LIFE CYCLE ASSESSMENT OF THE HANDLING AND TRANSPORTATION OF PALM OIL, PALM OLEIN AND PALM STEARIN

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FAUZIAH ARSHAD

ABSTRACT

Transportation is an important component of the palm oil supply chain and it is one of the main sources of greenhouse gas (GHG) arising from the use of fossil fuel. The scope of the study is to determine the environmental impacts of the refined bleached and deodorized (RBD) palm oil and its fractionated products namely palm olein and palm stearin along the palm supply chain which is from cradle-to-gate i.e. from the transportation of oil palm fruit bunches from the 'mother palm' to the seed producers, the transportation of the germinated seeds to the nurseries, the transportation of seedlings from nurseries to oil palm plantations, the transportation of fresh fruit bunches (FFB) from plantations to mills, the transportation of crude palm oil (CPO) from mills to refineries and finally the transportation of refined, bleached and deodorized (RBD) palm oil, RBD palm olein and RBD palm stearin from refineries/fractionation plants to ports and retailers by using the Life Cycle Assessment (LCA) approach. The Life Cycle Inventory (LCI) on the energy consumption and GHG emission is based on site-specific data collected from questionnaires sent to nurseries, plantations, mills and refineries throughout Malaysia including Sabah and Sarawak and calculated using emission factors. The LCI analysis on the energy consumption based on the production of 1 tonne RBD palm oil indicated that transportation of FFB from plantation to palm oil mill were the highest followed by transportation of RBD palm olein from refinery to retailers and CPO from mills to

refineries at 197.12 MJ, 192.78MJ and 151.50 MJ respectively. Based on the production of 1 tonne RBD palm oil, the GHG emissions during the transportation of FFB from plantations to mills and transportation of CPO from mills to refineries were 21.94 kg CO_2 eq. and 20.86 kg CO_2 eq. respectively. The weighted results of the life cycle impact assessment (LCIA) showed that the most significant environmental impacts from this study were contributed by the impact categories in the following order: fossil fuel, respiratory in-organics, acidification/eutrophication and climate change. The environmental impacts were highest during the transportation of FFB from the oil palm plantations to palm oil mills followed by the transportation of CPO from the mills to refineries. Mitigations for improvements include using other modes of transportation such as rail to transport the FFB and CPO and improved infrastructure for more pipelines to export the refined palm oil.

ABSTRAK

Pengangkutan adalah satu komponen penting dalam rantaian bekalan minyak sawit dan ia adalah salah satu sumber utama gas rumah hijau (GHG) yang timbul daripada penggunaan bahan api fosil. Skop kajian ini adalah untuk menentukan kesan alam sekitar terhadap minyak sawit tertapis, terluntur dan ternyahbau (RBD) dan produk hasil daripada pemeringkatan iaitu olein sawit dan stearin sawit di sepanjang rantaian bekalan sawit dari ‘cradle-to-gate’ iaitu daripada pengangkutan tandan buah kelapa sawit daripada ‘mother palm’ kepada pengeluar benih, pengangkutan benih bercambah kepada tapak semaian, pengangkutan benih dari tapak semaian ke ladang kelapa sawit, pengangkutan buah tandan segar (BTS) dari ladang kepada kilang sawit, pengangkutan minyak sawit mentah (MSM) dari kilang sawit ke kilang penapisan dan akhirnya pengangkutan RBD minyak sawit, RBD olein sawit dan RBD stearin sawit dari kilang penapisan / kilang pemeringkatan ke pelabuhan dan peruncit dengan menggunakan pendekatan Penilaian Kitaran Hayat (LCA). Inventori Kitaran Hayat (LCI) bagi penggunaan tenaga dan pelepasan GHG adalah berdasarkan data ‘on-site’ yang dikumpul daripada soal selidik yang dihantar ke tapak semaian, ladang sawit, kilang sawit dan kilang penapisan di seluruh Malaysia termasuk Sabah dan Sarawak dan dikira menggunakan ‘emission factors’. Hasil analisis LCI ke atas penggunaan tenaga berdasarkan kepada pengeluaran satu tan minyak sawit RBD menunjukkan bahawa pengangkutan BTS dari ladang kelapa sawit ke kilang adalah paling tinggi dan di ikuti

oleh pengangkutan RBD olein sawit dari kilang penapisan ke peruncit dan pengangkutan MSM dari kilang sawit ke kilang penapisan pada paras 197.12 MJ, 192.78MJ dan 151.50 MJ. Manakala pelepasan GHG bagi pengangkutan BTS dari ladang kelapa sawit ke kilang dan pengangkutan MSM dari kilang sawit ke kilang penapisan berdasarkan kepada pengeluaran satu tan minyak sawit RBD pula pada paras 21.94 kg CO_2 eq. and 20.86 kg CO_2 eq. Hasil penilaian impak kitaran hayat (LCIA) pula menunjukkan bahawa kesan impak kepada alam sekitar yang paling ketara daripada kajian ini telah disumbangkan oleh yang berikut: bahan api fosil, pernafasan inorganik, pengasidan / eutrofikasi dan perubahan iklim. Kesan alam sekitar adalah juga paling tinggi semasa pengangkutan buah tandan segar dari ladang kelapa sawit ke kilang kelapa sawit diikuti dengan pengangkutan minyak sawit mentah dari kilang ke kilang penapisan. Cadangan penambahbaikan termasuk menggunakan bentuk pengangkutan yang lain seperti kereta api untuk mengangkut BTS dan MSM dan infrastruktur lebih baik melalui pembianaan saluran paip untuk mengeksport minyak sawit bertapis.

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ABBREVIATIONS

B5	A blend of 5% palm oil biodiesel and 95% petroleum diesel
BD2,BD5,BD10, BD20	biodiesel blends of 2%, 5%, 10% and 20% of palm oil based biodiesel respectively
BD100	100% palm oil based biodiesel
CDM	Clean Development Mechanism
CFC	Chlorofluorocarbon
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon Dioxide
COP	Conference of Parties
CPO	Crude Palm Oil
D	Dura
DALY	Disability Adjusted Life Years
EFB	Empty Fruit Bunches
ELMIS	Environmental Life Cycle Management Information System
EPD	Environmental Product Declaration
FFB	Fresh Fruit Bunches
FELCRA	Federal Land Reclamation Authority
FELDA	Federal Land and Development Authority
GHG	Greenhouse Gas
GWP	Global Warming Potential
H_2O	Water Vapour
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment

LCI	Life Cycle Inventory
LCM	Life Cycle Management
LCIA	Life Cycle Impact Assessment
LPG	Liquid Petroleum Gas
MDF	Medium Density Fibreboard
MPOB	Malaysian Palm Oil Board
NMVOC	Non-methane hydrocarbon
N_2O	Nitrous Oxide
NOx	Nitrogen Oxides
P	Pisifera
PCR	Product Category Rules
PFAD	Palm Fatty Acid Distillate
PK	Palm kernels
PM	Particulate Matter
PO	Palm Oil
POo	Palm Olein
Pos	Palm Stearin
RBD	Refined, Bleached and Deodorized
RD & D	Research Development and Demonstration
RISDA	Rubber Industry Smallholders Development Authority
SBSTA	Subsidiary Body for Scientific and Technological Advice
SETAC	Society of Environmental Toxicology and Chemistry
SimaPro	**S**ystem for **I**ntegrated Environ**M**ental **A**ssessment of **Pro**ducts
SO_2	Sulphur dioxide
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
USLD	Ultra Low Sulphur Diesel
VOC	Hydrocarbon

WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

1.1 Background

Malaysia is one of the world's largest producers and exporters of palm oil, second only after Indonesia (Oil World Annual, 2015). The oil palm industry is currently the largest cultivated crop in Malaysia with a total planted area of 5.64 million hectares which produced 19.96 million tonnes of crude palm oil in 2015 (MPOB, 2016). Palm oil has gained worldwide market acceptance and is currently the leading edible oil traded in world market among the 17 major oils and fats. Malaysian palm oil products are currently exported to more than 130 countries worldwide. Malaysia's main export destinations include India, China, the European Union, Pakistan and the United States of America. The palm oil sector contributes significantly to the national agricultural GDP, generating RM60.2 billion in export earnings in 2015 and is one of the pillars in Malaysia's economy (MPOB, 2016). Palm oil and palm oil products are widely used throughout the world in food products, in non-foods and oleochemicals, and lately also as biofuels.

While palm oil contributes significantly to fulfill the world's demand for its oils and fats, the Malaysian oil palm industry continues to face with many challenges that the industry must address in order to stay ahead of its competitors such as soyabean oil, sunflower oil and rapeseed oil. Sustainable development, global warming and climate change are recent environmental issues affecting the world today and the oil palm industry is not exempted. Carbon dioxide, a known greenhouse gas (GHG) (Spielmann et al., 2004) is being held responsible for the global warming phenomena as the gas affects the temperature of the earth. Transportation is one of the main sources of GHG emissions from the burning of fossil fuels. This is because transport activities consume large quantities of energy, especially from fossil fuel, and due to the combustion processes in vehicle operation, transport is a major source of carbon dioxide and other gaseous pollutants such as nitrogen oxide and carbon monoxide. Emissions from the transport sector and particularly from road vehicles are detrimental to both human health and the environment (BTCE, 1995).

The Kyoto Protocol of the UN Framework Convention on Climate Change, adopted in 1997 requires developed countries to reduce their greenhouse gas (GHG) emissions by at least 5% against the baseline of 1990. Subsequently, the Doha Amendment to the Kyoto Protocol adopted in 2012 now requires developed countries to reduce their GHG emission by at least 18% against the baseline of 1990 (UNFCCC, 2014).

Although this issue regarding reduction of GHG level by countries, particularly developed countries, is still pending and continues being discussed at subsequent meetings on climate change under the United Nations, it is nevertheless a major step forward in tackling the problem of global warming and acknowledges the need for countries' commitment towards addressing this problem. The Protocol developed three innovative mechanisms - known as Emissions Trading, Joint Implementation and the Clean Development Mechanism (CDM), which provide for developed countries to earn and trade emissions credits through projects implemented either in other developed countries or in developing countries. These mechanisms also help identify opportunities for reducing emissions and attract private sector participation in emission reduction efforts (UNFCCC, 2008).

Malaysia, as a developing country is not required to reduce its GHG emissions under the Kyoto Protokol. However, at the United Nations Climate Change Conference in 2009 in Copenhagen, the Honourable Prime Minister of Malaysia has announced to voluntarily reduce its GHG emissions by 40% in terms of emissions intensity of gross domestic product (GDP) by the year 2020 compared to 2005 levels (Bernama, 2009). In this context, the Malaysian oil palm industry can offer many opportunities for the country to help reduce GHG emissions and contribute to slowing down climate change. One way for the industry to claim carbon credits from the reduction in GHG emissions is from reduced fossil fuel consumption from the reduction in carbon dioxide (CO_2) and other emissions such as nitrous oxide (N_2O) and carbon monoxide (CO) through transportation. The life cycle approach can be used to identify the major sources of GHG emissions along the transport chain.

The concept of conducting a detailed examination of the life cycle of a product or a process is relatively recent which emerged in response to increased environmental awareness among the general public, industry and governments. Life Cycle Assessment (LCA) considers the environmental impacts (e.g. the use of resources and the environmental consequences of its releases to the environment) of a product (or service e.g. transport) throughout its life cycle from raw material acquisition to production, use and final disposal (ISO, 2006). Research on environmental performance applying the

LCA approach is becoming more popular in recent years and is currently being used for various purposes e.g. by government to assist in policy making, industry for product improvements and universities for academic purposes.

1.2 Problem statement

Transport is responsible for nearly one-quarter of greenhouse gas emissions worldwide. It is also the sector where emissions are growing most rapidly. Road transport accounts for the largest proportion of this, over eighty percent in industrialized countries. Since 1970, the number of motor vehicles in the United States has grown at an average rate of 2.5% per year, in the rest of the world the growth has been almost twice as rapid at nearly 5% per year (Houghton, 2002). Energy-related carbon dioxide emissions accounted for 98 percent of U.S. carbon dioxide emissions in 2009 of which the predominant share of carbon dioxide emissions comes from fossil fuel combustion (US EIA, 2014).

Nearly all transport emissions come from the burning of petroleum products such as petrol, aviation fuels, diesel and liquid petroleum gas (LPG). In Australia, of all emissions from burning petroleum products, 70.3% are from transport. Road transport is the main source of transport emissions, accounting for 89.3% of the total, followed by air transport (5.9%), water transport (2.3%) and rail transport (2.5%) (BTRE, 2003). Base case study or 'business –as-usual' projections of fuel use and greenhouse gas emissions from the Australian transport sector conducted by the Bureau of Transport and Regional Economics (BTRE) predicted that emissions are likely to rise from about 69.6 million tonnes of CO_2 eq in 1998 to about 100.2 million tonnes in 2020. Emissions growth is highest for commercial road vehicles and for airlines. The results show that transport has an inherently high rate of growth in emissions, in line with its fairly direct link to economic and population growth (BTRE, 2002).

Similarly, in Malaysia, the greenhouse gas emissions from transportation also contributed significantly to the overall GHG emissions in the country. The CO_2 emitted from the transportation sector in Malaysia in 2011 was 22 million tonnes, (World Development Indicators, 2014).

1.3 Scope of work

The scope of this study is to determine the environmental impact of handling and transportation of the refined, bleached and deodorized (RBD) palm oil and its fractionated products namely RBD palm olein and RBD palm stearin within the boundary of the study which is along the palm oil supply chain from cradle-to-gate i.e. from the transportation of the fruit bunches from 'mother palm' from plantations to seed producers; to the transportation of the germinated seeds to nurseries; to the transportation of the seedlings from nurseries to oil palm plantations; to the transportation of the fresh fruit bunches from plantations to mills; to the transportation of the crude palm oil from mills to refineries; and finally to the transportation of the RBD palm oil, RBD palm olein and RBD palm stearin from refineries/fractionation plants to ports and retailers (please refer to figure 3.1) by using the life cycle assessment approach (Sima Pro version 7.1). The input data (energy resources) on the diesel consumption are obtained from questionnaires sent to the relevant stakeholders involved in the transportation of palm oil along its supply chain throughout Malaysia including Sabah and Sarawak. The output data (combustion emissions) are obtained through actual data on the tonnage of product transported and distance travelled from the questionnaires received and calculated using emission factors.

1.4 Objectives of research

The study has five objectives as follows:-

Objective 1:

To determine the environmental performance of the handling and transportation of the RBD palm oil, RBD palm olein and RBD palm stearin within the boundary of the study by conducting the life cycle inventory (LCI) on the energy consumption and the combustion emission gases generated from the vehicles used in the transportation process.

Objective 2:

To compare the data on the total GHG emission (CO_2 eq) from transportation of the oil palm products along the palm oil supply chain from this study with the total GHG emissions (CO_2 eq.) from transportation in the country.

Objective 3:

To profile the life cycle environmental impacts of the handling and transportation of the RBD palm oil, RBD palm olein and RBD palm stearin within the boundary of the study along the palm oil supply chain by conducting the life cycle impact assessment analysis.

Objective 4:

To determine the relative environmental contribution of the handling and transportation of RBD palm oil, RBD palm olein and RBD palm stearin compared to the environmental impacts of the production of palm oil along the palm oil supply chain.

Objective 5:

To determine the GHG savings from the implementation of the B5 biodiesel mandate under the National Biofuel Policy which requires for the mandatory blending of 5% palm biodiesel with 95% petroleum diesel compared with the GHG emissions from 100% petroleum diesel.

1.5 Significance of study

The results of the study would be able to identify at which stage of the handling and transportation of palm oil, palm olein and palm stearin throughout its supply chain that contributes to the environmental impacts. Recommendations based on the outcome of this study can assist policy makers and stakeholders in their strategic planning to improve on the existing transportation system and to address the environmental hot spots pertaining to transportation for a more positive impact on the environment, thus contributes to the sustainable development of the Malaysian oil palm industry. In addition, the data on the carbon foot print with regards to the transportation process from this LCA study can also be used to further enhance and promote the market of palm oil and palm oil products around the world.

1.6 Overview of thesis

This thesis consists of five chapters as follows:

Chapter 1- Introduction which explains the background of the issue, the problem statement, the scope of work, the objectives of the research, the significant of the study and overview of thesis.

Chapter 2- Literature Review incorporates the relevant literature which includes topics on the Malaysian oil palm industry, the oil palm fruit and its cultivation, the many uses of palm oil, the transportation process along the palm oil supply chain, global warming and climate change and their impact to the environment, the environmental and health impacts of transportation, sustainable development to slow down climate change, adaptation and mitigation options to reduce GHG emissions and slow down climate change and also elaborates on the life cycle assessment approach and the Sima Pro, which is the software used for the impact assessment analysis.

Chapter 3 - Research methodology.

Chapter 4- Results and discussion which include analysis on the results of the life cycle inventory on the energy consumption and the combustion emissions during the transportation process and the life cycle impact assessment analysis.

Chapter 5- Conclusion of the study, recommendations for improvement options, the limitations of the study and recommendations for future work are highlighted in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 History and development of Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a methodology that is being used to assess the environmental aspects of a product over its life cycle (Goedkoop et al., 2007). LCA started in the 1960s in the United States of America during this period when companies were concerned over the limitations of raw materials and energy resources. This concerns sparked interest to find ways to collectively account for the energy use and to project future resource supplies and use. In 1969, an internal study was conducted by the Coca-Cola Company that became the foundation for the current life cycle inventory analysis in the United States. The study compared the different beverage containers in order to determine which container had the lowest releases to the environment and least affected the supply of natural resources. It calculated the raw materials and fuels used for each container, as well as the environmental loads from the manufacturing processes (PE International, 2014).

Interest in LCA waned between 1975 to the early 1980's, because environmental concerns shifted to issues on hazardous and household waste management. However, in 1988 solid waste became a worldwide issue. LCA again emerged as a tool for analysing environmental problems. By 1991, there were concerns over the inappropriate use by product manufacturers of LCAs in making broad marketing claims. It became clear that uniform methods for conducting such assessments were needed particularly as to how this type of environmental comparison could be made non-deceptively (PE International, 2014).

At the same time, there was also growing pressure from environmental organisations to standardise LCA methodology. This later led to the development of the LCA standards on the International Standards Organisation (ISO) 14000 series (1997 through 2006).

In 2002, the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) launched the Life Cycle Initiative as an international partnership. The Initiative has three programs as follows, with the objective to put into practice life cycle thinking and improve this tool through better data and indicators:

1. **Life Cycle Management** (LCM) program.

   To create awareness and improves skills of decision-makers by producing information materials, establishing forums for sharing best practice, and carrying out training programs in all parts of the world.

2. **Life Cycle Inventory** (LCI) program.

   To improve global access to transparent, high quality life cycle data by hosting and facilitating expert groups whose work results in web-based information systems.

3. **Life Cycle Impact Assessment** (LCIA) program.

To increase the quality and global reach of life cycle indicators by promoting the exchange of views among experts whose work results in a set of widely accepted recommendations

(ISO, 2006).

Even though LCA was popular in the early nineties as a tool to support environmental claims to promote marketing, LCA application is currently more in the analysis of the environmental contribution of a product's life cycle stages over its total environmental load, with the aim to improve on product environmental performance or their processes. Another application is to compare between products or services. This is because these different products or services generally have a long history occurring over time which starts with the extraction of raw materials, the production and transportation of the components of the product, followed by the production of the product itself up to its consumption and final disposal or recycling. This is being referred to as the "cradle-to-grave" life cycle. LCA became the tool to provide the means to communicate to the stakeholders concerned regarding the environmental aspects in a more quantitative manner.

In recent years, however, life cycle thinking has become a key element in environmental policy making. Such example is the concept of IPP (Integrated Product Policy) as communicated by the EU. They have also been a marked increase in the development of Environmental Product Declaration (EPD). EPD is now becoming a major field of application of LCA of which thousands of products now has such a declaration. Product Category Rules (PCR) describes how an LCA should be made for the EPD (Goedkoop et al., 2007).

Major policies incorporating LCA that started from EPDs and IPP for regulatory use, surged into major federal level legislations which govern state and member states energy laws such as the EU Renewable Energy Directive (EU RED) in the EU (European Commission, 2009) and the Renewable Fuel Standards (RFS2) in the United States of America (United States Congress, 2007). LCA has expanded and has become an environmental tool which are tied to energy and bioenergy policies and GHG accounting (McMamus and Taylor, 2015).

Although traditionally LCA has been applied retrospectively to relatively contained (in terms of system boundaries) products or systems. This is known as attributional LCA (aLCA).

Recently, LCA has been applied to larger scale decision in which it affects how environmental impacts might change in response to potential policy decisions (Zamagni et al., 2012). This is known as consequential LCA (cLCA). Consequential LCA expands the system boundaries to include activities contributing to resultant changes. This made LCA more complex as the cLCA is broader, exploring not only the impacts of the production and use of a particular product but the wider changes to the overall system that may arise from using that product, and often exclude the unchanged elements (Sanchez et al., 2012). For example, consequential analysis of a renewable energy technology evaluates the impacts of a production, use and disposal of the technology, with increased emphasis on the impact of the offset of energy or other substituted product that would have been alternatively produced. Consequential analysis expands the system boundaries beyond those that have traditionally set and makes it useful to policy makers (Taylor and McManus, 2013). However, the expansion is not without problems as many of the consequential LCAs have been developed from a series of attributional LCAs which might be a simplification of the more complex reality, and some of these studies have been shown to give misleading results (Bento and Klotz, 2014). The issue of land use (both direct and indirect) change in the use of bioenergy has large scale policy impacts from GHG calculations for example in the EU RED and RFS2. In order for the LCA to develop effectively from an attributional tool to a far reaching consequential tool for use by policy makers, a transparent mechanism to convey uncertainty and comparability as well as data compilations to fill the data gaps and research into validation of feedback mechanisms in the method (McManus and Taylor, 2015).

2.2 Standards related to Life Cycle Assessment

There are two ISO standards specifically developed on LCA:

1. ISO 14040: Principles and Framework
2. ISO 14044: Requirements and Guidelines

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

ISO 14040 was prepared by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment*.

The second edition of ISO 14040, together with ISO 14044:2006, cancels and replaces ISO 14040:1997, ISO 14041:1998, ISO 14042:2000 and ISO 14043:2000, which have been technically revised (ISO, 2006).

For practitioners of LCA, ISO 14044 details the requirements for conducting an LCA.

LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

There are four phases in an LCA study:

- i) the goal and scope definition phase,
- ii) the inventory analysis phase,
- iii) the impact assessment phase, and
- iv) the interpretation phase.

The scope, including the system boundary of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA.

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study.

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition.

There are cases where the goal of an LCA can be satisfied by performing only an inventory analysis and an interpretation. This is usually referred to as an LCI study.

This ISO Standard covers two types of studies: life cycle assessment studies (LCA studies) and life cycle inventory studies (LCI studies). LCI studies are similar to LCA studies but exclude the LCIA phase. LCI studies are not to be confused with the LCI phase of an LCA study.

Generally, the information developed in an LCA or LCI study can be used as part of a much more comprehensive decision process. Comparing the results of different LCA or LCI studies is only possible if the assumptions and context of each study are equivalent. Therefore the Standard contains several requirements and recommendations to ensure transparency on these issues.

LCA is one of several environmental management techniques (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) and might not be the most appropriate technique to use in all situations. LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described in the Standard can be applied to these other aspects. This ISO Standard, like other International Standards, is not intended to be used to create non-tariff trade barriers or to increase or change an organization's legal obligations.

In view that the ISO standards are not quite clearly defined which make it difficult to evaluate whether an LCA has been conducted according to the standard. This is because unlike the 14000 series, one could not get an official accreditation that states that an LCA, LCA methodology or LCA software such as the Sima Pro was done according to the ISO standard. As a consequence, there are no software developer that can claim that LCAs made using certain software tools would conform to these standards.

An important consequence to adhering to ISO standard is that one needs to have a proper documentation on the goal and scope of the LCA study and the interpretation of the results. Therefore, the LCA practitioner will have a wide choice as to how to perform the LCA study, provided that they are carefully documented. Another consequence to adhering to the ISO standard is that one may need to consider a peer review by independent experts (ISO, 2006).

2.3 Previous LCA studies on oil palm

LCA studies with regards to oil palm have been conducted previously by earlier researchers. Yusoff and Hansen (2007) had performed a feasibility study on crude palm oil production in Malaysia using the LCA approach. The screening LCA study demonstrated that LCA could be used as a decision tool by the Malaysian Oil Palm Industry to evaluate processes that could impact the environment particularly processes that emitted CO_2 to the environment such as from the use of fertilizer, transportation and biogas production. The researchers from MPOB have also conducted LCA studies on the production of palm oil along the supply chain including biodiesel (Halimah et al., 2010; Puah et al., 2010; Tan et al., 2010; Vijaya et al., 2010; Zulkifli et al., 2010). The LCA study of the Malaysian oil palm products from mineral soils and including biodiesel was conducted with the objective to develop baseline information on the environmental performance of the Oil Palm Industry (Choo et al., 2011). The sub-systems included oil palm nurseries and plantations, palm oil mills, refineries, biodiesel plants and use of biodiesel in diesel engine vehicles. There were two different scenarios during the study: CPO production in a mill with no facility to capture the biogas released and another with the facility to capture the biogas from the palm oil mill effluent (POME). From the study conducted, it was found that the GHG emissions from plantations were most significant arising from the nitrogen fertilizer used, transport and traction energy while at the mill, the major contributor to the environment came from the production of biogas if not trapped. For the refinery subsystem, the boiler fuel and transporation were the main sources of GHG emissions. For the biodiesel production, the methanol and the refined palm oil being the raw material for the biodiesel production were major contributors to GHG emissions. The nursery did not contribute significant GHG emissions (Choo et al., 2011). More recently, Halimah et al. (2014) conducted an LCA study on the production of oil seeds to link to the earlier study to complete the supply chain.

However, the previous LCA studies reported by Choo et al. (2011) and Halimah (2014) did not make comparison on the environmental performance of the transportation for the different sub-systems along the palm oil supply chain. In view of the importance of the transportation component in the production of palm oil and palm oil products with regards to GHG emissions and climate change, the current study would be able to fill this knowledge gap. One of the objectives in this study is to determine the relative environmental contribution of the handling and transportation of RBD palm oil, RBD palm olein and RBD palm stearin compared to the environmental impacts of the production of palm oil along the palm oil supply chain. In this regard, the outcome and results from the study by Choo et al. (2011) will be used.

Presently, there are not many LCA studies that were conducted on the production of oleochemicals from palm oil as previous studies were mostly done on the polyol production derived from petroleum or from castor oil (Zolkarnain et al., 2015). Polyol is a major feedstock material in the manufacture of polyurethane products such as ceiling panel, flower foams, cushions and car seats. Palm based polyol can serve as a renewable resourse as an alternative from petroleum based polyols.

2.4 The oil palm and the Malaysian Oil Palm Industry

The history of the oil palm species (*Elaeis Guinensis*) dated back in 1807 from West Africa where it was first cultivated. It was brought to the East in 1848 to Indonesia where four seedlings were planted in the Botanical Gardens Bogor and from there to Singapore Botanical Gardens in 1870 and only then to Malaya in the late 1870s. During this early time the *Elaeis Guinensis* was not used as a commercial crop as it is today but as an ornamental plant (Whitmore 1973). Its commercial value was only realized around 1917 when the first oil palm estate was established in Tennamaran Estate in Batang Berjuntai, Selangor. Yusof (1995), quoted by Yusof (2000) stated that the key success to the growth of the oil palm industry in Malaysia was largely attributed to the Agricultural Diversification Policy introduced by the Government in late 1950s in Malaya which stimulated the shift from cultivation of rubber to oil palm. Since then, the Malaysian Palm Oil Industry has grown tremendously from just 55,000 hectares in 1960 its cultivated area had increased to 5.64 million hectares in 2015, making oil palm the largest cultivated crop in Malaysia (MPOB, 2016).

The success of the Federal Land Development Authority or better known as FELDA that was established by the government to oversee the land settlement schemes for the rural poor which focuses on opening smallholder farms cultivated with oil palm resulting in the dramatic increase in oil palm cultivation. Privately owned plantations also made the shift from rubber to oil palm. At present, FELDA is the largest among the government scheme, which manages around 712,956 hectares or 12.6% of the total planted area. The other Government Schemes which are the Federal Land Reclamation Authority (FELCRA), Rubber Industry Smallholders Development Authority (RISDA) and other state schemes manage 1.3 million hectares or 23.2% of the total hectarage. The total hectares owned by private estates accounts for 3.4 million hectares, which is 61.1% of the total cultivated area. The remaining 15.7% oil palm cultivated area is owned by the smallholders, which accounts for 883,004 hectares. The highest oil palm cultivation in the country is in the State of Sabah, which was more than 1.5 million hectares in 2015. Next is in the State of Sarawak with 1.4 million hectares, followed by the Johore (739,583 hectares), State of Pahang (725,239 hectares), State of Perak (398,314 hectares), State of Negeri Sembilan (177,741 hectares), State of Terengganu (172,587 hectares), State of Kelantan (151,973 hectares) and State of Selangor (137,336 hectares). The States of Kedah, Melaka, Pulau Pinang and Perlis all have oil palm planted area of less than 100,000 hectares with the following hectarage respectively: 87,244hectares; 54,603 hectares; 14,447 hectares and 294 hectares (MPOB, 2016).

2.5 Climatic conditions for oil palm cultivation

The country's tropical climate is most suited for oil palm cultivation as the oil palm thrives under the following climate conditions:

- Anuual rainfall of 1500-2000 mm or more, distributed evenly throughout the year without any marked dry season
- Mean maximum temperatures of 29^{o}C – 33^{o}C (85^{o}F- 90^{o}F) and mean minimum temperatures of 22^{o}C – 24^{o}C (72^{o}F – 75^{o}F)
- Continuous sunshine for at least five hours a day.
- Loose-textured soil on flat land, with no stones or gravel layer in the first 1.2m (4ft) below the surface or

- Loose-textures alluvial soil near the coast or a river and light clay with a layer of friable clay below or
- Shallow peat soil with a layer of friable clay below it.

(Rajanaidu, 1994).

Although countries located within 10 degrees latitude of the equator are said to be suitable for oil palm cultivation, some of these countries experience some months of drought which results in low oil yield. This has made it possible for Malaysia as well as Indonesia to emerge as the major world producers of palm oil (Yusof and Chan, 2004).

Oil palm can also be cultivated from ex-jungle, ex-rubber, ex-coconut or from oil palm plantations through the felling of the trees and piling-up of the wood for burning. The felled trees are pushed together to form several rows. After 6-8 weeks, burning should be carried out. The cleared ground is then covered with cover crops to minimize soil erosion and to protect the landscape. However, in the case of ex-oil palm areas, the trees are shredded into small pieces and spread to the land. This method of clearing involves no burning and is becoming popular because of environmental concerns (Rajanaidu, 1994).

In the oil palm cultivation, the number of fresh fruit bunches produced and the weight of each bunch will influence the FFB yields. As the palm ages, the bunch weight increases while the bunch number decreases. A number of factors i.e. frond production, sex ratio, abortion and bunch failure rates will affect the number of bunches produced per palm. In addition, drought will also reduce the bunch number as it can influence abortion rate and sex differentiation, where more male inflorescences are produced. Each palm tree yields around

150 kg of FFB (10 bunches x 15 kg) of FFB per year or 3 tonnes of palm oil per year (Rajanaidu, 1994).

The oil palm is the most productive oil bearing plant species compared to any other vegetable oils. Palm oil production is 10 times that of soya bean oil on per hectare basis. The oil palm's fresh fruit bunches (FFB) has an average yield of 18.48 tonnes per hectare per year. The *tenera* hybrid has an average yield of 3.78 tonnes of crude palm oil per hectare per year (MPOB, 2016).

2.6 Uses of palm oil products

The oil palm has many applications but the major uses of the oil palm products are in food applications and in non-food and oleo-chemical sectors and recently in the biomass and biofuel industry (Kushairi, 2013).

