UNIVERSITI PUTRA MALAYSIA

FORMULATION OF LIFE CYCLE SUSTAINABLE ASSESSMENT OF PALM OIL PRODUCTION IN JOHOR, MALAYSIA

NAJAT O. M. NASEB

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By

NAJAT O. M. NASEB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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August 2020

Chairman : Amir Hamzah Sharaai, PhD
Faculty : Forestry and Environment

Palm oil is one of the most important vegetable oils in the world and each year a million tonnes of palm oil has been traded globally to be consumed by millions of people around the world. The palm oil industry has evolved dramatically and hence produced varieties of products such as crude palm oil, palm kernel oil, palm kernel cake, oleo-chemical as well as new bio-fuel products to fulfil the demand. However, the rapid development of this industry in developing countries has become a subject of increasing international and national concern. Although the Malaysian palm oil is the most important agricultural commodity in this country and contributes substantially to the economy, the Malaysian palm oil industry has faced some negative reports that may affect the industry's future sustainability. This study aims to provide a comprehensive assessment on the impact of palm oil production on the basis of the three sustainability dimensions in order to assist in decision making for sustainable production. Therefore, this study developed a life cycle sustainability assessment (LCSA) methodology, which combined three life-cycle based methods, namely, life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA) using the scoring system method. Firstly, the three life-cycle-based methods were carried out to measure the impact on the product life cycle for a functional unit (FU) of 1 MT crude palm oil produced. Environmental impacts were assessed using the International Organization for Standardization (ISO) standardized LCA. Economic impacts were evaluated using life cycle costing. Social impacts were determined using a social life cycle assessment methodology. Two stakeholder categories were identified, including workers and the local community. Second, the three life-cycle based methods were integrated within the LCSA method using the scoring system method. Finally, a presentation technique was developed to visualize the LCSA results. The applicability and validity of this method were demonstrated using a case study. The case study evaluated the sustainability of crude palm oil at two selected based plantation mills in Johor. The proposed method facilitated the evaluation and interpretation of the results of the three dimensions and this provided a comprehensive

assessment of crude palm oil production. The results obtained show that crude palm oil production require more improvement to be a sustainable product. However, this study attempted to achieve better communication and comprehension of LCSA results by developing a presentation technique to visualize the results obtained from the three methods. The findings of this study made it feasible for the decision-makers to understand the significant hotspots related to various environmental economic and social impacts in order to promote the sustainability of crude palm oil production.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

FORMALASI BAGI KITAR HAYAT KEMAMPANAN PENGELURAN MINYAK KELAPA SAWIT DI JOHOR, MALAYSIA

Oleh

NAJAT O. M. NASEB

Ogos 2020

Pengerusi : Amir Hamzah Sharaai, PhD
Fakulti : Perhutanan dan Alam Sekitar

Minyak sawit adalah salah satu minyak sayuran terpenting di dunia dan setiap tahun sejuta tan minyak sawit telah diperdagangkan untuk kegunaan berjuta-juta orang di seluruh dunia. Industri kelapa sawit telah berkembang secara dramatik dan oleh itu telah menghasilkan pelbagai jenis produk seperti minyak sawit mentah, minyak inti sawit, sawit biji kernel, oleo-kimia serta produk bio-bahan bakar baru untuk memenuhi permintaan. Walau bagaimanapun, perkembangan pesat industri ini di negara-negara membangun telah menjadi satu subjek yang membimbangkan di peringkat antarabangsa dan nasional. Walaupun minyak sawit Malaysia adalah komoditi pertanian terpenting di negara ini dan memberi sumbangan besar kepada ekonomi, namun industri sawit Malaysia telah menerima beberapa laporan negatif yang mungkin akan mempengaruhi kelestarian industri di masa hadapan. Kajian ini bertujuan memberi penilaian secara komprehensif mengenai kesan pengeluaran minyak sawit berdasarkan tiga dimensi kemampanan untuk membantu dalam membuat keputusan untuk pengeluaran minyak sawit yang mampan. Oleh itu, kajian ini mengembangkan metodologi penilaian kitar hayat kemampanan (LCSA) yang menggabungkan tiga kaedah berdasarkan kitaran hayat iaitu penilaian kitaran hayat (LCA), kos kitaran hayat (LCC) dan penilaian kitaran hayat sosial (S-LCA) dengan menggunakan kaedah sistem penskoran. Pertama, tiga kaedah berasaskan kitaran hayat dilakukan untuk mengukur standard dan kesan terhadap kitar hayat produk berdasarkan unit berfungsi (FU) minyak sawit mentah 1 MT yang dihasilkan. Kesan persekitaran dinilai dengan menggunakan Organisasi Antarabangsa untuk Standardisasi (ISO) iaitu standardisasi LCA. Kesan ekonomi dinilai menggunakan kos kitaran hayat. Impak sosial ditentukan dengan menggunakan metodologi penilaian kitaran hayat sosial. Dua kategori pihak berkepentingan telah dikenal pasti iaitu pekerja dan masyarakat setempat. Kedua, ketiga-tiga kaedah berasaskan kitaran hayat disepadukan dalam kaedah LCSA menggunakan kaedah sistem penskoran. Akhir sekali, teknik pembentangan dibangunkan untuk menggambarkan hasil LCSA. Kebolehlaksanaan dan kesahan kaedah ini boleh ditunjukkan dengan menggunakan

