Tian Siang Group [Internet]. Tian Siang trading Sdn Bhd, marketing and product information. Available from: http://www.tiansiang.com/oilmill/tstrd/infomarketing.php [accessed June 2011].
[42] Roda J-M, Rathi S. Feeding China's expanding demand for wood pulp: a diagnostic assessment of plantation development, fiber supply, and impacts on natural forests in China and in the South East Asia region. Malaysia report [Internet]. Jakarta: Center for International Forestry Research. Available from:, http://hal.inria.fr/docs/00/19/60/37/PDF/Malaysia.pdf; 2006 [accessed May 2011].
[43] Official Malaysia's International Trade and Industry (MITI) portal. Industrial master plan [Internet]. Available from: http://www.miti.gov.my/ [accessed May 2011].
[44] Rushdan I, Mahmudin S, Latifah J, Mohd Nor MY. The potential growth of newsprint and packaging grades from oil palm fibers for china market. Forest Research Institute Malaysia (FRIM). Available from: http://www.icopb.com/pastevent/index.html [accessed July 2011].
[45] Rosnah MY, Ghazali A, Wan Rosli WD, Dermawan YM. Influence of alkaline peroxide treatment duration on the pulpability of oil palm empty fruit bunch. World Appl Sci J 2010;8(2):185–92.
[46] Law KN, Jiang X. Comparative papermaking properties of oil-palm empty fruit bunch. TAPPI J 2001;84(1):1–13.
[47] Gonzalo A, Sanchez JL, Escudero E, Marin F, Fuerters R. Pulp and paper production from EFB using a semichemical process. Available from: http://www.tappi.org/content/events/07epe/papers/07epe82.pdf; 2007 [accessed April 2011].
[48] Ng SH, Ghazali A, Leh CP. Anthraquinone-aided hydrogen peroxide reinforced oxygen delignification of oil palm (*Elaeis guineensis*) EFB pulp: a two-level factorial design. Cell Chem Technol 2011;45(1–2):77–87.
[49] Tanaka R, Wan Rosli WD, Magara K, Ikeda T, Hosoya S. Chlorine-free bleaching of kraft pulp from oil palm empty fruit bunches. JARQ 2004;38(4):275–9.
[50] Rushdan I. Structural, mechanical and optical properties of recycled paper blended with oil palm empty fruit bunch pulp. J Oil Palm Res 2003;15(2):28–34.
[51] Palm Oil Industrial Cluster (POIC) [Internet]. Available from: http://www.etawau.com/OilPalm/PulpPaperMill.htm [accessed June 2011].
[52] Mahmudin S, Mohd Nor YM. Inquiry for pulp and paper production from oil palm EFB [Online]. Forest Product Division, Forest Research Institute Malaysia (FRIM). Email to: Chiew YL; 4 May 2011.
[53] Goedkoop M, De Schryver A, Oele M, Sipke D, Roest DD. Introduction to LCA with SimaPro 7. Report version: 4.5. [monograph on the Internet]. Amersfoort NL: PRé Consultants. Available from:, http://www.pre-sustainability.com/manuals; November 2010 [cited November 2012].
[54] Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, et al. Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: guide. IIb: operational annex. III: scientific background. Dordrecht: Kluwer Academic Publishers; 2002.
[55] Oyadomari M. Biomaterial in Tokyo corporation. Kashiwanoha bioethanol cellulose plant process outline. Email to: Shimada S; 12 January 2011.
[56] Ecoinvent Centre. Ecoinvent data v2.0. Final ecoinvent reports No. 6, 9, 11, 15, & 17. Dübendorf (CH): Swiss Centre for Life Cycle Inventories; 2007.
[57] Tan HT, Lee KT, Mohamed AR. Second-generation ethanol (SGB) from Malaysian palm empty fruit bunch: energy and exergy analyses. Bioresour Technol 2010;101(14):5719–27.
[58] Sunquest Biomass Project [Internet]. Project Design Document (PDD) CDM, Version 3. Available from: http://www.sgsqualitynetwork.com/tradeassurance/ccp/projects/476/Sunquest%20Port%20Dickson%20PDD%20280308(Clean)%20(RN).pdf; 2008 [accessed July 2010].
[59] FELDA Trolak & Sampadi Composting Plants [Internet]. PDD CDM, Version 3. Available from: http://www.netinform.net/KE/files/pdf/FELDA_Trolak_Sampadi_PDD_III_F.pdf; 2009 [accessed August 2009].
[60] Co-composting of EFB and POME – MG BioGreen Sdn.Bhd (MGBG) [Internet]. PDD CDM, Version 3. Available from:

Source: Chiew, Y & Shimada, S. (2013). Current state and environmental impact assessment for utilizing oil palm empty fruit bunches for fuel, fiber and fertilizer - A case study of Malaysia. Biomass and Bioenergy, vol 51, 2013, p. 109-124. https://doi.org/10.1016/j.biombioe.2013.01.012

Appendix 3: Case 3: Economic valuation of the Leuser National Park

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Ecological Economics 44 (2003) 43–62

ECOLOGICAL ECONOMICS

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ANALYSIS

Economic valuation of the Leuser National Park on Sumatra, Indonesia

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Received 19 March 2002; received in revised form 15 July 2002; accepted 21 August 2002

Abstract

The Leuser Ecosystem in Northern Sumatra is officially protected by its status as an Indonesian national park. Nevertheless, it remains under severe threat of deforestation. Rainforest destruction has already caused a decline in ecological functions and services. Besides, it is affecting numerous economic activities in and around the Leuser National Park. The objectives of this study are twofold: firstly, to determine the total economic value (TEV) of the Leuser Ecosystem through a systems dynamic model. And secondly, to evaluate the economic consequences of deforestation versus conservation, disaggregating the economic value for the main stakeholders and regions involved. Using a dynamic simulation model, economic valuation is applied to evaluate the TEV of the Leuser National Park over the period 2000–2030. Three scenarios are considered: 'conservation', 'deforestation' and, 'selective use'. The results are presented in terms of (1) the type of benefits, (2) the allocation of these benefits among stakeholders, and (3) the regional distribution of benefits. The economic benefits considered include: water supply, fisheries, flood and drought prevention, agriculture and plantations, hydro-electricity, tourism, biodiversity, carbon sequestration, fire prevention, non-timber forest products, and timber. The stakeholders include: local community members, the local government, the logging and plantation industry, the national government, and the international community. The regions considered cover the 11 districts involved in the management of the Leuser Ecosystem. With a 4% discount rate, the accumulated TEV for the ecosystem over the 30-year period is: US $7.0 billion under the 'deforestation scenario', US $9.5 billion under the 'conservation scenario' and US $9.1 billion under the 'selective utilisation scenario'. The main contributors in the conservation and selective use scenarios are water supply, flood prevention, tourism and agriculture. Timber revenues play an important role in the deforestation scenario. Compared to deforestation, conservation of the Leuser Ecosystem benefits all categories of stakeholders, except for the elite logging and plantation industry.

Keywords: Natural resource valuation; Conservation; Deforestation; Indonesia

1. Introduction

The Leuser Ecosystem in Northern Sumatra (Indonesia) covers 25,000 km^2 and consists of a

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PII: S0921-8009(02)00224-0

Fig. 1. The boundaries of the pilot analysis.

national park and a buffer zone (Fig. 1). Deforestation in this ecosystem is widespread, despite its formally protected status (van Schaik et al., 2001). This is believed to have severe ecological consequences, such as the probable local extinction of the Sumatran orangutan, rhinoceros, tiger and elephant. In addition, the local economy could become structurally damaged as crucial ecological functions of the rainforest decline. Consequent damage caused by floods, erosion and loss of water supply can greatly exceed the revenues derived from timber extraction and land conversion.

The objectives of this study are to determine the total economic value (TEV) of the Leuser Ecosystem and evaluate the consequences of deforestation. A dynamic simulation model is applied to evaluate the TEV of the Park over the period 2000–2030. The originality of this study lies in the dynamic link exposed between ecological functions and their related economic values. In addition this study provides a breakdown of impacts on different stakeholder groups and geographic units.[1]

To determine both the complex systems dynamics of tropical rainforests and the stakeholder elements, the authors have closely collaborated with social and ecological experts working in

[1] Pet-Soede et al. (1999) presents one of the few economic valuation studies per stakeholder for blast fishing in Indonesia based on a much simpler systems model. Bockstael et al. (1995) present an economic valuation of ecosystems using a sophisticated systems dynamics but they did not consider stakeholder aspects.

Sumatra. The scenarios have been determined through consultations with local policy makers involved in the management of the national park. These include: (1) the 'conservation' scenario, implying that protection of the rainforest is strictly enforced and that logging will be excluded as an economic activity; (2) the 'deforestation' scenario, implying a continuation of the current trend of clear-cutting; and (3) the 'selective use' scenario, in which logging of primary forest is substantially reduced and replanting of logged forest is assumed to be compulsory. The results are presented in terms of the types of benefits, the allocation of these benefits among stakeholders, and the regional distribution of these benefits.

The paper is structured as follows: Section 2 elaborates on the general background of the Leuser Ecosystem, including its main threats and the foreseen scenarios. Section 3 provides a background of the applied methodology. Section 4 addresses the benefits outlined in the analysis. The results of the valuation process are presented in Section 5. Finally, conclusions are drawn in Section 6.

2. The Leuser Ecosystem

2.1. Threats

Despite its protected status, the Leuser Ecosystem is under enormous pressure. Its lowland forests are being rapidly logged and non-timber forest products (NTFP) are being overexploited. Furthermore continued illegal poaching will cause animal species to verge on extinction. An additional threat is the tourist industry which is being developed in an unsustainable manner. At present, 20% of the Leuser National Park has already been degraded (GIS Unit, LDP 2000). Most of this deforestation is taking place through legal or semi-legal conversion of former logging concessions into plantation estate crops (mainly oil palm and rubber). In addition the army is allegedly involved in largescale clear-cutting just inside the park boundaries. The remaining conversions are transmigration areas (often including a plantation component), other forestry plantations, infrastructure areas (roads and bridges), and regions of spontaneous settlement with associated small-scale agriculture. Both local governments and business interests view this development as the first step towards 'developing' the region.

2.2. Scenarios

Three macro-economic scenarios have been selected for further investigation:

2.2.1. Deforestation

In the 'deforestation' scenario, the current trend of controlled and uncontrolled logging and unsustainable harvesting of NTFP is assumed to continue. Eco-tourism will not be developed and international interests to invest in conservation and carbon sequestration funds declines. Furthermore natural functions of the rainforest decline which impacts local community use of these functions. If the current lack of enforcement remains, this development is quite likely to occur.

2.2.2. Conservation

The logging of primary and secondary forest entirely ceases in the 'conservation' scenario. No timber revenues and only a limited amount of NTFP accrue. Eco-tourism is developed to its maximum allowable potential and international interests to invest in conservation funds remain high. Carbon sequestration funds increase and natural functions of the rainforest are maintained for community use.

2.2.3. Selective use

In the 'selective use' scenario, logging of primary forest is substantially reduced and replanting of logged forest is assumed to be compulsory. Although the area of primary forest will decline, the overall forest area remains constant due to the increase of secondary forest. In addition, the harvesting of NTFP is actively developed. Despite efforts to develop eco-tourism, the tourist sector will not reach levels found in the conservation scenario, due to lower levels of biodiversity. Likewise, there is less international interest to invest in conservation and carbon sequestration. The natural functions of the rainforest (such as water supply and flood prevention) are only partially maintained.