2.6.1 Palm oil in food applications

The versatility of palm oil in the formulation of food products is well established. The palm oil has a unique characteristic of being semi-solid at ambient temperature which makes it suitable for many applications in food and non-food products. Palm oil and its products are often used as the raw materials in many products which have oils and fats as their ingredients. The frying industry is one of the examples where palm oil has been used as frying oil. It is most suited for frying as the oil is very stable due to its resistance to oxidation compared to some other vegetable oils, thus providing a longer shelf life. Palm oil is also excellent raw materials in the manufacturing of solid fat products because of its solid fat contents. Due to the fact that it is semi-solid at room temperature, it does not need to undergo hydrogenation process which produces the undesirable *trans* fatty acids. Other uses of palm oil in food products are for cooking/frying, shortenings, margarines and confectionery fats (Kushairi, 2013).

2.6.2 Palm oil in non-foods applications

Oleo-chemical Industry

Palm oil also has wide applications in non-food uses in the production of oleo-chemical products such as soap, surfactants and detergents, cosmetics and personal care products. Even though its applications in non-food offers more value addition, at the moment, less than 20% of the palm oil produced is used in non-food uses. Soap production is one of the applications of which its traditional raw materials used for the soap making were tallow and coconut oil. However, palm and palm kernel oils provide alternative raw materials in soap formulations because the fatty acid compositions are similar to tallow and coconut oil (Kushairi, 2013).

Biomass industry

In recent years, the use of oil palm biomass has gained momentum largely due to global concern over environmental pollution where these oil palm biomass used to be burnt when The biomass generated which includes the fronds, trunks, empty fruit bunches (EFB) can now be fully utilized to manufacture products such as particle board, medium density fibreboard (MDF) and plywood. Palm fibres are also being used for many applications such as flower pots, biodegradable mats for mulching and to control soil erosion and fillers for plastics sheets used in car components (Kushairi, 2013).

Palm oil as biodiesel

Renewable energy such as biodiesel has the potential to replace petroleum-derived transportation fuel in the future (Tan et al., 2015). The increase in energy demand worldwide and the decreasing fossil fuel reserves have prompted the development of sustainable energy sources to progress at a rapid pace to ensure energy security to meet world demand for energy. Currently, the most widely used renewable energy for transport is the first generation biofuel which is biodiesel. Biodiesel is alkyl esters derived from vegetable oils and animal fat. There are many pathways available to produce biodiesel. The commercially avalailable is mainly produced through the transesterification process using methanol in the presence of sodium hydroxide (Puah et al., 2010). According to Freedman et al. (1984), the advantage of using an alkaline catalyst over an acid catalyst is the high conversion in a shorter reaction time under mild conditions. An alternative approach to producing biodiesel is by esterification of fatty acids and alcohols in the presence of a solid acid catalyst (Choo and Goh, 1987; Choo and Ong, 1989).

Research and development of palm biodiesel in Malaysia has been conducted since the early 1980s. The main purpose for the development of a biodiesel at that time was to provide a safety net to stabilize palm oil price in the country during periods of over supply of the palm oil. MPOB had successfully developed a patented technology for producing biodiesel (Choo et al., 1992). The process involves mild reaction reaction conditions of transesterification to convert palm oil into palm biodiesel by methanol in the presence of a base catalyst (Choo et al., 1995).

Currently, there are also technologies available to produce a more advanced form of biodiesel which is the hydrogenated biodiesel that uses a technology known as ecofining that consists of two main processes which are hydrotreating and hydroprocessing (Boonrod et al., 2017). Palm oil can also be used as a feedstock for this product in view that it can be produced all year round. The hydrogenation process removes oxygen molecules from triglyceride molecules and fatty acids by reacting with hydrogen gas (H_2) to produce hydrocarbons similar to petroleum diesel (Bezergianni and Dimitriadis, 2013; Kiatkittipong et al., 2013).

2.7 Transportation process along the palm oil supply chain

The transportation incurred in the Malaysian palm oil supply chain can be divided into several sectors according to activities discussed below. However, in order to understand the transportation process of the oil palm products under study, one must first start with the oil palm fruits. The fruits are attached to spikelets, which are spirally arranged on a stalk to form a compact bunch commonly referred to as fresh fruit bunches (FFB). The fruit is made up of pulp (pericarp), shell (endocarp) and kernel (endosperm). The pericarp comprises of three layers: exocarp (external layer), mesocarp (outer layer) and endocarp (inner layer). The mesocarp is the primary oil storage tissue containing the palm oil. The endocarp and kernel form the nut. The endocarp is a hard shell encasing the kernel. The oil from the palm fruit produces two types of oils, namely palm oil-extracted from the mesocarp, and the palm kernel oil-extracted from the kernel (Latiff, 2000).

Nursery: The objective of the nursery is to provide planting materials of the highest quality for field planting. This is vital for the oil palm crop as the life cycle of the oil palm tree is at least 25 years. Transportation starts from the transport of the pollinated fruit bunches from 'mother palms' grown in selected oil palm plantations to the seed producers. The oil palm has three main types - *dura, tenera* and *pisifera*, differentiated by their shell thickness. The 'mother palm' is the oil palm from the *dura* type. *Pisifera* on the other hand is female sterile, i.e. it does not produce fruit bunches. It is instead used as the male parents to provide the pollens in the cross between the *dura* and the *pisifera* (Kushairi and Rajanaidu, 2000). The commercial planting material in Malaysia is the *tenera* which is a hybrid between the *dura* and *pisefera*. This is obtained through a controlled pollination process for the production of the *tenera* (*dura* X *pisifera* or D x P) seeds. The *dura* has a thick shell (2-8mm), while the *pisifera* is shell-less. Crossing between the *dura* and *pisifera* produces the *tenera* with thin shell.(0.5-4mm). The *tenera* is used as the commercial planting material because the *tenera* has a higher proportion of the oil-bearing mesocarp (75-85% of the fruit by weight) compared to the *dura* (20-65% of the fruit by weight*)* (Kushairi and Rajanaidu, 2000).

Transportation then continues from seed producers to the nursery where the germinated seeds are transported to the nursery to produce the oil palm seedlings at the nursery. There are two options in oil palm nursery: single stage where sowing of germinated seeds into big polythene bags (38cm X 51cm) are done in the main or field nursery and double stage which requires pre-nursery using small polythene bags (15cm X 23cm) before transferring the seedlings into the big polythene bags after three months at the main nursery (Kushairi and Rajanaidu, 2000). In view of this practice, in some two-stage nurseries, there may also be transportation between the pre-nursery and the main nursery. Ten to 12 months later, the seedlings are transported from the nursery to the oil palm plantations. In this study, the transportation of FFB from mother palms up to the transport of the seedlings to the plantation is referred as the nursery stage.

Plantation: Good quality seedlings of around 12-14 months are then transported to the plantations for field planting. The oil palm starts bearing fruit bunches after 2 ½ to 3 years after planting. Transportation of FFB to mills is normally by lorry or tractors with tippers if the mills are nearby. In plantations with flat terrain, FFB can also be transported by railway system using cages.

Palm oil mill: The crude palm oil (CPO) is extracted at the mill. CPO which is produced from the mesocarp of the oil palm fruit is obtained through mechanical extraction of the digested fruits using a twin screw press. The palm kernels (PK) which are obtained from the nuts of the fruits are important by-product of the palm oil mills. Palm oil mills are strategically located usually at the centre of the plantations (Sivasothy, 2000). CPO is transported from palm oil mills to palm oil refineries in road tankers having capacities ranging from 17 – 35 tonnes.

Palm oil refineries: The export of Malaysian palm oil started in the crude form. However, the establishment of the refineries in 1974 had changed this scenario as it enabled Malaysia to export refined or semi-processed yet ready for use palm oil instead of its crude form (Minister of Primary Industries, Malaysia, 2000). As at December 2015, there were 55 refineries in operation in the country with a total refining capacity of 26.95 million tonnes of CPO per year (MPOB, 2016). Most of the refineries are located close to ports to facilitate exports. These refineries also have facilities to fractionate CPO to produce palm olein and palm stearin. The refined products are then transported to the ports either by road tankers or by pipelines linked from refineries direct to ports for export. Some palm oil products are also transported to packers and retailers for local consumption such as palm olein as cooking oil or to manufacturers for further processing to other products. In this study, transportation from the refinery to the fractionation plants was not considered as the latter is located adjacent to the refining plant.

2.8 Global warming and climate change

Global Warming has become a very familiar topic in environmental discussions worldwide of late due to its impact on climate change. Global warming is an important indicator of global pollution (Houghton, 2002). Under the Intergovernmental Panel on Climate Change (IPCC), which is a scientific body that was established in 1988 under the World Meteorological Organization (WMO) and United Nations Environmental Programme (UNEP), Climate Change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of their properties, and which continues for decades or longer. It refers to any change in climate over time, as a result of natural variability or due to human activity (IPCC, 2007).

Warming of the climate system can be observed when the global average air and ocean increase, melting of snow and ice and when there is an increase in global average sea level. The IPPC observed that the global average of surface temperature during the period of 1906 to 2005 was 0.74^{o}C which was higher when compared to the increase during the corresponding year of 1901 to 2000 which was only 0.6^{o}C. The IPCC also observed that the trend in global warming over the 50 years from 1956 to 2005 was 0.13^{o}C per decade which is almost twice that for the 100 years from between 1906 to 2005 (IPCC, 2007). Observations since 1961 saw that the increase in the average global temperature has resulted in the increase in the ocean depths to at least 3000m and the ocean has been taking up over

80% of the heat being added as the result of the changes to the climate system. The increase in the sea level is also parallel with warming of global surface temperature. The rise of the global sea level saw an increase in the average rate of 1.8 mm per year between 1961 to 2003 as compared to the average rate of about 3.1 mm per year for the corresponding period between 1993 to 2003 (IPCC, 2007).

2.8.1 The greenhouse effect

The greenhouse effect in the atmosphere started with the introduction of the fossil-fueled industrial revolution in England during the eighteenth century from the use of coal. The burning of coal during that period filled the English skies with acrid smoke (Singh, 2008).

The nitrogen and oxygen gases that made up the bulk of the atmosphere do not absorb or emit any thermal radiation. However, water vapour, carbon dioxide and some other minor gases that are present in the atmosphere in smaller quantities can absorb some of the thermal radiation and acting as a partial blanket for this radiation. This causes a difference of about 21^{o}C between the actual average earth surface temperature which is about 15^{o}C and -6^{o}C which when the atmosphere contains nitrogen and oxygen only. This blanketing is known as the *natural greenhouse effect* while the gases are known as greenhouse gases. It is referred as 'natural' because all the atmospheric gases (except chlorofluorocarbons-CFCs) had been there even before human beings came on the scene (Houghton, 2002).

This process naturally warms the earth and its atmosphere. The radiation energy coming from the sun and the thermal radiation emitted from the earth and the atmosphere that is radiated to space need to be balanced. If this balance is disturbed for example by an increase in the level of carbon dioxide in the atmosphere, it will result in an increase in the earth's surface temperature. This is the concept of global warming (Houghton, 2002). Any changes in the atmospheric concentrations of the greenhouse gases and aerosols, land cover and solar radiation will affect the energy balance of the climate system and these changes are the drivers of climate change because they will affect the absorption, scattering and the emission of radiation within the atmosphere as well as at the Earth's surface. This positive or negative change in the energy balance is used to compare warming or cooling influences on global climate (IPCC, 2007).

The warming effect of the greenhouse gases in the atmosphere was first studied in 1827 by a French scientist Jean-Baptise Fourier, who observed similarity between what happens in atmosphere and what happens in the glass of a greenhouse, hence the name 'greenhouse effect'. A Swedish chemist, Svante Arrhenius later in 1896 calculated the effect of increasing the concentration of the greenhouses gases by doubling the concentration of carbon dioxide found that this will increase the global average temperature by 5^oC to 6^oC. Around 1940, GS Callendar, a scientist working in England, was the first to calculate the warming effect due to the increasing carbon dioxide arising from the burning of fossil fuels (Houghton, 2002).

Global GHG emissions as a result from human activities have grown significantly from pre-industrial times which observed an increase of 70% between 1970 and 2004 (IPCC, 2007). Continued GHG emissions at the current rates would result in further global warming and create many changes in the global climate system during the 21st century which would be larger than those observed earlier during the 20th century. According to the IPCC, the largest growth in GHG emissions came from energy supply, transport and industry, (IPCC, 2007).

2.8.2 The greenhouse gases (GHG)

The major greenhouse gases in the atmosphere are water vapor (H_20), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chloroflorocarbons (CFCs) and ozone (O_3). Apart from CFCs (which are man-made) all occur naturally. However, some greenhouse gasses concentrations are increasing substantially arising from human activity, creating the enhanced or *anthropogenic e*ffect (BTCE, 1995). CO_2, methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine) such as CFCs are four GHGs emitted from human activities (IPCC, 2007). Atmospheric concentrations of GHGs increase when there are larger emissions than the process for their removal. Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly due to human activities since 1750 and it is now far exceeding pre-industrial values (IPCC, 2007).

Carbon dioxide (CO_2) is by far the most important anthropogenic GHG. Increases in global CO_2 concentrations are mainly due to fossil fuel use, with land-use change providing another significant but smaller contribution. The increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use while the increase in N_2O concentration is primarily due to agriculture (IPCC, 2007).

In view that the total greenhouse effect is the result of the emissions of several different gases, those emissions need to be expressed based on a common unit. In order to do this, CO_2 equivalent emissions is used, which is calculated on the basis of the *global warming potential* (GWP) for each gas. The GWP is an index, defined as the warming effect over a given period from the emission of a particular gas, relative to an equal mass of CO_2 (BTRE, 1995). According to IPCC, 1 kg of CH_4 is equivalent to 23 kg of CO_2 emissions, I kg of N_2O is equivalent to 296 kg of CO_2 emissions (IPCC, 2006).

2.9 The environmental impacts of global warming and climate change

The IPCC in its 4th Report of the Assessment of the IPCC on Climate Change in November 2007 reported the following key findings regarding the impacts of climate change:

Impacts on ecosystems

Some examples of the numerous impacts on the ecosystems due to climate change include flooding, drought, wildfires and ocean acidification. Land-use change, pollution and overexploitation of resources are some of the drivers that lead to global change that impacts the ecosystem.

Impacts on food

In some regions, the droughts can result in decrease in crop productivity and may increase the risk of hunger.

Impacts on coasts

Climate change can also have an impact on coasts which can lead to coastal erosion and causes sea level to rise. These effects became worse by increasing human-induced pressures on coastal areas that can lead to flooding due to sea level rise.

Impacts on industry and society

The industries and societies that are mostly affected by the impacts of climate change are those communities which live around coastal and areas prone to floods as well as those whose economies are affected by the changes in the weather conditions.

Impact on health

The impacts on the health of the population due to climate change are increased deaths, increased in malnutrition, other diseases and injuries due to extreme weather conditions, increased diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change.

Impacts on water

The impact from climate change on water will be on population growth and economy including urbanisation. Water losses from the melting of glaciers and reductions in snow cover over in recent years are expected to reduce water availability even more.

Impacts on ocean acidification

The uptake of carbon from the environment since 1750 has made the ocean becoming more acidic. Increasing atmospheric CO_2 concentrations has resulted further acidification. The continuous acidification of oceans will have negative impacts on marine life such as corals and their dependent species (IPCC, 2007).

2.10 The environmental and health impacts of transportation

Pollution during vehicle operation is the result from incomplete combustion and from evaporation of the fuel itself. The first few minutes of a trip releases higher emission, a fact referred to as cold start emission (Spielmann et. al., 2004). The transport sector generates both *direct* (radiatively active) and *indirect* greenhouse gases. The main direct greenhouse gases emitted from the transport sector (apart from water vapour) are carbon dioxide, methane, nitrous oxide and chloroflorocarbons.

Indirect greenhouse gases such as carbon monoxide (CO), oxides of nitrogen other than nitrous oxide (N_2O), which is nitrogen oxide (NOx) and non-methane volatile organic compounds (NMVOCs) do not have a strong radiative effects themselves, but influence atmospheric concentrations of the direct greenhouse gases (BTCE, 1995).

Emissions from the transportation particularly from road vehicles, can have detrimental effects on both human wellbeing and the natural environment. The primary adverse impacts on the environment due to emission from the transport sector relate to the following:

Local air quality

The emission of noxious gases such as carbon monoxide and nitrogen dioxide can cause increased susceptibility to respiratory infections; the formation of low-level ozone (the main component of smog); from increases in urban levels of toxic substances such as lead, benzene and cadmium; the formation of highly reactive compounds (called atmospheric oxidants) are capable of damaging crops and buildings; the emission of sulfur dioxide which can cause acid rain; and the generation of suspended particle hazes (called aerosols), which reduce visibility and influence cloud formation.

Global atmospheric change

The effect to atmospheric change is through the depletion of stratospheric ozone, due to the release of chlorofluorocarbons (CFCs) from air-conditioners and refrigeration; and from the warming effect of certain gaseous emissions (*greenhouse effect*) (BTCE, 1995).

Particulate air pollution has received considerable attention lately as epidemiological studies show that increases in human mortality from respiratory and cardiovascular diseases can be associated with particulate concentrations lower than those previously believed to affect human health (Reichhardt, 1995). In literature, different size classes are distinguished. Established size fractions are: ultra-fine particles (diameter < 0.1 μm), the fine fraction with aerodynamic diameter smaller than 2.5 μm (PM2.5), the coarse fraction with an aerodynamic diameter between 2.5 and 10 μm (PM 10-2.5), and large particles with a diameter greater than 10 μm. Additional size classes often used in inventories are PM10, comprising all particles with a diameter less than 10 μm (i.e. the sum of the fine and coarse fraction) and

TSP (total suspended particles) comprising the fine, coarse and large particles (Lükewille et al. (2001).

Mobile sources are important contributors to total emissions of PM in particular to fine particulate matters. It has been demonstrated that concentrations of fine particles are high close to main roads and that road transport is a major source of fine particulates in urban areas (Koch, 2000). Particulate Matter emissions can be either primarily or secondary in nature. Primary particles are emitted by a source as particles and dispersed without any major chemical transformation. Secondary particulates are formed by transformation of gaseous pollutant (SO_2, NO_x, NH_3 and VOC sections) in the atmosphere. Primarily particle emissions from mobile sources have two entirely different origins: exhaust emissions due to fuel combustion and non-exhaust emissions, such as abrasion of tyres and breaks, abrasion of road surface and re-suspended road dust (Spielmann et. al., 2004).

Diesel emissions are mostly sub micrometer agglomerates of carbonaceous spherical particles. Larger particles contain up to 4000 individual spherical particles clustered as agglomerates up to 30 µm. Morawska et al. (1998). A significant proportion (estimated at about 90 percent) is smaller than 1 µm. Harrison et al. (2000). For gasoline vehicles, no particulate emissions are accounted for, thus information for the size distribution of PM emissions from gasoline is not required. However, in case that emission factors are available, particles from gasoline vehicle exhausts are mostly carbonaceous spherical sub-micro agglomerates ranging from ten to 80 nm, consisting of a carbon core with various associated compounds (Ristovski et al.,1998). In a recent US-study, Cadle et al. (2001) measured the size distribution for 30 light duty vehicles (1990-1997 models) and estimated that on average 95.1, 88.7 and 83.6 percent of mass was smaller than 12.2, 3.0 and 1.2 µm, respectively.

Heavy metals such as cadmium, copper, chromium, nickel, selenium and zinc can be found in fuels. Hassel et al. (1987) estimated the lead emissions by assuming that 75% of lead contained in the fuel is emitted into air. 25% are assumed to remain in the power train and exhaust system (Keller et al.,1995).

2.11 Sustainable development to slow and stabilize climate change

International response to climate change resulted in the development of the United Nations Framework Convention on Climate Change (UNFCCC). It was launched in December 1990 by the UN General Assembly and was adopted in May 1992. The UNFCCC sets out a framework for action with the objectives to stabilise atmospheric concentrations of greenhouse gases at a level that would prevent activities by human which could lead to "dangerous interference" with the climate system. The UNFCCC entered into force on 21 March 1994. It now has 186 Parties. Since its establishment, meetings of the Conference of Parties (COP) have taken place, as well as numerous workshops and meetings of the COP's subsidiary bodies, the Subsidiary Body for Scientific and Technological Advice (SBSTA) and the Subsidiary Body for Implementation (SBI). In 1995, the Ad Hoc Group on the Berlin Mandate was established by the first Conference of the Parties (or COP-1) to reach agreement on efforts to fight climate change (UNFCCC, 2009).

After intense negotiations at COP-3, held in Kyoto, Japan in December 1997, delegates agreed to a Protocol to the UNFCCC that commits developed countries and countries making the transition to a market economy to achieve quantified targets for decreasing their emissions of greenhouse gases. These countries, known under the UNFCCC as Annex I Parties, committed themselves to reducing their overall emissions of six greenhouse gases (i.e. carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride) by at least 5% below 1990 levels over the period between 2008 and 2012, with specific targets varying from country to country (UNFCCC, 2009; Houghton, 2002). Subsequently, the Doha Amendment to the Kyoto Protocol adopted in 2012 now requires developed countries to reduce their GHG emission to at least 18% against the baseline of 1990 (UNFCCC, 2014).

The Protocol also provided the basis for three mechanisms to assist Annex I Parties in meeting their national targets cost-effectively - an emissions trading system, joint implementation (JI) of emissions-reduction projects between Annex I Parties, and a Clean Development Mechanism (CDM) to encourage joint projects between Annex I and non-Annex I (developing country) Parties. However, it was left for subsequent meetings to decide on most of the rules and operational details that will determine how these cuts in emissions are achieved and how countries' efforts are measured and assessed. Although some countries have signed the Protocol, most are waiting until these operational details are negotiated before deciding whether to ratify. To enter into force, the Protocol must be ratified by 55 Parties to the UNFCCC, including Annex I Parties representing at least 55% of the total carbon dioxide emissions for 1990 (UNFCCC, 2009).

Since the adoption of the Convention, Parties have continued to negotiate in order to agree on decisions and conclusions that will advance its implementation. Critical issues for resolution included rules relating to the three mechanisms, a regime for assessing compliance, and accounting methods for national emissions and emissions reductions. Rules on crediting countries for carbon sinks were also to be addressed (UNFCCC, 2009).

Issues under the UNFCCC requiring resolution included questions of capacity building, the transfer and development of technology and assistance to those developing countries that are especially vulnerable to the adverse effects of climate change or to actions taken by industrialised countries to combat climate change (UNFCCC, 2009).

2.12 Adaptation and mitigation options to reduce GHG emissions to slow and stabilize climate change

The communities can respond to climate change by adapting the impacts and by reducing GHG emissions (mitigation), therefore resulting in reducing the rate and size of the change (IPCC, 2007). Changes in the lifestyle and behaviour can assist to mitigate climate change across all sectors. Management practices can also have a positive role. Some of the actions that can be taken in mitigating climate change include changes in consumption patterns, education and awareness as well as changes in policies that support and promote incentives to producers and consumers to encourage investment in low-GHG products, technologies and processes (IPCC, 2007).

Mitigation options that could be taken by countries and organizations to reduce their GHG emissions include:

- Initiatives through mechanisms developed under the Kyoto Protocol i.e. Joint Implementation (JI) which allows industrialized countries to implement projects that reduce emissions or increase removals by sinks in the territories of other industrialized countries. Examples of JI projects are replacement of a coal-fired power plant with a more efficient combined heat and power plant or the reforestation of an area of land; Clean Development Mechanism (CDM) allows industrialized countries to implement projects that reduce emissions in developing countries. The certified emissions can be used by industrialized countries to meet their emission targets while the projects can help developing countries to achieve sustainable development; and Emissions Trading which allows industrialized countries to purchase 'assigned amounts units' of emissions from other industrialized countries that find it easier to meet their emissions targets.

- Controlling on the use of chlorofluorocarbons (CFCs) as these substances, though not a greenhouse gas, they deplete the atmospheric ozone. Theses substances are already controlled under the Montreal Protocol.
- Reduction of deforestation
- Increase in forestation
- Reduction in methane emission. Methane is a less important greenhouse gas than carbon dioxide, contributing perhaps fifteen percent to the present level of global warming. The stabilization of its atmospheric concentration would contribute a small but significant amount to the overall problem. Examples where methane emission can be controlled are through biomass burning during deforestation, landfill sites where the methane production from the waste can be recycled and or used for energy generation by incineration or if arrangement can be made to collect the methane at landfill sites that could be used for energy generation or if the quantity is insufficient, turning the methane into carbon dioxide which molecule-for-molecule is less effective than methane as a greenhouse gas (Houghton, 2002).

- Increase in energy saving where in the transport sector, mitigation technologies and practices currently commercially available may include the use of more fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; higher efficiency aircraft; advanced electric and the use of hybrid vehicles with more powerful and reliable batteries.

- Increased implementation of renewable sources of energy supply. In the transport sector, the use of biofuels and biofuel blending are measures shown to be environmentally effective.

- Regulatory programmes such as enforcing CO_2 standards for road transport and mandatory fuel economy (IPPC, 2007).

2.13 Energy and transport for the future

The growing importance on the use of biofuels as a renewable source of energy supply in mitigating climate change has resulted in creating a competition of the raw materials for land as well as competing for the same materials as food (Choo et. al. 2009). The impacts of these concerns have increased the interest in developing 2nd generation biofuels. The 1st generation biofuels refer to bio-energy e.g biodiesel (fatty acid alkyl esters e.g methyl esters) and bio-ethanol derived from edible feedstock. These include bio-ethanol from sugar and starch crops and biodiesel from animal fats and oilseed crops. The 2nd generation biofuels refer to bio-oils, ligno-cellulosic bio-ethanol and biodiesel derived from non-edible feedstock including agriculture and forestry residues, algae and many forms of waste that contain high levels of organic matter such as municipal waste. The 2nd generation biofuels have been viewed as better candidates than the 1st generation biofuels in terms of GHG reduction benefits and the fact that they do not compete directly with food production (Choo et. al. 2009). The 3rd generation biofuels came into the picture only recently and they refer to biofuel derived from algae. Previously, algae were grouped together with 2nd generation biofuels. However, in view that algae have the potential for much higher yields compared to other feedstock, algae were moved to their own category (Biofuels, 2014).

Green diesel is a fuel of the 2nd generation type of biodiesel that is produced from oil field crops (both consumable and non-consumable) such as palm oil, soya bean oil, sunflower oil, rapeseed, and jatropha oil using a hydrogenation process (Hilbers et al., 2015; Mohammad et al., 2013;Uusitalo et al., 2014).

With regards to technologies for reducing carbon emissions from cars, an important recent development is the development of the hybrid electric car that combines an internal combustion engine with an electric drive train and battery. The gain in efficiency and therefore fuel economy is around fifty percent. They mainly arise from: i) use of regenerative braking (with the motor used as a generator and captured electricity stored in the battery, ii) running on the battery and electric traction only when in slow moving or congested traffic, iii) avoiding low efficiency modes of the internal combustion engine and iv) downsizing the internal combustion engine through the use of the motor/battery as a power booster. Both Toyota and Honda have introduced commercially available hybrid models and other manufacturers are not far behind (Houghton, 2002).

Other significant efficiency improvements have come from the use of lower weight structural materials, improvements in low-air resistance design and the availability of direct injection diesel engines, long used in heavy trucks, for automobiles and light trucks (Houghton, 2002).

2.14 The National Biofuel Policy

The use of biofuel is becoming increasingly important as an alternative energy sources to the fast depleting non-renewable fossil fuel. Worldwide environmental concern over fossil fuel particularly for its contribution to the increase in GHG emissions and the escalating of petroleum prices has given rise to the development of alternative fuels that are more sustainable. A number of countries such as the EU, United States, Japan and Brazil have embarked on their biofuels programme. For example the use of biodiesel from rapeseed oil in Europe has achieved widespread acceptance. Malaysia too needs to address the associated environmental issues, particularly greenhouse gas emissions. In this regard, the National Biofuel Policy was formulated to encourage the use of biofuel in line with the objectives of the UNFCC to which Malaysia is a party. The objectives of the National Biofuel Policy are as follows:

i. supplementing the depleting supply of fossil fuels with renewable resources

ii. mobilizing local resources for biofuels

iii. exploiting local technology to generate energy for the transportation and industrial sector.

iv. Paving the way for exports of biofuels

v. Benefiting from the spin-off effect of more stable prices for palm oil

(MPIC, 2006).

Malaysia has embarked on a comprehensive palm biodiesel programme since 1982 and has successfully established the use of palm methyl esters and the blend of processed palm oil (5%) with petroleum diesel (95%) as a suitable fuel for transportation and industrial sectors. In line with this Policy, Malaysia has implement the biodiesel mandate which requires that all petrol stations in the country to sell B5 (a blend of 5% palm oil biodiesel and 95% petroleum diesel) nationwide by the end of 2014. The B5 programme was launched in phases starting with the implementation in the Central region which encompasses Putrajaya, Melaka, Negeri Sembilan, Kuala Lumpur and Selangor between June and November 2011 and later expanded to the Southern region (Johor) in July 2013. The B5 programme was further expanded to cover the states under Northern region (Perlis, Kedah, Penang and Perak) in October 2013 and the Eastern region (Kelantan, Pahang and Terengganu) in January 2014 (The Star, 2014). It went nationwide by the end of the 2014 including Sabah and Sarawak when all the petrol stations were fully equipped with the blending facilities (Bloomberg, 2014). The implement of this mandate is expected to reduce the use of fossil fuels, minimize the emission of GHG (carbon dioxide), carbon monoxide, sulphur dioxide and particulates and will enhance the quality of the environment (MPIC, 2006).

The Honourable Minister of the Plantation Industries and Commodities launched the B7 which was a blend of 7% palm oil biodiesel and 93% petroleum diesel on 17 January 2015 (The Borneo Post, 2016). The government also studied the blending of 10% biodiesel with 90% petroleum diesel (B10) compatibility, however, the Minister of the Plantation Industries and Commodities made a statement on 17 November 2016 that the implementation of the B10 and the B7 programmes in the transportation and industrial sectors be deferred to a later date to take into account the difference in the crude palm oil and diesel prices in the current volatile market (BERNAMA, 2016).

2.15 Other countries biofuel policies

Many countries have also made initiatives to reduce dependence on fossil fuels by finding other renewable resources. These initiatives are done through laws and policies to ensure their compliance. This is important in view that the diference between vegetable oils and diesel prices varies and can be quite volatile. In Europe, the Renewable Energy Directive establishes an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfill at least 20% of its total energy needs with renewables by 2020 to be achieved through the attainment of individual countries national targets. All EU countries must also ensure that at least 10% of their transport fuels come from renewable sources by 2020 (European Commission, 2009). On 30 November 2016, the Comission published a proposal for a revised Renewable Energy Directive to make the EU a global leader in renewable energy and ensure that a target of at least 27% renewables in the final energy consumption in the EU by 20130 is met (European Commission, 2016).

The Renewable Fuel Standard (RFS) programme in the US is a national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel. The four renewable fuel categories under the RFS are:

- Biomass-based diesel

- Cellulosic biofuel
- Advanced biofuel
- Total renewable fuel

The program is being implemented by the US Environmental Protection Agency (EPA) in consultation with the U.S. Department of Agriculture and the Department of Energy. The RFS program sets a long term goals of 36 billion gallons of renewable fuel with yearly volume requirements to 2022 (US EPA, 2016).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Method

The study evaluates the environmental impacts of the handling and transportation of the RBD palm oil and its fractionated products, namely RBD palm olein and RBD palm stearin. The evaluation of the environmental impacts is done using the Life Cycle Assessment (LCA) approach. This is done by compiling and evaluating the input (energy resources) and the output (combustion emissions) and the potential environmental impacts of the transportation process within the scope of the study (Goedkoop et. al., 2007). This methodology also aligns with the principles and requirements as stipulated in the ISO International Standards namely the ISO 14040: Environmental Management – Life Cycle Assessment –Principles and Framework and the ISO 14044: Environmental Management- Life Cycle Assessment – Requirements and Guidelines (ISO, 2006).

The ISO standard describes the Life Cycle Assessment as comprising of the following four phases:

i) Identifying the goal definition and scope of the LCA study;

ii) Life Cycle Inventory (LCI) analysis;

iii) Life Cycle Impact Assessment (LCIA); and

iv) Interpretation of the results, which is the direct application of the LCA studies e.g. in product development and improvement, in strategic planning, policy making and in marketing and promotion of products or services (ISO, 2006).

3.2 Goal definition

The aim of this study is to use the life cycle assessment approach to identify at which stage of the palm oil supply chain that transportation contributes the most to the environmental impact within the boundary of the study as shown in Figure 3.1.

Recommendations based on the outcome of the study can be used by policy makers and the stakeholders in strategic planning to improve on the existing transportation system for a more positive impact on the environment. The data from this LCA study is also intended to be used in the marketing and promotion of palm oil and palm oil products.