kajian kes. Kajian kes tersebut telah menilai kemampanan minyak sawit mentah di dua buah kilang perladangan berpusat di Johor Bahru. Kaedah yang dicadangkan memudahkan penilaian dan pentafsiran bagi hasil ketiga-tiga dimensi tersebut serta memberikan penilaian komprehensif mengenai pengeluaran minyak mentah sawit. Berdasarkan hasil yang diperoleh, pengeluaran minyak sawit mentah memerlukan sedikit penambahbaikan untukmenjadikan produk tersebut lebih mampan. Walau bagaimanapun, kajian ini cuba meningkatkan komunikasi dan pemahaman yang lebih baik hasil LCSA dengan mengembangkan teknik persembahan untuk menggambarkan hasil yang diperoleh dari ketiga-tiga kaedah tersebut. Hasil kajian ini membolehkan para pembuat keputusan untuk memahami titik-titik penting berkaitan dengan pelbagai kesan persekitaran ekonomi dan sosial untuk menggalakkan kemampanan pengeluaran minyak sawit mentah.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Amir Hamzah Sharaai, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Ahmad Hariza bin Hashim, PhD
Professor
Faculty of Human Ecology
Universiti Putra Malaysia
(Member)

Mansor Ismail, PhD
Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
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Name and Matric No: Najat O. M. Naseb, GS43970

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Signature: _____
Name of Chairman of Supervisory Committee: Dr. Amir Hamzah Sharaai

Signature: _____
Name of Member of Supervisory Committee: Professor Dr. Ahmad Hariza bin Hashim

Signature: _____
Name of Member of Supervisory Committee: Professor Dr. Mansor Ismail

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
CPKO	Crude palm kernel oil
CPO	Crude Palm Oil
EFB	Empty Fruit Bunches
E-LCA	Environmental Life Cycle Assessment
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FFB	Fresh Fruit Bunch
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FELDA	Federal Land Development Authority
FU	Function Unit
GHGs	Greenhouse gases
GDP	Gross Domestic Product
I-CVI	content validity index)
ILCSA	Integrated Life Cycle Sustainability Assessment
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
LCSD	Life Cycle Sustainability Dashboard
MAVT	Multi-Attribute Value Theory

MCDA	Multi Criteria Decision Analysis
MPOB	Malaysian Palm Oil Board
MPOC	Malaysian Palm Oil Council
MRIO	Hybrid Multi-Regional Input-Output
MT	Metric Tonne
NGO	Non-Governmental Organization
NPV	Net Present Values
PBP	payback period
POME	Palm Oil Mill Effluent
RISDA	Rubber Industry Smallholders Development Authority
RSPO	Roundtable on Sustainable Palm Oil
SAM	Subcategory Assessment Method
SETAC	Society of Environment Toxicology and Chemistry
S-LCA	Social Life Cycle Assessment
SWOT	Strengths, Weaknesses, Opportunities, Threat
UNEP	United Nations Environment Programme
US	United States
%	percent

CHAPTER 1

INTRODUCTION

1.1 Overview of Palm Oil industry

Some countries such as Malaysia, Indonesia and Thailand have been considered the world's largest CPO producers in Southeast Asia (Andarani et al., 2018). According to MPOB (2020), Malaysia's total oil palm plantation area accounted for 5.90 million hectares in 2019 and 452 mills of palm oil operated in this field as shown in **Table 1.1**. In terms of economic benefits to the producer countries such as Malaysia, this industry is an essential agricultural industry. Malaysian palm oil is the country's most valuable agricultural commodity and it contributes significantly to the economy. After Indonesia, Malaysia is the world's second-largest palm oil producer and exporter. Approximately 15.4 million metric tonnes of palm oil and palm-based products were exported in 2018. These exports were estimated to be about 67.52 billion-ringgit Malaysia. The palm oil industry has contributed approximately 37.6 billion ringgit to the overall gross domestic product (GDP) of Malaysia (USDA, 2020) in all. The growth of the oil palm industry has made the Malaysian oil palm industry one of the major contributors to the Gross Domestic Product (GDP) of Malaysia, foreign exchange earnings, and job creation opportunities.

On average, the industry contributes 5% to 7% of the country's GDP, with export revenues averaging RM 64.24 billion annually over the last five years (MPOB, 2019) (Nambiappan et al, 2018). They shape the backbone of rural growth in Malaysia by improving the living standards and expanding the economy. The gross domestic product of palm oil was estimated at about 38 billion Malaysian ringgit in 2018. Palm oil was reported to have contributed about 38 percent of the GDP in the agricultural sector and 2.8 percent to Malaysia's overall GDP in that year (USDA, 2020).

Table 1.1 : Malaysian oil palm planted area and number of palm oil mills, 2019

	Planted area (million hectares)	Number of mills
Peninsular Malaysia	2.77	241
Sabah	1.54	130
Sarawak	1.59	81
Malaysia	5.90	452

[Source: MPOB (2020)]

The rapid growth of the global population led to an increase in food demand include the main 17 vegetable oils and fats to be used for food processing and cooking. In the past decade, oils and fats exports around the world have expanded at a higher rate than consumption and output. This clarifies the world development of demand and supply of 13 vegetable oils and of 4 animal fats. The Palm oil was the biggest product through all oils and fats which approximately 77% of its yearly output was exported in 2015,

compared with 26% in that of soybean oil, 50% in the case of sunflower seed oil, and 16% in that of rapeseed oil. As the biggest amount of palm oil production around the world concentrated in only some countries (Indonesia and Malaysia considered 85% of the total in 2015) (Mielke, 2018). However, Palm oil considering as the most significant vegetable oil in the global market. It has experienced the most growth in production and consumed compared to the other vegetable oil **(Figure 1.1)** comprising around one-third of the world 's intake of oils and fats (USDA, 2017).