2.3. Changes of ecological functions

As shown in the first column of Fig. 4, deforestation changes several ecological functions. The assumptions underlying these changes are described below. Because the study focused predominantly on the economic dimensions of deforestation, the ecological relationships have been somewhat simplified.

2.3.1. Reduction of forest area

In the deforestation scenario increased logging, especially during the first decade, is assumed. After 2010, the logging intensity declines because only the less financially-attractive highland forests remain. This non-linear process is depicted in Fig. 2. Due to the steep slopes of the highlands, only areas of low lands are converted into plantations. This causes an increase in so-called 'waste lands', mainly consisting of grasslands (i.e., alang alang). In the conservation scenario, the allocation of different forms of land use remains the same. In the 'selective use' scenario the area of primary forest will decline. This decline is compensated for by an increase in secondary forest. Because replanting is not successful in every soil type, ultimately wastelands will develop.

2.3.2. Increased erosion

Population pressure and inappropriate agricultural techniques cause local communities to encroach on the park. Given the mountainous landscape, people often farm steep slopes where soil depths are only between 50 and 100 cm. The removal or alteration of the forest vegetation has immediate repercussions. Studies have shown that the removal of the forest floor litter layers alone may cause a 20-fold increase in soil erosion (Edwards, 1994). In the Leuser Ecosystem, annual losses of up to 1,350 tonnes ha^{-1} of maize cultivation area have been measured. Within a few years, these lands will be unfit for any agricultural, forestry or tourist activity (BZD, 2000a). In this study, increased erosion has been incorporated indirectly as a degrading impact on

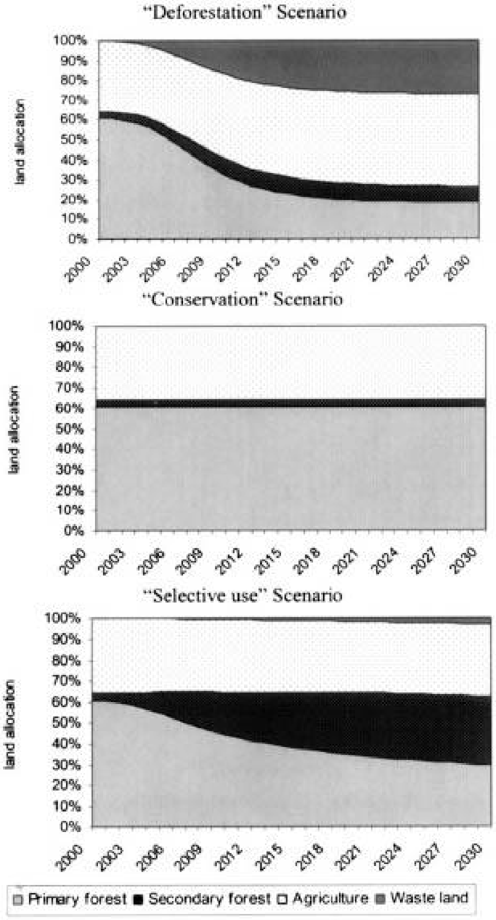

Fig. 2. Projected land allocation for each scenario (period 2000–2030).

agriculture. This influence varies for the type of crop and region considered.

2.3.3. Water retention

Deforestation reduces the water retention function of rainforests thereby increasing the frequency and intensity of floods and droughts. Moreover, due to the change in the micro-climatic conditions, less water is generated in perpetuity. These effects are clearly recorded: compared to 10 years ago, approximately 50% of the streams in Aceh have less than 50% of the typical water flow in the springtime. Furthermore 20% of the flows are completely dry throughout the year. For North Sumatra the situation is comparable: on average 80% of the rivers contain less than 50% of the usual water flow. Roughly 15% of the rivers have fallen completely dry (BZD, 2000b).

Fig. 3 shows how, due to reduced water availability, local communities' consumption of surface and groundwater provided by the Leuser Ecosystem declines in the deforestation scenario. If the rainforest is conserved, the availability of water is assumed to be sufficient to meet the demands of the local communities.

2.3.4. Reduced pollination and pest control

Rainforest flora and fauna provide indirect benefits by creating and maintaining the forest environment. In many ways they sustain the ecological services (e.g., pollination, decomposition, seed dispersal, seed predation, herbivory and predation) on which human livelihoods depend. They influence the reproductive success of plants, contribute to soil fertility and serve as regulators of pest populations (Redford, 1996). A typical example of this function in Leuser is the role of fruit bats. At least 443 products useful to man are derived from 163 plant species that rely to some degree on bats for pollination and seed dispersal. The destruction of the habitat of the fruit bat would, for example, lead to the disappearance of the popular durian (Mickleburgh et al., 1992). The degree of pest control is assumed to be proportional to the amount of remaining primary and secondary forest. Thus, as more forest is logged, the production costs of agriculture increase, while production levels fall.

2.4. Stakeholders

The stakeholder dimension can be viewed in two ways: (1) at the societal level (e.g., local, national, international level), and (2) at district or regency level (i.e., Kabupatens). At both levels stakeholders can gain or lose from deforestation depending on location-specific characteristics (for instance whether the stakeholder is located upstream or downstream from a certain logging concession). Both levels are considered here.

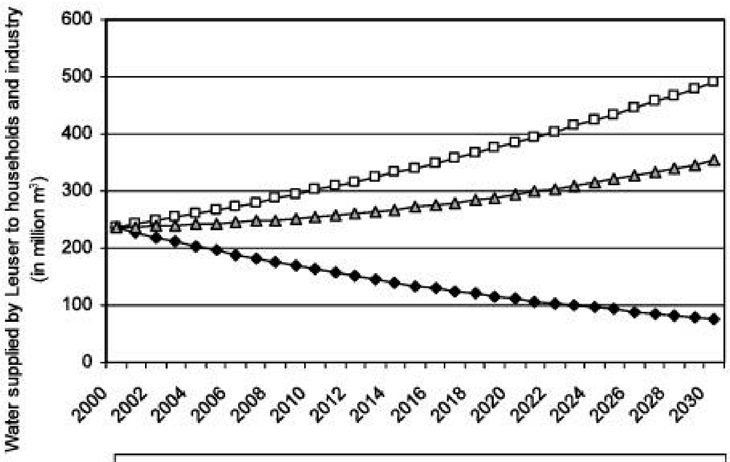

Fig. 3. Exogenously determined water supplies to households and industries.

2.4.1. Regency level

As indicated by the map in Fig. 1, the study region is limited to the 11 regencies that are part of the Leuser Ecosystem. Of these 11 regencies, 4 belong to the province of North Sumatra and 7 belong to the province of Aceh. Each regency benefits in a different manner from the Leuser Ecosystem, depending on the structure of the economy, population demographics, land cover, vulnerability to floods and fires. To illustrate these distinctions, and the results are presented at the level of the individual regencies.

2.4.2. Societal level

Table 1 shows how the changes in benefits are likely to affect the different stakeholders. An important question that is addressed by the stakeholder analysis is whether the potential imbalance between costs arising at the local level and benefits accruing at the national and international levels should be neutralised by compensating people living in or near protected areas for their losses (Ferraro and Kramer, 1997).

Five categories of stakeholders are identified: (1) local communities (households, small-scale farmers and entrepreneurs); (2) local government (a responsible body that maintains infrastructure and collects local taxes); (3) the elite logging and plantation industry (the owners of concessions); (4) the national government (a law enforcing body); and (5) the international community (representing global concerns for poverty, climate change and biodiversity loss).

3. Methodology

The road towards sustainable development involves improved integration of the environment into economic decision-making, in particular by using economic techniques to appraise projects and policies. In this study, economic valuation is used as the main analytical tool to compare the advantages and disadvantages of three scenarios in Leuser. Nowadays, most economists agree that the value of natural resources depends not only on the market prices of their direct uses, but also on all other components that generate value in the broadest sense. This is reflected in the concept of the so-called TEV. In this section, a brief description of the applied methodology is given.

3.1. Overall approach

In order to make sound policy decisions with regard to environmental problems, decision-makers need information on the benefits and costs of alternative options. An evident way to organise this information is to consider the underlying processes, starting with the cause, followed by the resultant physical impact and finally the social and economic effects. This is known as the 'impact pathway approach'.

The impact pathway for Leuser is shown in Fig. 4 indicating the physical and socioeconomic processes resulting from deforestation of the Leuser Ecosystem. The impact pathway approach proceeds in a series of methodological steps. These include (1) defining the study boundaries (i.e., impacts on ecological functions/services); (2) identifying the physical impacts that are economically significant; (3) quantifying the significant socioeconomic effects; and (4) calculating monetary values and conducting a sensitivity analysis. In reality this 'ideal' approach can rarely be followed completely. Often there is lack of information. Some impacts can be quantified reasonably well while others can be estimated only by order of magnitude. In these cases, it is particularly important to undertake a sensitivity analysis in order to understand which factors and assumptions influence the overall results the most. Further, the quantitative analyses can be complemented with more qualitative considerations.

3.1.1. Defining the boundaries of the study

To maintain a transparent and comprehensible overview of the TEV of the Leuser Ecosystem, only three scenarios are analysed (see earlier explanation). The temporal boundary of the project is 2000–2030. This period leaves enough time for the main environmental impacts to come into effect, while it is sufficiently short to estimate future developments. The geographic boundaries have two dimensions: the area where ecological impacts occur (the boundaries of the Leuser

Table 1
Impact of deforestation on the main stakeholders of the Leuser Ecosystem

	Local community	Local government	Elite (logging) industry	National government	International community
Water supply	Expensive water	Costs to change distribution system	–	Costs to change distribution system	–
Fishery	Loss of income	Loss of local taxes	–	Loss of federal taxes	–
Flood prevention	Casualties, house damage	Infra-structural damage	Damage to logging roads, perhaps compensation payments	Need for compensation payments	Increased costs of emergency support
Agriculture	Increase food prices, loss of production	Loss of local taxes	Lost production from plantations	Loss of federal taxes	–
Hydro-electricity	Production loss due to power cuts, expensive electricity	Loss of local taxes	Loss of revenue from electricity	–	–
Tourism	Loss of income	Loss of taxes	–	Loss of foreign revenues	Loss of WTP for recreational, less international travel
Biodiversity	–	Loss of foreign revenues	Loss of pharmaceutical benefits	Loss of foreign revenues	Loss of WTP for biodiversity, research
Sequestration	–	Loss of foreign revenues	–	Loss of foreign revenues	Loss of ghg reduction options
Fire prevention	Damage to crops, property and health	Damage to infrastructure	Loss of concession area	Loss of federal tax revenues	Damage to economy and health
Non-timber forest products	Short-term gain in production, long-term loss	Loss of taxes	Short-term gain in production, long-term loss	–	–
Timber	Short-term gain in production, long-term loss	Loss of taxes	Short-term gain in production, long-term loss	Loss of export revenues	–