3.3 Scope definition

The system boundary of the study which is from cradle to gate as shown in the system boundary in Figure 3.1. The transportation from systems that are directly related in the production of the RBD palm oil, RBD palm olein and RBD palm stearin will be included in the system boundary. Other systems such as the production of palm kernel oil at the kernel crushing plants is considered a different system, therefore the extraction of palm kernel oil will be outside the system boundary and its transportation will not be included.

The transportation included in the system boundary in the study is taken at the point of exit from one stage of the product system to the next stage along the palm oil suply chain and any transportation as part of the operation in the production of the product within the product system is not included in the study, i.e. the transportation of field collection of fresh fruit bunches is considered part of the operation in the production of the FFB within the plantation and is not included.

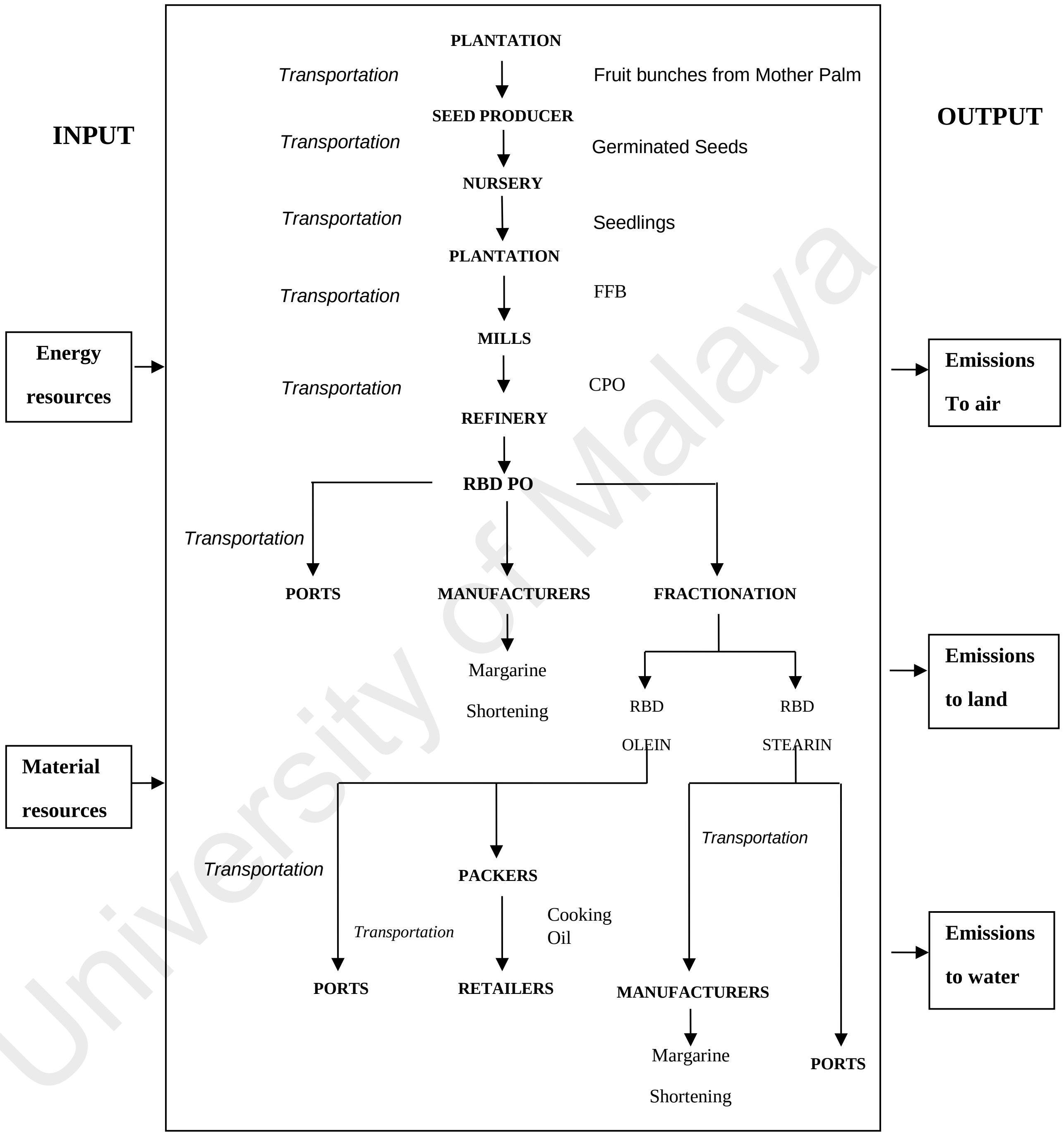

Figure 3.1: System Boundary for the Transportation of palm oil, palm olein and palm stearin along the palm oil supply chain

3.3.1 Exclusion

The production of capital goods such as machinery, buildings, vehicles manufacturing, vehicles maintenance and disposals, transport infrastructure and waste treatment are excluded.

3.3.2 Functional unit

The functional unit is to provide a reference to which the inputs and outputs are related. The reference is necessary to ensure comparability of LCA results. Comparability of LCA results is critical when different systems are assessed, to ensure that comparisons are made on a common basis (Goedkoop et al., 2007).

In the study, the functional units for the various products are as follows: fruit bunches: kgkm; seed: seedkm; seedling: seedlingkm; FFB: tkm; CPO: tkm; RBD palm oil: tkm; RBD palm olein: tkm and RBD palm stearin: tkm. One kgkm is defined as the transport of one kilogram of the fruit bunches over one kilometer and one tkm is defined as the transport of one tonne of the relevant palm product over one kilometer while one seedkm and one seedlingkm are defined as the transport of one unit of the seed and seedling over one kilometer respectively (Spielmann et al., 2004).

In this study, the functional units are as follows:

fruit bunches	:	kgkm
seed	:	seedkm
seedling	:	seedlingkm

FFB	:	tkm
CPO	:	tkm
RBD palm oil	:	tkm
RBD palm olein	:	tkm
RBD palm stearin	:	tkm

3.4 Allocation of co-products

It is noted that in the palm oil production chain, there are by-products that are being produced i.e. palm kernels at the mills during the production of crude palm oil and palm fatty acid distillate (PFAD), which is an important co-product of the refining process. The impacts of co-products produced will be calculated on the basis of allocation by weight. The allocation used in the case of crude palm oil production is 71:29 (CPO:PK) and for the refined palm oil production is 95.5:4.5 (RBD PO:PFAD). The allocation based on weight for the refined palm oil fractionation to produce RBD palm olein (RBD POo) and RBD palm stearin (RBD POs) is 75:25 (RBD POo:RBD POs) (Tan et. al., 2009).

3.5 Data collection and sampling design

Figure 3.2 shows the flowchart of the methodology adopted in this study. The study started with the sampling design in order to get a representative samples in the population for the data collection. Questionnaires were then developed and sent to all the stakeholders within the scope of the study.

The data received were validated through a verification process. The energy consumption and material used in the study were then calculated in the LCI stage after which the LCIA will be conducted using the LCI results. This will be followed by the interpretation of the results to form the conclusions in line with the goals and scope of the study and finally the recommended mitigation options.

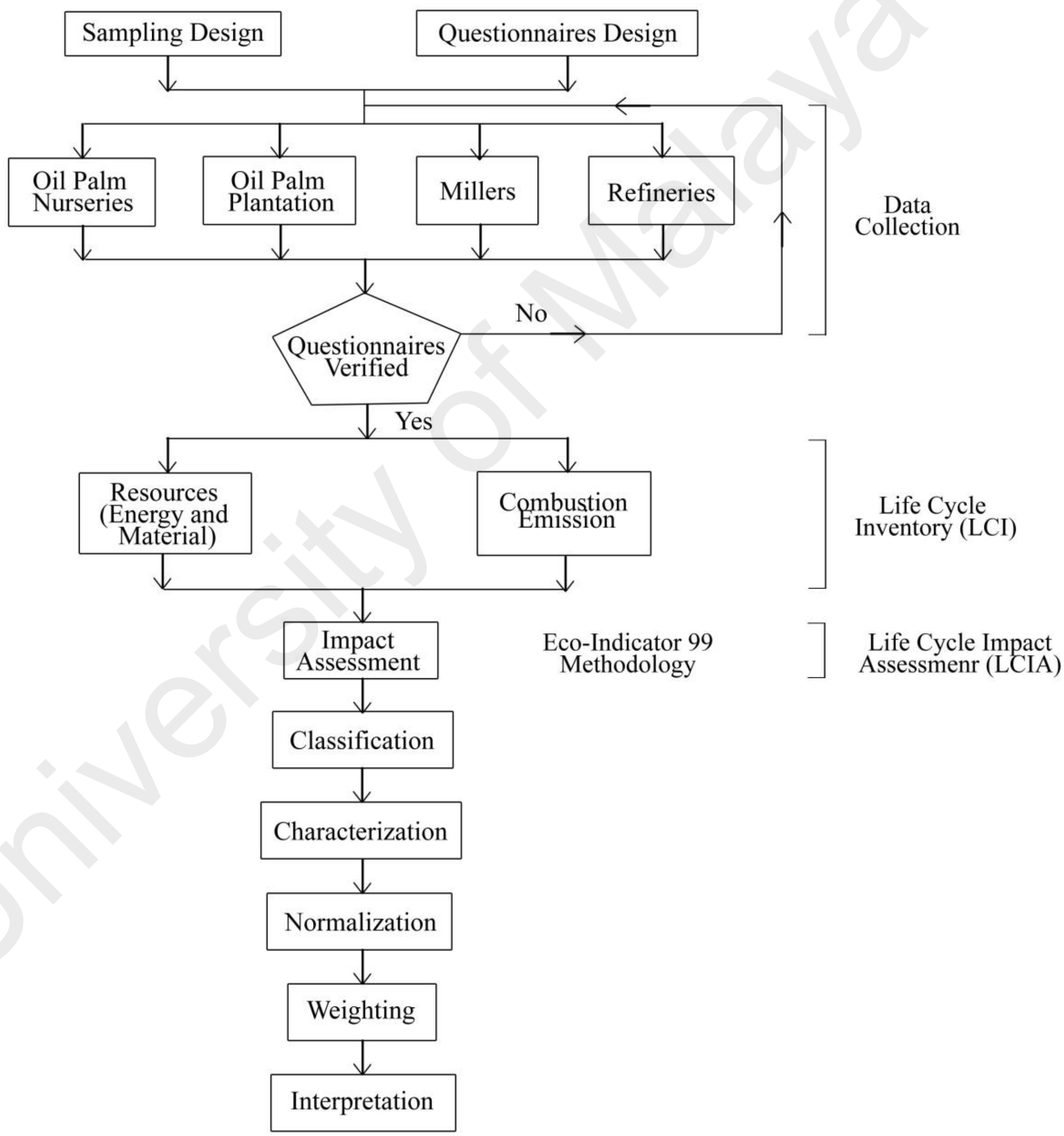

Figure 3.2: Flowchart of methodology in the study

The data were gathered from a survey through questionnaires sent to oil palm nursery managers, oil palm plantation managers, millers and refiners who transport the palm oil products to retailers and exporters across Malaysia. The oil palm industry was located throughout the country including in Sabah and Sarawak. The representativeness of the data collected was assured by sampling data from all regions in Malaysia including Sabah and Sarawak. In addition to the geographical coverage, the samples also covered the different sizes of the premises under study: estates (more than 1000 hectares) and small holders (less than 40 hectares); processing tonnage; different management and ownership: covering private companies, Government and state schemes and covering different types of transportation mode. In the determination of the average distance between the gates at each of the unit process, the different locations e.g. coastal and mainland was also considered in order to get good distribution coverage of the samples studied.

The data gathered from the questionainnaires for the transportation of the palm oil, palm olein and palm stearin along the palm oil supply chain was for the production year 2008. This is because during the study period (2008/9-2009/10), though the questionnaires requested for a three year data from 2006-2008, the data obtained were mostly from current figures which was for the year 2008.

In order for the data collected to be realiable, the data gathered were verified. The verifications of the data were conducted through on-site interviews and other forms of communication i.e. e-mails, telephones and faxes.

3.6 Development of questionnaires

In addition to providing general information on the name of the premises, locations and their size, the questionnaires were developed to gather foreground data for the calculations of the input and output in the LCI stage on the following variables:

i. Amount of product transported (tonne)

ii. Vehicle capacity (tonne)

iii. Unladen weight of vehicles (empty weight)

iv. Laden weight of vehicles (weight of vehicles with load)

v. Transportation distance (km)

vi. Type of fuel used

vii. Fuel consumption (L)

viii. Electricity consumption (kWh)

The data for the amount of products transported and vehicle capacity in the questionnaires were gathered from responses received which were obtained from the records at the respective seed producers, nurseries, plantation managers, mill managers and refineries who had participated in the study. The unladen weight and laden weight of the vehicles are obtained from information gathered from the questionnaires and by verification from the respondents as well as from transport operators including lorry drivers based on the amount of product transported. Transportation distance was determined from the distance travelled for each vehicle per month to transport certain amount of product of which the data were provided by the respondents. Type of fuel used and fuel consumption were obtained from responses received and verified from the transport operators. Electricity consumption was gathered from data given by respondents for some refineries which had transported the RBD palm oil and RBD palm olein to ports by pipelines.

The questionnaires that were developed and sent to all the stakeholders within the boundary of the study are attached as in Appendices1-5.

3.7 Life Cycle Inventory (LCI)

The Life Cycle Inventory phase of the LCA study is done by compiling and evaluating the input (resources) and the output (emissions) data from all the unit processes within the defined system boundary.

The life cycle inventory for transportation includes the energy requirements and emission generated (US EPA, 1993). This phase involves the collection of data to quantify the relevant inputs and outputs of all the unit processes within the system boundary. In this study, the input data includes data on the energy and material used and the combustion emissions released from the transportation process as the output data. The data collection in the LCI phase is a resource-intensive process of the LCA study as well as time consuming. Data collection in LCA studies are divided into two types i.e. foreground data, which are site-specific data obtained through questionnaires. The background data on the other hand is data that are taken from literature and data from databases (Goedkoop et al., 2007).

Table 3.1 shows the detail of the product system for each of the unit process and the source of the data. The input from the data in the study for the materials and energy were foreground data which are site specific obtained from the questionaires received. However, the data for the output (combustion emissions), examples methane, CO_2, N_2O, NO_x, CO, non-methane hydrocarbon, SO_2, particulate matter and heavy metals i.e. cadmium, copper, chromium, nickel, selenium, zink, lead and mercury were obtained using emission factors for the different vehicle classes which were sourced from the Ecoinvent database. The combussions emissions were calculated using these emission factors for the transportation of the palm oil, palm olein and palm stearin along the palm oil supply chain and from data on the amount of products and transportation distance of the products transported as the emissions were based on the amount of the emission for one functional unit of tkm. The calculation of the GHG emission for the electricity used to transport the RBD palm oil and RBD palm olein to ports by pipelines using data from the Malaysian database from SIRIM.

The outcome of the life cycle inventory analysis provides the starting point for the life cycle impact assessment.

Table 3.1: Product system of the transportation process along the palm oil supply chain and the data source

Product system	Unit process	Process starts	Nature of transmission	Process ends	Data source
Fruit bunches (from 'mother palm')	Transportation of fruit bunches (from 'mother palm')	Transportation from plantation gate to seed producer	Physical Chemical	Delivery of fruit bunches to seed producer gate	Foreground/ site specific Background /Ecoinvent database
Germinated seeds	Transportation of germinated seeds	Transportation from seed producer gate	Physical Chemical	Delivery of germinated seeds to nursery gate	Foreground/ site specific

					Background /Ecoinvent database
Seedlings	Transportation of seedlings	Transportation from the nursery gate	Physical Chemical	Delivery of seedlings to plantation gate	Foreground/ site specific Background /Ecoinvent database
Fresh fruit bunches (FFB)	Transportation of FFB	Transportation from the plantation gate	Physical Chemical	Delivery of FFB to mill gate	Foreground/ site specific Background /Ecoinvent database
Crude palm oil (CPO)	Transportation of CPO	Transportation from the mill gate	Physical Chemical	Delivery of CPO to refinery gate	Foreground/ site specific Background /Ecoinvent database
RBD palm oil (PO)	Transportation of RBD PO	Transportation from the refinery gate	Physical Chemical	Delivery of RBD PO to port gate	Foreground/ site specific Background /Ecoinvent database Electricity from from Malaysian database (SIRIM)
RBD palm olein (POo)	Transportation of RBD POo	Transportation from the refinery gate	Physical Chemical	Delivery of RBD POo to port gate	Foreground/ site specific Background /Ecoinvent database Electricity from from Malaysian

					database (SIRIM)
RBD palm stearin (POs)	Transportation of RBD Pos	Transportation from the refinery gate	Physical Chemical	Delivery of RBD POs to port gate	Foreground/ site specific Background /Ecoinvent database
RBD PO	Transportation of RBD PO	Transportation from the refinery gate	Physical Chemical	Delivery of RBD PO to retailers gate	Foreground/ site specific Background /Ecoinvent database
RBD POo	Transportation of RBD POo	Transportation from the refinery gate	Physical Chemical	Delivery of RBD POo to retailers gate	Foreground/ site specific Background /Ecoinvent database
RBD POs	Transportation of RBD POs	Transportation from the refinery gate	Physical Chemical	Delivery of RBD POs to retailers gate	Foreground/ site specific Background /Ecoinvent database

3.8 Life Cycle Impact Assessment (LCIA)

The life cycle impact assessment (LCIA) phase of the LCA is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system using the LCI results. The LCIA phase also provides information for the life cycle interpretation phase. This process involves associating the inventory data with specific environmental impact categories, (which represents the environmental issues of concern) and category indicators, (the quantifiable representation of the impact category, which is based on the LCI results) thereby attempting to understand these impacts. In the LCIA phase, the selection of the impact categories is therefore critical and should be consistent with the goals and scope of the LCA study to ensure that the goals and scope of the LCA study is achieved (ISO, 2006).

Most LCA experts do not develop impact assessment methodologies. They prefer to select one that has already been published. Therefore, an important step in LCA studies is the selection of the methods and the appropriate impact categories. This choice is guided by the goal of the study. The selection is also guided by the endpoints. Endpoints are understood as issues of environmental concerns such as human health, extinction of species, availability of resources for future generations etc. (Goedkoop et al., 2007).

In this study, the Eco-indicator 99 methodology was used for the impact assessment. This is a damaged oriented approach or end-point approach for the impact assessment. The impact categories considered in this methodology include the following:

- Carcinogens
- Respiratory organics
- Respiratory inorganics
- climate change
- radiation
- ozone layer depletion
- ecotoxicity

- acidification/ eutrophication
- land use
- mineral and fossil fuel

3.9 Classification

The inventory result of an LCA usually contains hundreds of different emissions and resource extraction parameters. Once the relevant impact categories are determined, these LCI results must be assigned to these impact categories. For example, CO_2 and CH_4 are both assigned to the impact category *Global warming* while SO_2 and NH_3 are both assigned to impact category *Acidification* (Goedkoop et al., 2007).

3.10 Characterization

Once the impact categories are defined and the LCI results are assigned to these impact categories, it is necessary to define characterization factors. These factors should reflect the relative contribution of an LCI result to the impact category indicator result. For example, on a time scale of 100 years, the contribution of 1 kg of CH_4 to global warming is 42 times as high as the emission of 1 kg of CO_2. This means that if the characterization factor of CO_2 is 1, the characterization factor of CH_4 is 42. Thus, the impact category indicator result for global warming can be calculated by multiplying the LCI result with the characterization factor (Goedkoop et al., 2007).

Endpoints and midpoints

The ISO allows the use of impact category indicators that are somewhere between the inventory results (i.e. emission) and the "endpoint" indicators that are chosen between the inventory results and the "endpoint" are sometimes referred to as indicators at "midpoint level". Generally, indicators that are chosen close to the inventory results have a lower uncertainty, as only a small part of the environmental mechanism needs to be modeled, while indicators near endpoint can have significant uncertainties. However, indicators at endpoints are much easier to understand and interpret by decision makers than indicators at midpoint. For example, for the Eco-Indicator 99, the indicator for climate change is expressed in Disability Adjusted Life Years (Daly). This is a unit used by WHO and World Bank to evaluate health statistics. The impact category indicator for acidification is expressed in the percentage of decreased biodiversity over an area during a certain period. These indicators are much more difficult to calculate as the complete environmental model has to be taken into account, and in that model many assumptions has to be made. There are thus more uncertain. However, their meaning is easier to understand and evaluate.

There is a trade-off between uncertainty in the model of the environmental mechanism and the uncertainty in the interpretation. It depends on the goal and scope and the ability of the targeted audience to understand the results, which choice is made (Goedkoop et al., 2007).

3.11 Normalization

Normalization is a procedure needed to show to what extent an impact category has a significant contribution to the overall environmental problem. This is done by dividing the impact category indicators by a "normal" value. There are many ways to determine the normalized value. An example would be in the determination of the impact category indicator for a region during a year by dividing the result by the number of inhabitants in that area.

Normalization serves the following purpose:

1. Impact categories that contribute only a very small amount compared to other impact categories can be left out of consideration, thus reducing the number of issues that need to be evaluated.

2. The normalized results show the order of magnitude of the environmental problems generated by the products life cycle, compared to the total environmental loads in a region.

3.12 Weighting

Weighting is the most controversial and most difficult step in the life cycle impact assessment, especially at midpoint methods as it is a subjective issue. Several solutions have been proposed to solve or simplify the weighting problem:

1. Use a panel that assess the impact category and proposes default weights. However, there are several problems to this approach. It is difficult to explain to a panel the meaning of the impact category indicator as they are too abstract. In midpoint approach, the number of indicators to be assessed is usually rather large (10 to 15). Panels tend to give a small range of weights (usually between 1 and 3).

2. Distance to target. If it is possible to set a reduction target for an impact category, this target can be used as a weighting factor. If the difference is high then the weight is also high. This approach has also some difficulties as in the case of policy targets, it is not clear if all targets are equally important. Policy targets are usually formed as compromised between interest groups and need not reflect the "real" need to reduce environmental impacts. In cases where scientific targets are used, different types of damages need to be weighted.

In the Eco-Indicator 99 methodology, some of the problems associated with the weighting have been reduced or solved, but the weighting step will always remain difficult. Hofstetter et al. (1999) developed an interesting approach using a weighting triangle (only possible after using the grouping methodology: Resources, Ecosystem quality and Human Health) as shown in Figure 3.3 below. This triangle can be used to graphically depict the outcome of product comparisons for all possible weighting sets. Each point within the triangle represents a combination of weights that add up to a 100%. The weighting factors can display the result of an LCA without knowing the weighting factors.

According to Hofstetter, such a representation is a useful tool to enhance the transparency of the weighting process as it shows under which conditions (which weighting factors) product A is better than product B. The stakeholders do not have to set discrete weights, but they have to agree whether it is plausible that the weights would fulfill the conditions under which A is better than B. Such a discussion process turns LCA into a consensus building process, instead of a toll that produces simple single truths. Another important feature is that it is also possible to draw lines of indifference (Figure 3.4) of which the lines represent weighting factors for which A and B has the same environmental loads. The lines of indifference divide the triangle into areas of weighting sets for which product A is better than product B and vice versa (Goedkoop et. al., 2007).

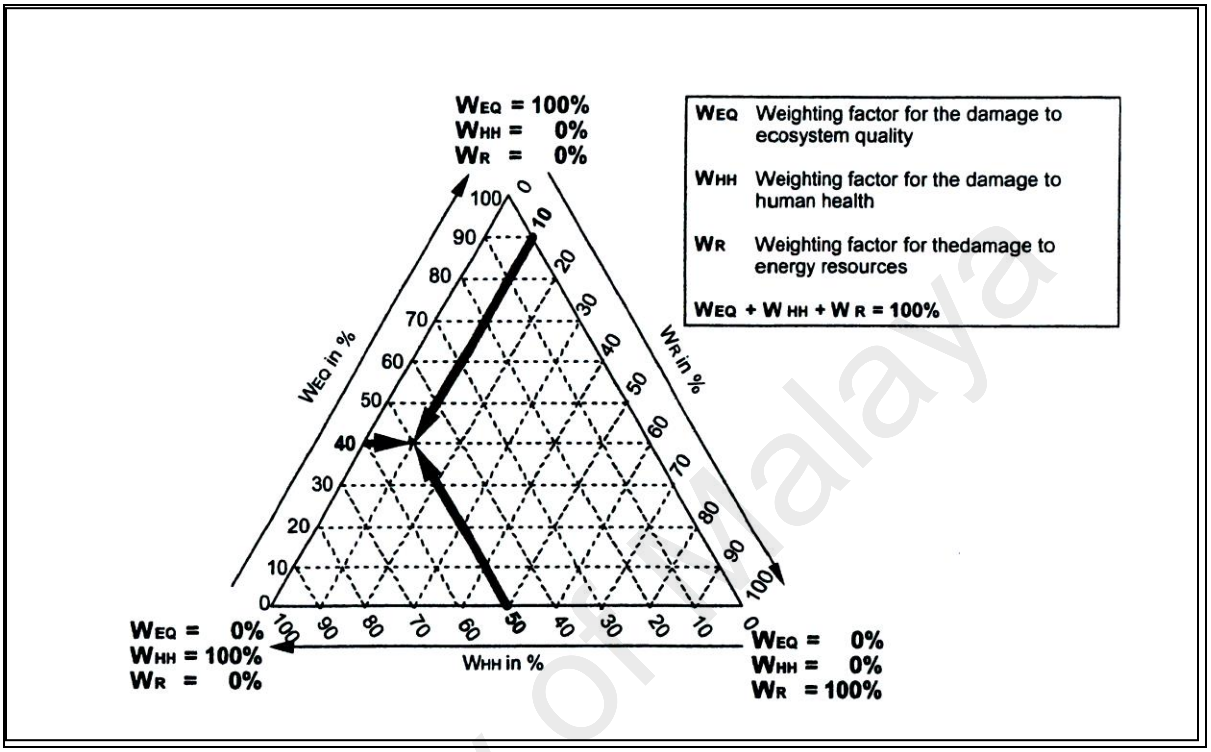

Figure 3.3: The trangle concept as alternative to fixed weights

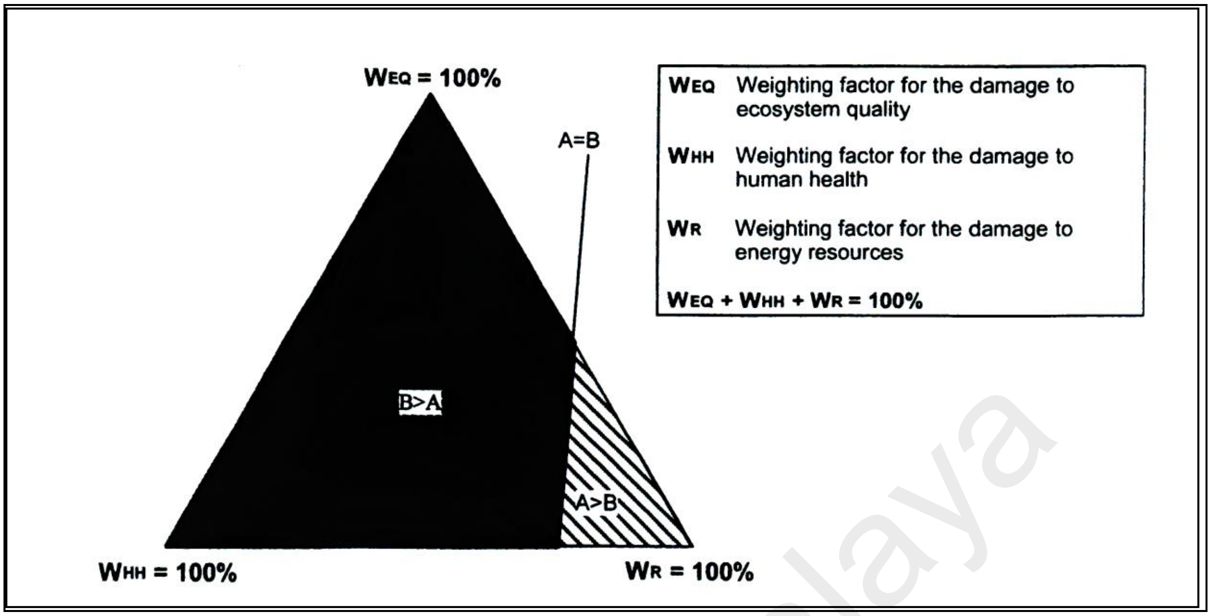

Figure 3.4: The lines of indifference in the weighting triangle.

In this study, the LCIA results were based on the weighted results as according to the SimaPro Version 7.1 in view that the weighted results would be more appropriate to draw conclusions in line with the goal definition as identified at the beginning of the study.

3.13 Life cycle impact assessment software

The SimaPro software version 7.1 was used for the impact calculations. The SimaPro (**S**ystem for **I**ntegrated environ**M**ental **A**ssessment of **PRO**ducts) LCA software is chosen for this study as it is an established software currently used by many LCA practitioners around the world. The SimaPro software is also in line with the ISO guidelines. It comes with a large number of standard impact assessment methods and flexible as it allows users to add or delete impact categories from or to a method. The SimaPro is practical as the software allows for the following studies:

i. Screenings

ii. Short studies

iii. Extensive studies

iv. Continuous LCA operations

Screening studies using the SimaPro can provide for quick results if speed and budget are the main constraint. Screening can be done using the available data in the SimaPro database. The most important issue in screenings is to have large database with commonly used materials and processes. Contribution analysis allows the identification of which processes contribute most to the overall results.

Short internal LCAs can be conducted in order to take a decision that will influence on the product development process or communication strategy but not to use the LCA report to communicate externally. For such a study, the goals can include the determination of what are the causes for the environmental load in the production phase, the use and the disposal phases, how is our products compare to our competitors and which of the business that could be considered as sustainable. In such studies, issues such as representatively, regional aspects, system boundary and allocations need to be defined.

External LCA studies for publications are needed when one wishes to make detailed environmental claims and use the LCA reports for public debate. According to ISO 14040, an independent peer review should be included in this process. For this type of studies, data quality and interpretation issues will become important.

The ISO standards and many LCA specialists consider LCA implicitly as an ad-hoc activity and as such the activity will stops until a new decision that needs to be supported.

However, there is a growing trend as more organizations view LCAs as a continuously maintained Environmental Life Cycle Management Information System (ELMIS) (Goedkoop et al., 2007).

3.14 Life cycle interpretation/improvement analysis

The results of the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) provide the information for the life cycle interpretation. This would enable the conclusions to be drawn in line with the goal and scope of the study. Improvement options to improve on the existing transportation practices to be proposed to the stakeholders concerned to mitigate climate change and thus assisted towards the sustainable development of the oil palm industry in the country.

3.15 Assumptions and limitations of the study

For this study, the emission factors used were based on the transportation studies done in Europe and as such the assumptions that emissions emitted would be the same. However, the vehicles used in Europe where the emission factors were generated and the vehicles used to transport the products in the study would not be the same and in view of this there may be variations in the actual emissions to the environment.

The weighted results from the SimaPro also were based on the weighting factors as according to the European conditions from European stakeholders. The assumption is that the weighting factors would be the same. However, the conditions and weighting factors such as damage to the human health and the eco-system quality coming from Malaysian stakeholders may give rise to a different set of weighting factors. Uncertainties in the form of variability can be attributed to either errors or fluctuations in the data (Curran, 2013). These uncertainties can be a limitation in the study.

The brand and age of the vehicles in the study were varied. Even though the questionnaires included request on these information, however, it was not possible to take this aspect into consideration as the people interviewed could not provide such information. The assumption is that the vehicles used in the study consumed the same amount of fuel based on the weight transported and distance travelled. The actual fuel used however varied according to a number of factors such as the type of engine, age and vehicle maintenance, the traffic at a particular time and the speed of the vehicle, the topography of the road, maintenance of the road, the load of the vehicles and even the attitude of the driver (André et al.,1999; INFRAS, 2000).

The data provided was based on the information given from the questionnaires. The verified data and the number of samples particularly from the nursery and the seed producers were limited as good information very much depended on the commitment and observant nature of the person filling the questionnaires. In addition, the nursery and seed producers were not as established and organized as compared to mills and refineries as some nurseries were small businesses and record keeping of such information may not be important and some information were based on estimation.