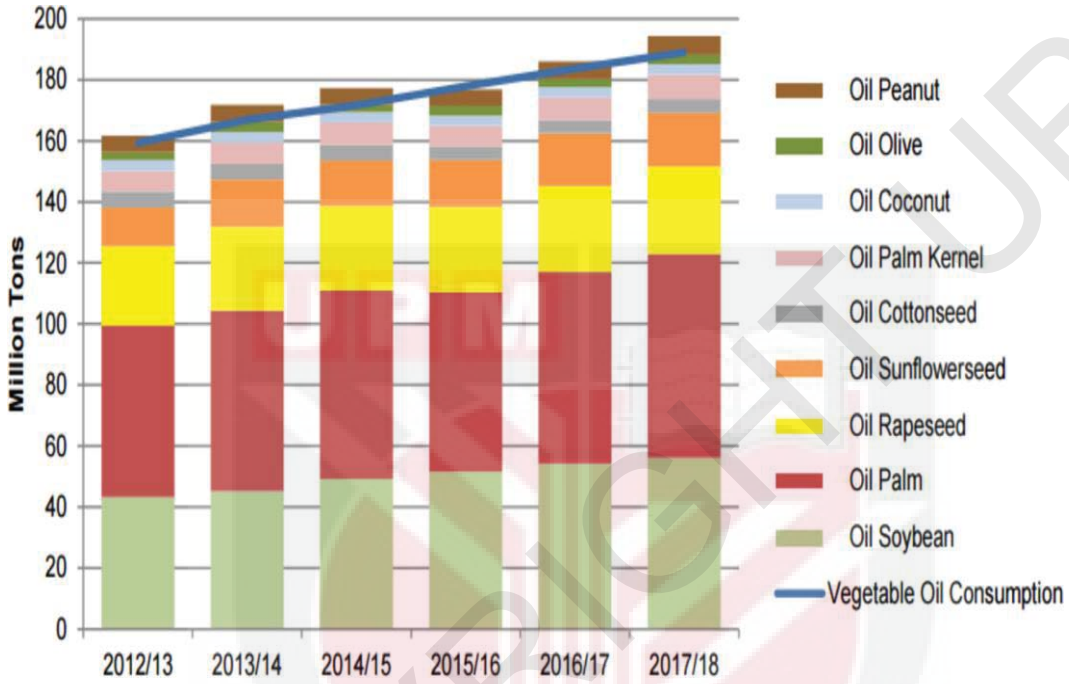

Figure 1.1 : Global vegetable oil production and consumption
(Source: USDA, 2017)

With the rapidly rising of global supplies, palm oil has obtained growing acceptance from industry. Palm oil now being consumed and imported in more than 150 countries around the world. In order to meet the requirements, the palm oil industry has expanded significantly, manufacturing varieties of products such as crude palm oil, palm kernel oil, palm kernel cake, oleo-chemical and new bio-fuel products. In 2018, 23.93 million tonnes of total exports of palm oil products, including palm oil, palm kernel oil, palm kernel cake, oleo chemicals and finished products, were assessed (Kushairi & Nambiappan, 2018). However, the need for a more sustainable production across many agricultural commodity supply chains, including palm oil, has increased the global demand in the past several years.

1.2 Palm Oil Industry Supply Chain

There has been a growing consciousness in recent years of the need for a more sustainable production across many agricultural commodity supply chains which includes palm oil. The palm oil industry is one of the highly integrated sectors of the agriculture system which consist of the upstream and downstream sectors that effectively complement each other to become a more developed and diversified sector. However, the growth of this industry is still heavily biased towards upstream activities and the downstream is still to be thoroughly explored (Mahat, 2012). The rapid growth of oil palm cultivation in Malaysia from its modest beginnings in 1960 increased from 3000ha to 5.8 million hectares in 2017 **(Figure 1.2)** which have led to unprecedented socio-economic developments in the country (Kushairi, 2017). Palm oil is the most consumed oil in the world with the global consumption rising from 14.6 million tonnes in 1995 to 70.5 million tonnes in 2018 (Oil world, 2019). The palm oil supply chain generally can be divided into four broad categories: upstream production, midstream activities (trade and transport), downstream processing and consumer production (Sime Darby, 2009). The Malaysia's palm oil industry has six segments of players across the entire supply chain which include plantations, millings, crushings, refineries, oleochemicals and market distributions. According to Omain et al. (2010), these players are related from upstream to downstream.