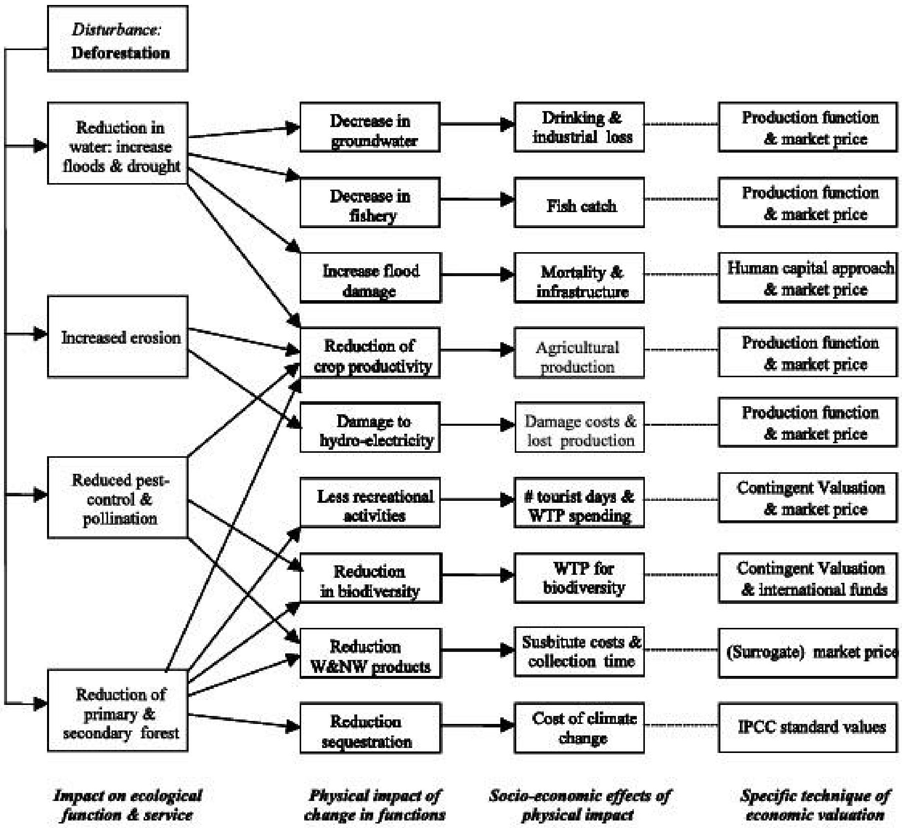

Fig. 4. Impact pathway of deforestation of the Leuser Ecosystem.

Ecosystem) and the area where changes in benefits take place. The beneficiaries are not limited to the Leuser Ecosystem. For example, tourism benefits for travel agents abroad may change as a result of deforestation. This economic loss, however, is partly avoided because rather than not making the journey, tourists may simply choose another destination.

3.1.2. *Identifying impacts that are economically significant*

Effects may be economically significant or insignificant. Only the former category is relevant to this appraisal. Inevitably, judgement must be used in deciding what is and is not significant. To judge the magnitude of environmental effects, the following criteria are used: (a) the location, timing and reversibility of the effect; (b) the potential effect on the natural, human, chemical and physical environment; and (c) whether the effect is positive or negative.

3.1.3. *Physically quantifying the significant impacts*

To assist in the prediction of the approximate physical consequences of the scenarios, a dynamic simulation model was developed. The model approximates the main effects of each scenario on the various benefit categories and evaluates the changes for the various stakeholders (i.e., local/national/international agents and the involved regencies). To calculate these impacts, simplifying assumptions have been adopted for certain aspects (for example, climatic/hydrological conditions and future economic activities).

3.1.4. Calculating monetary values and conducting a sensitivity analysis

Having established and tabulated the full range and significance of the effects, changes are valued in monetary terms. The main impact pathways, including nine categories, will be covered in the following sections. The last column of Fig. 4 shows the specific valuation technique applied to estimate the economic value of a particular effect. The selection of a valuation technique depends on the characteristics of the cost or benefit to be valued. We lack the space to elaborate on the techniques applied. Dixon and Sherman (1990) and Brown et al. (1993) and Bann (1998) provide a practical and detailed description of the steps involved in applying the methods described, specifically for the valuation of tropical rainforest.

3.2. Calculating the overall value

Most scenarios yield benefits at least intermittently over their lifetimes, and usually they incur costs over that lifetime. Because the distribution of these costs and benefits may vary for different scenarios over time, they need to be converted to net present values (NPVs) by discounting both categories of values. The choice of the appropriate discount rate remains a controversial issue because it may have a significant impact on the outcome of the analysis. The usual way to deal with this is to apply different discount rates so as to allow the decision-maker to choose the most appropriate rate. Following Pearce and Ulph (1995) we adopt a 4% discount rate as a starting point and report values for other discount rates as well.

Not all effects can be expressed in monetary units and some effects can only be assessed qualitatively. Therefore, NPVs of different scenarios cannot always be directly compared. This underlies part of the variation in earlier studies investigating the NPV of rainforest conversion. Therefore, the NPV based on the quantifiable parts of the TEV should not be the sole criterion for selection.

We acknowledge that there are many conceptual and empirical problems inherent in producing TEV estimates for the Leuser Ecosystem under the given scenario conditions. For example, the valuation approach taken here assumes that there are no sharp thresholds, discontinuities or irreversibilities in the ecosystem respond functions. Also, different valuation techniques have been used simultaneously to estimate the TEV. Although we have carefully prevented overlapping values, such an approach is rather uncommon in valuation studies. Studies that have attempted similar exercises have been criticised in the scientific community for their disregard for the significant uncertainties in the data and their underlying assumptions (e.g., Constanza et al., 1997). We stress, however, that given the uncertainties involved, we may never have a precise estimate of the TEV of the Leuser Ecosystem. Nevertheless, the crude estimate we have assembled is a useful starting point for further research.

4. Benefits

Because the focus of the study is limited to the first-order effects, the valuation of individual benefits of the Leuser Ecosystem can be considered as separate and independent analyses. This assumption is plausible because benefits are largely compatible. The analyses are based on a number of methodological and empirical assumptions (van Beukering et al., 2001), which will be summarised in this section.

4.1. Water supply

As mentioned, the first signs of reduced water replenishment have already been seen in and around the Leuser Ecosystem. Groundwater reservoirs are rapidly being exhausted and several rivers fall completely dry during part of the year. This has severe consequences for the local community. Both households and industries need to anticipate water shortages and higher costs for water.

The economic damage of reduced water supply from the Leuser Ecosystem for households and industries is based on a 'quantitative' component (volume of water provided per m^3 of ecosystem) and a 'price' component (focusing on the minimal cost (Rp. m^{-3})). The 'quantitative' component refers to reduced water availability. In the deforestation scenario, this water shortage increases (Fig. 3) and demand will have to be met by another water source. The dependency on water from Leuser declines from 74% in 2000 to 12% in 2030. In the conservation scenario, the water supply is sufficient to meet the increasing demand. The 'price' component of the water value refers to the cost-reducing impact of water supply. In the deforestation scenario, water will be retrieved from more costly sources with prices increasing by 0.3% annually. In the conservation scenario, prices remain constant at their 2000 level.

4.2. Fishery

Coastal fisheries and aquaculture in and around Leuser are very important. They provide a large portion of the animal protein in local people's diets and generate ample foreign exchange. Their annual value currently exceeds US $171 million. If the Leuser Ecosystem is degraded, the decline in fresh water may have a detrimental impact on the functioning of the fishery sector. In the valuation of the Leuser fishery sector the following subdivisions are used: (1) maritime fishery, (2) brackish water fishery, (3) brackish water aquaculture, and (4) freshwater aquaculture.

The dependency of fisheries on Leuser varies across these different categories and between the regencies. The average share of the fishery sector dependent on Leuser is estimated at 2% for the maritime fishery, 9% for brackish water fishery and 100% for brackish and freshwater aquaculture (van Beukering et al., 2001). This generated an economic value of US $33 million in the year 2000. In the 'conservation' scenario, this value is assumed to remain constant. In the 'deforestation' scenario, support from the Leuser Ecosystem is expected to decline at an annual rate of 1% and the prices are assumed to increase at 0.5% annually.

4.3. Flood and drought prevention

Flooding generally becomes more frequent and more destructive as a result of converting forests to other uses. Annual storm flows from a secondary forest are about threefold higher than from a similar-sized primary forest catchment area (Kramer et al., 1995). In Aceh, local farmers have reported an increasing frequency of drought and damaging floods due to degradation of the water-catchment area. In May 1998, over 5,000 ha of intensive rice growing areas were taken out of active production. This was the result of the failure of 29 irrigation schemes due to a water shortage. Furthermore, floods in December 2000 cost the lives of at least 190 people and left 660,000 people homeless. This cost the Aceh province almost US $90 million in losses (Jakarta Post, 2000a). Logging companies are slowly recognising their role in increased flooding and have made large donations to support the victims (Jakarta Post, 2000b).

For this study, the following three damage categories of floods and droughts are identified: (1) residential houses; (2) infrastructure (such as bridges and roads); and (3) mortality.[2] The probability of a flood occurring in the area is assumed to increase linearly with the area of deforestation.

4.4. Agriculture and plantations

Agriculture is a major source of income for the local communities around Leuser. Large rubber and oil palm plantations in northern Sumatra play a major role in the national economy. Almost all remaining lowland forest has been given out officially for oil palm plantations. Yield decline has been recorded, however, in several Leuser

[2] The individual values of impacts are estimated to be US $3000 per residential house, US $5000 for 1 km of road, and US $15000 for a mortality case. The first two values are based on local prices while the latter value was derived through benefit transfer of the value of mortality in Western Europe (US $3 million) corrected for purchasing power parity differences between the Europe and Indonesia.

regencies. This decline can be ascribed mainly to a deterioration of nutrients in the soil, along with soil erosion, drought and floods, and an increase in weeds. Clearly, these causes of decline are linked to the deforestation of Leuser. For example, the logging of water-catchment areas in Leuser is found to be responsible for taking 94% of failed irrigation areas out of production (BZD, 2000a).

A simplified dose–response relationship is applied to estimate agricultural losses due to flooding, erosion and droughts. In the case of flooding, damage is estimated based on the following parameters: area of inundation, and depth, duration, seasonality, intensity and frequency of flood events. Kramer et al. (1995) calculated that all 654 ha would be lost over a period of 100 years. For year 1, this results in a damage of US $51 700, given an average annual net return of US $453 on 1 ha. The damage in the 'with park' scenario is only US $50 800. Therefore, the NPV of conservation for avoided crop loss is US $900 per year. To determine the economic value of the agricultural sector of the Leuser Ecosystem, three types of crops are considered: (1) rice, (2) vegetables and (3) cash crops.

Deforestation is assumed to result in a reduction of output volumes and an increase in the production costs. As shown in Fig. 5, deforestation has two types of impacts on the volume of agricultural production. On the one hand, converting forest-land to other uses will have a positive effect on the overall agricultural yield. However, steeps slopes in the high lands and soil acidity in peat swamps makes agriculture in these areas unviable in the long term; production will decline after a few years. Also, deforestation will have negative structural effects on off-site agriculture. We therefore assume an annual decline in off-site agricultural output of 2%. In addition, the costs of production are assumed to increase by 0.1% per year.

4.5. Hydro-electricity

Several regencies, such as Aceh Tenggara., have hydro-electricity plants that use water from Leuser. The plants operated in Aceh Tenggara are designed as small-scale economic activities, and may therefore be considered as supplementary to the conservation scenario. It appears that the operational conditions for the hydro-plants have worsened in recent years. Increased erosion of the waterways has forced the operators to remove excessive sediments from their turbines. This has led to frequent interruption of the power supply, higher operational costs and damage to the blades of the turbines. One plant closed down due to lack of water supply. Most of these disturbances are considered abnormal and may therefore be attributed to deforestation.