LCA is an analytical tool which captures the overall environmental impacts of a product, process or human activity from from raw material acquisition, through its production and use, to waste management. Although the ISO provides a general framework for conducting an assessment, it leaves much to the interpretation by the practitioner. The implication of this is that results in different LCA studies by different LCA practitioners may give rise to different LCA results for seemingly the same product (Curran, 2013). This is because the interpretation would depend on the results based on the assumptions as well as the goal and scope of the study.

Multifunctional processes which produces different co-products and how the allocation is done either by collecting more detailed data or by expanding the system boundary to include the sub-processess involved in the production of the co-products also effects the interpretation of the results. These allocation problems arise when it is not feasible to split the multifunctional processes into subprocesses connected to specific products (Sandin et al., 2015).

In view of these limitations, future works which involves a larger sampling size are recommended to verify the data from the current study. LCA studies on the other sub-processess are also recommended to include the transportation of other by-products not included in this study which are the transportation of the biomass such as the empty fruit bunches (EFB) from the mills after the FFB were processed into CPO. Future works to expand the system boundary from 'cradle-to-grave' are also recommended for the LCA on the handling and transportation of RBD palm oil, RBD palm olein and RBD palm stearin during shipment until these products arrives at the manufacturing plants and or the consumer's doorsteps at the consuming importing countries.

The data obtained from the current study would be a good source of background data to compare results of future studies and to verify the interpretation based on the current assumptions.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Overview of the respondents in the study

4.1.1 Respondents

The total number of responses received from the questionnaires sent is shown in Table 4.1.

Table 4.1: Summary of the number of responses received according to premises which the questionnaires were sent to

Types of Premise	Total Number (as at end 2008)	Number Sent	Number Received
Nursery	345	107	13
Plantation	3736	522	144
Mills	410	147	62
Refinery	52	43	10
TOTAL	**4543**	**822**	**229**

As shown in Table 4.1, the response from the refineries were only ten. This was because the total number of refineries in the country is relatively small at only 52 (as at the end of 2008). For the nursery, the small number of responses was because of the difficulty in getting the data as this sector of the oil palm industry is not very well organized as compared to the other sectors such as the plantations, the mills and the refineries. Information on the type of vehicles used and the distance of the journey traveled to transport the seedlings was particularly difficult to obtain because many nurseries do not keep the information of their buyers. The lack of information at the nurseries resulted in the poor response. The nurseries that did respond were from those respondents who were diligent and committed and went out of their way to check their files and filled the gaps as best they could by calling their buyers for the necessary information. Another reason was because in the study, the system boundary for the transportation process for the nursery stage was expanded to begin from the transport of the fruit bunches (from the 'mother palm') to the seed producer, and the transport of the germinated seeds to the nursery and the transport of the seedlings to the oil palm plantations. Due to this expanded system boundary, the failure to respond to the needed information were also from the seed producer and from the plantations concerned for the transport of the pollinated fruit bunches from the 'mother palms'.

4.1.2 Representativeness

To ensure the representativeness of the data collected, Tables 4.2, 4.3, 4.4 and 4.5 show the breakdown of the premises according to different regions and states in Malaysia (geographical coverage), size of premises (covering estates and small holders) and different management and ownerships.

Table 4.2: The breakdown of the nurseries used in the study according to geographical coverage in Malaysia, size of premises and ownership

No	Geographical Coverage	Size of Nursery (hectare)	Ownership
1	Dungun, Terengganu	23.25	Nursery of Government scheme plantation
2	Tawau, Sabah	3.5	Individually owned nursery
3	Tangkak, Johor	7.14	Nursery of privately owned plantation
4	Kulai, Johor	20.19	Nursery of Government scheme plantation
5	Serdang, Kedah	4	Nursery of privately owned plantation
6	Kuantan, Pahang	10	Individually owned nursery
7	Batu Pahat, Johor	3.27	Nursery of privately owned plantation
8	Masai, Johor	3	Nursery of privately owned plantation

Table 4.3: The breakdown of the plantations used in the study according to geographical coverage in Malaysia, size of premises and ownership

No	Geographical Coverage	Size of Plantation (hectare)	Ownership
1	Kuala Lipis, Pahang	1432.15	Privately owned
2	Raub, Pahang	1462	Privately owned
3	Jengka, Pahang	1711	Government scheme
4	Benta, Pahang	1397	Privately owned
5	Jengka, Pahang	1356	Government scheme
6	Kota Tinggi, Johor	924	Privately owned
7	Maran, Pahang	2140	Privately owned
8	Chemor, Perak	234	Small holder

9	Kg Gajah, Perak	706	State scheme
10	Lambor, Perak	1069	State scheme
11	Bruas, Perak	788	Privately owned
12	Rantau, Negeri Sembilan	1292	Privately owned
13	Gemenchih, N. Sembilan	1911	Privately owned
14	Lenggeng, Negeri Sembilan	181.4	Small holder
15	Nilai, Negeri Sembilan	2204	Privately owned
16	Carey Island, Selangor	5708.3	Privately owned
17	Dengkil, Selangor	169.9	Small holder
18	Sepang, Selangor	6472.72	Privately owned
19	Sg. Buloh, Selangor	2103	Privately owned
20	Chenih Baru, Terengganu	1607.16	Government scheme
21	Kemaman, Terengganu	390.5	Small holder
22	Kulai, Johor	2875.5	Privately owned
23	Paloh, Johor	3082.83	Privately owned
24	Paloh, Johor	2029	Privately owned
25	Tangkak, Johor	2725.15	Privately owned
26	Air Hitam, Johor	614.63	Small holder
27	Muar, Johor	631	Small holder
28	Kuantan, Pahang	2793.93	Privately owned
29	Kota Tinggi, Johor	1317.88	Government scheme
30	Labis, Johor	834	Government scheme
31	Kluang, Johor	455.28	Small holder
32	Maran, Pahang	2113.3	Privately owned
33	Segamat, Johor	1892.12	Privately owned
34	Kluang, Johor	1574.3	Privately owned
35	Skudai, Johor	449.5	Small holder
36	Kulai, Johor	2053.26	Privately owned

37	Masai, Johor	377.3	Small holder
38	Kluang, Johor	108.2	Small holder
39	Labis, Johor	1621.4	Government scheme
40	Tangkak, Johor	1188.4	Privately owned
41	Muar, Johor	402.4	Small holder
42	Masai, Johor	301.74	Privately owned
43	Segamat, Johor	1800.7	Privately owned
44	Segamat, Johor	2029.57	Privately owned
45	Segamat, Johor	158.64	Small holder
46	Muar, Johor	3201	Privately owned
47	Johor Bahru, Johor	922.38	Privately owned
48	Kluang, Johor	1989	Privately owned
49	Mukah, Sarawak	3779	Privately owned
50	Lahad Datu, Sabah	1397.83	Government scheme
51	Tawau, Sabah	1969.86	Government scheme
52	Sandakan, Sabah	2141	Privately owned
53	Lahad Datu, Sabah	483	Government scheme
54	Lahad Datu, Sabah	2003.9	Privately owned
55	Sandakan, Sabah	1060.85	Privately owned
56	Sarikei, Sarawak	88	Small holder
57	Lawas, Sarawak	1175.49	Privately owned
58	Miri, Sarawak	309.22	Small holder
59	Lundu, Sarawak	1472.99	Government scheme
60	Sandakan, Sabah	373.76	Small holder
61	Lahad Datu, Sabah	48.69	Small holder
62	Lahad Datu, Sabah	36.15	Small holder
63	Lahad Datu, Sabah	5744	Privately owned
64	Lahad Datu, Sabah	943	Privately owned

65	Sandakan, Sabah	2046.18	Privately owned
66	Sandakan, Sabah	895	Privately owned
67	Keningau, Sabah	55	Small holder
68	Sandakan, Sabah	242	Small holder
69	Lahad Datu, Sabah	3244	Privately owned
70	Lahad Datu, Sabah	2802	Privately owned
71	Tawau, Sabah	1536.79	Government scheme
72	Lahad Datu, Sabah	294	Small holder
73	Kunak, Sabah	3377	Privately owned
74	Sandakan, Sabah	66.3	Small holder
75	Tawau, Sabah	282.81	Small holder
76	Tawau, Sabah	158.45	Small holder
77	Kuala Terengganu, Terengganu	393	Small holder
78	Selama, Perak	279	Small holder
79	Maran, Pahang	433	Small holder
80	Grik, Perak	672.66	Government scheme
81	Gemas, Negeri Sembilan	424.25	Government scheme
82	Jempol, Negeri Sembilan	2031	Privately owned
83	Triang, Pahang	1813.98	Government scheme
84	Jengka, Pahang	1941	Privately owned
85	Air Tawar, Perak	822.4	Privately owned
86	Gemas, Negeri Sembilan	2319.89	Government scheme
87	Rompin, Pahang	1819.49	Government scheme
88	Kuala Krau, Pahang	785	Government scheme
89	Kunak, Sabah	2822	Privately owned
90	Lahad Datu, Sabah	2603	Privately owned
91	Kemaman, Terengganu	207.9	Small holder
92	Jeram, Selangor	2024.24	Privately owned

93	Raub, Pahang	1131.32	Government scheme
94	Kemaman, Terengganu	399.37	Government scheme
95	Sabak Bernam, Perak	65	Small holder
96	Ajil, Terengganu	105	State scheme
97	Lawas, Sarawak	3403	Privately owned
98	Kuching, Sarawak	2705	State scheme
99	Sandakan, Sabah	164.11	Small holder
100	Sandakan, Sabah	4586.56	Privately owned
101	Bau, Sarawak	2309	State scheme
102	Keningau, Sabah	1577.21	Privately owned
103	Mukah, Sarawak	1987	Government scheme
104	Sandakan, Sabah	127.91	Small holder
105	Lahad Datu, Sabah	510.36	Small holder
106	Tawau, Sabah	741	Small holder
107	Sibu, Sarawak	1751.7	Privately owned
108	Serendah, Selangor	580	Privately owned
109	Ajil, Terengganu	1233.96	Government scheme
110	Sibu, Sarawak	3357.75	Privately owned
111	Kubak, Sabah	3218.07	Privately owned
112	Lundu, Sarawak	1472.99	Government scheme
113	Simunjan, Sarawak	3382	Privately owned

Table 4.4: The breakdown of mills according to geographical coverage in Malaysia.

No	Geographical Coverage
1	Paloh, Johor
2	Layang-layang Johor
3	Kluang, Johor
4	Kota Tinggi, Johor
5	Segamat, Johor
6	Kluang, Johor
7	Yong Peng, Johor
8	Sungai Siput, Perak
9	Slim River, Perak
10	Pantai Remis, Perak
11	Batu Anam, Johor
12	Kota Tinggi, Johor
13	Johor Bahru, Johor
14	Kluang, Johor
15	Paloh, Johor
16	Temerluh, Pahang
17	Gemenchih, Negeri Sembilan
18	Kluang, Johor
19	Temerluh, Pahang
20	Tanah Merah, Negeri Sembilan
21	Bidor, Perak
22	Batang Berjuntai, Selangor
23	Kuala Lipis, Pahang
24	Maran, Pahang
25	Sepang, Selangor
26	Keratong, Pahang

27	Maran, Pahang
28	Bera, Pahang
29	Keratong, Pahang
30	Sandakan, Sabah
31	Mukah, Sarawak
32	Keningau, Sabah
33	Sandakan, Sabah
34	Sibu, Sarawak
35	Muadzam Shah, Pahang
36	Bintulu, Sarawak
37	Lahad Datu, Sabah
38	Sandakan, Sabah
39	Tawau, Sabah
40	Sandakan, Sabah
41	Kota Tinggi, Johor

Table 4.5: The breakdown of the refineries used in the study according to geographical coverage in Malaysia.

No	**Geographical Coverage**
1	Sandakan, Sabah
2	Sandakan, Sabah
3	Masai, Johor
4	Bintulu, Sarawak
5	Bintulu, Sarawak
6	Pasir Gudang, Johor
7	Pasir Gudang, Johor
8	Taiping, Perak
9	Ipoh, Perak

4.1.3 Samples for calculations

Out of all the responses received, the actual number of samples that were used for the calculation on the energy consumption and the emissions generated from the vehicles used in the transportation for the Life Cycle Inventory are shown in Table 4.6. The reason for the reduction in the number of samples was due to the incompleteness of data and information received from some of the respondents in spite of the follow-ups and verification efforts.

Table 4.6: The number of samples used in the study according to premises which the questionnaires were sent to

Types of Premise	**Total Number of Respondents**
Nursery Stage	8
Plantation	113
Mills	41
Refinery	9
TOTAL	**172**

4.1.4 Classification of Vehicles

The classification of motor vehicles in Malaysia under the Road Transport Act 1987 falls into two broad categories i.e. motor vehicles which are constructed to carry a load or passengers and where the unladen weight (empty weight of vehicles) exceeds three thousand kilograms (Section 5 (1) (e)) and motor vehicles which are constructed to carry a load or passengers and the unladen weight does not exceed three thousand kilograms (Section 5 (1) (f) (KKR, 2007). In view of this broad category, the classification of vehicles according to that used by Switzerland was adopted as in Table 4.7 (Spielmann et al., 2004).

Table 4.7: Classification of vehicles (Switzerland classification)

Vehicle Classes	**Vehicle Category**	**Allocated Gross Vehicle Weight Range (tonne)**	**Vehicle types included**	**Engine types**
transport vehicle <3.5t	Delivery van, light good vehicle	< 3.5	All	Petroleum and diesel
Vehicle 16 t	Heavy duty vehicle	3.5 - 7.5 >7.5 - 14 >14 – 20	Single unit lorry; Articulated lorry	Diesel
Vehicle 28 t	Heavy duty vehicle	>20 - 28	Single unit lorry; Articulated lorry	Diesel
Vehicle 40 t	Heavy duty vehicle	>28 – 40	Single unit lorry; Articulated lorry	Diesel

4.2 Life Cycle Inventory (LCI)

The values of the palm characteristics in the various stages of the palm oil supply chain used for the LCI in the study are shown in Table 4.8.

Table 4.8: Palm characteristics used in the study

Plantation size (ha)	36-6472
Average weight of fruit bunch (kg)	20
Average no. of fruits in a bunch	1500
Germination of seeds (%)	85
Weight of germinated seeds with box (kg) (2500 seeds/box)	11
Culling of seedlings (%)	25
Average weight of a 12 month old seedling (kg)	20
FFB yield (t/ha/yr)	21.51
Palm per hactare	142
Palm lifetime (year)	25
FFB to produce 1 tonne CPO (t)	3.61
CPO to produce 1 tonne RBD PO (t)	1.05
RBD PO to produce 1 tonne RBD POo (t)	1.29
RBD PO to produce 1 tonne RBD POs (t)	4.62

(Source: Choo et. al. 2009, Corley and Tinker, 2016 and author's current study)

The amount of materials used were derived from the values as stipulated in Table 4.8 above, i.e. the average number of seeds in a fruit bunch and the percentage of seed germination were taken into account in the consideration for the amount of fruit bunch (from 'mother palm') to produce one germinated seed where:

One fruit bunch=20kg (1500 fruits)

Germination of seeds=85% (to produce 1275 germinated seeds).

The amount of fruit bunch to produce one germinated seed=20,000g/1275= 15.69 g.

The consideration for the amount needed to produce one seedling took into account the percentage of culling which is normally done at the nurseries to discard poor quality seedlings (Corley and Tinker, 2016) where:

75 seedlings are produced from 100 germinated seeds due to culling process.

The amount of germinated seed needed to produce one seedling = 100/75= 1.33 germinated seed.

The FFB yield, the palm density, which is the number of palms planted in a hectare in the plantations as well as the palm lifetime, which normally takes about 25 years before replanting were used to consider the amount of seedling needed to produce one tonne of the FFB where:

21.51 tonnes of FFB was produced/hectare/year (based on the data from this study). Therefore, the amount of seedling needed to produce one tonne of FFB = (142/21.51) ÷ 25 = 0.26 seedling.

It is also to be noted that the amount of FFB used in the production of one tonne CPO was lower at 3.61 tonne (i.e. 5 tonne FFB is normally processed to produce one tonne CPO) to take into account the allocation by weight for the production of palm kernels, a co-product in CPO production (Choo et al., 2009) while 1.05 tonne of the CPO was consumed in the production of the refined palm oil to take into account the allocation by weight for the production of palm fatty acid distillate (PFAD) which is a co-product of CPO processing to produce the refined palm oil (Tan et al., 2010).

For the refined products, it is also noted that 1.29 tonnes and 4.62 tonnes of RBD palm oil are needed for the production of one tonne RBD palm olein and RBD palm stearin respectively (Tan et al., 2009). However, in the study, the emission for the RBD palm olein and the RBD palm stearin was based on the production of one tonne RBD palm oil in view that the refined palm olein and palm stearin were transported from the same location and using similar vehicles as the refined palm oil.

4.2.1 Consumption of energy

The inventory results on the diesel consumption for the transportation process at each stage along the palm oil supply chain from the transport of the fruit bunch (from 'mother palm') to the refined palm oil, palm olein and palm stearin to ports and retailers were based on the study of 8 nurseries, 113 plantations, 41 mills and 9 refineries. For this transportation study, the loads were considered full load capacity on its outward journey and the return trips were empty, therefore a load factor of 0.5 (50%) was given. However, in view that the computation of the diesel consumption was based on actual calculations, a factor of 0.8 was used for the return trip to take into account the diesel used on the empty return journey as based on the calculations used in the Swiss transport study for fuel consumption for empty and fully loaded vehicles (Spielmann et al., 2004).

The energy was calculated based on the conversion where:

1 kilowatt hour (kWh) = 3.6 MJ, 1 liter of diesel fuel = 35.9 MJ –LHV (Energy contents are expressed as either High (gross) Heating Value (HHV) or Lower (net) Heating Value (LHV). LHV is closest to the actual energy in most cases (Energy Measurements and Conversions, 2010).

The consumption of energy during the transportation process in the study was calculated based on the amount needed for the production of each functional unit for each stage of the supply chain where:

5.5 tonne of the fruit bunches (from 'mother palm') were transported to seed producers Amount of diesel consumed = 170L.

Amount of diesel needed to transport 15.69g of fruit bunches = (15.69g x 170L) ÷ 5500,000g

$=4.85 \times 10^{-4}$ L

Amount of energy needed $=4.85 \times 10^{-4} \times 35.9$ MJ = 0.017MJ.

For the germinated seeds, the number of seeds transported in a box = 2500 seeds/11kg (weight of box).

The number of seeds transported in 1.371 tonne = (1371 kg x2500)÷11kg =311,590 seeds.

The amount of diesel consumed to transport 1.33 seed = 1.33 x 149/311590 = 6.36×10^{-4} L

The amount of energy consumed $=6.36 \times 10^{-4}$L x 35.9 MJ = 0.023MJ.

The diesel consumption for the transportation of seedlings = 20,401L/385,202t= 0.053L/tonne where:

One seedling =20 kg x 0.053 /1000kg = 1.06 $X10^{-3}$ L.

The diesel consumption based on the functional unit for the production of one tonne FFB

= 0.26 x 1.06 $X10^{-3}$ L = 2.76 $X10^{-4}$ L.

The amount of energy consumed = 2.76 $X10^{-4}$ L x 35.9 = 9.9 $X10^{-3}$ MJ

The diesel consumption for the other oil palm products transported was calculated based on the amount needed for the production of one tonne of CPO and one tonne of refined palm oil respectively.

Table 4.9 shows the overall consumption of energy during the transportation process of each stage along the palm oil supply chain from the transport of the fruit bunches (from ‘mother palm’) to the refined products based on the respective functional unit for each stage of the supply chain. Table 4.10 gives the breakdown of the energy consumption during the transportation along the chain based on the different sizes of the vehicles used. The diesel consumption for the transportation of each stage along the palm oil supply chain for the different vehicle sizes were derived from the data gathered from the questionnaires received.

Table 4.9: Consumption of energy for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	From	Average distance (km)	Amount material used	Based on the production of	Energy
			Nursery Stage		
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	15.69 g	1 unit of germinated seed	4.85×10^{-4} L (0.017 MJ)
Germinated Seeds	Seed Producer to nursery	86	1.33 seeds	1 unit of seedling	6.36×10^{-4} L (0.023 MJ)
Seedlings	Nursery to plantation	70	0.26 seedling	1 tonne of FFB	2.76×10^{-4} L (9.89×10^{-3} MJ)
			Plantation		
Fresh fruit bunches	Plantation to mill	31	3.61 t	1 tonne of CPO	5.23 L (187.76 MJ)
			Palm Oil Mill		
Crude Palm Oil	Mill to refinery	164	1.05 t	1 tonne of RBD PO	4.22 L (151.50 MJ)
			Palm Oil Refinery		
			Refined oils for export		
RBD Palm Oil	Refinery to ports	67	1 t	1 tonne of RBD PO	Electricity: 0.45 kWh (1.62 MJ)

					Diesel: 0.32 L (11.49 MJ) Total (13.11 MJ)
RBD Palm Olein	Refinery to ports	21	1 t	1 tonne of RBD PO	Electricity: 0.47 kWh (1.69 MJ) Diesel: 0.84 L (30.16 MJ) Total (31.85 MJ)
RBD Palm Stearin	Refinery to ports	18	1 t	1 tonne of RBD PO	Electricity: 0.46 kWh (1.66 MJ) Diesel: 0.59 L (21.18 MJ) Total (22.84 MJ)
Refined oils for retailers					
RBD Palm Oil	Refinery to retailers	44	1 t	1 tonne of RBD PO	2.11 L (75.75 MJ)
RBD Palm Olein	Refinery to retailers	53	1 t	1 tonne of RBD PO	5.37 L (192.78 MJ)
RBD Palm Stearin	Refinery to retailers	63	1 t	1 tonne of RBD PO	2.56 L (91.90 MJ)

Table 4.10: Consumption of energy according to vehicle size for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, fresh fruit bunches, seedlings, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	From	Distance according to vehicle size (km)	Vehicle size	Amount material used	Based on the production of	Energy
			Nursery Stage			
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	30	Vehicle <3.5 t	15.69 g	1 unit of germinated seed	2.83×10^{-4} L (0.010 MJ)
Same as above	Same as above	72	Vehicle 16 t	15.69 g	1 unit of germinated seed	6.46×10^{-4} L (0.023 MJ)
Germinated Seeds	Seed Producer to nursery	86	Vehicle <3.5t	1.33 seeds	1unit of seedling	6.36×10^{-4} L (0.023 MJ)
Seedlings	Nursery to plantation	61	Vehicle 16t	0.26 seedling	1 tonne of FFB	2.60×10^{-4} L (0.01MJ)
Same as Above	Same as above	150	Vehicle 28t	0.26 seedling	1 tonne of FFB	3.51×10^{-4} L (0.01 MJ)
Same as above	Same as above	128	40t	0.26 seedling	1 tonne of FFB	3.72×10^{-4} L (0.01 MJ)
			Plantation			
Fresh fruit bunches	Plantation to mill	19	Vehicle 16t	3.61t	1 tonne of CPO	4.96 L (178.06 MJ)

Same as above	Same as above	38	Vehicle 28t	3.61t	1 tonne of CPO	6.30 L (226.17 MJ)
Same as above	Same as above	55	Vehicle 40t	3.61t	1 tonne of CPO	5.08 L (182.37 MJ)
Palm Oil Mill						
Crude Palm Oil	Mill to refinery	107	Vehicle 28t	1.05t	1 tonne of RBD PO	1.28 L (45.95 MJ)
Same as above	Same as above	167	Vehicle 40t	1.05t	1 tonne of RBD PO	4.37 L (156.88 MJ)
Palm Oil Refinery						
Refined oils for export						
RBD Palm Oil	Refinery to ports	205	Vehicle 28t	1t	1 tonne of RBD PO	6.11 L (219.34 MJ)
Same as above	Same as above	21	Vehicle 40t	1t	1 tonne of RBD PO	0.30 L (10.77 MJ)
RBD Palm Olein	Refinery to ports	21	Vehicle 40t	1t	1 tonne of RBD PO	0.84 L (30.16 MJ)
RBD Palm Stearin	Refinery to ports	22	Vehicle 28t	1t	1 tonne of RBD PO	0.90 L (32.31 MJ)
Same as above	Same as above	16	Vehicle 40t	1t	1 tonne of RBD PO	0.42 L (15.08 MJ)
Refined oils for retailers						
RBD Palm Oil	Refinery to retailers	140	Vehicle 28t	1t	1 tonne of RBD PO	4.94 L (177.35 MJ)

Same as above	Same as above	12	Vehicle 40t	1t	1 tonne of RBD PO	0.87 L (31.23 MJ)
RBD Palm Olein	Refinery to retailers	74	Vehicle 28t	1t	1 tonne of RBD PO	4.87 L (174.83 MJ)
Same as above	Same as above	48	Vehicle 40t	1t	1 tonne of RBD PO	5.42 L (194.58 MJ)
RBD Palm Stearin	Refinery to retailers	57	Vehicle 28t	1t	1 tonne of RBD PO	2.40 L (86.37 MJ)
Same as above	Same as above	69	Vehicle 40t	1t	1 tonne of RBD PO	2.84 L (101.96 MJ)

4.2.1.1 Transportation modes

During the study, it was found that the transportation that was involved was mostly road transport, where the fuel used was petroleum diesel. However, pipelines were also used to transport the RBD palm oil, RBD palm olein and the RBD palm stearin from some of the refineries to the ports. While for the transportation of some of the germinated seeds to the nursery, the train was also used as one of the modes of transport. This is combined with road transportation to transport the seeds from the seed producer to the railway station and from the railway station to the nursery. It was also found that transport vehicles of < 3.5t were used only during the transportation of the fruit bunches (from 'mother palm') from the plantation to the seed producer and from the seed producer to the nursery. This is in view of the small quantity of the products transported i.e. less than one tonne at a particular time. Vehicles with capacity ranging from 3 tonnes to 25 tonnes were used to transport seedlings from the nurseries to the plantations. For the transportation of the FFB from the plantations to the mills, it was found that 16t; 28t and 40t vehicles were used. The vehicle type ranges from tractors with tippers when the mills are nearby, to single unit lorries and articulated lorries with trailers with capacity of up to 30 tonnes when the mills are further away.

CPO was transported from palm oil mills to palm oil refineries in lorry tankers of various capacities ranging from 17 – 35 tonnes but mostly CPO was transported in 40t vehicles (28-40 tonnes gross weight). For the transportation of the refined palm oil and its fractionated products, it was found that while some of the refined products were transported to ports using pipelines, the transportation of the RBD POs by road using lorry tanker was preferred. This is due to the fact that palm stearin has a higher melting point compared to RBD palm olein and RBD palm oil and thus may not be suitable to be transported by pipelines because of clogging problems. The transportation by road of these refined oils was also by lorry tankers of similar capacity with those transporting the CPO.

For the overall energy consumption, it was found that the transportation of the fresh fruit bunches from plantations to mills, the transportation of the crude palm oil from palm oil mills to refineries and during the transport of the palm olein from refineries to retailers consumed the highest energy. The factor of 3.61 in the computation of the energy used contributes to this high value as that much FFB tonnage was needed to produce each tonne of the crude palm oil. For the transport of the CPO, the average distance from the mills to the refinery was found to be the furthest compared to the other stages, and this contributes to the high diesel consumption. While the transport of palm olein to retailers also contributes to high diesel consumption due to the fact that the oil is being transported within and across the states in the country to plants to be re-packed as cooking oil and for further processing into other products.

4.2.1.2 Comparison on energy consumption

In order to make the comparison on the overall energy consumption between the different stages along the palm oil supply chain, the calculation was made on the basis of a common functional unit i.e. based on the production of one tonne of the refined palm oil as shown in Table 4.11. It was found that the transportation of the fresh fruit bunches from plantations to mills, the transportation of the crude palm oil from palm oil mills to refineries and during the transport of the palm olein from refineries to retailers consumed the highest energy. The factor of 3.61 in the computation of the energy used contributes to this high value as that much FFB tonnage was needed to produce each tonne of the crude palm oil. For the transport of the CPO, the average distance from the mills to the refinery was found to be the furthest compared to the other stages, and this contributes to the high diesel consumption. While the transport of palm olein to retailers also contributes to high diesel consumption due to the fact that the oil is being transported within and across the states in the country to plants to be re-packed as cooking oil and for further processing into other products. In comparison, the transportation at the nursery stage contributed the least in terms of energy consumption in the production of one tonne refined palm oil because of the small amount needed for the production of one tonne refined palm oil.

Table 4.11: Consumption of energy for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin on the basis of one tonne of refined palm oil (RBD PO)

Product Transported	**From**	**Average distance (km)**	**Amount material used**	**Based on the production of**	**Energy**
Nursery Stage					
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	20.55 (15.69 x1.31)	1 tonne of RBD PO	6.35×10^{-4} L (0.02 MJ)
Germinated Seeds	Seed Producer to nursery	86	1.31 seeds (0.99x1.33)	1 tonne of RBD PO	6.26×10^{-4} L (0.02 MJ)
Seedlings	Nursery to plantation	70	0.99 seedling (0.26x3.79)	1 tonne of RBD PO	1.05×10^{-3} L (0.04MJ)
Plantation					
Fresh fruit bunches	Plantation to mill	31	3.79 (3.61x1.05)	1 tonne of RBD PO	5.49 L (197.12 MJ)
Palm Oil Mill					
Crude Palm Oil	Mill to refinery	164	1.05 t	1 tonne of RBD PO	4.22 L (151.50 MJ)
Palm Oil Refinery					
Refined oils for export					
RBD Palm Oil	Refinery to ports	67	1 t	1 tonne of	Electricity:

				RBD PO	0.45 kWh (1.62 MJ) Diesel: 0.32 L (11.49 MJ) Total (13.11 MJ)
RBD Palm Olein	Refinery to ports	21	1 t	1 tonne of RBD PO	Electricity: 0.47 kWh (1.69 MJ) Diesel: 0.84 L (30.16 MJ) Total (31.85 MJ)
RBD Palm Stearin	Refinery to ports	18	1 t	1 tonne of RBD PO	Electricity: 0.46 kWh (1.66 MJ) Diesel: 0.59 L (21.18 MJ) Total (22.84 MJ)
Refined oils for retailers					
RBD Palm Oil	Refinery to retailers	44	1 t	1 tonne of RBD PO	2.11 L (75.75 MJ)
RBD Palm Olein	Refinery to retailers	53	1 t	1 tonne of RBD PO	5.37 L (192.78 MJ)
RBD Palm Stearin	Refinery to retailers	63	1 t	1 tonne of RBD PO	2.56 L (91.90 MJ)

4.2.1.3 Factors affecting diesel consumption

The diesel consumed is influenced by the size of the vehicle. While it is generally understood that the heavier the vehicle is, the higher is the fuel consumption, however, in the long run, it was observed that a bigger capacity vehicles consumed less diesel compared to smaller vehicles when required to transport the same amount of product. This is because smaller vehicles carry a lesser load and consequently affects the number of trips needed to transport the product, and this eventually affects the total diesel consumed as more diesel is needed for the increased trips. However in the study, as shown in Table 4.10, the diesel used to transport the FFB for the production of one tonne CPO were 4.96 L, 6.3 L and 5.08 L for the 16t, 28t and 40t respectively. This inconsistency was because during the study, the average distance covered by different sized vehicles was not the same. The average distance to the mill for the 40t vehicle was the longest at 55km followed by the 28t and 16t vehicles at 38km and 19km respectively. From the study, it was found that for the diesel inventory during the transportation of the FFB from the plantations to the mills, the diesel used for the 16t, 28t and 40t vehicles were 24.99 L/100km; 35.99 L/100km; and 43.40 L/100km respectively.

When the amount of the FFB and the distance were normalized at 1000t and 50km respectively, the diesel consumptions were 1574 L (For example: 1000 tonne/16 tonne capacity = 62.5 rounded up to 63 trips. 63 x 100 km (two way journey) = 6300km x 24.99 L/100 km = 1574L), 1,295 L (For example:1000/28 tonne capacity = 36 trip x 35.99 = 1295.64 L) and 1085 L(For example: 1000/40 tonne capacity = 25 trip x43.4 =1085 L) for the 16t, 28t and 40t vehicles respectively. The total amount of the diesel consumption therefore depended on the capacity of the vehicle and the distance travelled. Due to these two important factors, it was found that when based on different vehicle capacity, the transportation of RBD palm oil to ports and retailers transported in 28t vehicles also resulted in relatively high energy consumption. This was because of the long distance to transport the refined palm oil from the refinery located in the inland.