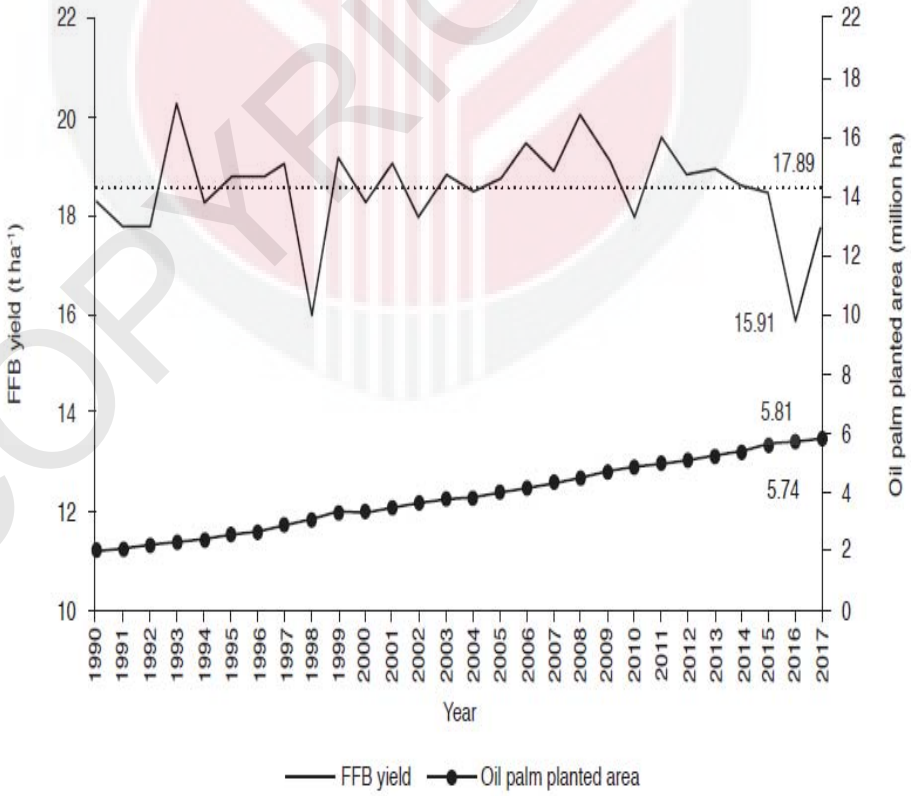

Figure 1.2 : Palm oil planted area from 1990-2017 (Kushairi et al, 2018)

The upstream section is made up of farmers and millers. The cultivation of palm oil which includes nursery planting, palm oil planting and the production of fresh fruit bundles (FFB) involves the upstream sector. The upstream sector is made up of a variety of groups of producers who have important role to play in ensuring the continued supply of this important vegetable oil to the world. The palm oil sector has a peculiar mix of ownership and is primarily divided into two large, privately-held and smallholder entities. Smallholders in the palm oil supply chain fall generally into two main groups (as recognised by the RSPO) depending on the level of external support they receive such as the independent smallholders who tend to be self-organised, self-managed and self-funded, and have more control in choosing how to use their land, what crops to grow, and how to manage it. They are not contractually bound by any specific factory or organisation. However, they can obtain funding or extension services from the government agencies (RSPO, 2009).

Consolidated smallholders, on the other hand, are defined as farmers who are contractually bound by a loan agreement and some planning that is supervised by either government schemes or mills in planting and management techniques. Supported smallholders are smallholders who are structurally bound by a contract or a loan arrangement to a specific mill. They also have minimal autonomy to choose which crop they grow and are coordinated and supervised by planting and crop management techniques and managed by the mill, estate or scheme to which they are connected (RSPO, 2009). It is noted that supported smallholders may receive assistance in the form of seedlings, fertilisers, pesticides and access to technical assistance or credit (Teoh, 2010). Based on **Figure 1.3**, out of 5.81 million hectares of oil palm plantations, 61 percent belongs to private holdings, 17 percent to independent smallholders and the remainder to state schemes or government agencies such as the Federal Land Development Authority (FELDA), the Federal Land Consolidation and Reconstruction Authority (FELCRA) and the Rubber Industry Smallholders Development Authority (RISDA).

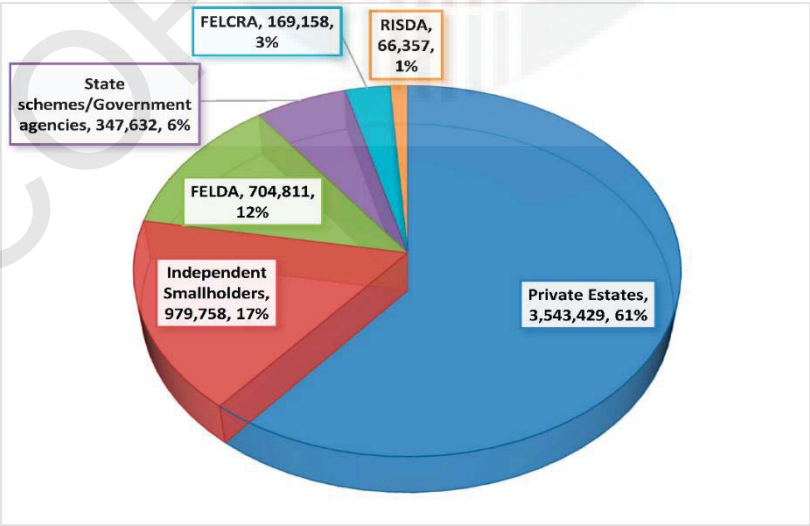

Figure 1.3 : Oil palm planted area by category (MPOB, 2018)

However, the main commodity in the plantation of palm oil is the fresh fruit package (FFB). A hectare of palm oil generates approximately 10-35 tonnes of fresh fruit bundles (FFB) annually (Singh et al, 2010). According to Mahat, (2012), the lifespan of the oil palm is up to 200 years, but the economic life is approximately 22 to 25 years. The first time the oil palms are harvested is at about three years old, and the harvest period is between 25 and 30 years with an average of 27 years. The harvesting method involves the cutting of ripe bunches by chisel or sickle manually every ten to fifteen days. The two fronds under the fruit bundle are pruned and stacked in tidy piles between the palms as a mulch usually. A compact bundle called a fresh fruit bundle (FFB) of oil palm are created during this harvesting method. The harvested FFB are then taken to the roadside where 5-to and 10-t trucks will collect them to be transported to the mills. After 25 to 30 years, the oil palms are replanted when the yields become poor and the harvesting of tall palms become difficult. According to Zulkifli et al. (2010), palms are cut and chipped and the chips are used in planting of replants as a nutrient source.