To determine the value of power generation dependent on the Leuser Ecosystem, the amount of electricity potentially produced through hydropower technologies is estimated at 22%. In the conservation scenario, this share will stay constant over time. In the deforestation scenario, this share is assumed to decline from 22 to 16%. Furthermore, the cost of electricity generation is assumed to increase by 2% per year.

4.6. Tourism

Low-impact eco-tourism can be one of the most important sustainable, non-consumptive uses of Leuser, thereby giving local communities powerful incentives for conservation. Wildlife tourism accounts for approximately 20–40% of international tourism and in 1988 there were between 157 and 236 million international eco-tourists world-wide (Ceballos-Lascuráin, 1996). Fig. 6 depicts the number of visiting tourists in the period 1989–1999, showing the dramatic decline since 1995 in response to the security problems in Aceh. Nevertheless, given the opportunities to view wildlife such as orang-utans, some experts view eco-tourism as a major potential source of revenue for communities living around Leuser (van Schaik, 1999).

To improve our understanding of the motivations and preferences of local and foreign tourists, a survey was conducted in 2000–2001. Special attention was paid to spending patterns and willingness to pay (WTP) for the conservation of the Leuser Ecosystem. Table 2 provides an overview of the results. Interestingly, the differences in spending patterns between local and foreign tourists are much lower than expected. Respondents

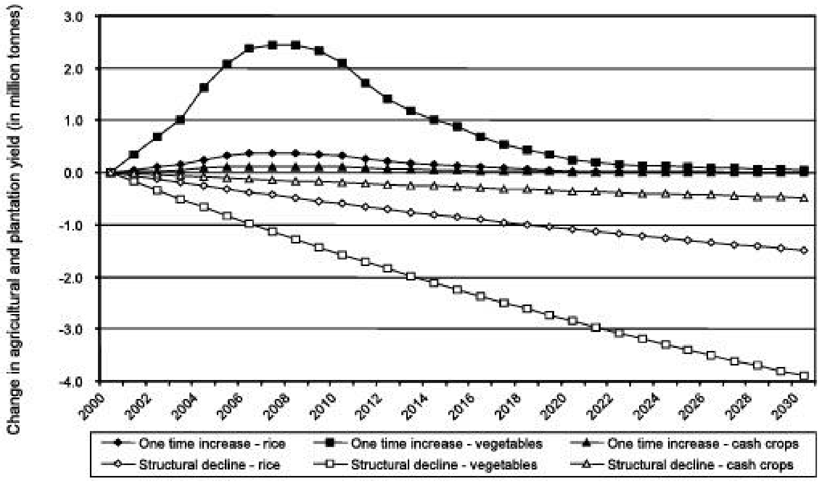

Fig. 5. Assumed change in production due to deforestation.

were also asked about their WTP a 'general' donation for the purpose of biodiversity conservation in Indonesia, regardless of whether they would ever visit a natural park. This value represents the non-use value of biodiversity. Here, a large difference between local and foreign tourists can be observed. The main reason for not providing any donation is not so much a disinterest in nature but more a distrust in the institution that collected the donation.

The number of tourist days is assumed to decline annually by 5% in the deforestation scenario. Furthermore, the spending and WTP for the entrance fee is assumed to decrease by 2% annually due to reduced attractiveness of Leuser. The local tourist sector also fears that orang-utans

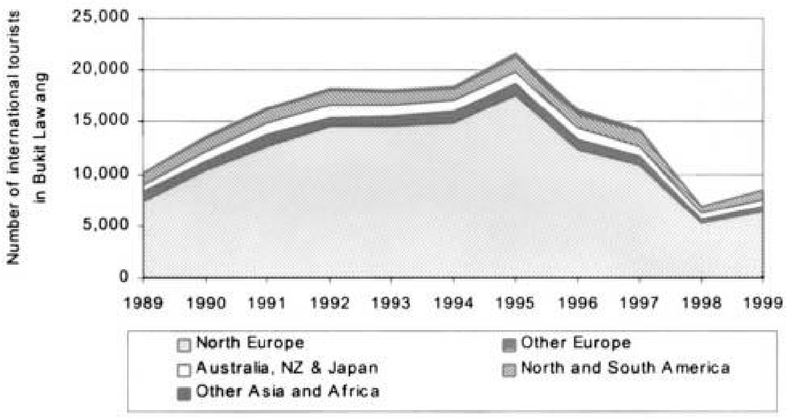

Fig. 6. Number of foreign visitors to the Bukit Lawang entrance to Leuser. Statistics based on visitor numbers provided by the park ranger of Bukit Lawang in 2000.

Table 2
Spending patterns of local and foreign tourists in WTP-survey (in Rp.)

	Local tourists	Foreign tourists
Actual spending	68030	72206
WTP entrance fee	783	3800
WTP donation	4008	51145

Note: 1US$ equals approximately Rp. 10000 in mid 2001.

will become locally extinct. In the conservation scenario, tourist numbers are assumed to increase gradually until a maximum is reached, with the WTP and spending increasing by 2% annually. Note that few tourists travel to Sumatra just to visit Leuser. Therefore, only half of the ticket cost is included in the calculation.

4.7. Biodiversity

People living in areas with a high biodiversity value tend to be relatively poor. Hence, the highest economic values for biodiversity are likely to be found within institutions and people in wealthy countries. Funds can come from several sources, including bio-prospecting, the GEF and grants from international NGOs (with donations possibly being proportional to biodiversity value) (Wind and Legg, 2000). In the Leuser Ecosystem, both research and conservation interests are active. The Leuser Development Programme was initiated in 1996 as a seven year EU-funded programme with annual costs of US $6 million or Rp. 57.7 billion (LDP, 1994). Of the total amount, 22% is spent on European input (consultants, monitoring) and 78% is used on Sumatra-based inputs (labour, equipment, training, etc.). It is assumed that 50% of European inputs benefit the local community given that certain EU funds are conditional. The programme will continue to run on the same financial basis if the Leuser National Park remains in good condition. If deforestation continues it is expected that the EU will gradually pull out.

Similar assumptions hold for the current national and international research and bio-prospecting interests in the Leuser Ecosystem. The valuation of this research benefit is based on actual expenditures within the park. Although such expenditures do not represent economic value per se, they do indicate a minimum WTP to take advantage of the park resources (IIED, 1994). Also, the potential return from commercial drugs derived from plants species is one strong argument for identifying and preserving the world's biodiversity. About 25% of all Western prescription drugs and 75% of developing world drugs are based on plants extracts. To determine the bio-prospecting value, we used several literature sources such as Pearce and Moran (1995) and Simpson and Craft (1996), and Nunes and van den Bergh (2001). The estimates referring to the value of land for medicinal plants vary substantially from location to location. In the case of the Leuser National Park we have assumed an intermediate value of US $1 ha^{-1} of primary forests. The other types of forest are ignored.

4.8. Carbon sequestration

Anthropogenic increases in the concentrations of greenhouse gases (such as CO_2) in the atmosphere are widely believed to lead to climate change. Carbon sequestration by rainforest ecosystems therefore has an economic value, since the carbon fixed in the ecosystem reduces atmospheric concentrations. For example, according to Aylward et al. (1995), following Pearce (1990), conserving 1 ha of tropical forest would be worth $2,000 in avoided damage.

Each type of conversion generates a different amount of carbon release (Brown et al., 1993). Combining the prevailing conversion pattern in Leuser with standard carbon release values gives these releases. Estimates of the marginal damage costs range between US $6.3 and 228 per tonne of carbon. In this study, the most recent estimates from the FUND model are adopted (Tol, 1999). The carbon value in Indonesia is set 50% lower due to the difficult investment climate, leading to a price of Rp. 50000 (US $5) for 1 tonne of carbon.

4.9. Fire prevention

The forest fires that engulfed vast areas in Indonesia in 1997 and 1998 were a true disaster. A prolonged dry season caused by El Nino created conditions for uncontrollable forest fires, often initially started by local people as part of slash-and-burn agriculture. Nearly 10 million ha burned, exposing some 20 million people across Southeast Asia to harmful smoke-borne pollutants. Economic damages due to tourism and transportation losses, destruction of crops and timber, health care costs, and other costs have been estimated at around US $10 billion (Barber and Schweithelm, 2000).

To what extent does primary rainforest have a fire prevention function, and thus an additional value for preventing economic damage? There are various factors that make disturbed forest more prone to fires than primary forests. The likelihood that a forest will burn depends on the level of fire hazard and fire risk: (1) fire hazard is a measure of the amount, type, and dryness of potential fuel in the forest. Logged forest has relatively large amount of dry logging wastes lying around; (2) Fire risk is a measure of the probability that the fuel will ignite. In the presence of abandoned logging roads, which provide easy access to otherwise remote forests, the fire risk is greatly increased when settlers use fire for land clearance.

Two impact categories for fires are identified. These include (1) damage to the local economy, and (2) damage to the international economy (e.g., Singapore and Malaysia). The main question is: would damage from fires change if the forest in the Leuser Ecosystem were degraded? In other words this addresses the avoided damage from an intact forest. To calculate the avoided damage for the local economy, we multiplied the total average local damage of a fire event for a specific regency with the probability that the event will occur. The average damage is assumed to grow proportionally with the local economy for each regency. The probability of a fire occurring in the area due to deforestation is determined by the current probability of fire events in different forms of land use multiplied by an indicator of the current composition of land uses. For example, a fire event in a primary forest is assumed to occur once every 50 years. In contrast, fire events in grasslands are assumed to occur every five years.

4.10. Non-timber forest products

NTFP can provide local communities with cash as long as exploitation does not surpass a threshold level. Here, we assume that harvested NTFP in Leuser does not exceed this threshold, although in reality, this may not be the case. An analysis by Homma (1996) of NTFPs in Brazil suggests that in small markets, extractive activities can survive. However, as markets grow, such as in the Leuser Ecosystem, supply from the extractive sector becomes inadequate, substitutes are developed and the extractive economy can eventually collapse. Moreover, increased market demand may lead to short-term overexploitation and even to local extinction of plants and animals in high demand (Arnold and Pérez, 1998).

Annual values range from US $5 ha^{-1} in the Brazilian Amazon to US $422 ha^{-1} for the Peruvian jungle. Here, we generated the value of NTFP by using local field surveys, as well as expert judgements from LDP staff and local statistics. Three types of products are identified, for which production and prices are given in Table 3. They are categorised according to their value. We assume that in the 'deforestation' scenario, overexploitation of NTFP will occur. As a result, a short-term increase in harvested NTFP will be observed in the first decade after which this sector collapses. This phenomenon can already be seen for rattan, turtles and cobras (van Dijk et al., 1999).