The determination of environmental interventions of vehicle operation is not straightforward and depends on numerous causal factors according to André et al. (1999); INFRAS (2000). These included:

• Vehicle Characteristics: weight category, load factor, fuel consumption and efficiency, type of engine and fuel, exhaust gas treatment, age, maintenance.

• Vehicle Fleet composition: kilometric performance of the various vehicle classes

• Travel Characteristics: speed, acceleration, number of cold starts.

• Geographical Patterns and Network Condition: topography, road maintenance, density of transport,

• Political Conditions: speed limitations, emission regulations, regulations on the composition of fuel, fuel taxes, maximum load.

• Individual Performance: attitude of the drivers

4.2.2 Emissions

4.2.2.1 GHG emissions

Table 4.12 shows the overall greenhouse gas emission (GHG) during the transportation process at each stage along the palm oil supply chain from the fruit bunches from the 'mother palm' to the refined products based on the respective functional unit for each stage of the supply chain. Table 4.13 gives the breakdown of the emission during the transportation along the chain based on the different sizes of the vehicles used.

Table 4.12: Greenhouse Gas Emission (GHG) for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	From	Average distance (km)	Amount material used	Based on the production of	GHG Emission (kg CO_2 eq.)
			Nursery Stage		
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	15.69 g	1 unit of germinated seed	9.89×10^{-4}
Germinated Seeds	Seed Producer to nursery	86	1.33 seeds	1 unit of seedling	5.32×10^{-3}
Seedlings	Nursery to plantation	70	0.26 seedling	1 tonne of FFB	8.36×10^{-2}

Plantation					
Fresh fruit bunches	Plantation to mill	31	3.61 t	1 tonne of CPO	20.90
Palm Oil Mill					
Crude Palm Oil	Mill to refinery	164	1.05 t	1 tonne of RBD PO	20.86
Palm Oil Refinery					
Refined oils for export					
RBD Palm Oil	Refinery to ports	67	1 t	1 tonne of RBD PO	Electricity: 0.45 kWh (0.31 kg) Diesel: 7.37 kg Total (7.68 kg CO_2eq.)
RBD Palm Olein	Refinery to ports	21	1 t	1 tonne of RBD PO	Electricity: 0.47 kWh (0.32 kg) Diesel: 2.14 kg Total (2.46 kg CO_2eq.)
RBD Palm Stearin	Refinery to ports	18	1 t	1 tonne of RBD PO	Electricity: 0.46 kWh (0.32 kg) Diesel: 1.93 kg Total (2.25 kg CO_2eq.)

Refined oils for retailers					
RBD Palm Oil	Refinery to retailers	44	1 t	1 tonne of RBD PO	4.78
RBD Palm Olein	Refinery to retailers	71	1 t	1 tonne of RBD PO	6.80
RBD Palm Stearin	Refinery to retailers	63	1 t	1 tonne of RBD PO	8.50

Table 4.13: Greenhouse Gas Emission (GHG) according to vehicle size for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	From	Average distance according to vehicle size (km)	Vehicle size	Amount material used	Based on the production of	GHG Emission (kg CO_2 eq.)
			Nursery Stage			
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	30	Vehicle <3.5t	15.69g	1 unit of germinated seed	2.05×10^{-3}
Same as above	Same as above	72	Vehicle 16t	15.69g	1 unit of germinated seed	2.91×10^{-4}
Germinated Seeds	Seed Producer to nursery	86	Vehicle <3.5t	1.33 seeds	1 unit of seedling	3.63×10^{-3}

Seedlings	Nursery to plantation	61	Vehicle 16t	0.26 seedling	1 tonne of FFB	1.27×10^{-1}
Same as above	Same as above	150	Vehicle 28t	0.26 seedling	1 tonne of FFB	1.25×10^{-1}
Same as above	Same as above	128	Vehicle 40t	0.26 seedling	1 tonne of FFB	7.59×10^{-2}
Plantation						
Fresh fruit bunches	Plantation to mill	19	Vehicle 16t	3.61t	1 tonne of CPO	17.15
Same as above	Same as above	38	Vehicle 28t	3.61t	1 tonne of CPO	21.41
Same as above	Same as above	55	Vehicle 40t	3.61t	1 tonne of CPO	23.57
Palm Oil Mill						
Crude Palm Oil	Mill to refinery	107	Vehicle 28t	1.05t	1 tonne of RBD PO	17.83
Same as above	Same as above	167	Vehicle 40t	1.05t	1 tonne of RBD PO	20.98
Palm Oil Refinery						
Refined oils for export						
RBD Palm Oil	Refinery to ports	205	Vehicle 28t	1t	1 tonne of RBD PO	32.55
Same as above	Same as above	21	Vehicle 40t	1t	1 tonne of RBD PO	2.27
RBD Palm Olein	Refinery to ports	21	Vehicle	1t	1 tonne of RBD PO	2.14

			40t			
RBD Palm Stearin	Refinery to ports	22	Vehicle 28t	1t	1 tonne of RBD PO	3.49
Same as above	Same as above	16	Vehicle 40t	1t	1 tonne of RBD PO	1.62
Refined oils for retailers						
RBD Palm Oil	Refinery to retailers	140	Vehicle 28t	1t	1 tonne of RBD PO	22.23
Same as above	Same as above	12	Vehicle 40t	1t	1 tonne of RBD PO	1.33
RBD Palm Olein	Refinery to retailers	74	Vehicle 28t	1t	1 tonne of RBD PO	11.41
Same as above	Same as above	71	Vehicle 40t	1t	1 tonne of RBD PO	7.82
RBD Palm Stearin	Refinery to retailers	57	Vehicle 28t	1t	1 tonne of RBD PO	8.72
Same as above	Same as above	69	Vehicle 40t	1t	1 tonne of RBD PO	8.39

The GHG emissions were calculated based on the exhaust emission factors (g/vkm) for an average (50%) load factor for light-duty vehicle (transport vehicle < 3.5t) and exhaust emission factors (g/tkm) for an average 50% load factor for the heavy duty vehicles (vehicle 16t, 28t and 40t) sourced from the Ecoinvent database (data v1.1) (Spielmann et. al., 2004).

The exhaust emission factors for the light-duty vehicle (transport vehicle < 3.5t) and for the heavy duty vehicles (vehicle 16t, 28t and 40t) are shown in Tables 4.14 and 4.15 respectively.

Table 4.14: Light duty vehicle exhaust emission factors (g/vkm) for an average (50%) load factor

Emission	Formula	Van (CH-average)	Van (diesel)	Van (gasoline)
		g/vkm	g/vkm	g/vkm
Benzene	C_6H_6	0.017	n.a	n.a
Methane	CH_4	0.026	n.a	n.a
Carbon monoxide	CO	5.12	0.67	7.85
Carbon dioxide	CO_2	307	308	306
Nitrous oxide	N_2O	0.023	n.a	n.a
Ammonia	NH_3	0.013	n.a	n.a
Non-methane hydrocarbons	NMVOC	0.44	n.a	n.a
Nitrogen oxides	NOx	0.98	0.95	0.99
Particulate matter (PM 10)	PM	0.06	0.17	0
Sulphur dioxide	SO_2	0.04	0.059	0.027
Toluene	C_7H_8	0.039	n.a	n.a
Xylene		0.033	n.a	n.a

Source: Spielmann et al., (2004).

Table 4.15: Heavy duty vehicle exhaust emission factors (g/tkm) for an average (50%) load factor

Emission	**Formula**	**16t**	**28t**	**40t**
		g/tkm	**g/tkm**	**g/tkm**
Benzene	C_6H_6	7.74E-0.3	2.94E-0.3	1.61E-0.3
Methane	CH_4	9.78E-0.3	3.72E-0.3	2.03E-0.3
Carbon monoxide	CO	5.25E-0.1	2.16E-0.1	1.18E-0.1
Carbon dioxide	CO_2	2.34E+0.2	1.57E+0.2	1.13E+0.2
Nitrous oxide	N_2O	1.27E-0.2	5.67E-0.3	3.41E-0.3
Ammonia	NH_3	1.93E-0.3	5.67E-0.3	3.41E-0.3
Non-methane hydrocarbons	NMVOC	3.98E-0.1	1.51E-0.1	8.25E-0.2
Nitrogen oxides	NOx	2.15E+00	1.52E+00	1.02E+00
Particulate matter (PM 10)	PM	1.32E-01	6.67E-02	3.48E-02
Sulphur dioxide	SO_2	4.45E-0.2	2.99E-0.2	2.16E-0.2
Toluene	C_7H_8	3.26E-0.3	1.24E-0.3	6.76E-0.4
Xylene		3.26E-0.3	1.24E-0.3	6.76E-0.4

Source: Spielmann et. al., (2004).

The values in vehicle kilometer (vkm) for the emission factors were converted to tkm values by dividing the vkm values with the average load (Frischknecht, 2010). For this transportation study, the loads were considered full load capacity on its outward journey and the return trips were empty, therefore a load factor of 0.5 (50%) was given (Spielmann et. al., 2004). The CO_2 eq. values were the total of the emission gases for methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). The conversion factor to CO_2 eq. was based on IPCC 2006: 1 kg of CH_4 is equivalent to 23 kg CO_2, 1 kg of N_2O is equivalent to 296 kg CO_2 (IPCC, 2006). The emission factor in the Malaysian Database produced by SIRIM Bhd is 0.69 kg CO_2 /kWh electricity (Ahmad, 2009).

The GHG emission for the transport of fruit bunches (from 'mother palm' to seed producers was calculated where:

tkm (for vehicle < 3.5 t) = volume of fresh bunches transported per trip (0.16 tonne) x distance to seed producer (18km) = 2.88.

The tkm value for the emission for methane was calculated by dividing the value of g/vkm of the emission factor from Table 4.14 where:

The average load for methane = [0.026 ÷ (0.16/0.5)] x 2.88 = 0.936

Conversion to CO_2 eq. = 0.936 x 23 = 21.53.

The emission for nitrous oxide = [0.023÷(0.16/0.5)] x 2.88=0.828

Conversion to CO_2 eq. = 0.828 x 296 =245.09.

The emission for CO_2 = [308÷(0.16/ 0.5)] x 2.88 = 11,088 CO_2 eq.

CO_2 eq based on IPPC = 21.53 +245.09 + 11,088 = 11,354.62 g.

The total GHG emission per tonne for this sector = 98374.59 g/1.56 t = 63,060.63 g/t = 63.06kg/t CO_2 eq.

The GHG emission based on the functional unit for the transport of the fruit bunch (from 'mother palm') = 63.06 kg x 15.69g/1000,000g = 9.89×10^{4} kg CO_2 eq emitted.

The GHG emission for the transport of the germinated seed to nursery where:

The GHG emission per tonne = 376,071.62 g CO_2 eq/0.4135 t = 909,483.97 g/t = 909.48 kg/t. In 11 kg of the germinated seeds = 11 x 909.48 /1000 = 10.00 kg which contained 2500 germinated seeds.

Therefore, the transportation of 2500 seeds emitted 10.00 kg CO_2 eq.

In 1.33 seeds = 1.33 x 10.00/2500 = 5.32×10^{-3} kg of CO_2 eq emitted.

The GHG emissions for the transportation of seedlings to nurseries where:

The GHG emission per tonne = 1937799 g CO_2 eq/120.5 t = 16,081.32 g/t =16.08 kg /t.

Emission by one seedling (20kg) = 16.08 kg x 20/1000 = 0.32 kg CO_2 eq.

Based on the functional unit, the CO_2 eq emission = 0.3216 x 0.26 = 8.36×10^{-2} kg CO_2 eq.

Table 4.16: Greenhouse Gas Emission (GHG) for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the production of one tonne RBD PO

Product Transported	From	Average distance (km)	Amount material used	Based on the production of	GHG Emission (kg CO_2 eq.)
			Nursery Stage		
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	20.55 (15.69 x1.31)	1 tonne of RBD PO	1.30×10^{-3}
Germinated Seeds	Seed Producer to nursery	86	1.31 seeds (0.99x1.33)	1 tonne of RBD PO	5.24×10^{-3}
Seedlings	Nursery to plantation	70	0.99 seedling (0.26x3.79)	1 tonne of RBD PO	0.32

Plantation					
Fresh fruit bunches	Plantation to mill	31	3.79 (3.61x1.05)	1 tonne of RBD PO	21.94
Palm Oil Mill					
Crude Palm Oil	Mill to refinery	164	1.05 t	1 tonne of RBD PO	20.86
Palm Oil Refinery					
Refined oils for export					
RBD Palm Oil	Refinery to ports	67	1 t	1 tonne of RBD PO	Electricity: 0.45 kWh (0.31 kg) Diesel: 7.37 kg Total (7.68 kg CO_2eq.)
RBD Palm Olein	Refinery to ports	21	1 t	1 tonne of RBD PO	Electricity:

					0.47 kWh (0.32 kg) Diesel: 2.14 kg Total (2.46 kg CO_2eq.)
RBD Palm Stearin	Refinery to ports	18	1 t	1 tonne of RBD PO	Electricity: 0.46 kWh (0.32 kg) Diesel: 1.93 kg Total (2.25 kg CO_2eq.)
Refined oils for retailers					
RBD Palm Oil	Refinery to retailers	44	1 t	1 tonne of RBD PO	4.78
RBD Palm Olein	Refinery to retailers	53	1 t	1 tonne of RBD PO	6.80
RBD Palm Stearin	Refinery to retailers	63	1 t	1 tonne of RBD PO	8.50

Table 4.16 showed the comparison for the transportation during the different stages along the palm oil supply chain on the basis of the production of one tonne of refined palm oil. As shown in Table 4.16, for the overall GHG emission, the highest emissions were during the transportation of the FFB from plantations to mills and the transportation of CPO from palm oil mills to refineries. The higher value for the GHG emissions from FFB transport was due to the amount needed (i.e. 3.61 tonne) for the production of one tonne CPO. For the transport of the CPO, the long distance from the mills to the refineries is the contributing factor for the higher emissions as it was observed that the average distance from the mill to the refinery is the furthest compared to the average distance of the other stages along the palm oil supply chain. This is due to the distribution of the palm oil mills in the country where most of the refineries are located near the ports whereas the mills are located nearer to the plantations thereby resulting in the transportation of the CPO over greater distances to be refined.

The GHG emission during the transportation of the refined palm oil to the port was also relatively high. This is because some refineries are located inland. The GHG emissions were also relatively high when the refined palm oil, refined palm olein and refined palm stearin were transported to retailers. This is due to the fact that these oils are being transported within and across the states in the country to plants to be re-packed as cooking oil and for further processing into other products. Similarly, for the GHG emission, the transportation at the nursery stage contributed the least in comparison to the other stages.

When the emissions were calculated based on the different vehicle sizes, it was found that the GHG emissions were less when the products were transported in bigger capacity vehicles. From the results in Table 4.13, though the values of the emission for the bigger capacity vehicles appear to be higher, (e.g. the emissions generated for the transport of FFB from plantations to mills for the production of one tonne CPO from a 16t, 28t and 40t vehicles were 17.15kg CO_2 eq.; 21.41kg CO_2 eq.; and 23.57kg CO_2 eq. respectively), these higher values were because the distances traveled were much further for the bigger capacity vehicles (i.e. 19km, 38km and 55km for the 16t, 28t and 40t vehicles respectively). When the distance was normalized, the emissions generated to transport one tonne of a product would be the least for the 40t vehicle while the emissions for the 16t vehicle would be the most, as the exhaust emission factors (g/tkm) were lowest for the 40t vehicle compared to the 28t and 16t vehicles as shown from Table 4.15, i.e. the emission factors for CO_2 are 113 g/tkm; 157 g/tkm; and 234 g/tkm for the 40t, 28t and 16t vehicles respectively. For these same reasons, the transport of RBD PO to the port transported in 28t vehicles generated the highest GHG emissions due to the long distance from the refinery that is located in the inland to the port and using smaller capacity tankers.

4.2.2.2 Other emission gases

The other emission gases were similarly calculated using the exhaust emission factors in Table 4.15. Table 4.17 shows the overall gas emission (other than GHG) for carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and non-methane hydrocarbons (NMVOC) during the transportation process at each stage along the palm oil supply chain from the fruit bunches from the ‘mother palm’ to the refined products based on the respective functional unit for each stage of the supply chain. The comparison on the emission of these gases during transportation between each sector of the palm oil supply chain was given in Table 4.18 while Table 4.19 gives the breakdown of the emission during the transportation along the chain based on the different sizes of the vehicles used.

Table 4.17: Emission Gases (other than GHG) for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	**From**	**Average distance (km)**	**Amount material used**	**Based on the production of**	**CO (kg)**	**NOx (kg)**	**SO2 (kg)**	**Non-methane hydrocarbons (NMVOC)(kg)**
Nursery Stage								
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	15.69 g	1 unit of germinated seed	2.02×10^{-6}	3.94×10^{-6}	1.73×10^{-7}	1.36×10^{-6}
Germinated Seeds	Seed Producer to nursery	86	1.33 seeds	1 unit of seedling	7.73×10^{-6}	1.05×10^{-5}	6.80×10^{-7}	5.07×10^{-6}
Seedlings	Nursery to plantation	70	0.26 seedling	1 tonne of FFB	1.51×10^{-4}	7.57×10^{-4}	1.56×10^{-5}	1.12×10^{-4}

Plantation								
Fresh fruit bunches	Plantation to mill	31	3.61 t	1 tonne of CPO	3.08×10^{-2}	1.92×10^{-1}	3.97×10^{-3}	2.22×10^{-2}
Palm Oil Mill								
Crude Palm Oil	Mill to refinery	164	1.05 t	1 tonne of RBD PO	2.16×10^{-2}	1.85×10^{-1}	3.91×10^{-3}	1.51×10^{-2}
Palm Oil Refinery								
Refined oils for export								
RBD Palm Oil	Refinery to ports	67	1 t	1 tonne of RBD PO	9.42×10^{-3}	6.94×10^{-2}	1.39×10^{-3}	6.58×10^{-3}
RBD Palm Olein	Refinery to ports	21	1 t	1 tonne of RBD PO	2.22×10^{-3}	1.92×10^{-2}	4.07×10^{-4}	1.55×10^{-3}
RBD Palm Stearin	Refinery to ports	18	1 t	1 tonne of RBD PO	2.19×10^{-3}	1.76×10^{-2}	3.65×10^{-4}	1.53×10^{-3}
Refined oils for retailers								
RBD Palm Oil	Refinery to retailers	44	1 t	1 tonne of RBD PO	6.14×10^{-3}	4.51×10^{-2}	9.02×10^{-4}	4.30×10^{-3}

RBD Palm Olein	Refinery to retailers	71	1 t	1 tonne of RBD PO	8.97×10^{-3}	7.46×10^{-2}	1.56×10^{-3}	6.29×10^{-3}
RBD Palm Stearin	Refinery to retailers	63	1 t	1 tonne of RBD PO	9.80×10^{-3}	7.80×10^{-2}	1.61×10^{-3}	6.85×10^{-3}

Table 4.18: Emission Gases (other than GHG) for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the production of one tonne RBD PO.

Product Transported	From	Average distance (km)	Amount material used	Based on the production of	CO (kg)	NOx (kg)	SO2 (kg)	Non-methane hydrocarbons (NMVOC)(kg)
				Nursery Stage				
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	20.55 (15.69 x1.31)	1 tonne of RBD PO	2.64×10^{-6}	5.16×10^{-6}	2.27×10^{-7}	1.78×10^{-6}
Germinated Seeds	Seed Producer to nursery	86	1.31 seeds (0.99x1.33)	1 tonne of RBD PO	7.61×10^{-6}	1.03×10^{-5}	6.70×10^{-7}	4.99×10^{-6}

Seedlings	Nursery to plantation	70	0.99 seedling (0.26x3.79)	1 tonne of RBD PO	5.75 x 10^{-4}	2.88 x 10^{-3}	5.94 x 10^{-5}	4.26 x 10^{-4}
Plantation								
Fresh fruit bunches	Plantation to mill	31	3.79 t (3.61x1.05)	1 tonne of RBD PO	3.23 x 10^{-2}	2.02 x 10^{-1}	4.17 x 10^{-3}	2.33 x 10^{-2}
Palm Oil Mill								
Crude Palm Oil	Mill to refinery	164	1.05 t	1 tonne of RBD PO	2.16 x 10^{-2}	1.85 x 10^{-1}	3.91 x 10^{-3}	1.51 x 10^{-2}
Palm Oil Refinery								
Refined oils for export								
RBD Palm Oil	Refinery to ports	67	1 t	1 tonne of RBD PO	9.42 x 10^{-3}	6.94 x 10^{-2}	1.39 x 10^{-3}	6.58 x 10^{-3}
RBD Palm Olein	Refinery to ports	21	1 t	1 tonne of RBD PO	2.22 x 10^{-3}	1.92 x 10^{-2}	4.07 x 10^{-4}	1.55 x 10^{-3}

RBD Palm Stearin	Refinery to ports	18	1 t	1 tonne of RBD PO	2.19×10^{-3}	1.76×10^{-2}	3.65×10^{-4}	1.53×10^{-3}
Refined oils for retailers								
RBD Palm Oil	Refinery to retailers	44	1 t	1 tonne of RBD PO	6.14×10^{-3}	4.51×10^{-2}	9.02×10^{-4}	4.30×10^{-3}
RBD Palm Olein	Refinery to retailers	71	1 t	1 tonne of RBD PO	8.97×10^{-3}	7.46×10^{-2}	1.56×10^{-3}	6.29×10^{-3}
RBD Palm Stearin	Refinery to retailers	63	1 t	1 tonne of RBD PO	9.80×10^{-3}	7.80×10^{-2}	1.61×10^{-3}	6.85×10^{-3}

Table 4.19: Emission Gases (other than GHG) according to vehicle size for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	**From**	**Average distance according to vehicle size (km)**	**Vehicle size**	**Amount material used**	**Based on the production of**	**CO (kg)**	**NOx (kg)**	**SO2 (kg)**	**Non-methane hydrocarbons (NMVOC) (kg)**
				Nursery Stage					
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	30	Vehicle <3.5t	15.69g	1 unit of germinated seed	4.35×10^{-6}	6.17×10^{-6}	3.83×10^{-7}	2.86×10^{-6}
Same as above	Same as above	72	Vehicle 16t	15.69g	1 unit of germinated seed	6.42×10^{-7}	2.63×10^{-6}	5.44×10^{-8}	4.87×10^{-7}
Germinated Seeds	Seed Producer to nursery	86	Vehicle <3.5t	1.33 seeds	1 unit of seedling	7.73×10^{-6}	1.05×10^{-5}	6.80×10^{-7}	5.07×10^{-6}

Seedlings	Nursery to plantation	61	Vehicle 16t	0.26 seedling	1 tonne of FFB	1.70×10^{-4}	6.95×10^{-4}	1.44×10^{-5}	1.29×10^{-4}
Same as above	Same as above	150	Vehicle 28t	0.26 seedling	1 tonne of FFB	1.68×10^{-4}	1.19×10^{-3}	3.45×10^{-4}	1.18×10^{-4}
Same as above	Same as above	128	Vehicle 40t	0.26 seedling	1 tonne of FFB	7.85×10^{-5}	6.79×10^{-4}	1.44×10^{-5}	5.49×10^{-5}
Plantation									
Fresh fruit bunches	Plantation to mill	19	Vehicle 16t	3.61t	1 tonne of CPO	4.04×10^{-2}	1.65×10^{-1}	3.41×10^{-3}	3.03×10^{-2}
Same as above	Same as above	38	Vehicle 28t	3.61t	1 tonne of CPO	3.00×10^{-2}	2.11×10^{-1}	4.15×10^{-3}	2.10×10^{-2}
Same as above	Same as above	55	Vehicle 40t	3.61t	1 tonne of CPO	2.36×10^{-2}	2.04×10^{-1}	4.32×10^{-3}	1.65×10^{-2}
Palm Oil Mill									
Crude Palm Oil	Mill to refinery	107	Vehicle 28t	1.05t	1 tonne of RBD PO	2.43×10^{-2}	1.71×10^{-1}	3.36×10^{-3}	1.70×10^{-2}

Same as above	Same as above	167	Vehicle 40t	1.05t	1 tonne of RBD PO	2.15×10^{-2}	1.85×10^{-1}	3.93×10^{-3}	1.50×10^{-2}
				Palm Oil Refinery					
				Refined oils for export					
RBD Palm Oil	Refinery to ports	205	Vehicle 28t	1t	1 tonne of RBD PO	4.43×10^{-2}	3.12×10^{-1}	6.13×10^{-3}	3.10×10^{-2}
Same as above	Same as above	21	Vehicle 40t	1t	1 tonne of RBD PO	2.36×10^{-3}	2.04×10^{-2}	4.32×10^{-4}	1.65×10^{-3}
RBD Palm Olein	Refinery to ports	21	Vehicle 40t	1t	1 tonne of RBD PO	2.22×10^{-3}	1.92×10^{-2}	4.07×10^{-4}	1.55×10^{-3}
RBD Palm Stearin	Refinery to ports	22	Vehicle 28t	1t	1 tonne of RBD PO	4.75×10^{-3}	3.34×10^{-2}	6.58×10^{-4}	3.32×10^{-3}
Same as above	Same as above	16	Vehicle 40t	1t	1 tonne of RBD PO	1.68×10^{-3}	1.45×10^{-2}	3.07×10^{-4}	1.17×10^{-3}

Refined oils for retailers									
RBD Palm Oil	Refinery to retailers	140	Vehicle 28t	1t	1 tonne of RBD PO	3.02×10^{-2}	2.13×10^{-1}	4.16×10^{-3}	$2.11. \times 10^{-2}$
Same as above	Same as above	12	Vehicle 40t	1t	1 tonne of RBD PO	1.38×10^{-3}	1.19×10^{-2}	2.53×10^{-4}	9.66×10^{-4}
RBD Palm Olein	Refinery to retailers	74	Vehicle 28t	1t	1 tonne of RBD PO	1.55×10^{-2}	1.09×10^{-1}	2.15×10^{-3}	1.09×10^{-2}
Same as above	Same as above	71	Vehicle 40t	1t	1 tonne of RBD PO	8.10×10^{-3}	7.00×10^{-2}	1.48×10^{-3}	5.66×10^{-3}
RBD Palm Stearin	Refinery to retailers	57	Vehicle 28t	1t	1 tonne of RBD PO	1.19×10^{-2}	8.35×10^{-2}	1.64×10^{-3}	8.29×10^{-3}
Same as above	Same as above	69	Vehicle 40t	1t	1 tonne of RBD PO	8.68×10^{-3}	7.50×10^{-2}	1.59×10^{-3}	6.07×10^{-3}

From Table 4.18, the overall emissions of the other gases, showed a similar trend as the GHG emission with the highest emissions during the transportation of the FFB from plantations to mills and the transportation of CPO from palm oil mills to refineries. Similarly, the higher value for the other gas emissions from FFB transport was due to the amount needed (i.e. 3.61 tonne) for the production of one tonne CPO. For the transport of the CPO, the long distance from the mills to the refineries is the contributing factor for the higher emissions as the average distance from the mill to the refinery was highest compared to the average distance of the other stages along the palm oil supply chain resulting in the transportation of the CPO over long distances to be refined, hence the higher emissions emitted to the environment.

The study showed that the emissions of carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and non-methane hydrocarbons (NMVC) during the transportation of the refined palm oil to the port was also relatively high, the same trend as the emission for the GHG gases. The emissions were also relatively high when the refined palm oil, refined palm olein and refined palm stearin were transported to retailers. Again, this was due to the fact that these oils were being transported within and across the states in the country to plants to be re-packed as cooking oil and for further processing into other products. Similar with the GHG emission, the transportation at the nursery stage produced the least emissions of carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO2) and non-methane hydrocarbons compared to the other stages.

When the emissions were calculated based on the different vehicle sizes, for carbon monoxide (CO), the emissions values generated for the transport along the chain were found to be smaller when the products were transported in bigger capacity vehicles. For example, from the results in Table 4.19, for the emissions generated for the transport of FFB from plantations to mills for the production of one tonne CPO from a 16t, 28t and 40t vehicles were 0.04kg; 0.03kg; and 0.024kg respectively. These values were smaller despite the fact that the distances traveled were much further for the bigger capacity vehicles (i.e. 19km, 38km and 55km for the 16t, 28t and 40t vehicles respectively). The lower value was because the exhaust emission factors (g/tkm) from Table 4.15 was lowest for the 40t vehicle compared to the 28t and 16t vehicles, i.e. the emission factors for CO were 0.118 g/tkm; 0.216 g/tkm; and 0.525 g/tkm for the 40t, 28t and 16t vehicles respectively. Due to this lower emission factor, the CO emission generated for the 40t vehicle would be very much smaller when compared to the emission generated for the transport of one tonne of a product using a 16t vehicle when the distance was normalized.

From the study, the values of the emissions during the transportation along the chain using different vehicles sizes for the different gases did not show a consistent trend. While the emission values for carbon monoxide (CO) and non-methane hydrocarbons (NMVC) were smaller for the bigger capacity vehicles used during the transportation along the chain for the production of one tonne RBD PO, it was found that for nitrogen oxides (NO_x) and sulphur dioxide (SO_2), the emission values were found to be slightly higher for the bigger capacity vehicles during transportation of seedling from nursery to plantation, during transportation of FFB from plantation to mills and during transportation of CPO from mills to refinery. However, the emissions generated for these gases during the transportation from refineries to ports and from refineries to retailers were smaller when transported in bigger capacity vehicles. The overall emissions emitted however, were smaller when using bigger capacity vehicles due to the emission factors as demonstrated earlier. From Table 4.15, the emission factors for NO_x, SO2 and NMVC were 1.02 g/tkm, 1.52 g/tkm and 2.15 g/tkm; 0.0216 g/tkm, 0.0299 g/tkm and 0.0445 g/tkm; and 0.0825 g/tkm, 0.151 g/tkm and 0.398 g/tkm for the 40t, 28t and 16t vehicles respectively (Spielmann et al., 2004). Similarly with the GHG emissions, the transport of RBD PO to the port transported in 28t vehicles generated the highest emissions for CO, NO_x, SO2 and NMVC due to the long distance from the refinery that is located in the inland to the port and using smaller capacity tankers.

4.2.2.3 Particulate Matter and Heavy Metals

Tables 4.20 shows the overall emission of particulate matter and heavy metals during the transportation process at each stage along the palm oil supply chain from the fruit bunches from the 'mother palm' to the refined products based on the respective functional unit for each stage of the supply chain. The comparison on the emission of the particulate matter and heavy metals during transportation between each sector of the palm oil supply chain was given in Table 4.21. Tables 4.22 and 4.23 give the breakdown of the emissions during the transportation along the chain based on the different sizes of the vehicles used.