It is crucial that, after harvesting, the fruit is immediately taken to the milling process, where the mills are received by the FFB hoppers, and moved to the sterilisation process using steam in the sterilisation cages. The individual fruits are extracted from the stalks or bunch in order to inactivate enzymes and microorganisms which is done through the sterilisation process. The FFB is sent to the stripper where the fruit is removed from the stalk or bunch after the sterilisation process which is now called the empty fruit bundles (EFB). Then the FFB goes through a mechanical stirring process where it is sent to the digester to be transformed into a homogeneous oily mash to extract most of the crude palm oil (CPO). According to Subramaniam et al., (2010) the CPO produced at this point is a mixture of oil, water and fruit solids. According to Subramaniam et al. (2010), at this point in time, the CPO formed at this stage is of a mixture of oil, water and fruit solids. These elements are screened on a vibrating screen to remove as many solids as possible and then moved to a dryer to remove moisture. Finally, the CPO is pumped into storage tanks to be delivered to the refineries for exporting or refining.

According to Lau et al. (2011), the milling process particularly can be broadened to make many products such as Crude Palm Oil (CPO), Kernel, Empty Bunch, Shell and Fiber. A variety of solid waste such as the EFB, pressed mesocarp fiber, shells and boiler ash along with palm oil mill effluent (POME) as liquid waste are produced through the milling process. Emissions also emerge as gaseous emissions from the boiler stack and bio gas from the effluent treatment ponds, **Figure 1.4** shows the flow chart of the milling process.

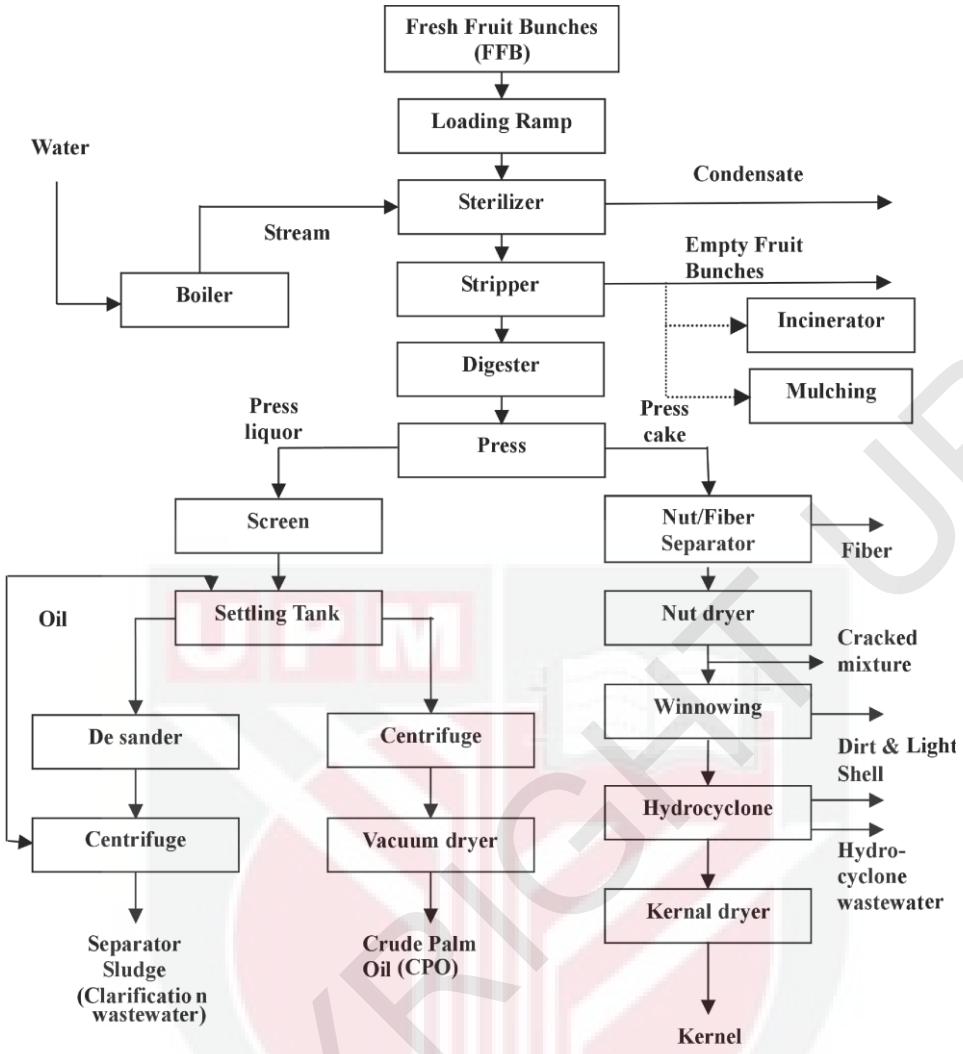

Figure 1.4 : Flow chart of palm oil mill process (Subramaniam et al., 2010)

Sustainability concerns related to palm oil production nevertheless have recently gained increased attention. This issue, where the palm oil industry is export-oriented and is heavily dependent on the global market, has become a critical issue in Malaysia. According to Din, (2016) and Martrade, (2017), 8.22% of their overall export sales (RM64.59 billion out of RM785.93 billion) in 2016 were contributed by palm oil products alone. As the world's second largest producer of palm oil, there is a need for Malaysia to establish sustainable palm oil production strategies not only to stay competitive on the global market, but also to compete with other oil products such as soya bean oil and sunflower oil in the European, Indian and Chinese markets as stated by Din (2016).