4.11. Timber

The total timber value is derived by applying the market price for a unit of timber to the estimated quantities that could be sustainably harvested from an area of forest (Bann, 1998). In Leuser, this condition of sustainability does not necessarily hold because the purpose of this study is to determine the costs and benefits of unsustainable logging practises, while the conservation scenario assumes a strict ban on logging. Note that the costs of harvesting and transporting timber must be deducted from the market price to establish the net standing timber in the forest. The cost of extraction is assumed to be US $17 m^{-3} (Brown,

Table 3
Overall production and market prices for NTFP in Leuser Ecosystem

NTFP	Production (tonne)	Price in Medan (US$/tonne)
Low value NTFP		
Cotton tree (Randu)	1177	45
Rattan (Rotan)	18064	45
Resin (Damar)	319	60
Rumbia/Nipah/Sagu	2645	75
Gum benzoin (Kemenyan)	37	100
Medium value NTFP		
Palm sugar (Gula Aren)	870	300
Nutmeg (Pala)	8416	700
Aromatic oil (Nilam)	334	800
Candlenut (Kemiri)	27027	1000
Cinnamon (Kayu Manis)	156	1000
High value NTFP		
Honey (Madu)	1	3000
Vanilla	233	5000
Bird nest (Sarang Burung)	2209	10000

Sources: Badan Pusat Statistik (1999), and field study in Leuser Ecosystem.

1999). Market prices should also be corrected for any known market and policy failures. Timber prices in Indonesia are far below international standards due to subsidies, non-tariff barriers and because the market is flooded with illegal timber. Red meranti, for example, is currently sold for US $50 m^{-3}; without distortions it could sell for US $80 (Brown, 1999). The rent for a cubic metre sold at US $80 is roughly US $58. To establish the economic value of timber, an approach comparable to that applied to NTFP was used.

A future increase in wood prices is a real threat for Indonesia. In 1995, the first signs of a national wood shortage were noticed. A study by the World Bank (1995) stressed that the remaining virgin forest in companies' concessions will last no more than 10–15 years. In addition, it is doubtful that the conditions for regenerating forests will allow for adequate supply beyond that period. The pattern of logging in the three scenarios is shown in Fig. 2. We assume that the harvesting efficiency of meranti, hardwood in general and other types of wood from primary forest is 0.5, 5 and 2 m^3 ha^{-1}, respectively. For secondary forest the logging efficiency for these species is much lower, at 0.25, 2.5 and 1 m^3 ha^{-1}, respectively. To determine the value of the harvested timber we assume a round wood/plywood ratio of 2:1 (Monk et al., 1997).

5. Results

The results are presented in several forms: (1) TEV at different levels of discounting; (2) distribution of TEV among different sectors; (3) distribution of TEV among different regencies; and (4) distribution of TEV among different stakeholders.

5.1. Overall total economic value

By aggregating the net benefits over time, the TEV for the individual scenarios can be determined. Fig. 7 shows the annual net benefits for the scenarios over the period 2000–2030. Until 2010, the deforestation and selective use scenario generate higher socio-economic benefits than the conservation scenario. This is the result of two underlying mechanisms: (1) large revenues are generated from increased logging and harvesting of NTFP, and (2) the negative impacts of deforestation are still manageable. After 2010, however, the net annual benefits of conservation outweigh

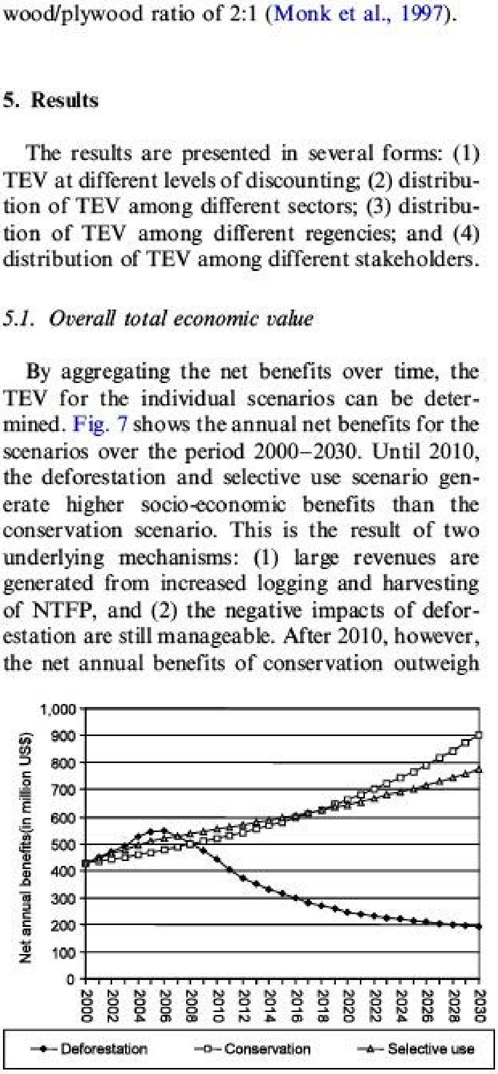

Fig. 7. Net annual benefits over time of Leuser National Park.

the benefits of increased logging. The 'low-hanging-fruits' have been picked and their branches destroyed. The forest that is left is difficult to reach and therefore less attractive to logging industries. Moreover, the negative effects of declining water retention, reduced pest control, increased erosion, and more frequent floods and droughts, now start to take their toll. The net annual benefits of the conservation scenario, on the other hand, increase as the growing economy becomes more efficient in utilising the 'goods and services' of the Leuser Ecosystem. Various sectors, such as the tourist industry, agriculture, and hydro-electricity, gain from the existence of the rainforest. They both expand their activities and generate higher per unit benefits (Fig. 7).

Based on the annual benefits the TEV can be calculated. The choice of the discount rate is crucially important for the calculation of the NPV and hence for the TEV. Fig. 8 shows the TEV for the three scenarios as a function of the discount rate. Discount rates ranging from 0 to 15% have been used. The higher the rate, the more future benefits will be discounted away. Fig. 8 shows the converging TEV of the deforestation, conservation and selective use scenarios with increasing discount rates. This confirms that the former scenario generates high benefits in the short-term while the benefits of the conservation scenario materialise in the long run. Although the curves converge, the NPV of the scenarios only coincide at a 15% discount rate. This implies that within the time frame and the range of discount rates considered, the conservation scenario remains largely superior from a TEV perspective. The results of this study are in line with results from previous research. All values of different land use types lie between US $500 and 7,000 ha^{-1}, depending on type of conversion and discount rate.

5.2. Sectors

The TEV comprises numerous benefits of ecosystem goods and services provided by Leuser Ecosystem. The composition of the accumulated benefits is shown in Table 4. The configuration varies widely between the three scenarios. A trivial difference between the scenarios is the role of timber, which is significant in the deforestation scenario but absent in the conservation scenario. What is also typical is the fact that the average net value for agriculture is higher in the deforestation scenario. This is the result of the short-term encroachment of farmers after the forest has been cleared. Besides timber and agriculture, all

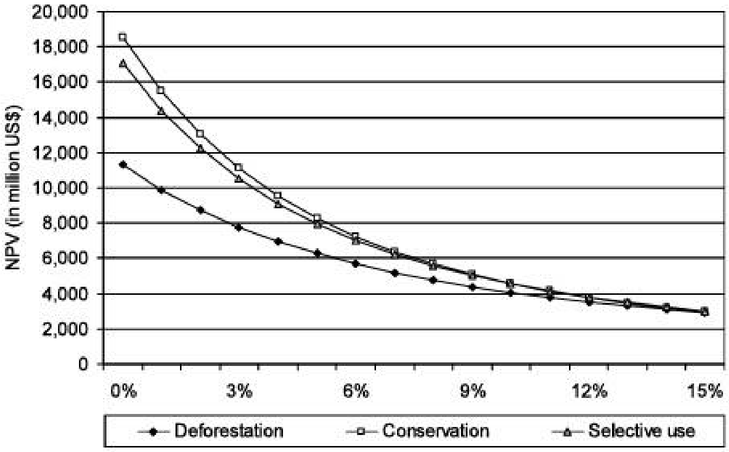

Fig. 8. TEV of Leuser Ecosystem per hectare for different discount rates.

Table 4
Distribution of benefits to the different sectors (in million US$)

	Deforestation		Conservation		Selective use	
	Value	Proportion (%)	Value	Proportion (%)	Value	Proportion (%)
Water supply	699	10	2419	25	2005	22
Fisheries	557	8	659	7	674	7
Flood prevention	1223	18	1591	17	1396	15
Agriculture	2499	36	1642	17	1016	11
Hydro-power	252	4	898	9	696	8
Tourism	171	2	828	9	407	4
Biodiversity	56	1	492	5	92	1
Carbon sequestration	53	1	200	2	125	1
Fire prevention	30	0	715	7	643	7
NTFP	235	3	94	1	1222	13
Timber	1184	17	0	0	825	9
Total	6958	100	9538	100	9100	100

Note: for the period 2000–2030, at a discount rate of 4%.

other benefits are higher in the conservation and selective use scenario. The most important benefits in these latter two scenarios include water supply and flood prevention. In the selective use scenario, NTFP comprise an important share of the TEV.

5.3. Regencies

Table 5 presents the distribution of the TEV across the 12 regencies. The allocation of the benefits depends on geographical characteristics, the size of the economy and the level of dependency on the park. Aceh Utara and Aceh Tengah receive only a small share; Langkat and Deli Sardang generate a high TEV. The regencies in North Sumatra are least affected by the negative impacts of deforestation. All regencies in the province of Aceh, however, remain net losers in the deforestation scenario. Typically, most of the political and military power in the region is concentrated in North Sumatra. This may be considered the driving force of this unbalanced distribution of losses of deforestation.

5.4. Stakeholders

Table 6 shows the distribution of the NPV among the stakeholders for the different scenarios. Several typical features can be observed. The local communities are by far the main beneficiaries of the Leuser Ecosystem. As such, their share will grow in the conservation scenario. As expected, deforestation benefits mainly the logging industry in the short run. In the long run, however, deforestation also harms the wealthier stakeholders to a certain extent. As owners of large plantations and industries, they suffer negative consequences of reduced ecological services from the Leuser Ecosystem. The local and national government may also gain in the short-term by collecting part of the rent from the harvested timber. In the long run, however, infrastructural damages increase while tax income decline. The international community only benefits from conservation of Leuser. Both the biodiversity and sequestration values are important gains for developed countries.

A striking element is that the elite (logging) industry collects a much larger share of the total value in the deforestation scenario (23%). If the Leuser Ecosystem were strictly conserved, their share would only be 11%. This reduction in value for the elite industry in the conservation scenario contrasts with benefits for the local and international community. The power structure of the elite (logging and plantation) industry and the socio-spatial distribution of the local and the international community, however, prevents the conser-

Table 5
Distribution of the NPV of Leuser Ecosystem among the regencies over the period 2000–2030

Regency	TEV Deforestation [a] (million US$)	TEV Conservation [a] (million US$)	TEV Selective use [a] (million US$)
Aceh utara	274	540	498
Aceh tengah	290	319	354
Aceh barat	293	417	422
Aceh selatan	452	559	612
Aceh tenggara	602	552	668
Aceh timur	285	523	474
Aceh singkil	380	351	411
Langkat	1331	1811	1590
Karo	671	778	748
Diari	390	458	460
Deli serdang	1165	898	1082
Medan	829	2334	1781
Total	6961	9538	9101

[a] TEV calculated as NPV for a time period of 30 years and a 4% discount rate.

vation scenario from being realised. For similar reasons, compensation of the latter by the former group is constrained.