Table 4.20: Particulate matter (PM) and heavy metals for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	From	Particulate Matter (PM) (kg)	Cadmium (kg)	Copper (kg)	Chromium (kg)	Nickel (kg)	Selenium (kg)	Zinc (kg)	Lead (kg)	Mercury (kg)
Nursery Stage										
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	5.02E-07	1.09E-11	1.85E-09	5.43E-11	7.62E-11	1.09E-11	1.09E-09	4.04E-12	2.74E-14
Germinated Seeds	Seed Producer to nursery	1.96E-06	6.74E-12	1.45E-09	2.65E-11	5.94E-11	6.74E-12	6.74E-10	1.05E-11	4.32E-14
Seedlings	Nursery to plantation	3.99E-05	1.82E-10	3.10E-08	9.10E-10	1.28E-09	1.82E-10	1.82E-08	2.01E-12	3.69E-13

Plantation										
Fresh fruit bunches	Plantation to mill	8.55E-03	4.03E-08	6.68E-06	6.10E-07	2.83E-07	4.03E-08	4.03E-06	4.42E-10	8.03E-11
Palm Oil Mill										
Crude Palm Oil	Mill to refinery	6.37E-03	3.05E-08	5.18E-06	2.19E-07	2.14E-07	3.05E-08	3.05E-06	3.36E-10	6.11E-11
Palm Oil Refinery										
Refined oils for export										
RBD Palm Oil	Refinery to ports	2.88E-03	1.20E-08	2.05E-06	6.02E-08	8.42E-08	1.20E-08	1.20E-06	1.33E-10	2.41E-11
RBD Palm Olein	Refinery to ports	6.56E-04	3.56E-09	6.03E-07	1.77E-08	2.49E-08	3.56E-09	3.56E-07	3.91E-11	7.11E-12
RBD Palm Stearin	Refinery to ports	6.56E-04	3.42E-09	5.81E-07	1.71E-08	2.39E-08	3.42E-09	3.42E-07	3.75E-11	7.12E-12
Refined oils for retailers										
RBD Palm Oil	Refinery to retailers	1.88E-03	7.65E-09	1.31E-06	3.83E-08	5.36E-08	7.65E-09	7.65E-07	8.42E-11	1.53E-11

RBD Palm Olein	Refinery to retailers	2.67E-03	1.33E-08	2.26E-06	6.62E-08	9.30E-08	1.33E-08	1.33E-06	1.46E-10	2.66E-11
RBD Palm Stearin	Refinery to retailers	2.95E-03	1.21E-08	2.05E-06	6.02E-08	8.48E-08	1.21E-08	1.21E-06	1.32E-10	2.44E-11

The emissions for particulate matter was also calculated based on the exhaust emission factors (g/vkm) (Table 4.14) for an average (50%) load factor for light-duty vehicle (transport vehicle < 3.5t) and exhaust emission factors (g/tkm) for an average 50% load factor for the heavy duty vehicles (vehicle 16t, 28t and 40t) (Table 4.15) sourced from the Ecoinvent database (data v1.1) (Spielmann et al., 2004). For the emissions on heavy metals, the calculations were based on the heavy metal fuel combustion emission factors (g/vkm) for vans and heavy-goods vehicles for an average 50% load factor also sourced from the Ecoinvent database (data v1.1) (Spielmann et al., 2004) as shown in Table 4.24. The values in vehicle kilometer (vkm) for the emission factors were converted to tkm values by dividing the vkm values with the average load (Frischknecht, 2010). For this transportation study, the loads were considered full load capacity on its outward journey and the return trips were empty, therefore a load factor of 0.5 (50%) was given (Spielmann et al., 2004).

As shown from Table 4.21, when the comparison was made based on the production of one tonne of RBD PO, the study showed that for the overall particulate matter and heavy metal emissions, the highest emissions were also during the transportation of the FFB from plantations to mills and the transportation of CPO from palm oil mills to refineries. Similar with the result of the other emissions, the higher value for the particulate matter and heavy metal emissions from FFB transport were due to the amount needed (i.e. 3.61 tonne) for the production of one tonne CPO. For the transport of the CPO, the long distance from the mills to the refineries is the contributing factor for the higher emissions was due to the average distance from the mill to the refinery. The emissions of particulate matter and heavy metals were also observed to be relatively high during the transportation of the refined palm oil to the port due to same reason as some refineries used in the study were located inland. The particulate matter and heavy metal emissions were also relatively high when the refined palm oil, refined palm olein and refined palm stearin were transported to retailers as these oils were transported within and across the states in the country to plants to be re-packed as cooking oil and for further processing into other products. As with the other emissions, the transportation at the nursery stage contributed the least in terms of particulate matter emissions and heavy metal emissions. For the heavy metal emissions, the emissions of copper were found to be highest, followed by the emissions of zinc, nickel, chromium, cadmium and selenium, lead and mercury being the lowest emission amongst all the heavy metals emitted during the study.

When the particulate matter and the heavy metal emissions were calculated based on the different vehicle sizes, from the results in Table 4.22, it was found that while the emissions of particulate matter were generally less when the products were transported in bigger capacity vehicles, for the emissions of heavy metals for cadmium, copper, chromium and nickel, there appeared to be slightly higher heavy metals emitted in bigger capacity vehicles during the transportation of FFB from plantation to mills and during transportation of CPO from palm oil mills to refineries. The heavy metals emissions were lower when transported in bigger capacity vehicles during transportation of the refined palm oil and palm oil products from refineries to ports and retailers. From the study, there was no consistent trend in the emissions of heavy metals during transportation during refinery stage. The heavy metals emission for selenium, zinc, lead and mercury for the transportation along the palm oil supply chain transported in different vehicle capacity were shown in Table 4.23. From the table, it was shown that the trends in the emissions generated were similar as the emissions for heavy metals were lower when transported in bigger capacity vehicles during transportation of the refined palm oil and palm oil products from refineries to ports and retailers. There was no consistent trend in the emissions of heavy metals during transportation during nursery stage.

Table 4.21: Particulate matter (PM) and heavy metals for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the production of one tonne RBD PO

Product Transported	From	Particulate Matter (PM) (kg)	Cadmium (kg)	Copper (kg)	Chromium (kg)	Nickel (kg)	Selenium (kg)	Zinc (kg)	Lead (kg)	Mercury (kg)
Nursery Stage										
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	6.57E-07	1.43E-11	2.42E-09	7.11E-11	9.98E-11	1.43E-11	1.43E-09	5.29E-12	3.59E-14
Germinated Seeds	Seed Producer to nursery	1.93E-06	6.64E-12	1.43E-09	2.61E-11	5.85E-11	6.64E-12	6.64E-10	1.03E-11	4.26E-14
Seedlings	Nursery to plantation	1.52E-04	6.93E-10	1.18E-07	3.47E-09	4.87E-09	6.93E-10	6.93E-08	7.65E-12	1.41E-12
Plantation										
Fresh fruit bunches	Plantation to mill	8.98E-03	4.23E-08	7.01E-06	6.40E-07	2.97E-07	4.23E-08	4.23E-06	4.64E-10	8.43E-11

Palm Oil Mill										
Crude Palm Oil	Mill to refinery	6.37E-03	3.05E-08	5.18E-06	2.19E-07	2.14E-07	3.05E-08	3.05E-06	3.36E-10	6.11E-11
Palm Oil Refinery										
Refined oils for export										
RBD Palm Oil	Refinery to ports	2.88E-03	1.20E-08	2.05E-06	6.02E-08	8.42E-08	1.20E-08	1.20E-06	1.33E-10	2.41E-11
RBD Palm Olein	Refinery to ports	6.56E-04	3.56E-09	6.03E-07	1.77E-08	2.49E-08	3.56E-09	3.56E-07	3.91E-11	7.11E-12
RBD Palm Stearin	Refinery to ports	6.56E-04	3.42E-09	5.81E-07	1.71E-08	2.39E-08	3.42E-09	3.42E-07	3.75E-11	7.12E-12
Refined oils for retailers										
RBD Palm Oil	Refinery to retailers	1.88E-03	7.65E-09	1.31E-06	3.83E-08	5.36E-08	7.65E-09	7.65E-07	8.42E-11	1.53E-11
RBD Palm Olein	Refinery to retailers	2.67E-03	1.33E-08	2.26E-06	6.62E-08	9.30E-08	1.33E-08	1.33E-06	1.46E-10	2.66E-11
RBD Palm Stearin	Refinery to retailers	2.95E-03	1.21E-08	2.05E-06	6.02E-08	8.48E-08	1.21E-08	1.21E-06	1.32E-10	2.44E-11

Table 4.22: Particulate matter (PM) and heavy metals according to vehicle size for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	From	Average distance according to vehicle size (km)	Vehicle size	Particulate Matter (PM) (kg)	Cadmium (kg)	Copper (kg)	Chromium (kg)	Nickel (kg)
				Nursery Stage				
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	30	Vehicle <3.5t	1.10E-06	4.76E-12	8.16E-10	2.38E-11	3.33E-11
Same as above	Same as above	72	Vehicle 16t	1.47E-07	1.45E-11	2.47E-09	7.24E-11	1.02E-10
Germinated Seeds	Seed Producer to nursery	86	Vehicle <3.5t	1.96E-06	6.74E-12	1.45E-09	2.65E-11	5.94E-11
Seedlings	Nursery to plantation	61	Vehicle	4.27E-05	1.90E-10	3.23E-08	9.48E-10	1.33E-09

			16t					
Same as above	Same as above	150	Vehicle 28t	5.20E-05	2.12E-10	3.61E-08	1.06E-09	1.48E-09
Same as above	Same as above	128	Vehicle 40t	2.32E-05	1.39E-10	2.35E-08	6.93E-10	9.73E-10
Plantation								
Fresh fruit bunches	Plantation to mill	19	Vehicle 16t	1.01E-02	3.29E-08	5.06E-06	1.65E-07	2.31E-07
Same as above	Same as above	38	Vehicle 28t	9.26E-03	4.37E-08	6.79E-06	2.19E-07	3.06E-07
Same as above	Same as above	55	Vehicle 40t	6.96E-03	4.41E-08	7.50E-06	2.19E-07	3.09E-07
Palm Oil Mill								
Crude Palm Oil	Mill to refinery	107	Vehicle 28t	7.49E-03	2.75E-08	4.68E-06	1.38E-07	1.93E-07
Same as above	Same as above	167	Vehicle 40t	6.33E-03	3.06E-08	5.14E-06	2.22E-07	2.15E-07

Palm Oil Refinery								
Refined oils for export								
RBD Palm Oil	Refinery to ports	205	Vehicle 28t	1.37E-02	5.24E-08	8.94E-06	2.63E-07	3.66E-07
Same as above	Same as above	21	Vehicle 40t	6.96E-04	3.86E-09	6.54E-07	1.92E-08	2.70E-08
RBD Palm Olein	Refinery to ports	21	Vehicle 40t	6.56E-04	3.56E-09	6.03E-07	1.77E-08	2.49E-08
RBD Palm Stearin	Refinery to ports	22	Vehicle 28t	1.47E-03	5.31E-09	9.06E-07	2.67E-08	3.72E-08
Same as above	Same as above	16	Vehicle 40t	4.95E-04	3.04E-09	5.16E-07	1.52E-08	2.13E-08
Refined oils for retailers								
RBD Palm Oil	Refinery to retailers	140	Vehicle 28t	9.34E-03	3.58E-08	6.12E-06	1.79E-07	2.50E-07
Same as above	Same as above	12	Vehicle 40t	4.08E-04	2.09E-09	3.56E-07	1.04E-08	1.47E-08

RBD Palm Olein	Refinery to retailers	74	Vehicle 28t	4.79E-03	1.83E-08	3.14E-06	9.17E-08	1.28E-07
Same as above	Same as above	71	Vehicle 40t	2.39E-03	1.26E-08	2.14E-06	6.29E-08	8.83E-08
RBD Palm Stearin	Refinery to retailers	57	Vehicle 28t	3.66E-03	1.39E-08	2.38E-06	6.96E-08	9.74E-08
Same as above	Same as above	69	Vehicle 40t	2.56E-03	1.11E-08	1.88E-06	5.51E-08	7.76E-08

Table 4.23: Heavy metals according to vehicle size for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Product Transported	**From**	**Average distance according to vehicle size (km)**	**Vehicle size**	**Selenium (kg)**	**Zinc (kg)**	**Lead (kg)**	**Mercury (kg)**
Nursery Stage							
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	30	Vehicle <3.5t	4.76E-12	4.76E-10	5.92E-12	2.43E-14
Same as above	Same as above	72	Vehicle 16t	1.45E-11	1.45E-09	2.93E-12	2.91E-14
Germinated Seeds	Seed Producer to nursery	86	Vehicle <3.5t	6.74E-12	6.74E-10	1.05E-11	4.32E-14

Seedlings	Nursery to plantation	61	Vehicle 16t	1.90E-10	1.90E-08	2.09E-12	3.87E-13
Same as above	Same as above	150	Vehicle 28t	2.12E-10	2.12E-08	2.33E-12	4.26E-13
Same as above	Same as above	128	Vehicle 40t	1.39E-10	1.39E-08	1.53E-12	2.79E-13
Plantation							
Fresh fruit bunches	Plantation to mill	19	Vehicle 16t	3.29E-08	3.29E-06	3.63E-10	6.60E-11
Same as above	Same as above	38	Vehicle 28t	4.37E-08	4.36E-06	4.81E-10	8.76E-11
Same as above	Same as above	55	Vehicle 40t	4.41E-08	4.41E-06	4.84E-10	8.81E-11
Palm Oil Mill							
Crude Palm Oil	Mill to refinery	107	Vehicle 28t	2.75E-08	2.75E-06	3.03E-10	5.71E-11

Same as above	Same as above	167	Vehicle 40t	3.06E-08	3.06E-06	3.37E-10	6.13E-11
Palm Oil Refinery							
Refined oils for export							
RBD Palm Oil	Refinery to ports	205	Vehicle 28t	5.24E-08	5.24E-06	5.76E-10	1.05E-10
Same as above	Same as above	21	Vehicle 40t	3.86E-09	3.86E-07	4.24E-11	7.70E-12
RBD Palm Olein	Refinery to ports	21	Vehicle 40t	3.56E-09	3.56E-07	3.91E-11	7.11E-12
RBD Palm Stearin	Refinery to ports	22	Vehicle 28t	5.31E-09	5.31E-07	5.83E-11	1.24E-11
Same as above	Same as above	16	Vehicle 40t	3.04E-09	3.04E-07	3.34E-11	6.08E-12
Refined oils for retailers							
RBD Palm Oil	Refinery to retailers	140	Vehicle 28t	3.58E-08	3.58E-06	3.94E-10	7.18E-11

Same as above	Same as above	12	Vehicle 40t	2.09E-09	2.09E-07	2.30E-11	4.20E-12
RBD Palm Olein	Refinery to retailers	74	Vehicle 28t	1.83E-08	1.83E-06	2.01E-10	3.69E-11
Same as above	Same as above	71	Vehicle 40t	1.26E-08	1.26E-06	1.39E-10	2.52E-11
RBD Palm Stearin	Refinery to retailers	57	Vehicle 28t	1.39E-08	1.39E-06	1.53E-10	2.85E-11
Same as above	Same as above	69	Vehicle 40t	1.11E-08	1.11E-06	1.21E-10	2.21E-11

Table 4.24: Heavy metal fuel combustion emission factors (g/vkm) for van and heavy-good vehicles

Pollutant	**Van**	**16t**	**28t**	**40t**
	g/vkm	**g/vkm**	**g/vkm**	**g/vkm**
Cadmium	7.34E-0.7	1.58E-0.6	2.17E-0.6	2.61E-0.6
Copper	1.25E-0.4	2.69E-0.4	3.70E-0.4	4.43E-0.4
Chromium	3.67E-0.6	7.92E-0.6	1.09E-0.5	1.30E-0.5
Nickel	5.14E-0.6	1.11E-0.5	1.52E-0.5	1.83E-0.5
Selenium	7.34E-0.7	1.58E-0.6	2.17E-0.6	2.61E-0.6
Zink	7.34E-0.5	1.58E-0.4	2.17E-0.4	2.61E-0.4
Lead	9.14E-0.7	1.74E-0.8	2.39E-0.8	2.87E-0.8
Mercury	3.74E-0.9	3.17E-09	4.35E-09	5.22E-0.8

Source: Spielmann et. al., (2004).

4.3 Life Cycle Impact Assessment (LCIA)

The characterization and weighted results of the Life Cycle Impact Assessment (LCIA) within the system boundary were based on the transportation of one tonne of the refined palm oil. The characterization values and characterization results of the LCIA are attached as in Appendices 6-16 and Appendices 17- 27 respectively while the weighted values are as attached in Appendices 28- 38 and the weighted results are as shown in Figures 4.1-4.15 respectively.

The characterized results indicated that for all the stages along the palm oil supply chain, fossil fuel depletion, ecotoxicity, acidification/eutrophication, climate change, respiratory in-organics, respiratory organics and carcinogens contributed to the impact categories. These impact categories were contributed by the transportation from the vehicles used to transport the products along the palm oil supply chain. From the study it was shown that there were no significant contribution on the impact from radiation, ozone layer, land use and minerals during the transportation at all the stages along the palm oil supply chain.

The characterized results were weighted using the weighting factors as in the eco-indicator 99 version 2.03. When the characterized results were weighted, the results showed that the most significant environmental impacts from this study were contributed by the impact categories in the following order: fossil fuel, respiratory in-organics, acidification/eutrophication and climate change. The impacts on ecotoxicity, respiratory organics, carcinogens and ozone layer were insignificant while there were no environmental impact observed from this study on radiation, land use and minerals. The impacts on fossil fuel, respiratory in-organics, acidification/eutrophication and climate change came from the use of the transport vehicles as well as from the diesel used during the transport of the materials at all the various stages along the palm oil supply chain. Air pollution is considered to be a main environmental impact of motor vehicle transport (Spielmann et al., 2004).

During the combustion process, automotive engines emitted several types of pollutants which include sulphur oxides (SO_x), nitrogen oxides (NO_x) and volatile organic compounds as well as particulate matter (Spielmann et al., 2004). People's health can be affected from the particulate matter from even at lower level than previously believed (Reichhardt (1995). Particulate matter can come either from the diesel exhaust emissions due to fuel combustion or from non-exhaust emissions such as from abrasions of tyres and breaks as well as abrasion of road surface and re-suspended road dust. Automotive vehicles are also a major source of CO_2 emission that contributes to the effects on climate change. The heavy metals found in the diesel fuel used also contributed to these impacts. In addition, heavy metals can also be released to the environment from tyre abrasion. These heavy metals are emitted to both air and soil. While the fossil fuel, respiratory in-organics and climate change impact categories relate to air emission of these gaseous and heavy metals, the acidification/eutrophication relates to water emission (Spielmann et al., 2004

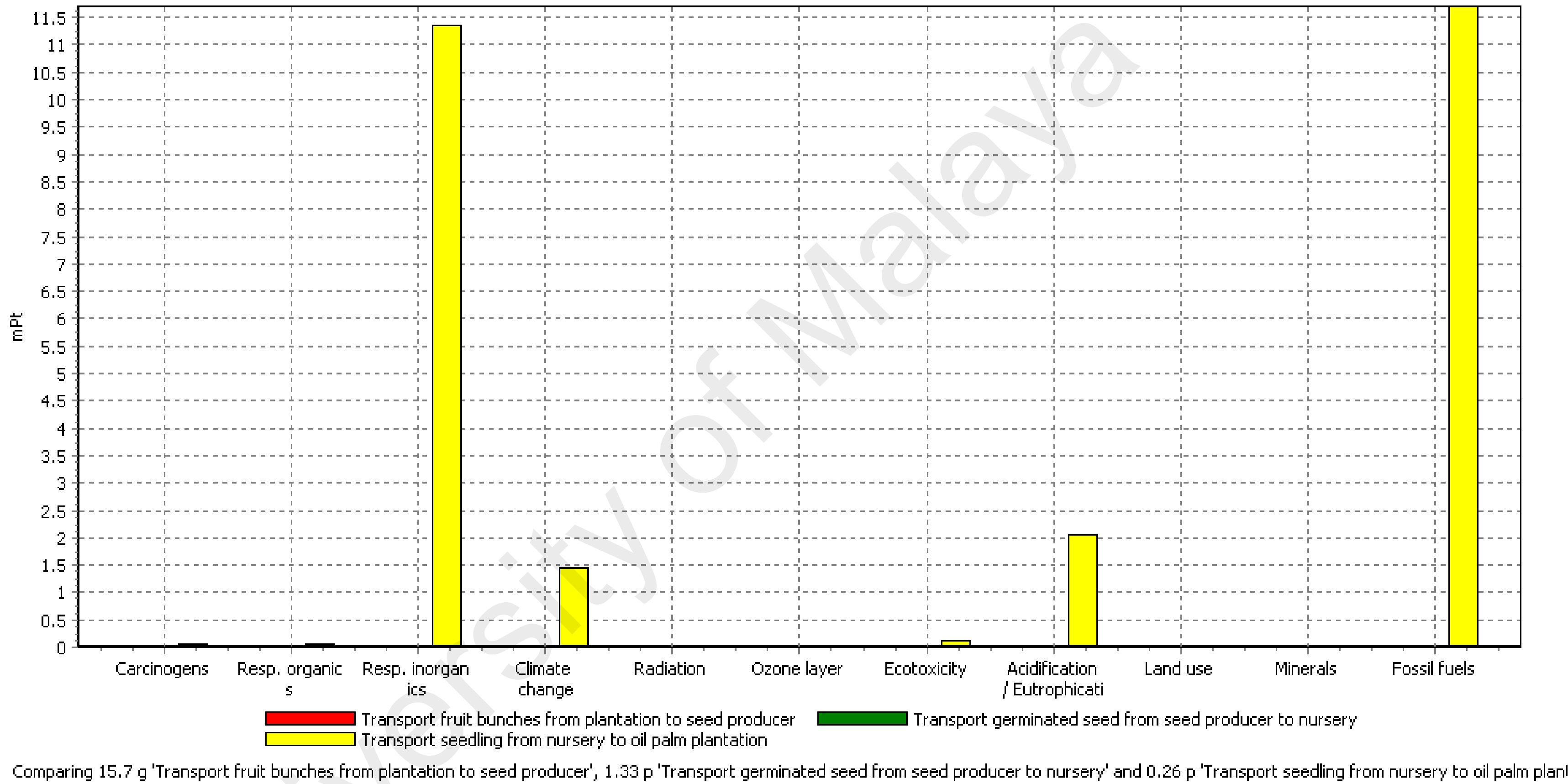

Figure 4.1: Comparison of weighted results for the transport of fruit bunches, germinated seeds and seedlings based on the production of one tonne RBD palm oil.

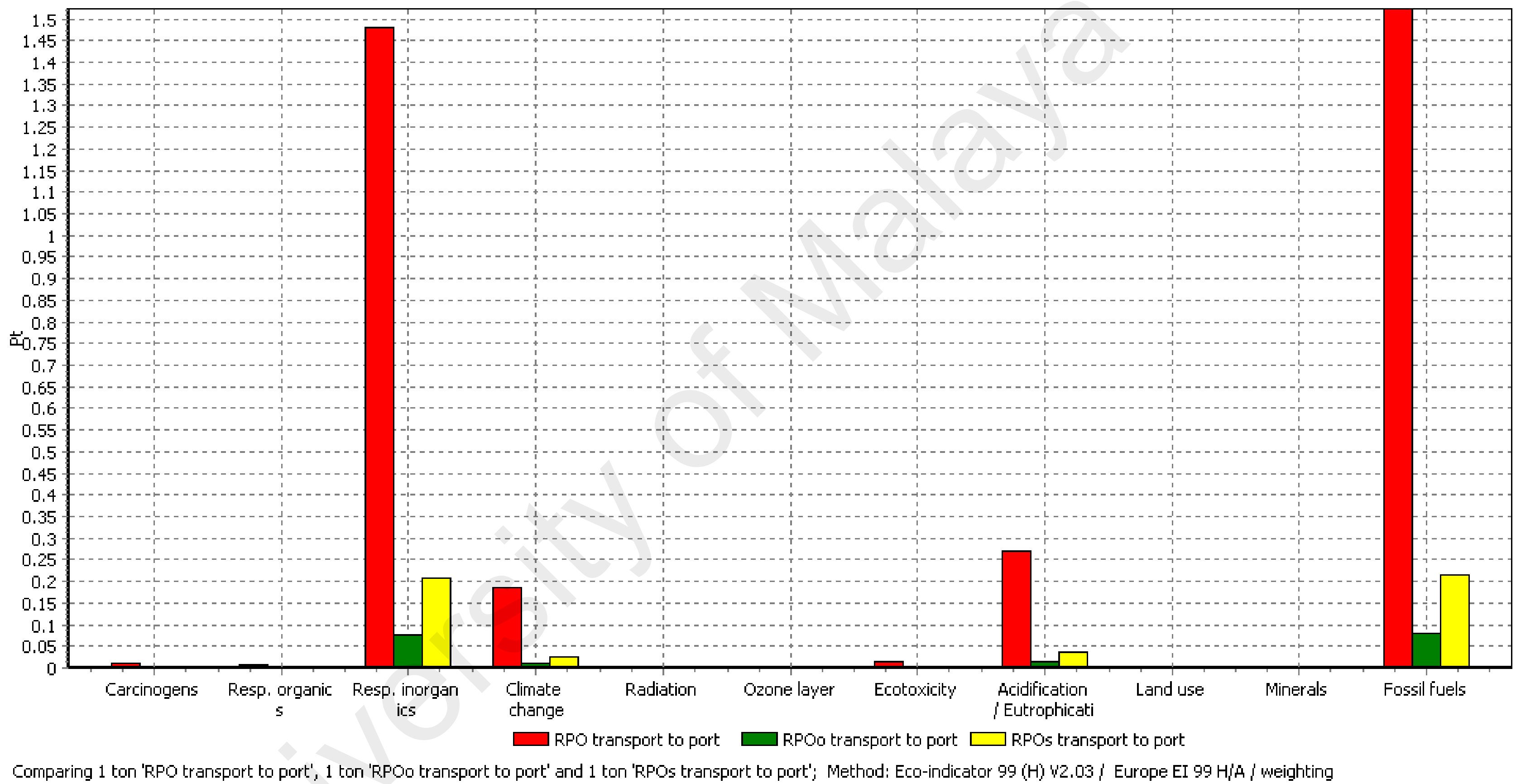

Figure 4.2: Comparison of weighted results for the transport of RBD palm oil, RBD palm olein and RBD palm stearin from refinery to ports based on the production of one tonne RBD palm oil.

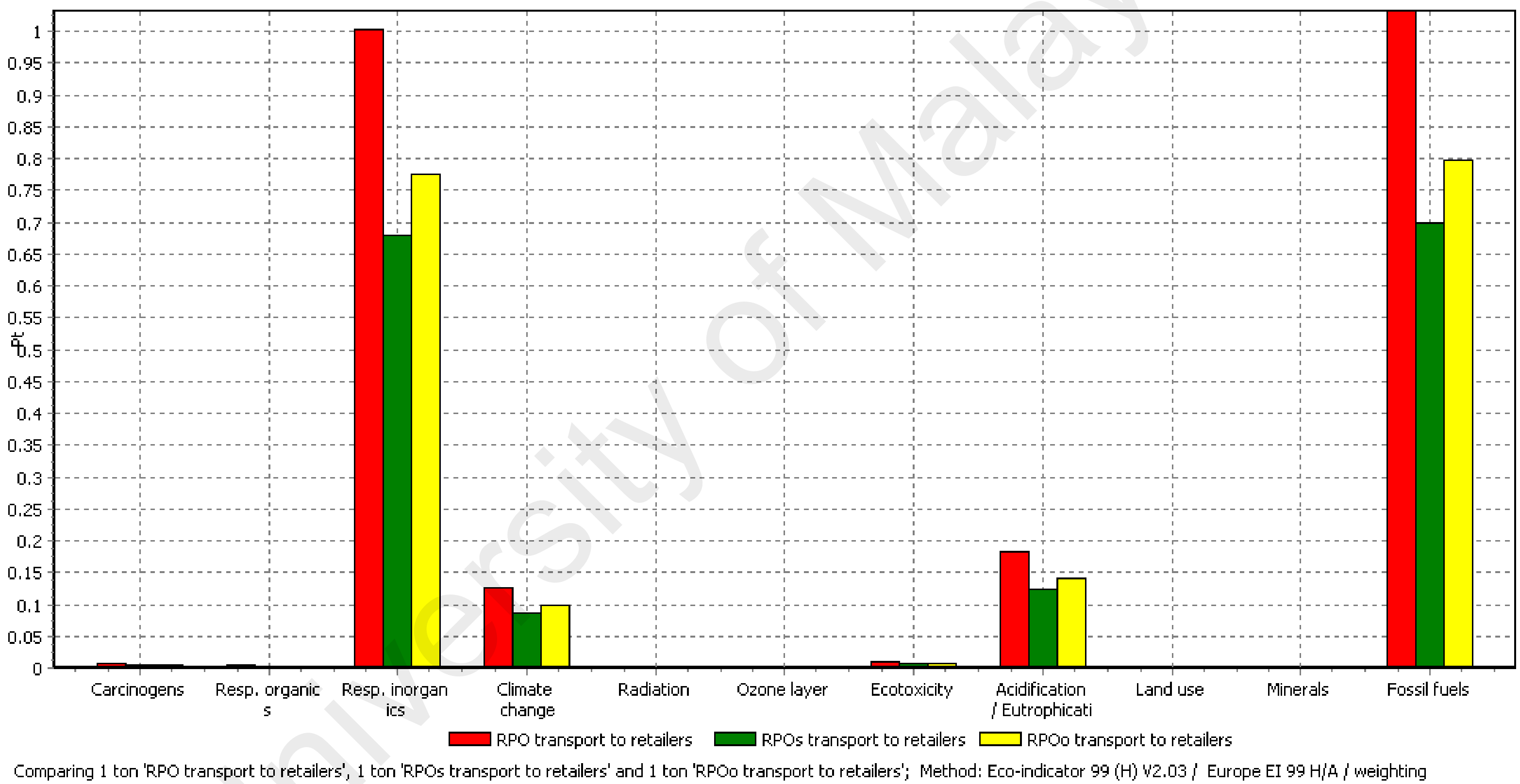

Figure 4.3: Comparison of weighted results for the transport of RBD palm oil, RBD palm olein and RBD palm stearin from refinery to retailers based on the production of one tonne RBD palm oil.

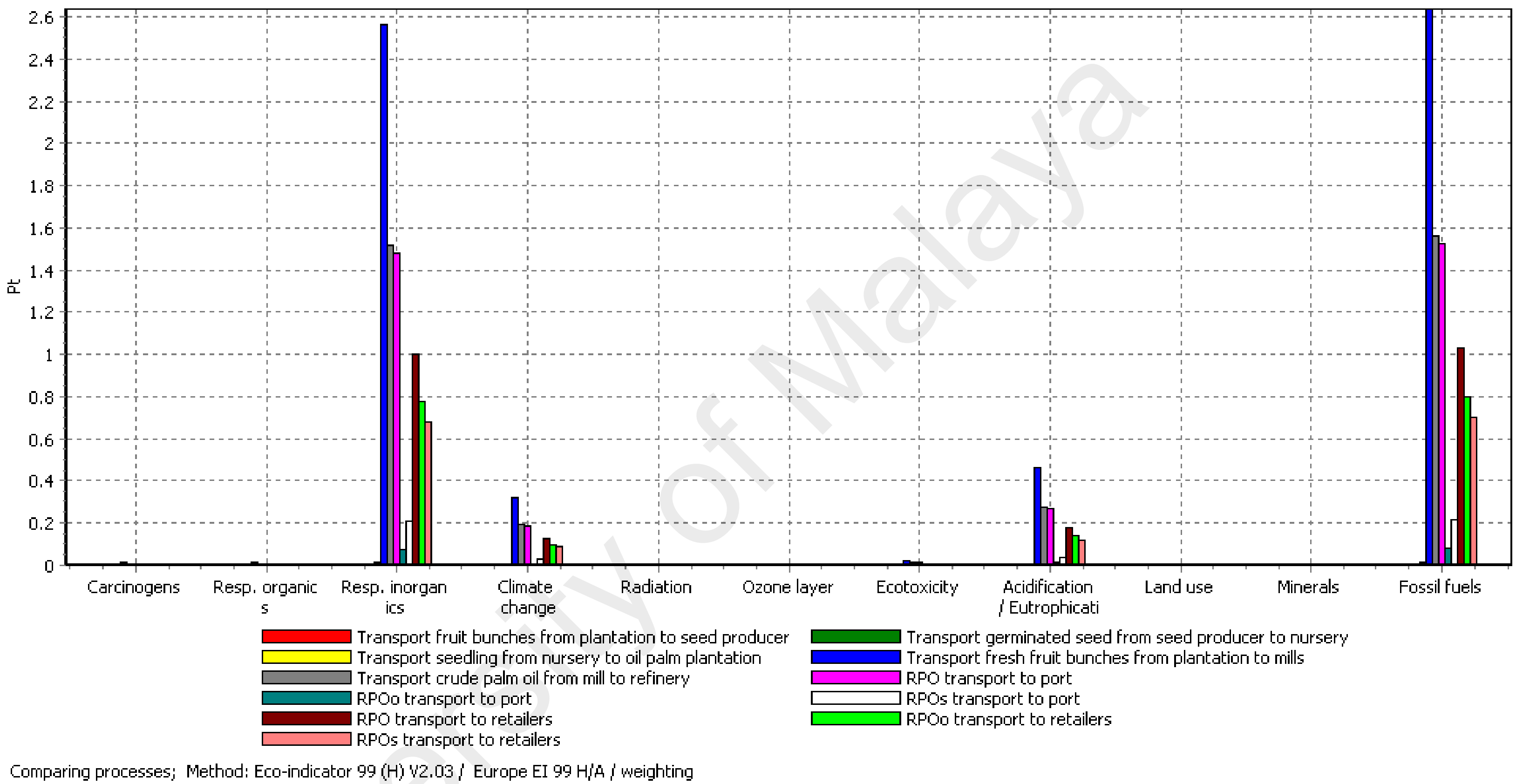

Figure 4.4: Comparison of weighted results for the transport of fruit bunches, germinated seeds, seedlings, fresh fruit bunches, crude palm oil, RBD palm oil, RBD palm olein and RBD palm stearin based on the respective functional unit for each stage of the supply chain

Figure 4.1 showed the comparison of weighted results for the transport of the fruit bunches from mother palm, germinated seeds and seedlings. Figures 4.2 and 4.3 showed the comparison for the transport of the RBD palm oil, RBD palm olein and RBD palm stearin to ports and retailers respectively while Figure 4.4 showed the comparison for the transport of all the materials at the different stages along the palm oil supply chain for the production of one tonne of the refined palm oil from the transport of the mother palm to the transport of the refined palm oil products to ports and retailers. Based from Figure 4.4, this study showed that the environmental impacts were highest during the transportation of the fresh fruit bunches from the oil palm plantations to palm oil mills followed by the transportation of crude palm oil from the mills to refineries. This finding concurred with the study by Zulkifli et al. (2010) on the life cycle assessment for oil palm fresh fruit bunches production of which data collection was also done during the period 2007/2008 also found that the most significant impact came from fossil fuel from the use of field machinery (tractors) and the use of transport vehicles to bring the materials to the plantations and transporting the FFB to the mills.