1.3 Palm Oil Industry and its Sustainability

The Interestingly, the crude palm oil industry has evolved, producing a variety of products like biofuels, food, cosmetics as well as other goods. It is important to realise that the crude palm oil industry has played a major role in economic growth. As stated by the Department of Statistics, (2018), the gross crop production in 2015 was recorded at RM 50,763.3 million, of which RM 47,162.6 million came from the oil palm industry. The price of palm oil was at RM 2378 per metric tonne according to MPOC, (2018) as of May 2018. As compared to 0.40 t / ha / year for soybean, 0.55 t/ha/year for sunflower and 0.72 t/ha/year for rapeseed, oil palm is also a highly productive crop with an average oil yield of 3.72 t/ha/year. This means that the average oil yield of palm oil is almost 10 times higher than that of soybean and more than 5 times higher than that of rapeseed, rendering palm oil as a highly economically viable commercial crop (Shimizu & Desrochers, 2012). Various social, economic and environmental impacts of the palm oil industry have developed despite its important role **(Table 1.2)**. There has been a rapid increase in global demand for palm oil in the last decade which has led to a greater use of land for palm oil cultivation in the producer countries. The growth of palm oil plantation in tropical countries has clearly brought about the environmental degradation. This growth has driven major problems such as the displacement of rural populations, deforestation, soil degradation and the loss of biodiversity.

Palm plantations are being developed by the cutting down of forests and the clearing of new land via forest fires to save the cost of clearing land (Laurance et al., 2010). These measures will result in the extinction of orangutan, restrict the range of biodiversity, damage land quality, habitat, and may even cause the extinction of flora and fauna (Nilsson, 2013). In addition, biodiversity and carbon sinks in forests are also lost and their functions are compromised due to the development of oil palms, with significant risks of destruction that is beyond repair (Tincliffe & Webber, 2012). However, the environmental impacts of palm oil production, however, are not only due to the plantation, but come also from the crude palm oil mill. According to Sadyadharma et al. (2013), the crude palm oil mill uses high amount of water and energy as inputs in the production process, while producing a significant amount of wastewater and solid waste as a result of the output.

As far as the economic dimension is concerned, there are various negative impacts associated with the processing of palm oil, including replanting costs. Replantation takes place after the maturation of palm oil plants and bears extremely high costs. This poses tremendous financial pressure on farmers (Rist et al., 2010; Enden, 2013). Moreover, the market price fluctuations often have an economic effect (Rist et al., 2010; Enden, 2013). Although there is a strong market demand for palm oil, according to Mahat (2012), this demand is highly responsive to the changes in the prevailing price. A decline in palm oil production would lead to a rise in palm oil prices and in the prices of other foods that use palm oil as their main component. Enden (2013) noted that palm oil production companies face business risks and barriers to their commercial operations due to the unsustainable palm oil production that leads to the denigration of these companies. Palm oil companies therefore need to concentrate on

sustainability in order to develop their business and ensure future economic sustainability.

Table 1.2 : Summary of the main environmental, economic and social impacts associated with palm oil industry

Dimension	Impacts	References
Environmental	Both deforestation and fires cause the GHG emissions, haze and climate change; the orangutan extinction, damage the land quality and habitat, and limit the biodiversity range	Tan et al, (2009); Laurance et al, (2010); Nilsson, (2013)
	Drainage of peat lands for planting resulting in CO2 emissions and climate change	Tan et al, (2009); Laurance et al, (2010)
	Methane emissions associated with palm oil mill effluent treatment lead to further climate change	Pleanjai and Gheewala, (2011)
	Destroying the biodiversity and carbon sinks within forests and species loss because of the forest degradation from conversion to palm oil monoculture	Tincliffe and Webber, (2012)
	Excessive energy and water use, generates a big amount of wastewater and solid waste	Sadyadharma et al, (2013)
	Excessive use of pesticides and fertilizers	Mahat, 2012
Economic	The high cost of the replanting process causes great financial stress on farmers	Rist et al, (2010); Enden, (2013)
	The fluctuations in market prices	Mahat, (2012); Rist et al, (2010); Enden, (2013)
	Unsustainable palm oil production that leads to the denigration of palm oil production companies, thus these companies are facing obstacles in implementing their commercial operations	Mahat, (2012)
Social	Displacement of people and the native communities due to loss of land use rights and conflicts with imported labour	Colchester and Chao, (2011); Cooke, (2012)
	Conflicts between communities and plantation developers, reducing the quality of soil and freshwater, and then affects local communities who depend on these ecosystem products for their live	Russo and Perrini, (2010)
	Poor and unsafe labour conditions for workers	Mahat, (2012)
	The dependency of the Malaysia's oil palm sector on foreign workers	Borneo Post Online, (2017); Azman and Simeh, (2012)
	The clearing and expansion of large areas for palm oil cultivation have affected the food supply	Susanti and Burgers, (2013); Enden, (2013)
	Affecting the native communities' natural resources and rights to land territories	Colchester and Chao, (2011); Mahat, (2012)
	Negative feedback or protests from NGOs	Datamonitor, (2010); Nikoloyuk et al., (2010)