5.5. *Sensitivity analysis*

A large number of assumptions have been made in order to generate the results given data, budget and time constraints. These assumptions need not be problematic as long as the results are relatively robust vis-à-vis changes in the assumed parameter values. Several crucial parameters are tested for robustness (van Beukering et al., 2001). These include population growth, the deforestation rate and the value of timber and water. None of these parameters change the results fundamentally. Therefore, the conclusions still hold.

6. Conclusions

Economic valuation has proved to be a strong and useful tool in the analysis of welfare changes for the different scenarios in the Leuser Ecosystem. Several lessons can be learned from the analysis: (1) with a 4% discount rate, the accumulated TEV for the ecosystem over the 30-year period is: US $7.0 billion under the 'deforestation scenario', US $9.5 billion under the 'conservation scenario' and US $9.1 billion under the 'selective utilisation scenario';. (2) Conservation spreads the benefits of Leuser equally among regencies and thus prevents further social conflict, while deforestation widens the regional income gap and thus may be a source of conflict. This may form a strong incentive for the regencies to develop and enforce a common plan; and (3) Finally, conserva-

Table 6
Distribution of NPV among stakeholders (in%)

Scenario	Local community (%)	Local government (%)	Elite industry (%)	National government (%)	International community (%)
Deforestation	45	11	23	7	13
Conservation	56	9	11	5	19
Selective use	53	10	14	5	18

Note: NPV over the period 2000–2030 at a discount rate of 4%.

tion promotes social and economic equity because it mainly supports the underprivileged majority of society. Deforestation widens the gap between rich and poor.

Despite these positive features of conservation, deforestation continues uninterrupted in the Leuser Ecosystem. The main reason for this destruction is the strong political power of the logging and plantation industries as well as the wide dispersion of the main beneficiaries of conservation. This stops the most economically desirable scenario from occurring and prevents the losers of deforestation being compensated by those who gain.

Acknowledgements

The authors would like to thank the staff of the Leuser Development Programme. In particular the support of Kathryn Monk and Mike Griffith is much appreciated. We would also like to thank Jack Ruitenbeek and Joshua Dickinson for providing very useful comments in the review process. Finally, we are grateful to Annabelle Aish for her language advice.

References

Aylward, B., Echeverría, B.J., and Barbier, E.B., 1995. Economic Incentives for Watershed Protection: A Report on an Ongoing Study of Arenal, Costa Rica. CREED Working Paper No.3, IIED, London.

Arnold, J.E.M., Pérez, M.R., 1998. The role of non-timber forest products in conservation and development. In: Wollenberg, E., Ingles, A. (Eds.), Incomes from the Forest: Methods for the Development and Conservation of Forest Products for Local Communities. Centre for International Forestry Research (CIFOR), Bogor.

Badan Pusat Statistik Kabupaten, 1999. Kabupaten dalam Angka 1998. Kutacane: Bappeda dan Badan Pusat Statistik semua Kabupaten. Statistics for all disctricts, Statistical Regional Office, Medan.

Bann, C., 1998. The economic valuation of tropical land use options: a manual for researchers. Economy and Environment Program for Southeast Asia, Singapore.

Barber, C., and Schweithelm, J., 2000. Trail of fire: Forest fires and forest policy in Indonesia's era of crisis and reform. World Resources Institute (WRI), Washington DC.

Bockstael, N., Costanza, R., Strand, I., Boynton, W., Bell, K., and Wainger, L., 1995. Ecological economic modeling and valuation of ecosystems. Ecological Economics, 14 (2), 143–159.

Brown, D.W., 1999. Addicted to Rent. Corporate and Spatial Distribution of Forest Resources in Indonesia; Implications for Forest Sustainability and Government Policy. Indonesia-UK Tropical Forest Management Programme, Jakarta.

Brown, K., Pearce, D., Perrings, C., Swanson, T., 1993. Economics and the Conservation of Global Biological Diversity. Global Environment Facility, Working Paper 2, Washington DC.

BZD, 2000a. Creating awareness of the consequences of environmental degradation. Buffer Zone Division (BZD), Leuser Development Programme, Medan.

BZD, 2000b. Consequences of logging and clearing catchments in the Leuser Ecosystem: a survey of failed irrigation schemes close to the Leuser Ecosystem. Buffer Zone Division (BZD), Leuser Development Programme, Medan.

Ceballos-Lascuráin, H. 1996. Tourism, eco-tourism, and protected areas: the state of nature-based tourism around the world and guidelines for its development. IUCN—The World Conservation Union. Gland.

Constanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387 (15), 255–260.

Dixon, J.A., Sherman, P.B., 1990. Economics of Protected Areas: a New Look at Benefits and Costs. East West Center. Island Press, Washington DC.

Edwards, D.S., 1994. A Tropical Rainforest: the Nature of Biodiversity in Borneo at Belalong, Brunei. The Royal Geographic Society, Sun Tree Publishing, London, Singapore.

Ferraro, P.J., Kramer, R.A., 1997. Tropical forest biodiversity protection: who pays for it and why? In: Kramer, R., van Schaik, C., Johnson, J. (Eds.), Last Stand: Protected Areas and the Defence of Tropical Biodiversity. Oxford University Press, New York.

Homma, A.K.O., 1996. Modernisation and technological dualism in the extractive economy in Amazonia. In: Pérez, M.R., Arnold, J.E.M. (Eds.), Current issues in Non-Timber Forest Products Research. Proceedings of the Workshop 'Research on NTFP', Hot Springs, Zimbabwe, August 28–September 2, 1995. Centre for International Forestry Research (CIFOR), Bogor.

IIED, 1994. Economic valuation of tropical forest land use options: a review of methodology and applications. International Institute for Environment and Development, London.

Jakarta Post, 2000. Relief work goes on amid foul weather, December 1, 2000.

Jakarta Post, 2000. Logging industry supports flood victims, December 6, 2000.

Kramer, R.A., Sharma, H., and Munasinghe, M., 1995. Valuing Tropical Forest: Methodology and Case Study of Madagascar. World Bank Environment Paper 13, Washington DC.

Leuser Development Programe, 1994. Financing memorandum antara Komisi Europa dan Republik Indonesia. Memorandum No. ALA/94/26. Medan.

Mickleburgh, S.P., Hutson, A.M., Racey, P.A., 1992. Old world fruit bats: an action plan for their conservation. IUCN/SSC Chiroptera Specialist Group, Gland, Switzerland.

Monk, K.A., De Fretes, Y., Reksodiharjo-Lilley, G., 1997. The ecology of Nusa Tenggara and Maluku. In: The Ecology of Indonesia Series, vol. V. Periplus Editions, Singapore.

Nunes, P.A.L.D., van den Bergh, J.C.J.M., 2001. Economic valuation of biodiversity: sense or non-sense? Ecological Economics 39, 203–222.

Pearce, D.W., 1990. An economic approach to saving the tropical forest. LEEC Discussion Papers DP 90-06, IIED, London.

Pearce, D.W., Moran, D., 1995. The Economic Value of Biodiversity (In association with the Biodiversity Programme of IUCN). Earthscan Publication Ltd, London.

Pearce, D.W., Ulph, D., 1995. A social discount rate for the United Kingdom. Centre for Social and Economic Research on the Global Environment, University College London, London.

Pet-Soede, C., Cesar, H.S.J., and Pet, J.S., 1999. An economic analysis of blast fishing on Indonesian reefs. Environmental Conservation 26, 83–93.

Redford, K.H., 1996. Not seeing the animals for the trees (Chapter 3). In: J.E.M. Arnold and M.R. Pérez (eds.).

Simpson, R.D., Craft, Am.B., 1996. The social value of using biodiversity in new pharmaceutical product research. Discussion Paper 96–33, Resources for the Future, Washington DC.

Tol, R.S.J., 1999. The Marginal Costs of Greenhouse Gas Emissions. The Energy Journal 20 (1), 61–81.

van Beukering, P.J.H., Cesar, H., Janssen, M.A.,2001. Economic valuation of the leuser ecosystem on Sumatra, Indonesia: a Stakeholder Perspective. Leuser Development Programme (LDP), Medan.

van Dijk, P.P., Stuart, B.L., and Rhodin, A.G.J., 1999. Asian Turtle Trade : Proceedings of a Workshop on Conservation and Trade of Freshwater Turtles and Tortoises in Asia. Phnom Penh, Cambodia, 1–4 December 1999. Chelonian Research Monographs Number 2, pp. 164.

van Schaik, C.P, Monk, K.A., Robertson, J.M.Y., 2001. Dramatic decline in orang-utan numbers in Northern Sumatra. Oryx 35 (1), 1–22.

van Schaik, C.P., 1999. Integrating eco-tourism with conservation in the swamps in Southern Aceh Selatan. Mission Report of Short Term Technical Assistance for the Leuser Development Programme. Medan.

Wind, J., and Legg C., 2000. Spatial distribution of the biodiversity value of the Leuser National Park: a GIS based approach. Technical Report. DHV Consultants, Amersfoort, The Netherlands.

World Bank, 1995. The economics of long term management of Indonesia's natural forests: draft forestry report. The World Bank, Washington DC.

Source: Beukering, P. Cesar, H. Janssen, M. (2003). Economic valuation of the Leuser National Park on Sumatra, Indonesia. Ecological Economics, 2003, 44(1), 43-62.
https://doi.org/10.1016/S0921-8009(02)00224-0

Appendix 4: Discussion paper - Trym Skiebe Alsaker

Responsibility in business

I will here discuss the topic of responsibility as a general concept, but also in relation to my co-written master thesis on the topic of the environmental impact and sustainability in the palm oil Industry in Indonesia and Malaysia. The following discussion will be laid out starting with a brief explanation of the thesis, an introduction to the concept of sustainability, then some relevant theoretical data which combines theory on responsibility with that from the case, the concept in relation to the research questions, and finally a discussion and conclusion based on the presented data.

Our case

The palm oil industry has experienced exponential growth over the last four decades and has brought with it economic freedom and poverty alleviation for millions of people. It is easy to grow in tropical rainforests and provide high yields. It has been a vital part of growing the Indonesian economy and contributes a considerable amount to the country's agricultural GDP. Palm oil in itself is a versatile product which is used in a waste array of different products which spans across categories such as food, biofuel, cosmetics, and cleaning products. But another effect the palm oil industry has had has been environmental destruction and the release of high amounts of greenhouse gases. We have in our master thesis aimed to assess the extent of the environmental impact the cultivation of oil palm and the production of crude palm oil have had. We have also aimed to assess who the drivers of this more or less unchecked destruction are, and who are the ones fighting to stop the further destruction of both the tropical rainforests in Indonesia and the global climate. Our ultimate goal has therefore been to contribute to the conversation around how the Indonesian palm oil industry can move in a more sustainable direction. We do so by exploring the following questions: 1. What are the major negative environmental impacts of the current and expanding palm oil industry in Indonesia? 2: How can economists contribute by taking the environment into account when calculating profitability, and how can the negative environmental impacts be measured? 3. What are the most efficient drivers of sustainable action for the palm oil industry?

Introduction

Responsibility is one of those concepts that can be easy to define but still leaves behind thousands of questions that need to be answered. A simple definition of the word responsibility is the obligation that we as individuals have to the world and the people in it. But what does it mean to be responsible? To whom do we owe what level of obligation? Who decides when that obligation has, or has not, been fulfilled? As the only beings possessing an understanding of the individual self and morals, humans are the only ones who can be expected to bear responsibility. What is considered responsible will differ between different individuals in different situations and is always subject to change as we change. When we extend this concept beyond individuals and apply it to an industry such as the palm oil industry in Indonesia, we also complicate the questions surrounding responsibility further, and we create even more questions than before. Now there are a whole host of various actors that affect others and are in turn affected by them.