The transportation of RBD palm oil to ports was also shown to have a high impact on the environment. This finding was consistent with the LCI data on the higher diesel consumption for the transport of RBD palm oil to ports as some of the refineries studied were located inland and this contributed to the environmental impact. The transportation of the RBD palm oil, RBD palm olein and RBD palm stearin to retailers also gave some impact due to the distance of the premises for repacking for use as cooking oil or for further processing. Tan et al. (2010) who studied the life cycle assessment of refined palm oil production and fractionation also highlighted in her study that the environmental hotspot during the refining and fractionation of palm oil was also fossil fuels and respiratory in-organics originating from transport activities to carry the materials from the plantations and the transport of CPO to the refinery. The data collection for this study was also during 2007/2008. Halimah et al (2010) studied the life cycle assessment of the oil palm seedling production of which the system boundary began with the transportation of the germinated seeds to the nursery and ended with the transportation of the 12-month-old seedlings to the plantations (data collection during 2007/2008). She concluded that the production of seedlings in the nursery has insignificant impact on the environment. This studied concurred with the study done by Halimah et al. (2010) as from the LCIA weighted results in Figure 4.4 also indicated that the environmental impact during the transportation at the nursery stage was also not significant when compared with the transportation during other stages along the palm oil supply chain. However, as indicated in Figure 4.1, when compared just during the nursery stage, the transportation of seedlings gave the highest impact compared to transportation of fruit bunches from the ‘mother palm’ and transportation of the germinated seeds to nurseries. For the comparison of the transport of the refined oils to ports, as shown in Figure 4.2, the transportation of the RBD palm oil to ports gave the highest impact, while for the transport of the refined oils to retailers, the impact from the transport of the RBD palm oil, RBD palm olein and RBD palm stearin were about the same.

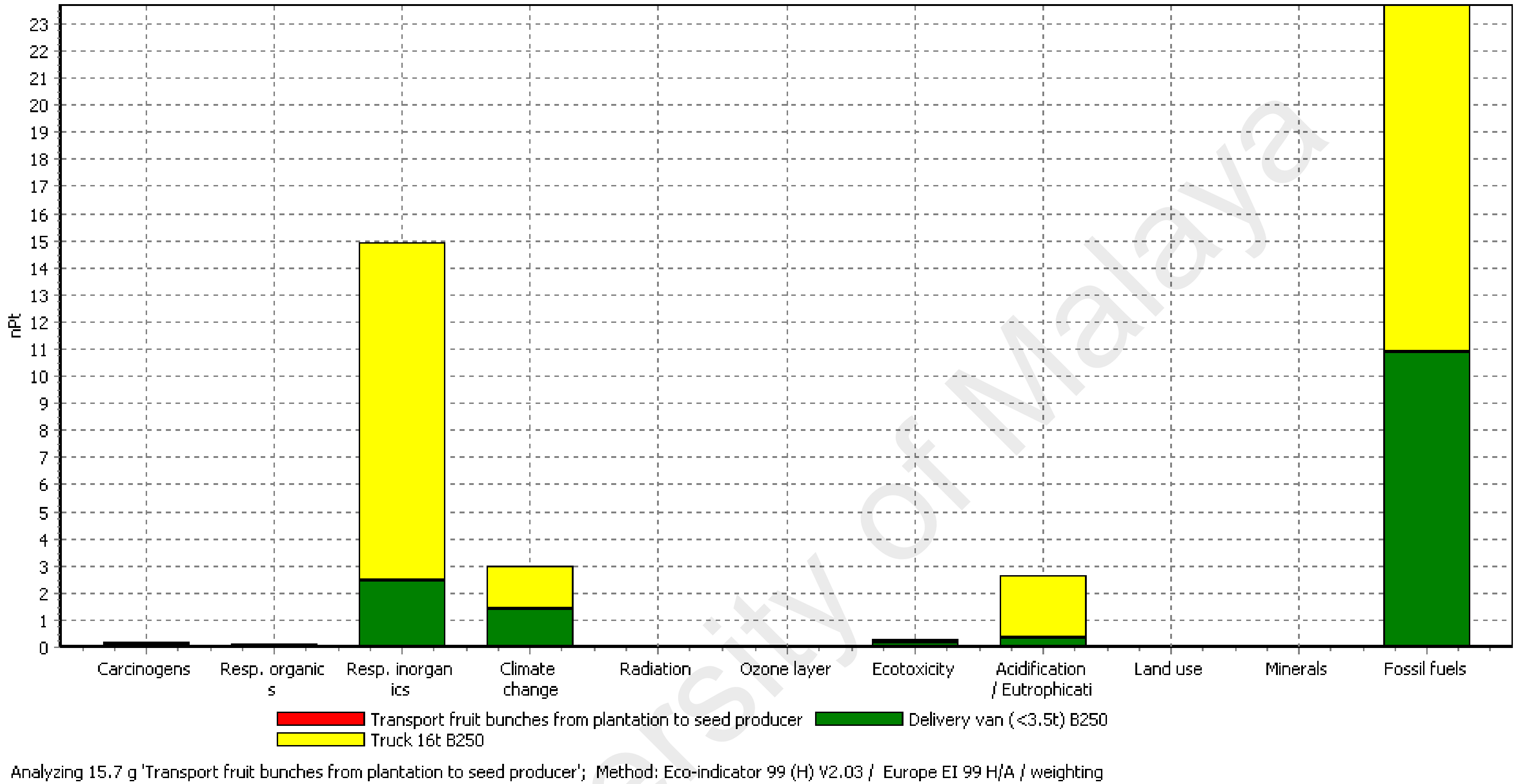

Figure 4.5: Weighted results for the transport of fruit bunches from plantation to seed producer for the production of one germinated seed

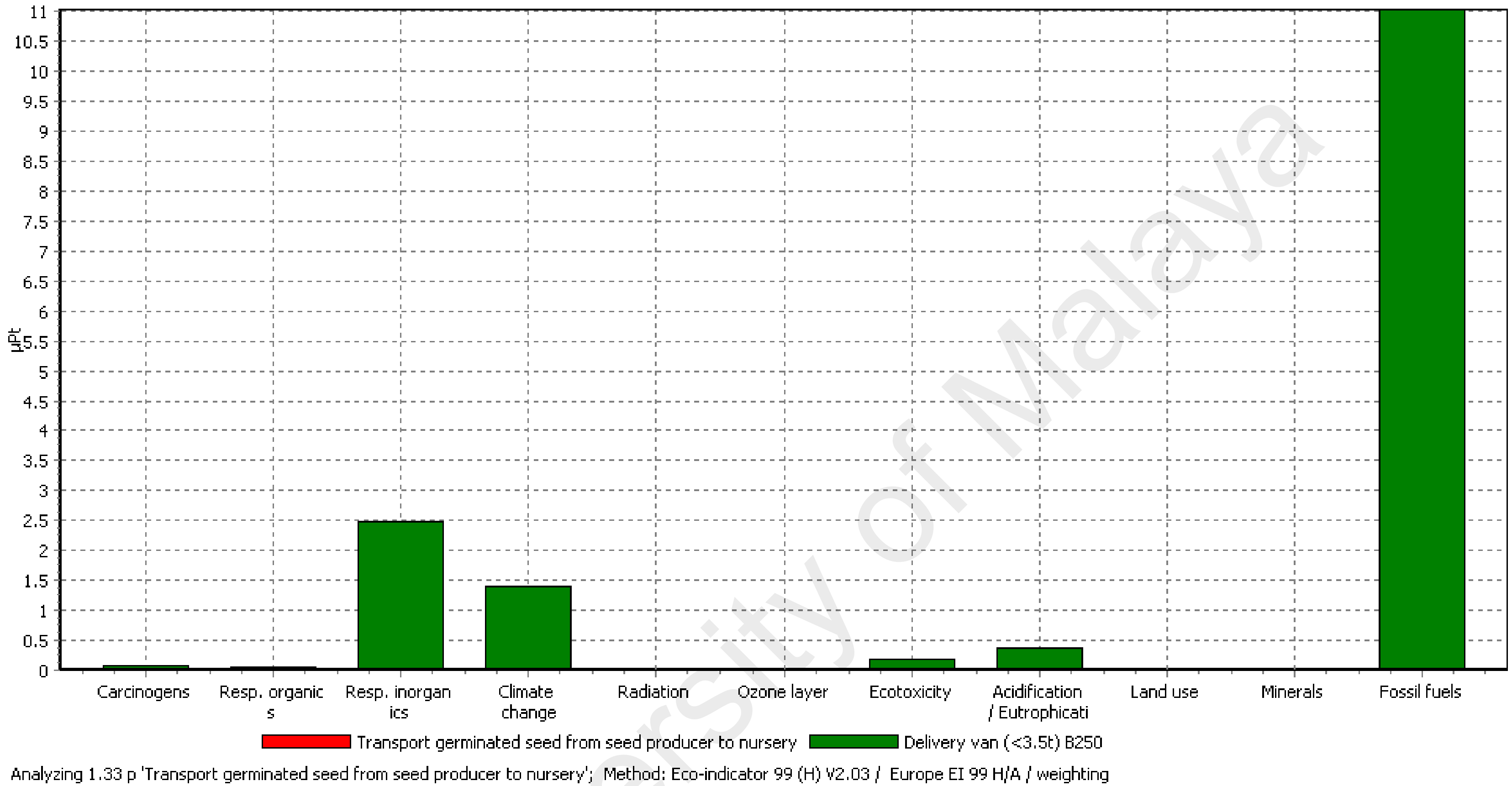

Figure 4.6: Weighted results for the transport of germinated seeds from seed producer to nursery based on the production of one seedling

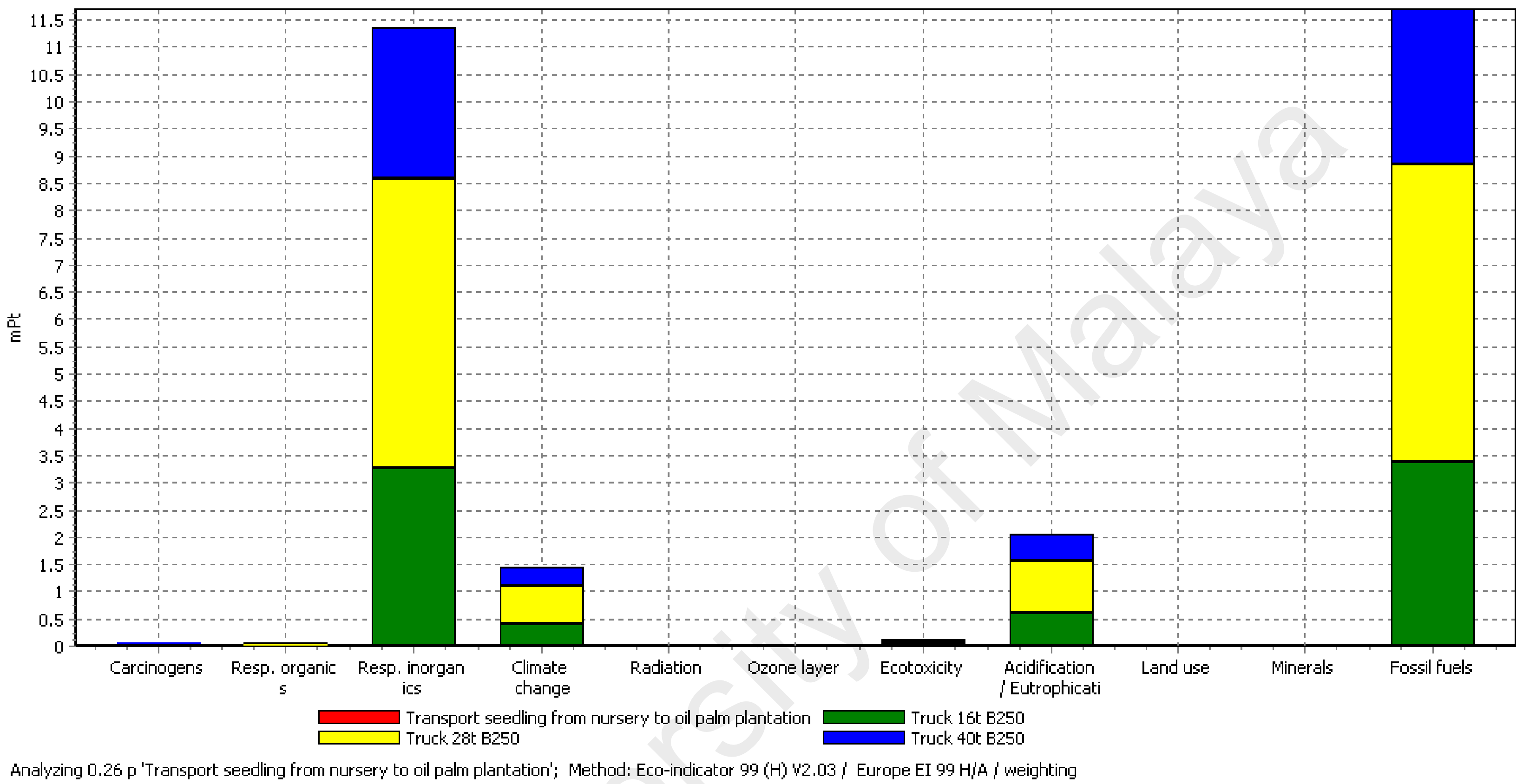

Figure 4.7: Weighted results for the transport of seedlings from nursery to oil palm plantations based on the production of one tonne FFB

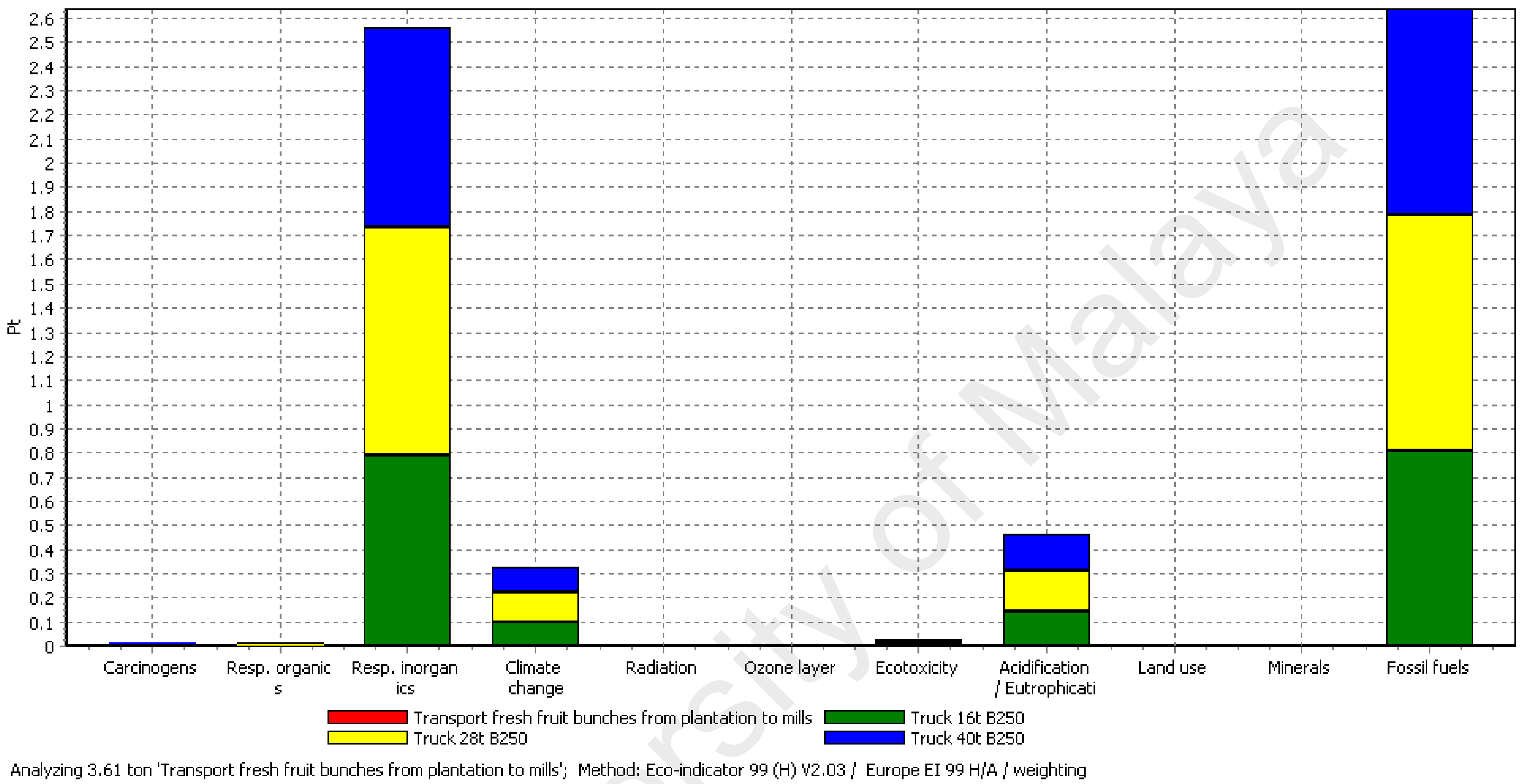

Figure 4.8: Weighted results for the transport of fresh fruit bunches from plantation to mill based on the production of one tonne CPO

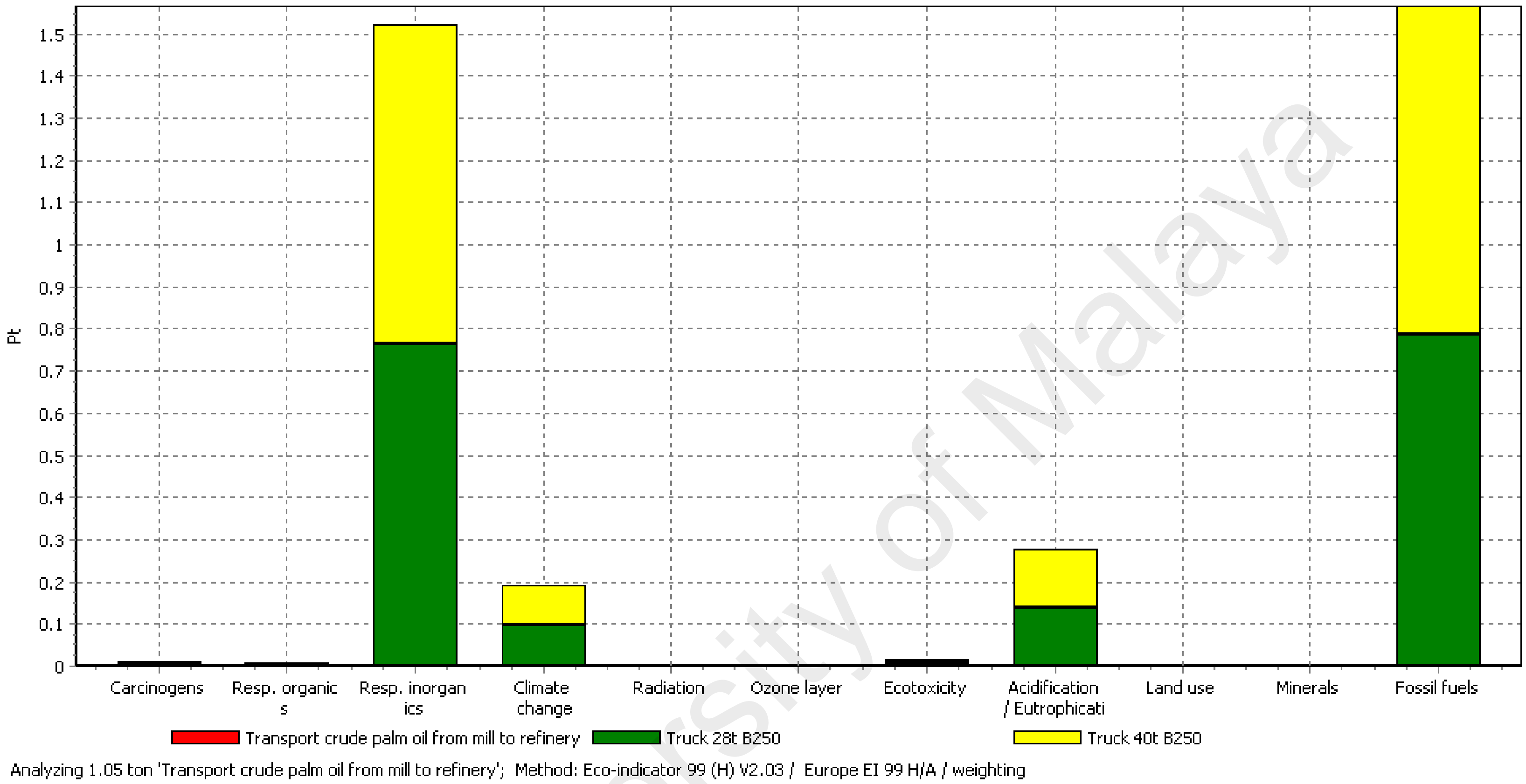

Figure 4.9: Weighted results for the transport of crude palm oil from mill to refinery based on the production of one tonne RBD palm oil

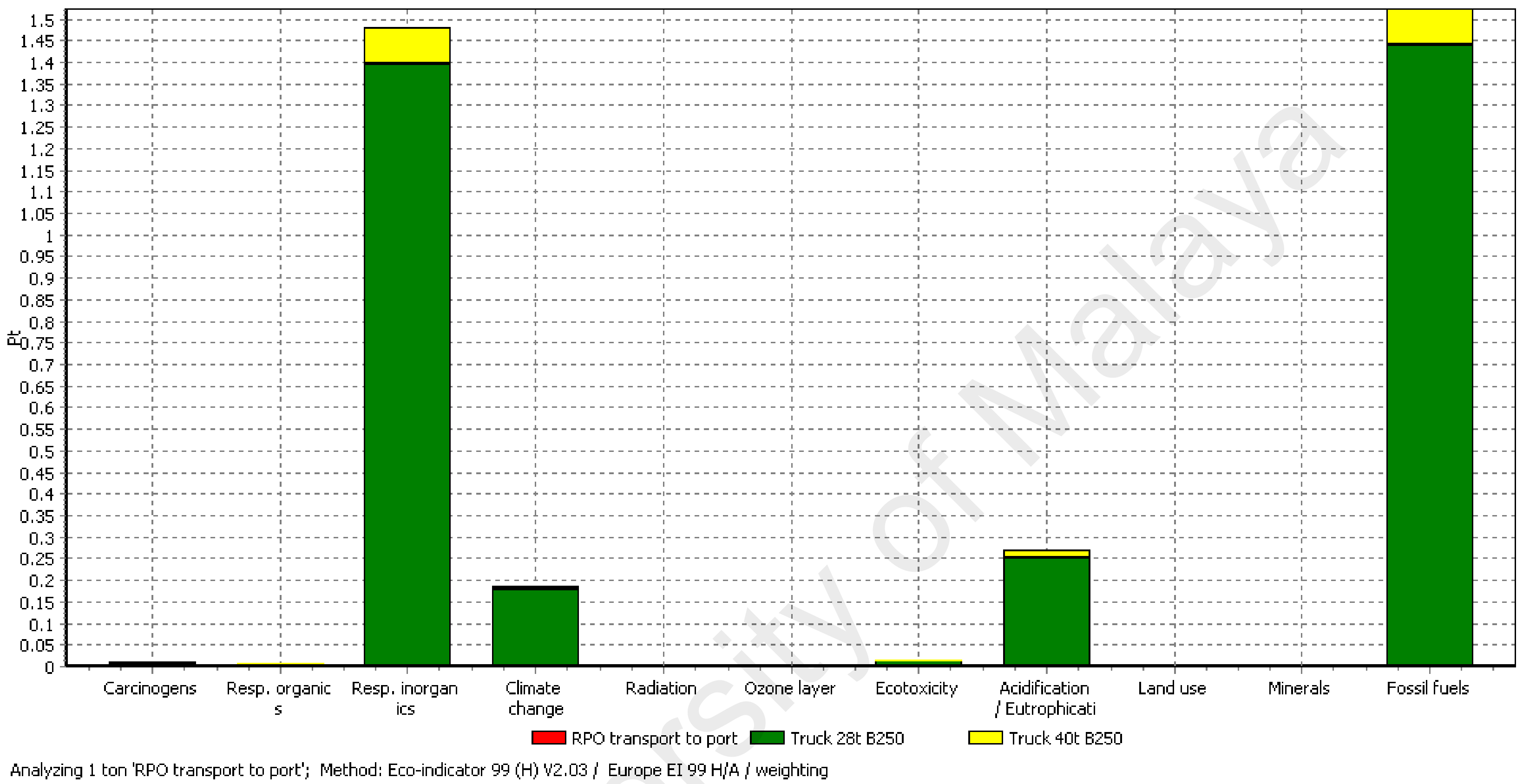

Figure 4.10: Weighted results for the transport of RBD palm oil from refinery to port based on the production of one tonne RBD palm oil

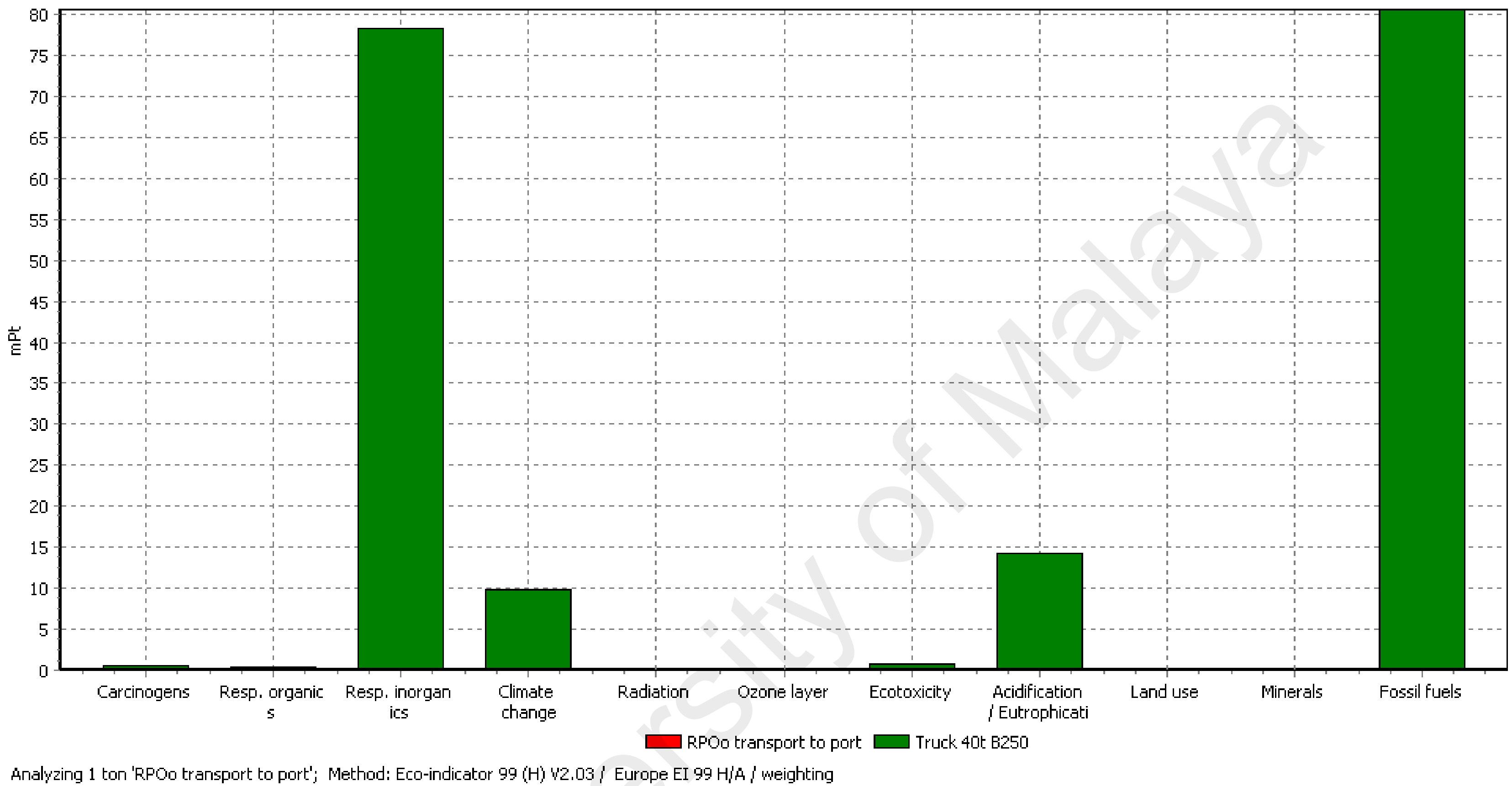

Figure 4.11: Weighted results for the transport of RBD palm olein from refinery to port based on the production of one tonne RBD palm oil

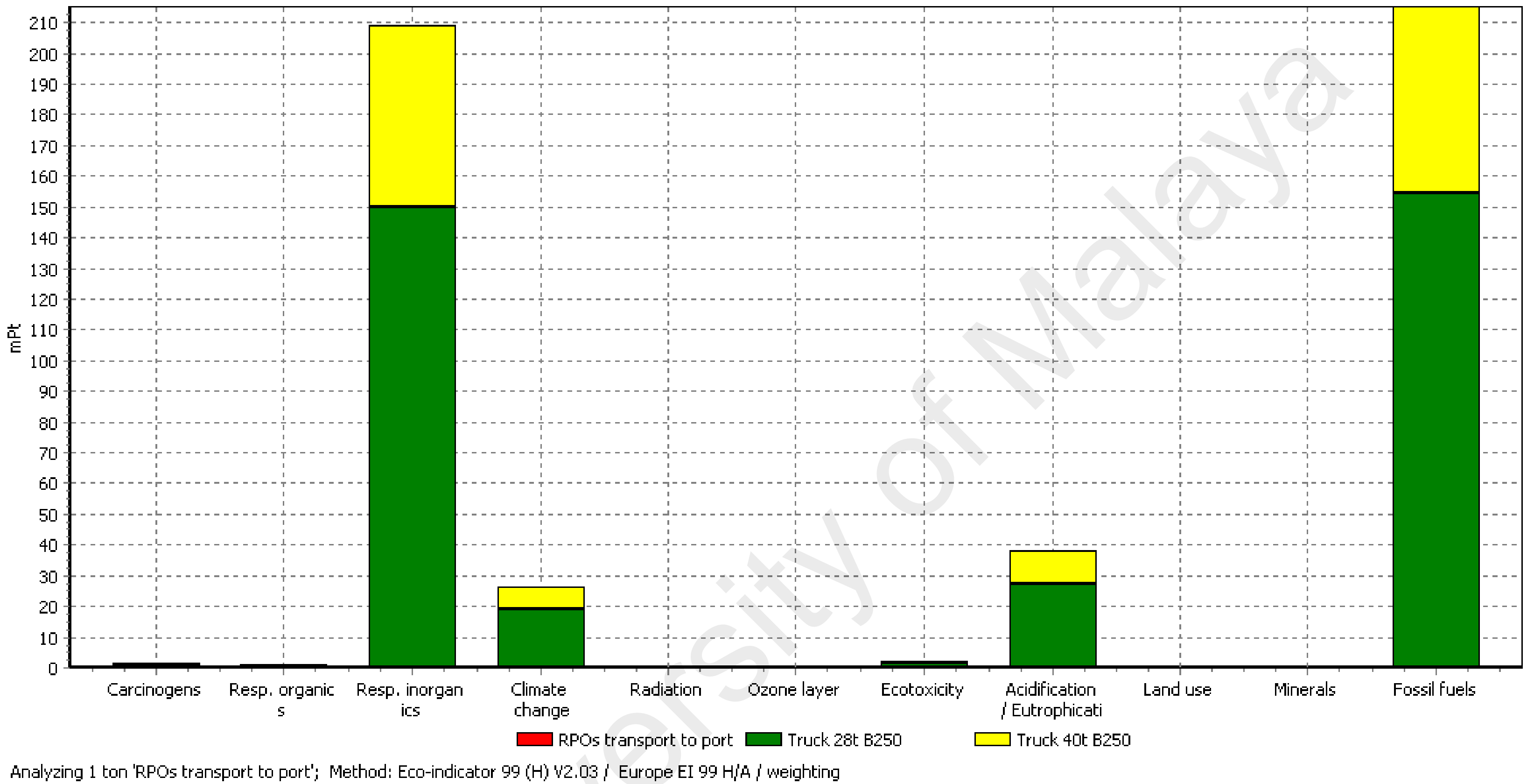

Figure 4.12: Weighted results for the transport of RBD palm stearin from refinery to port based on the production of one tonne RBD palm oil