Other negative impacts of the palm oil industry are related to the negative impacts on aboriginal communities where the growth of the palm oil industry has impacted their natural resources and land rights. The phase of deforestation and changes linked to this industry also contributes to the displacement of people and native communities (Colchester & Chao, 2011; Mahat, 2012). In addition, land expansion and clearance of large areas of palm oil land have affected food supplies by overwhelmingly concentrating on oil palm cultivation whilst ignoring the cultivation of other food supplies such as rice , vegetables, and many more (Susanti & Burgers, 2012; Van Der Ende, 2013). The lack of labour in the initial stages of the process for the palm oil industry, according to Veloo, (2012), has become a major problem. This industry relies heavily on foreign labour for the cultivation, fruit growing and other general maintenance jobs. As claimed by Azman and Simeh, (2012), Indonesians dominate the workforce at 88.77 percent of the total international workforce working as field workers. With Malaysia expanding the palm oil area from 5 million hectares in 2011 to about 5.8 million hectares in 2020, labour shortages in the palm oil plantation sector will continue. Considerable attention is required in seeing these problems as stated by Krolczyk et al. (2014). He also emphasized on the need to enhance the sustainability of Malaysia's palm oil mill for a more environmentally friendly and resource-friendly environment, not only for the success of companies in the future, but also for the health and well-being of future generations.

According According to Krolczyk et al. (2014), Sustainable development or sustainable production have, in regards to a sustainable approach, played an important role in research. The need for a sustainable palm oil especially in the field of palm oil production, has brought about the creation of the Round Table on Sustainable Palm Oil (RSPO, 2012). This round table aimed at understanding the various stakeholders of palm oil at the international level and to translate this understanding into common actions to ensure the sustainability of palm oil production through the use of these actions in its entire supply chain to be achieved. The sustainability of palm oil production is defined as a legal, economically viable, environmentally appropriate, and socially beneficial through a policy known as the RSPO Principles and Criteria (Veloo, 2012), according to RSPO. While a set of standards and criteria for sustainable production has been formulated by this Round Table, the scheme to provide certified full traceability for sustainable palm oil has not yet been implemented (Guan et al., 2016). The palm oil industry has been prompted to build a sustainable strategy on the unintended consequences of the social, environmental and economic problems caused by the rapid development of the population, economy and natural resource use due to the rising world demand for sustainable goods.

It is important to define and evaluate the driving force of Malaysian palm oil sustainability to understand the relation between sustainability and Malaysian palm oil in order to establish a sustainable strategy. It is debated by Lim and Biswas (2018), that Malaysia's palm oil industry is driven by environmental awareness, economic escalation as well as social commitment. These three main dimensions are interlinked and are the proof of progress towards sustainable practices. This holistic, three-dimensional sustainable development (environment, economy and society), however, has become a core issue in many areas. Still, addressing sustainability issues and

concerns in the absence of a structured global institution to control palm oil production is very challenging. Taking this into account, it is clear that identifying, quantifying, addressing and promoting sustainability in the palm oil industry is a matter of urgency due to the rising value of the sector, the rising environmental and social problems resulting from this sector, and the lack of presence of a structured regulatory institution.

1.4 Problem Statement

One of the world's most traded agricultural commodities is the palm oil. Palm oil production is rising around the world every year. The palm oil industry plays a significant role in providing a sustainable development by improving the socio-economic and environmental conditions of the country. However, the rapid growth of the palm oil industry has had negative environmental, economic and social impacts in Malaysia (Lim et al., 2015). These impacts are related to the work of palm oil factories that are concerned with the displacement and destruction of the animal and human population as a result of the rapid production of palm oil. Other than that, soil carbon sequestration in forests are also lacking. Environmental and human rights problems have become the primary topics of provoking discussion on the areas around the industry. The palm oil industry, especially in the South East Asian region, has, as a result, suffered criticisms and negative reports from the international non-governmental organisation on sustainability. The palm oil industry has also been receiving criticisms from international advocacy organisations including Geenpeace, the Action Network and the World Wildlife Fund, for current unsustainable production practises (Datamonitor, 2010). It has been claimed by these organisations that the palm oil industry does not function within a sustainable business boundary (Nikoloyuk et al., 2010).

Nonetheless, the effects of palm oil production can be reduced with the help of management decisions to improve its sustainability. The Roundtable on Sustainable Palm Oil (RSPO) was developed in 2004 to promote the development and utilisation of sustainable palm products through reliable global standards and engagement with stakeholders. Through certification and dissemination of information on innovations in oil palm plantation, processing and distribution, the RSPO has helped to minimise negative social and environmental impacts on this globally significant commodity (Walker et al., 2018). The efforts to implement sustainability by RSPO in 2004 were not supported by all parties even though the effort is to achieve sustainability of the palm oil industry (Levin et al., 2012). The increasing world demand for sustainable goods has prompted the palm oil industry to build a sustainable strategy on the unintended consequences of the social, environmental and economic problems caused by rapid population development, economic development and natural resource use. It is important to identify and evaluate the drivers of Malaysian palm oil sustainability in order to understand the relation between sustainability and Malaysian palm oil to establish a sustainable strategy. The driving factors of Malaysia's palm oil industry include environmental consciousness, economic escalation and social engagement.

According to Ilyana et al. (2015), these three main dimensions are interlinked and they contribute to progress towards sustainable practices. In order to ensure the longevity of this industry, a systematic evaluation of the effects of this industry must therefore be carried out on the basis of the three dimensions of sustainability (Lim et al, 2015). To this end, the researchers are speeding up efforts to develop and apply various scientific methods to measure manufacturing sustainability. The methods seem to be a viable outcome to solve the problem but a clear and standardized method has yet to be proposed. Even though LCSA approach is seen as a very viable life-cycle approach to sustainability assessment, the existing undeveloped state of the LCSA approach with vague or poorly discussed methodological specifics, considered as challenges when apply LCSA methodology, not to mention the absence of its implementation in biobased products. In addition, since LCSA is an approach that incorporates three separate methods, the integration of the different approaches is complicated and contributes to the difficulty of interpreting and presenting the findings to non-experts in a detailed and understandable way. The production of a detailed and meaningful presentation of LCSA outcomes is therefore a primary objective of this research.