The various actors are as discussed in the thesis the industry itself which includes both large multinational companies and poor farmers with hardly enough to survive, anyone who works in the palm oil value chain, the countries where the industry operates, and the entire world as both consumers and people being impacted by the environmental damage caused by the industry. Many people depend on the palm oil industry to various degrees in order to make money and even to survive, while the entire world could depend on the industry indirectly as a considerable contributor to climate change. Should the palm oil industry even feel, if we even consider a corporate structure as being able to feel, responsibility towards those who urgently and directly rely on it to survive, or is the global climate a more serious concern so the industry should act responsible in a way that is in line with this problem? Perhaps the answer is neither, and the sole responsibility of an industry lies in the various organizations that exist within it and their shareholders that expect their investments to be managed in a profit maximizing way.

Views on responsibility - Friedman

Milton Friedman is among those who argue for the latter assumption made above. In his essay, A Friedman doctrine – The social responsibility of business is to increase its profits (1970), Friedman argues that corporations in and of themselves do not carry any responsibility beyond that creating, growing, and sustaining profits, as responsibility is something only humans can have. If a corporation does take responsibility in any shape, way, or form, then that is a consequence of the choices made at the individual level. He also argues that corporations may very well use social responsibility as a cloak to shield themselves from criticism. The problem as he sees it is that the cloak hides the true intentions of the organization's leaders and might cause harm to the movements they pretend to support out of a social responsibility, but the true intention is still to make greater profits. Examples of this can be found in the palm oil industry in several ways.

The first is how most of the certified plantations, meaning they have committed to “no deforestation, no peat, no exploitation”, are older ones that contain little to no native forestry left anyways (Carlson, Heilmayr, Gibbs, Noojipady, Burns, Morton & Kremen, 2018), meaning the certificate neatly fits into Friedman's concept of cloaking. Another example is the criticism that Greenpeace has had for the Roundtable of Sustainable Palm Oil (RSPO), a palm oil certification NGO, which Greenpeace called out on the grounds that certified sustainable palm oil is a con (Young, 2019). This touches upon a rather complex philosophical question about whether it is the outcome or the means that matter, but without trying to answer that in general, I would argue that they do not in the case of the palm oil industry. The reason why is because there is even a debate about whether palm oil can truly be sustainable, and regardless we can see that it has been used to mislead the public in order to achieve higher markups on palm oil. An example from the logging industry showed that FSC certified timber could get as much as 15-25% more at auction when compared to non-certified timber (Conniff, 2018).

Views on responsibility – Carroll

Archie B. Carroll argued in his 1979 paper, A Three-Dimensional Conceptual Model of Corporate Performance, that social responsibility is one of four obligations that businesses have, and even reference Friedman's paper as forceful and the originator of the real debate around corporate responsibility. In Carroll's view it is economic and legal responsibilities that are the absolute requirements for a business to operate in a market, and that the ethical and discretionary (voluntary philanthropic activities that a corporation takes with no direct financial payback) responsibilities can offer anything between no benefit and massive success. By aligning industry or corporate goals with that of social issues such as the environment, one can increase one's own standing among the consumers and receive financial benefits in the form of new and more loyal customers.

Carroll also points out that these four concepts often overlap with each other and that you can achieve success in regard to another responsibility when fulfilling another. His example is that you can achieve economic success by motivating workers, which could mean higher productivity, through ethical and discretionary means. In the palm oil Industry, the most fitting example that could demonstrate what that looks like is the correlation between increased awareness and boycotts of palm oil by consumers (Hutabarat, Slingerland, Rietberg & Dries, 2018; NG, 2020), with the emergence and growing demand for certification schemes in the industry. Since a loss of reputation can be viewed as a cost for a company (Brandi, Cabani, Hosang, Schirmbeck, Westermann & Wiese. 2013), it would be unwise and could come at an economic cost for the palm oil industry, and those who in turn use palm oil in their products and services, to disregard the responsibility that is being forced upon them by the market.

Responsibility applied to the thesis research question

In the thesis we used the triple bottom line definition of sustainability which argues that sustainability is made up of an equilibrium between people, profit, and planet. We also include the definition made by Herman Daly, which paraphrased, says that the use of renewable resources and release of pollutants, should not exceed their renewal limit or the development of new sustainable technologies and the assimilative capacity of the environment (Elkington, J. 1999). With the total economic valuation (TEV) of the Leuser ecosystem in Indonesia (Beukering, Cesar & Janssen, 2003) which we used as a case study in our thesis, we provided data that supports the statement that these three concepts are related and influence each other. The case illustrated the relationship between the environment and economic profits especially well. The most lucrative methods for utilizing the ecosystem were those that took the most care to not cause harm to the environment, and they were both more economically and environmentally sustainable.

This does imply that the most responsible and ethical path would be the more sustainable one. However, the problem is that while the long-term economic benefit is greater by aligning one's own business practices with environmental responsibility, it can be costly in the short run, which could impact various stakeholders, especially poor farmers and workers at oil palm plantations. We can see this type of argument permeate much of the discussion on the global climate and who we should hold responsible for enacting the necessary changes required to curb climate change. As an example, we know that China and India as highly populated countries with rapidly growing economic development are only expected to release more and more greenhouse gases over the coming years. We also know that most of the greenhouse gases that have already been released into the atmosphere have been caused by the western world both during and after being established as a modern developed part of the world (Kroeze, Vlasblom, Gupta, Boudri & Blok, 2004).

As stated this leaves a question about who holds the responsibility of reducing future emissions, since these and most of the world's developing countries depend on technologies that use non-renewable resources. Since it is developing countries that release the most greenhouse gases currently, should they be burdened with the responsibility of reaching the world's climate goals? Or is it the western world which releases less gases but is the originator of the state of the environment today? The ethical problem with trying to place this responsibility on developing countries comes primarily from how these countries can have great numbers of people who live in poverty and literally cannot afford or have the option of more sustainable choices.

When we discuss how economists can contribute by taking the environment into consideration, we uncover that one of the ways they do so is by identifying the most critical sources of impacts and the level of impact. This can be used to create more specific identification for which impact sources we should address. With this in mind it would be easier to say that perhaps the shipping industry, which is one of the greatest single sources of CO_2 emissions (Wan, Zhu, Chen & Sperling, 2016), should be one of the first to be held responsible for its emissions and should be one of the first areas that are targeted.

If we step away from the discussion of whether or not corporate entities can or should carry responsibility and worry about ethical implications, then those that contribute the most to negative impacts on people and nature should be the same that are held responsible first, given that we accept this stance. The palm oil industry in Indonesia is a major driver of deforestation, and other negative environmental impacts that result from it. But here we also find the same ethical challenge as above, some of the most impactful drivers are the large multinational corporations that makes up a considerable portion of industry, but also the often poor smallholders which contribute around 1/3 of the feedstock used in the production of crude palm oil, despite them taking up closer to 40-50% of the land area used for oil palm cultivation, due to poor cultivation and harvesting practices, leading them to destroy more forest to compensate (Jelsma, Woittiez, Ollivier & Dharmawan, 2018).

Conclusion

I think that in the time since Carroll, Friedman, and several others, first started the debate around corporate responsibility, that the world has changed a great deal when it comes to the power and impact that corporations have over people and the environment. I would argue that we all carry responsibility to the world around us and that we should feel somewhat obligated to act ethically towards others and nature. Friedman makes no attempt at denying the responsibility that the individual holds, rather he argues that this is where responsibility lies, but it is individuals that make up corporations, which in my opinion translates to a need for these individuals to find a common stand on responsibility and ethical issues that the organization should actively work towards. NGOs are examples of organizations that are formed out of a common feeling of responsibility and determination to have other organizations adapt the same sense of responsibility.

There is a strong connection between economic profits, which should be the foremost concern for any corporation, and social responsibility, as both Carroll and Elkington point out. As corporations play a larger part in shaping the world and how everything in it interacts, so grow their responsibility.

There is no single answer to all or any of the ethical dilemmas that arises when trying to figure out who is responsible and how to fix problems such as poverty and sustainability. Qualified individuals need to make educated and careful considerations for each individual problem, that use the same profound ideas that make up the triple bottom line theory, namely taking people, profit, and planet into consideration. It is not an especially satisfactory conclusion, but we each need to recognize that we hold at least some responsibility, and when we take this with us when doing business, we can enact change or a much grander scale than that of an individual.

Literature list

Beukering, P. Cesar, H. Janssen, M. (2003). Economic valuation of the Leuser National Park on Sumatra, Indonesia. *Ecological Economics*, 2003, 44(1), 43-62. https://doi.org/10.1016/S0921-8009(02)00224-0

Brandi, C., Cabani, T., Hosang, C., Schirmbeck, S., Westermann, L., & Wiese, H. (2013). *Sustainability certification in the Indonesian palm oil sector: benefits and challenges for smallholders* (No. 74). Studies.

Carlson, K. M., Heilmayr, R., Gibbs, H. K., Noojipady, P., Burns, D. N., Morton, D. C., ... & Kremen, C. (2018). Effect of oil palm sustainability certification on deforestation and fire in Indonesia. *Proceedings of the National Academy of Sciences*, *115*(1), 121-126.

Carroll, A. (1979). A Three-Dimensional Conceptual Model of Corporate Perfermance. *The Acadamy of Management Review*, vol 4, No. 4, 1979, p.497-505. http://www.jstor.org/stable/257850

Elkington, J. (1999). Cannibals with forks: the triple bottom line of 21st century business. Oxford: *Capestone Publishing Ltd*.

Friedman, M. (1970). A Friedman doctrine – The Social Responsibility Of Business Is to Increase Its Profits. *The New York Times*, September 13, 1970, p. 17.

Hutabarat, S., Slingerland, M., Rietberg, P., & Dries, L. (2018). Costs and benefits of certification of independent oil palm smallholders in Indonesia. *International Food and Agribusiness Management Review*, *21*(1030-2018-3328), 681-700.

Jelsma, I., Woittiez, L., Ollivier, J., & Dharmawan, A. (2018). Do wealthy farmers implement better agricultural practices? An assessment of implementation of Good Agricultural Practices among different types of independent oil palm smallholders in Riau, Indonesia. *Agricultural Systems*, volume 170, March 2019, p. 63-76. https://doi.org/10.1016/j.agsy.2018.11.004

Ng, E. (2020). No grand pronouncements here...: Reflections on cancel culture and digital media participation. *Television & New Media*, *21*(6), 621-627.

Young, N. (2019). 5 problems with 'sustainable' palm oil. *Greenpeace*. https://www.greenpeace.org/aotearoa/story/5-problems-with-sustainable-palm-oil/

Appendix 5: Discussion paper - Susanne Caroline Grytten

Introducing our theses
The topic of our thesis is “Towards a Sustainable Palm Oil Industry” and the problem statement we wished to investigate were “Environmental impacts of the palm oil industry, particularly in Indonesia, and how the industry can move towards sustainability”. The research questions more specifically investigate what the major negative environmental impacts of the current and expanding palm oil industry in Indonesia is, how economists can contribute by taking the environment into account when calculating profitability, how the negative environmental impacts can be measured, and lastly what the most efficient drivers of sustainable action for the palm oil industry is.

Palm oil is made from the pulp of fruit that grows on oil palm trees which grows naturally in the rain forests (D'Antone, & Spencer, 2015). The palm oil industry in Indonesia has had rapid development in the last 20 years and is the largest producer of palm oil in the world (Worldbank, 2019: Zahan & Kano, 2018). This has brought on economic growth for the country, generating employment and rural poverty alleviation. With that said, the industry has also brought on detrimental environmental impacts on the natural forests, wildlife, biodiversity and the global climate (Vijay et al., 2016). Deforestation and destruction of peatlands occurs at high rates in order to make room for palm oil plantations, causing numerous other negative environmental impacts. A central issue when identifying how the industry can move towards sustainability is to find how this can be done without significantly compromising Indonesia's economic growth. We presented much descriptive information about sustainability, palm oil and the palm oil industry, environmental impacts such as deforestation, loss of biodiversity and greenhouse gas emission. Further, we dived into awareness of unsustainable palm oil in the industry, from non governmental organizations and consumers, as well as the role of policy and certification schemes. We implemented different cases and environmental impacts assessments to help answer our research questions in a structured and quantifiable manner, providing more holistic and comprehensive information.

The concept “responsible” and ethical questions
This discussion paper addresses the concept “responsible”. In my understanding and interpretation the word responsible means that you are the cause of something and therefore the one to blame or give credit too, or that you are accountable for something. The concept “responsible” is very relevant to our topic and problem statement. Our thesis does essentially seek to clarify the palm oil industry's responsibility and how it is handled. The industry is responsible for various negative environmental impacts, such as loss of rainforests, destruction of peatlands, loss biodiversity, and greenhouse gas emission. However, the industry is also responsible for much of Indonesia's economic growth, which has had a major positive effect for the country. We have discussed how the industry can take responsibility for its negative implications affecting Indonesia and the global climate while still maintaining its responsibility to the country through economic growth.

The industry as a whole, and the individual links in the palm oil supply chain, has a responsibility in regards to transparency to each other and to consumers as well as non-governmental organizations (NGOs). Transparency has been hard to achieve since it is not required to disclose consequences maps. Certification schemes have a responsibility to hold the industry to their standards and NGOs have a responsibility to hold the industry accountable and spread awareness. Consumers and NGOs' awareness of the industry have therefore been essential in our thesis, and will be discussed further below.

I'm now going to discuss ethical or potential ethical challenges related to the topic, research questions, units of analysis or their operating environment, findings and conclusions. When discussing responsibility, sustainability and ethical challenges, the concept of social responsibility seems relevant. Social responsibility has a long history and is closely tied to ethics (Carroll, 1999). Milton Friedman's opinion is that "*the social responsibility of Business is to Increase its profits*" (Friedman, 2007, p. 1). This is the corporate social responsibility the industry implements as of now. The problem here is that this viewpoint does not take into account ethical issues outside of increasing profits. Indonesia is a country where both profits and sustainability are important. If the industry in Indonesia keeps operating in an unsustainable way, they could risk decreased profits in the future, since there are limited resources. Archie Carroll on the other hand states that social responsibility consists of four layers, including economic, legal, ethical and philanthropic (Carroll, 1999). Carroll's approach is more holistic and all four of the dimensions are factors discussed in our thesis. If the industry integrated corporate social responsibility, following Carroll's pyramid, into the supply chain it would help manage responsibility and ethical questions.

Sustainability and sustainable development are a central theme in our thesis. Our research topic addresses Indonesia's road towards a sustainable palm oil industry, and looks at ethical challenges brought on by the industry. We evaluate if the industry is performing in an ethical manner. Sustainable development can be defined as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (World Commission on Environment and Development, 1987). This is extremely relevant to the ethical challenge in which the palm oil industry faces, where the country experiences economic growth now, but it can't continue in perpetuity with these unsustainable practices, since the plantations leave behind useless soil. Additionally, deforestation and peatland reduce biodiversity, which disturbs the ecosystem and stops it from operating normally (Moron, Sheppard & Lonsdale, 2014).

We have concluded that the industry causes major negative environmental impacts, damaging for the wildlife, society, and the global climate. We can therefore say that the industry does not perform in an ethical manner. On the other hand, our unit of analysis takes place in Indonesia which is a country embossed with poverty and is dependent on the palm oil industry in order to improve its conditions, grow economically and evolve socially (Kasryno, 2015). Ethical challenges emerge when discussing if the industry needs to change and potentially slow down, since this could have a damaging effect on the country's growth and society. The hard question left to answer is how the industry can change with a more practical approach, maintaining concern for the industry's vital role in improving conditions.

The Indonesian government has a huge responsibility and significant power, but they do not use it as well as they should. This is mainly due to corruption, decentralized power and poor implementation of certain measures. The government has in fact played a significant role in the palm oil industry growth instead of slowing it down or modifying it (Choiruzzad et al. 2021). Certification schemes such as the "Roundtable on Sustainable Palm Oil Certification" and policies such as "No Deforestation, No peatland Development, and No Exploration" are supposed to manage ethical challenges and hold their members accountable, but this is not always the case, as we have discussed in the thesis. Furthermore, consumers have substantial power and play a significant role in pushing the industry towards sustainability and therefore have a huge responsibility. Consumers have in the past pushed many companies such as Nestle and Wilmar to take sustainable action. They have for instance done this by initiating boycotts and trends on the internet. Famous bloggers and social media influencers have also spread negative information about palm oil as an ingredient, giving it a bad reputation. This has led companies such as Nidar to market their products as "Palm oil free" by writing it on their packaging with large fonts. This illustrates the power consumer awareness holds over companies. Consumer awareness is therefore an important solution or tool to manage some of these ethical issues by putting pressure on the industry.

With that said, boycotting palm oil might not be the most practical or best solution for anyone. Oil palm grows naturally in the rain forests, however, the industry destroys and burns the natural rain forests down and plants large fields with oil palm trees, making it unnatural and unsustainable. Regardless, palm oil is in itself eco-friendly and sustainable, and is in fact a highly productive crop compared to other oilseed crops (D'Antone, & Spencer, 2015). Boycotting palm oil and replacing it with other oilseed crops, which will likely be produced with the same unsustainable practices, will not solve the sustainable issue and could potentially make it worse. Palm oil production is one of the most profitable uses of land in tropical regions, and replacing palm oil production with other oil production would be damaging to Indonesia's economy. 17% of Indonesia's agricultural gross domestic product in 2014 came from the palm oil industry, illustrating how the industry also works as a positive force, generating employment and higher living standards (Purnomo et al., 2020). It is therefore clear that palm oil production should be modified, but not stopped. The issues regarding responsibility and ethics occur when actors in the supply chain do not consider their social responsibility or the needs of future generations.

Our research question number two is "How can economists contribute by taking the environment into account when calculating profitability, and how can the negative environmental impacts be measured?". This research question talks about combining ethical issues with economic calculations, and evaluates if economists take ethical issues into account. Economists play an important role in moving the palm oil industry towards sustainability, and their responsibility is therefore important. The industry's goal is to be profitable, not sustainable, economists therefore hold much power.

We also take part in this responsibility by researching and writing about the matter. When writing the thesis, we also have a responsibility to not be confirmation biased and to portray the industry accurately, and not exaggerate the negative aspects of the industry or understate the positive aspects. It is important to paint a real picture of the situation, for Indonesia's and the industries sake. To manage this issue, we have investigated and compared many different sources from different publishers to achieve triangulation. Furthermore, we carried out a case study where we took a deep dive into three different elements in the industry: the production and disposal of empty fruit bunches, the triple bottom line, and economic evaluation of parts of the rainforests in Indonesia. This gave us an understanding and insight into the realities of the situation.

Our findings bring light to and identify which negative environmental impacts are most detrimental. We therefore know, based on our research and empirical studies, that reducing deforestation and destruction of peatlands is of great importance. By identifying ethical questions and problems of the industry, we have been able to investigate different solutions and drivers for sustainable action such as pressure from NGOs and consumers, policy and certification schemes, and different treatment options for recycling of empty fruit bunches such as composting.

The industry is portrayed in a very negative way. There is much data out there displaying the negative environmental impacts. However, there is a lack of information and research of environmental impact assessments and sustainable solutions. There is also a lack of data investigating the positive impacts, and how to become sustainable without compromising growth, revealing a need for more research, which might help manage and answer ethical questions.

Summary and conclusion

The industry is responsible for much environmental damage, but it is also responsible for much of Indonesia's economic growth. It is therefore important that the industry move towards sustainable solutions that meet the needs of the present without compromising future generations' needs. The government, NGO's and consumers have a responsibility to hold the industry accountable and are important drivers for sustainable change. Certification schemes should be considered in the discussion of becoming sustainable, although it is not bulletproof. We as writers have a responsibility to conduct an ethical research process that evaluates all aspects of the matter without being confirmation biased. We contribute to the responsibility of spreading awareness by researching and analyzing information in an ethical manner, and sharing our findings to a field where there is a lack of research. Actors in the industry as well as spectators taking and upholding the responsibilities mentioned in the discussion is also what will help guide the industry and manage ethical questions.

References:

Carroll, A. B. (1999). Corporate social responsibility: Evolution of a definitional construct. *Business & society*, *38*(3), 268-295.

Choiruzzad, S. Tyson, A. Varkkey, H. (2021) *The ambiguities of Indonesian Sustainable Palm Oil certification: internal incoherence, governance rescaling and state transformation*. Asia Eur J (2021). https://doi.org/10.1007/s10308-020-00593-0

D'Antone, S., & Spencer, R. (2015). Organising for sustainable palm oil consumption: A market-based approach. *Consumption Markets & Culture*, *18*(1), 55-71.

Friedman, M. (2007). The social responsibility of business is to increase its profits. In *Corporate ethics and corporate governance* (pp. 173-178). Springer, Berlin, Heidelberg.

Kasryno, F. (2015). Consulting Study 15: The economic impacts of palm oil in Indonesia.

Moron, S. Sheppard, A. Lonsdale, M. (2014) *Biodiversity*. Collingwood VIC 3066 Australia: CSIRO Publishing. https://www.publish.csiro.au/ebook/download/pdf/6967

Purnomo, H. Okarda, B. Dermawan, A. Ilham, Q. Pacheco, P. Nurfatriani, F. Suhendang, E., (2020). *Reconciling oil palm economic development and environmental conservation in Indonesia: A value chain dynamic approach*, Forest Policy and Economics, Volume 111, 2020, 102089, ISSN 1389-9341. https://doi.org/10.1016/j.forpol.2020.102089

The Carbon Stock, 1-31.
https://www.simedarbyplantation.com/sites/default/files/sustainability/high-carbon-stock/consulting-reports/socio-economic/hcs-consulting-report-15-the-economic-impacts-of-palm-oil-in-indonesia.pdf

Vijay, V., Pimm, S. L., Jenkins, C. N., & Smith, S. J. (2016). The impacts of oil palm on recent deforestation and biodiversity loss. *PloS one*, *11*(7), e0159668.

World Commission on Environment and Development. (1987). Our common future. Oxford; New York: Oxford University Press.

Worldbank. (2019). GDP (current US$) – Indonesia.
https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=ID

Zahan, K. A., & Kano, M. (2018). Biodiesel production from palm oil, its by-products, and mill effluent: a review. *Energies*, *11*(8), 2132.