1.5 Research Questions

The research questions of this study are all connected to the impacts of the palm oil industry and assessment of the sustainability in this industry. The following questions are generated in order to achieve the objectives of this study:

1- What are the potential environmental impacts that are generated during palm oil production?
2- What is the sustainability level of palm oil industry based on the potential costs incurred that are generated during palm oil production?
3- What is the sustainability level of palm oil industry based on the potential social impacts that are generated during palm oil production?
4- How can the alternative life cycle sustainable assessment method contribute to sustainability assessment of oil palm industry through the three dimensions?

1.6 Research Objectives

The main objective of this study is to provide a holistic assessment on the palm oil production based on the environmental, economic, and social dimensions that are required by the decision makers to monitor the industry for sustainable production.

The objectives of this study are:

1- To determine the sustainability level of oil palm industry based on the potential environmental impacts generated from palm oil production
2- To assess the sustainability level of oil palm industry based on the costs incurred through palm oil production.

3- To evaluate the sustainability level of oil palm industry based on the potential social issues alongside the palm oil production.
4- To develop a scheme to assess the sustainability of oil palm industry through three dimensions (social, environmental and economics).

1.7 Significance of the Study

In the case of achieving a sustainable production of palm oil, one needs to get to the source of the problem. It is essential to use the three dimensions of sustainability (environmental, economic, and social) in order to evaluate the sustainability of palm oil production (Lim and Biswas, 2018). Therefore, in order to examine the sustainability of palm oil by taking into account the three dimensions of sustainability, a rigorous assessment method is required. The aim of this study is to enhance knowledge and provide amount of data required for our means to achieve a sustainable production. This study may be of help in order to drive the sustainability of the palm oil industry and its importance lies in raising the awareness of decision-makers by providing comprehensive information on the palm oil sector, especially regarding the issues on environmental, economic and social implications of the industry, so that they can understand the important hotspots associated with different environmental economic and social effects. All the data collected will also be used to develop and assess a sustainable production of palm oil, while helping to provide recommendations and implementing measures to improve the social, environmental and economic dimensions of palm oil production processes, which are primarily targeted at mitigating the negative social, environmental and economic implications of palm oil production and deflect all pessimistic views on palm oil as well as developments toward a better future.

At the same time, knowledge on the experience of Malaysian in the growth of this sector can be utilized as an essential tool to lead other newly generating countries in this field. However, the combination of many approaches is complicated and makes it very difficult for non-experts to understand the data (Ekener et al, 2018). This research established a scoring system approach that stakeholders can conveniently use and comprehend in order to evaluate the findings of LCSA while maintaining the holistic perspective of sustainability assessment. Besides that, a rigorous and detailed presentation of the three dimensions of sustainability outcomes is important to strengthen the communication of the LCSA findings (Onat et al, 2017; Cihat et a, 2019). Hence, this research established a presentation technique to illustrate the findings. However, testing this technique in order to verify the usability will provide more details about its use in assessing the sustainability in the palm oil industry and also in other industries.

1.8 Study scope

This study was carried out in March 2019 in Johor, Malaysia. This area was selected as it has the largest oil palm production in comparison with the other states of

Peninsular Malaysia. Moreover, it is as claimed by the Malaysian Palm Oil Board (MPOB) database, Johor is considered as the highest producer of palm oil in Peninsular Malaysia at 747,562 ha (MPOB, 2018). Based on MPOB (2018), crude oil production continues to increase year by year, especially in Johor. Total crude oil production in 2014 was 3,047,049 tonnes and it rose in 2015 and 2017 to 3,117,619 tonnes and 3,142,522 tonnes respectively. The scope of this study focused on CPO production, where the majority of emissions occur at the CPO mill level, which accounts for approximately half of the emissions of the production (48%) (Egeskog, 2016). The crude oil palm production essentially requires FFB, which are harvested from oil palm plantations. Thus, the system boundary included oil palm plantation where the Fresh Fruit Bunch (FFB) until the milling process to produce CPO. In other words a cradle-to-gate study. One metric tonne of CPO production was the functional unit selected in this study.

1.9 Organization of Thesis

In the **Chapter 1**, a general introduction, which details the problem statement, objectives, research questions, the expected value of this study, and the research structure are presented. The chapter describes the background of the palm oil industry which included the importance of the industry, its activities and supply chain as well as its sustainability.

In the **Chapter 2**, the theoretical development of sustainability concept are introduced, followed by the three pillar of sustainability assessment and their relationship to Palm Oil, the life cycle based assessment methods are discussed in this chapter. The last part of **Chapter 2** focus on the systematic reviews to life cycle sustainability assessment method and its application in the palm oil industrial development.

In the **Chapter 3**, the methodology and research design are discussed to show how this study is conducted. The chapter starts with an overview developed life cycle sustainability assessment method, followed by an explanation of the tools that are used in the sustainability assessment.

For **Chapter 4**, According to the research aims, the research is focused on sustainable palm oil assessment in two different phases in palm oil life cycle. This chapter will analyze the environmental, economic and social impacts related to palm oil production. Followed by the discussion and the analysis and of the LCSA and the presentation technique results.

Finally, **Chapter 5** concluded the findings of the study and any conclusions within the research scope and to evaluate its objectives that have been set for the study. Contributions of this study and possible recommendations for future research are also outlined in this chapter.

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