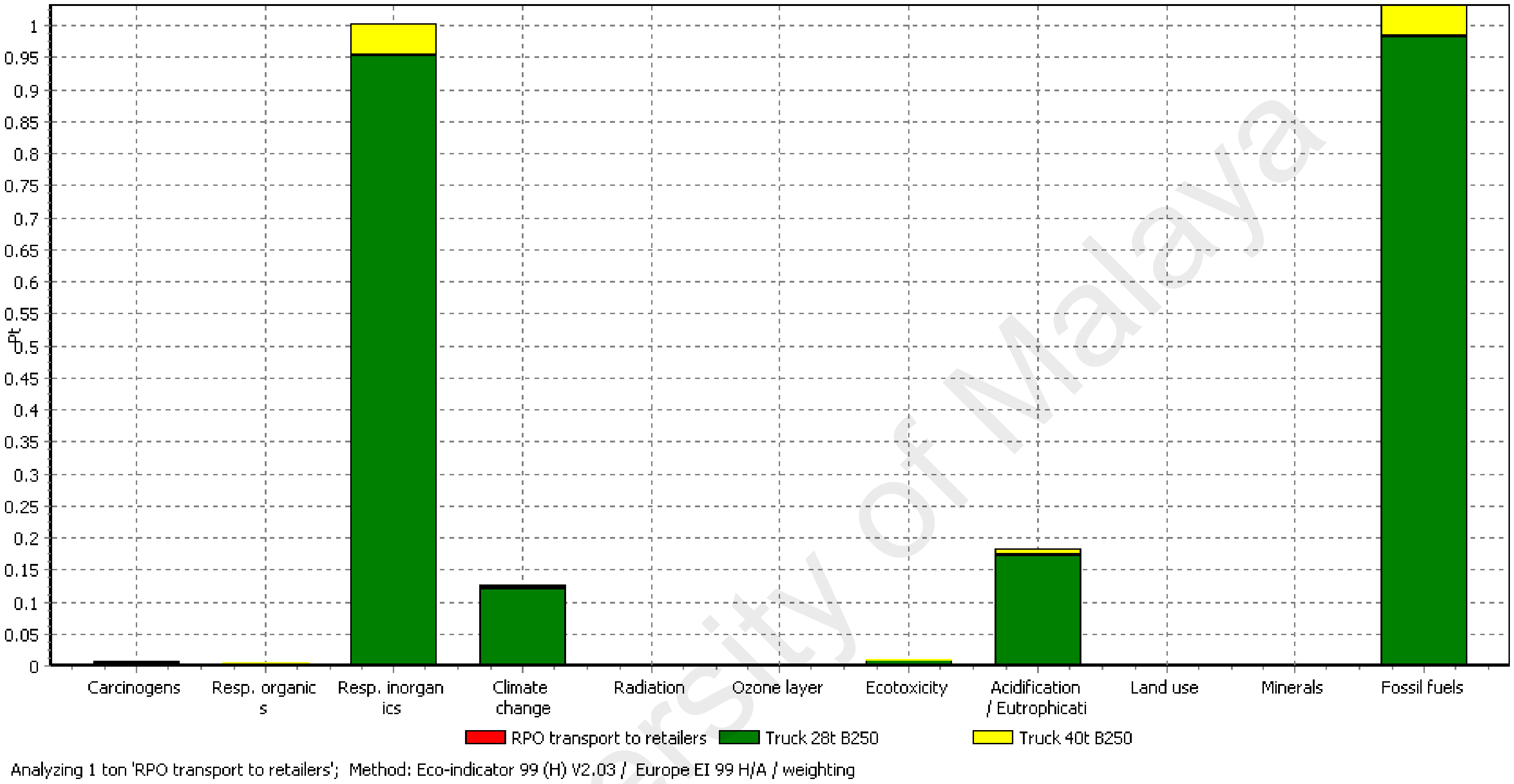

Figure 4.13: Weighted results for the transport of RBD palm oil from refinery to retailers based on the production of one tonne RBD palm oil

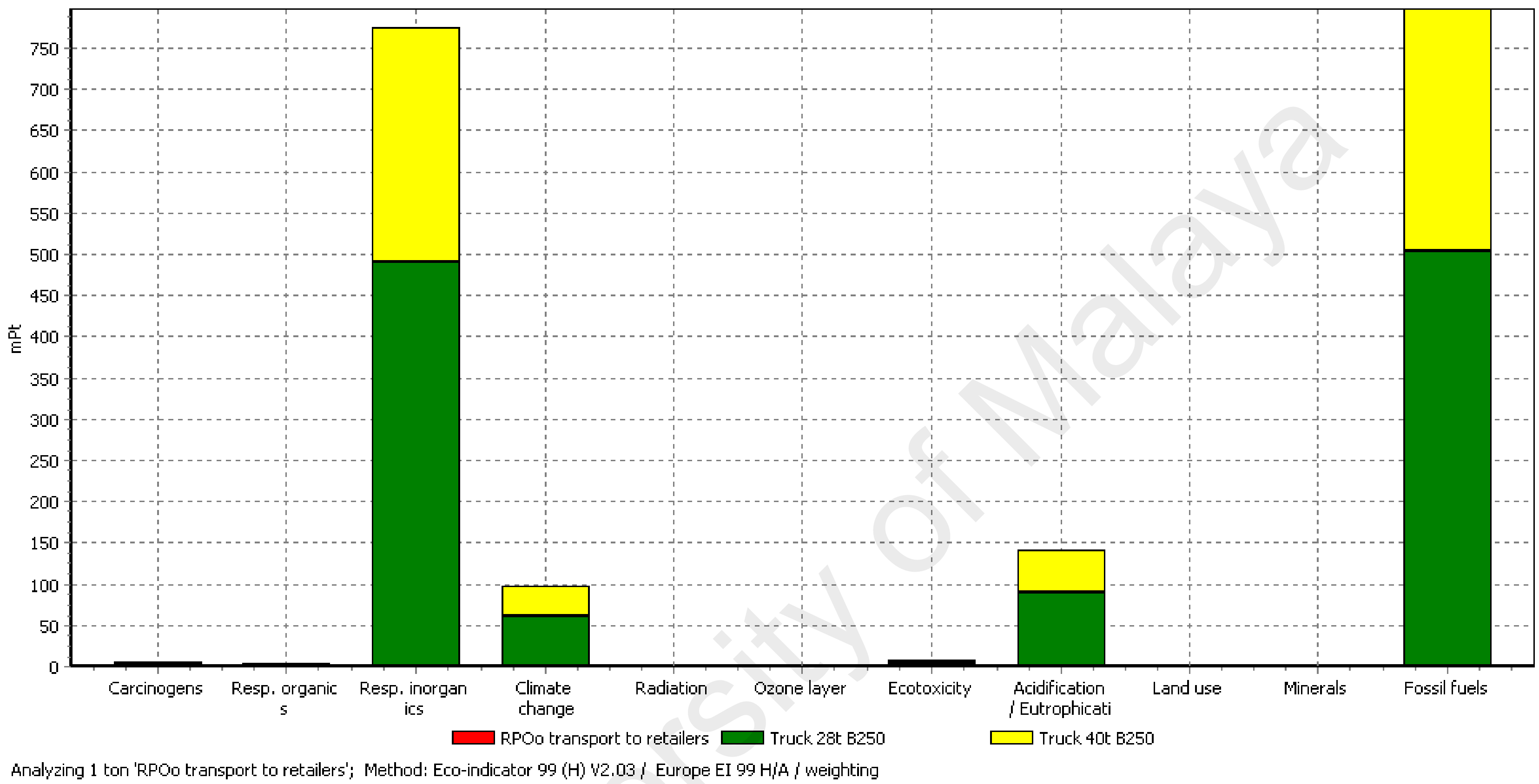

Figure 4.14: Weighted results for the transport of RBD palm olein from refinery to retailers based on the production of one tonne RBD palm oil

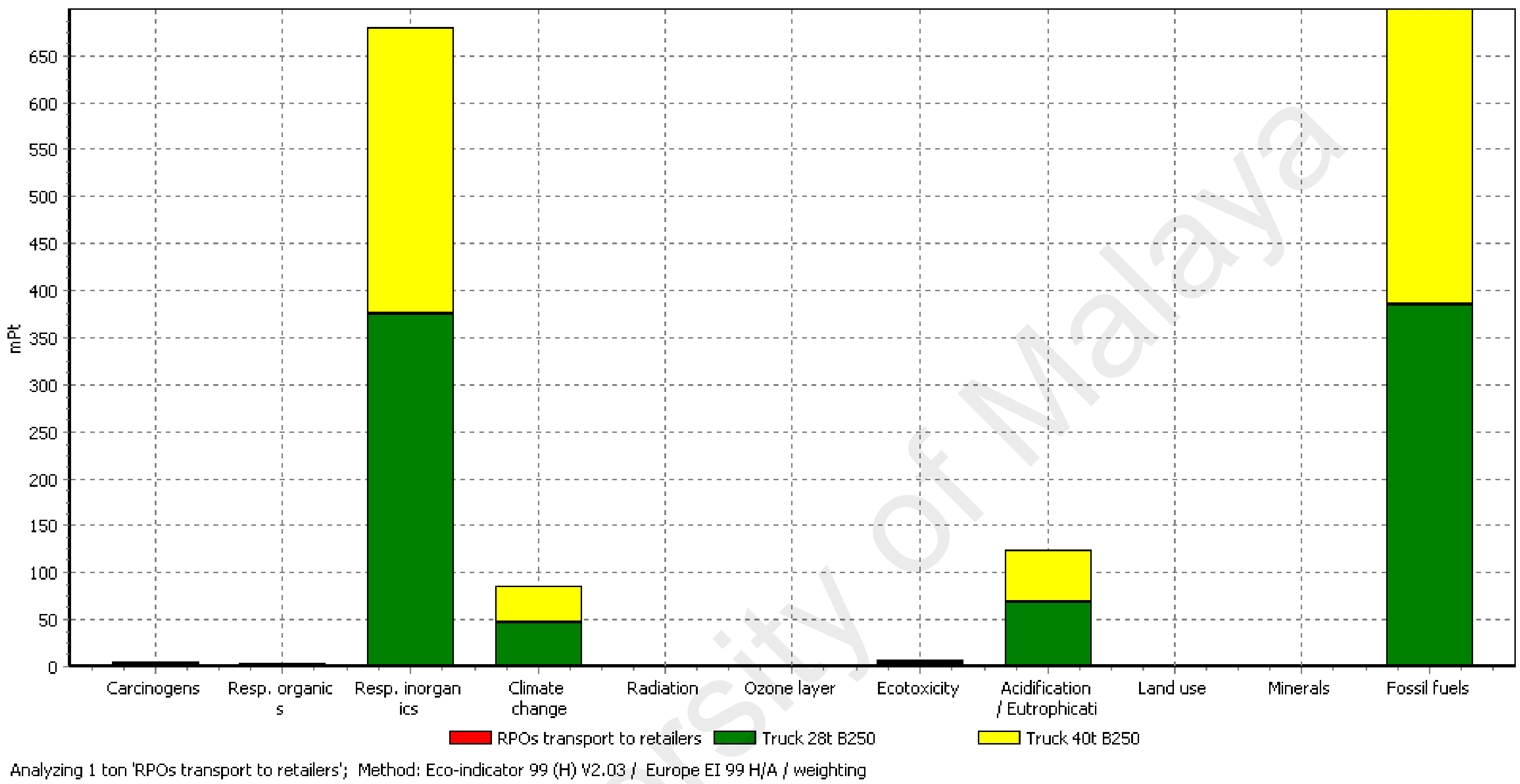

Figure 4.15: Weighted results for the transport of RBD palm stearin from refinery to retailers based on the production of one tonne RBD palm oil

Based on the weighted results, it was also observed that the impacts on the categories were contributed by the types of vehicles used to transport the materials along the palm oil supply chain. As observed in Figure 4.5, for the transportation of the 'mother palm' to the seed producer, the impact from 16t vehicles was higher compared to smaller vehicles of <3.5t. During the transportation of the germinated seeds to nursery, the impact was solely from <3.5t vehicles as only this type of vehicles were used to transport the germinated seeds in the study (Figure 4.6). For the transport of seedlings to plantations, the impact was higher from 28t vehicles (Figure 4.7). During the transportation of the FFB from oil palm plantation to mill and the transportation of CPO from mill to refinery, the impact came from 16t, 28t and 40t vehicles as all these vehicles sizes were used to transport the FFB and CPO respectively (Figures 4.8 and 4.9). During the transport of RBD palm oil from refinery to ports and refinery to retailers, the impact from 28t vehicle was higher compared to 40t vehicles (Figures 4.10 and 4.13). For the transport of RBD palm olein from refinery to ports, only 40t vehicles were used in the study (Figures 4.11). However, for transport of RBD palm olein to retailer, the impact from 28t vehicles was higher compared to 40 t vehicles (Figures 4.14). During the transport of RBD palm stearin to ports and retailers, the impact was higher from 28t vehicles (Figures 4.12 and 4.15).

The weighting element in LCA has always been a controversial issue because this element requires the incorporation of social, political and ethical values. Apart from that, the weighting factors and the type of weighting method are also controversial (Finnviden et al., 2009). Despite these controversies, weighting is widely used. Evaluating the weighting method is not easy as the values involves are difficult to identify and evaluate. Nevertheless, all the weighting methods use data and methods taken from different scientific disciplines which can be evaluated and the value choices can be identified and clarified. According to Finnveden et al. (2002), methods for weighting can be classified in different ways such as by a distinction between panel methods and monetization method. In panel method, a group of people are asked about their values whereas in monetization method, the values are expressed in a monetary measure. Another method is by distance-to-target where the weigting factors are calculated as a function of some type of target value. However, this method can be questioned as the different targets are not weighted against each other (Finnveden et al., 2002). Several weighting methods that were developed in the 1990s are still used. An example is the Ecoindicator 99 which is an end-point or damage methods based on a panel approach (Goedkoop and Spriensma, 2000).

This study was using the Ecoindicator 99 method based on panels from Europe. As such, their views may not be the same if the panels were from Malaysia. This is a limitation from the LCIA results in this study.

4.4 Total Greenhouse Gas (GHG) Emission from Transportation by the Malaysian Oil Palm Industry

Tables 4.25 and 4.26 show the total energy consumption and the amount of GHG emission produced during the transportation process along the palm oil supply chain within the scope of the study based on the production of the materials in 2013 respectively. The refined palm olein and palm stearin for the retailers were calculated based on the difference between the total palm olein and palm stearin produced and exported respectively. However, in view that the fractionation of the refined palm oil to produce palm olein and palm stearin (1.29 tonne palm oil was needed to produce one tonne of palm olein and 4.62 tonne of palm oil was needed to produce one tonne of palm stearin (Tan et al, 2009), the refined palm oil for the retail was based on the balance of the refined palm oil after deduction to produce the palm olein and palm stearin and refined palm oil exported.

As shown from Table 4.25, when the energy consumption was based on the actual production of the materials transported for the whole year by the Malaysian oil palm industry, it was shown that the highest energy consumption in terms of diesel consumption was during the transportation of the fruit bunches from the plantation to the palm oil mills and from the transportation of the CPO from the mills to the refinery at 100,502,080.6 L and 62,530,989.4 L respectively. Apart from the reasons that was already highlighted for the high consumption of energy for the transportation of these sectors of the palm oil supply chain within the system boundary based on the functional unit at the sectors concerned, the total amount of the materials produced for the CPO and the RBD palm oil production at 19,216,459 tonnes and 14,817,770 tonnes respectively (Economy and Industrial Development Division, MPOB, 2014) resulted in the these sectors being the highest in terms of energy consumption. The total petroleum consumption for Malaysia in 2013 was 623,000 barrels/day (U.S Energy Information Administration, 2014). 623 barrel oil = 99049 L (Metric Conversions, 2014) which is equivalent to 99,049,000 L/day x 395 = 36,152,885,000 L/year. The total diesel consumption at 185,031,617.87 L contributes to only 0.51 % to the total petroleum consumption in the country.

From Table 4.25, based on the data of the GHG emission derived from this study, it was found that a total of 779,858.80 tonne CO_2 eq was produced during the transportation along the palm oil supply chain. However, this contributed only 3.54% from the total emissions of 22 million tonnes of CO_2 emitted from the combustion of fuel for all transport activity in the country regardless of the sector, except for international marine bunkers and international aviation. This includes domestic aviation, domestic navigation, roads, rail and pipeline transport (World Development Indicators, 2014).

Table 4.25: Consumption of energy for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin on the basis of actual production

Product Transported	From	Average distance (km)	Based on the production of	Energy consumption based on production of 1 unit or 1 tonne of materials	Production in 2013 (Economy and Industrial Development Division, MPOB, 2014)	Energy consumption for transportation based on the production of materials in 2013
			Nursery Stage			
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	1 unit of germinated seed	4.85×10^{-4} L (0.02 MJ)	112,259,510 number of germinated seeds supplied	54,445.86 L (1,954,606.46 MJ)
Germinated Seeds	Seed Producer to nursery	86	1 unit of seedling	6.36×10^{-4} L (0.02 MJ)	31,072,241	19,761.95 L (709,453.84 MJ)
Seedlings	Nursery to plantation	70	1 tonne of FFB	2.76×10^{-4} L (0.50MJ)	95,728,589 tonnes of FFB received by mills	26,421.09 L (948,517.15 MJ)
			Plantation			
Fresh fruit bunches	Plantation to mill	31	1 tonne of CPO	5.23 L (187.76 MJ)	19,216,459 tonnes of CPO produced	100,502,080.6 L (3,608,024,692 MJ)

Palm Oil Mill						
Crude Palm Oil	Mill to refinery	164	1 tonne of RBD PO	4.22 L (151.50 MJ)	14,817,770 tonnes of RBD PO	62,530,989.4 L (2,244,862,519 MJ)
Palm Oil Refinery						
Refined oils for export						
RBD Palm Oil	Refinery to ports	67	1 tonne of RBD PO	Electricity: 0.45 kWh (1.62 MJ) Diesel: 0.32 L (11.49 MJ) Total (13.11 MJ)	1,626,422 tonnes of RBD PO exported	Electricity: 2,634,803.64 MJ Diesel: 520,455.04 L (18,684,335.94 MJ) Total: 21,319,139.58 MJ
RBD Palm Olein	Refinery to ports	21	1 tonne of RBD PO	Electricity: 0.47 kWh (1.69 MJ) Diesel:	8,769,277 tonnes of RBD palm olein exported	Electricity: 14,820,078.13 MJ Diesel:

				0.84 L (30.16 MJ) Total (31.85 MJ)		7,366,192.68 L (264,446,317.2 MJ) Total: 279,266,395.3MJ
RBD Palm Stearin	Refinery to ports	18	1 tonne of RBD PO	Electricity: 0.46 kWh (1.66 MJ) Diesel: 0.59 L (21.18 MJ) Total (22.84 MJ)	1,617,771 tonnes of RBD palm stearin exported	Electricity: 2,685,499.86 MJ Diesel: 954,484.89 L 34,266,007.55 MJ Total: 36,951,507.41 MJ
Refined oils for retailers						
RBD Palm Oil	Refinery to retailers	44	1 tonne of RBD PO	2.11 L (75.75 MJ)	116,166	245,110.26 L (8,799,458.33 MJ)

RBD Palm Olein	Refinery to retailers	53	1 tonne of RBD PO	5.37 L (192.78 MJ)	1,807,830	9,708,047.1 L (348,518,890.9 MJ)
RBD Palm Stearin	Refinery to retailers	63	1 tonne of RBD PO	2.56 L (91.90 MJ)	1,212,355	3,103,628.8 L (111,420,273.9 MJ)
Total						**185,031,617.67 L** **6,642,635,072.00 MJ**

Table 4.26: Total Greenhouse Gas Emission (GHG) for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin on the basis of actual production.

Product Transported	From	Average distance (km)	Based on the production of	GHG Emission ($kg\ CO_2$ eq.) during transportation based on production of 1 unit or 1 tonne of materials	Production in 2013 (Economy and Industrial Development Division, MPOB, 2014)	GHG Emission ($tonne\ CO_2$ eq.) during transportation based on the production of materials in 2013
Nursery Stage						
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	1 unit of germinated seed	9.89×10^{-4}	112,259,510 number of germinated seeds supplied	111.02
Germinated Seeds	Seed Producer to nursery	86	1 unit of seedling	5.32×10^{-3}	31,072,241	165.30
Seedlings	Nursery to plantation	70	1 tonne of FFB	8.36×10^{-2}	95,728,589 tonnes of FFB received by mills	8,002.91

Plantation						
Fresh fruit bunches	Plantation to mill	31	1 tonne of CPO	20.90	19,216,459 tonnes of CPO produced	401,623.99
Palm Oil Mill						
Crude Palm Oil	Mill to refinery	164	1 tonne of RBD PO	20.86	14,817,770 tonnes of RBD PO	309,098.68
Palm Oil Refinery						
Refined oils for export						
RBD Palm Oil	Refinery to ports	67	1 tonne of RBD PO	Electricity: 0.45 kWh (0.31 kg) Diesel: 7.37 kg Total (7.68 kg CO_2eq.)	1,626,422 tonnes of RBD PO exported	12,490.92

RBD Palm Olein	Refinery to ports	21	1 tonne of RBD PO	Electricity: 0.47 kWh (0.32 kg) Diesel: 2.14 kg Total (2.46 kg CO_2eq.)	8,769,277 tonnes of RBD palm olein exported	21,572.42
RBD Palm Stearin	Refinery to ports	18	1 tonne of RBD PO	Electricity: 0.46 kWh (0.32 kg) Diesel: 1.93 kg Total (2.25 kg CO_2eq.)	1,617,771 tonnes of RBD palm stearin exported	3,639.98
Refined oils for retailers						
RBD Palm Oil	Refinery to retailers	44	1 tonne of RBD PO	4.78	116,166	555.27
RBD Palm Olein	Refinery to retailers	53	1 tonne of RBD PO	6.80	1,807,830	12,293.24

RBD Palm Stearin	Refinery to retailers	63	1 tonne of RBD PO	8.50	1,212,355	10,305.02
Total						**779,858.80**

4.5 Comparison between the amount of GHG emission from transportation and the amount of GHG Emissions from the production of seedlings, FFB, CPO, RBD PO and its Fractions

Based on the data for the transportation of germinated seeds for the production of one seedling from Table 4.12 above, it was shown that 5.32 X 10^{-3} kg of CO_2 eq. was emitted to the environment. From the earlier study by Choo et al. (2011) who found that 0.05 kg CO_2 eq. was released during the production of one seedling. This amount was found to be more than the GHG emissions observed during this study. The higher value could be attributed to the fact that the transportation included other materials in the production of the seedlings such as the fertilizer and polybags used in the production while in this study only the transport of the germinated seeds was studied during this sub-system. From the LCI data for the calculation of GHG emissions in her study, Choo et al. also found that this sub-system contributed insignificant amount to GHG emissions accounting for only 0.01% of the share in the production of one tonne FFB.

From this study, it was observed that the transportation of seedlings for the production of one tonne FFB only contributed to 8.36 X 10^{-2} kg of CO_2 eq. This was due to the fact that only 0.26 seedling was used in the production of one tonne FFB. In the study conducted by Choo et al. (2011), it was found that the plantation sub-system emitted 119 kg of CO_2 eq. During the study by Choo et al., the transportation of the FFB to the mill was included in the system boundary. Choo et al. also found that for the production of one tonne of FFB, the major portion of the emission came from the use of N fertilizer (48.7%) followed by emissions resulting from the manufacture of raw materials such as fertilizers and pesticides (32.0 %) while transportation contributed to 11.1% of the total GHG emissions. In the study by Choo et al., no land use change was considered. The emissions from transportation in the plantation sub-system for the transportation during the production of one tonne FFB in the study by Choo et al. based on the percentage of GHG from transportation was 13.2 kg of CO_2 eq. which was slightly less than the emission observed during this study. No comparison can be made with transportation during the production of one tonne CPO as the system boundary during the study by Choo et al did not include the transportation of FFB to the mill (Choo et al. 2011). The study for the production of CPO by Choo et al. studied two scenarios i.e. based on a mill with a system with biogas capture from the palm oil mill effluent (POME) and one without a system for biogas capture from POME.

The GHG emission during the transport of the CPO for the production of one tonne of the refined palm oil from the study was calculated at 20.86 kg of CO_2 eq. The study by Choo et al. found that the GHG emission for the production of one tonne refined palm oil was 1,113 kg of CO_2 eq. if CPO is supplied from a mill without a system for capturing biogas, and the value was reduced to 626 kg of CO_2 eq. if the CPO is from a mill which captured biogas. The study found that the major contribution in the production of refined palm oil was the boiler fuel used (38%) while transport of raw materials contributed 23% of the GHG emission in the refined palm oil production sub-system (Choo et al., 2011). Taking into account that transportation accounted for 23% of the total GHG emissions, the emissions from the study by Choo et al. from mill without biogas capture and mill with biogas capture were 256 kg of CO_2 eq. and 144 kg of CO_2 eq. respectively. In comparison, the GHG emission from this study was 20.86 kg of CO_2 eq. The lower value in this study can be attributed to the fact that the value was only calculated from the transportation of the CPO while the study by Choo included the transportation of other materials used in the production of the refined palm oil such as the transport of the boiler fuel, phosphoric acid and bleaching earth to refinery and the spent bleaching earth from refinery to landfills. Similar to the findings from this study, the study by Choo et al. also observed that GHG emissions in this sub-system could be reduced by improving the transport logistics by routing delivery of the materials e.g. CPO for the shortest distance between supplier and the refinery (choo et al., 2011).

4.6 Comparison of the amount of GHG Emissions between 100% petroleum diesel and B5 Blends of 95% petroleum diesel and 5% palm oil biodiesel

The GHG emission that was calculated from this study was based on 100% petroleum diesel. However, the implementation of the B5 biodiesel mandate under the National Biofuel Policy to reduce dependency on petroleum diesel especially in the transport sector. This requires that all petrol stations in the country to sell B5 (a blend of 5% palm oil biodiesel and 95% petroleum diesel) nationwide by the end of 2014. The B5 programme was launched in phases starting with the implementation in the Central region which encompasses Putrajaya, Melaka, Negeri Sembilan, Kuala Lumpur and Selangor between June and November 2011 and later expanded to the Southern region (Johor) in July 2013. The B5 programme was further expanded to cover the states under Northern region (Perlis, Kedah, Penang and Perak) in October 2013 and the Eastern region (Kelantan, Pahang and Terengganu) in January 2014 (The Star, March 2014). It went nationwide by the end of the 2014 including Sabah and Sarawak when all the petrol stations be fully equipped with the blending facilities (Bloomberg, 2014).

Beer et al. (2007) has shown that the tailpipe emissions (g per km) for the use of ultra low sulphur diesel (ULSD as compared to biodiesel blends where the use of biodiesel contributes to lower emissions of carbon dioxide, carbon monoxide and particulate matter. The use of biodiesel increases the emissions of nitrogen oxides while there are similar emissions of methane, nitrous oxide and non-methane hydrocarbon as compared to ULSD (Table 4.27). BD2, BD5, BD10, BD20 and BD100 = biodiesel blends of 2%, 5%, 10% and 20% of palm oil based biodiesel respectively.

Table 4.27: Tailpipe emissions (g per km) for ultra low sulphur diesel biodiesel blends using palm oil

Impact Category	**ULSD**	**BD2**	**BD5**	**BD10**	**BD20**	**BD100**
Carbon dioxide	692	679	659	626	560	0
Methane	0.01	0.01	0.01	0.01	0.01	0.01
Nitrous oxide	0.016	0.016	0.016	0.016	0.016	0.015
Carbon monoxide	2.81	2.78	2.75	2.69	2.57	1.79
Nitrogen oxides	8.68	8.71	8.76	8.84	8.99	10.33
Non-methane hydrocarbon	0.72	0.71	0.71	0.71	0.71	0.71
Particulate matters (PM 10)	283	278	271	260	238	119

Assuming that the diesel used in Malaysia is the same type that is used in developed countries, the use of B5 blend would be able to reduce the GHG emissions in the country with the implementation of the B5 biodiesel mandate. From Table 4.28 it was shown that the use of 5% blends of palm based biodiesel with 95% petroleum diesel produced resulted in a 4.77% reduction in carbon dioxide emissions (692-659 g per km/692 x100 = 4.77% reduction). From the Table, it was also shown that there were no reduction in the emission of methane and nitrous oxide from the biodiesel blends.

The reduced CO_2 emission was calculated by using a factor of 0.9523 [(100%-4.77%)/100]. The total reduced CO_2 emission was added with the total emission for methane and nitrous oxide for the transport of fruit bunches (mother palm) from plantation to seed producer.

The re uced CO_2 eq. emission = 91792.92 x 0.9523 = 89496.15 g/1.56t

CO_2 eq. emission per tonne = 57,369.33 g/t = 57.34 kg/t

The emission based on production of one germinated seed = (15.69 g x 57.34 kg) ÷ 1000,000g = 9.00 x 10^{-4} kg CO_2 eq

Total CO_2 eq emission for the transport of fruit bunches (from 'mother palm') = 9.00 x 10^{-4} kg CO_2 eq x 112,259,510 number of germinated seeds supplied (based on data in Table 4.25) = 101,033.56 kg CO_2 eq = 101.03 t CO_2 eq.

The same method of calculation was used to calculate the GHG emission based on the functional unit for each sector of the transportation along the palm oil supply chain.

The total amount of GHG emissions based on the production of materials in 2013 from the B5 programme from Table 4.27 = 736,570.33 tonnes of CO_2 eq.

The savings in GHG emissions from the use of biodiesel blends =779,858.80 tonnes CO_2 eq. minus 736,570.33 tonnes CO_2 eq = 43,288.47 CO_2 eq. per year.

This savings would be greater when the blends incorporated higher amounts of biodiesel in the blends as indicated from the study by Beer et al. (2007)

Table 4.28: Total Reduction in the Greenhouse Gas Emission (GHG) for the transportation of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, fresh fruit bunches, crude palm oil and RBD palm oil, RBD palm olein and RBD palm stearin from the incorporation of 5 % palm oil based biodiesel blends in the petroleum diesel**.**

Product Transported	From	Average distance (km)	Based on the production of	GHG Emission ($kg\ CO_2$ eq.) during transportation based on production of 1 unit or 1 tonne of materials	Reduction in GHG Emission during transportation from the use of B 5 blends based on 1 unit or 1 tonne of materials ($kg\ CO_2$ eq.)	GHG Emission during transportation from the use of B 5 blends based on actual production of materials ($tonne\ CO_2$ eq.)
Nursery Stage						
Fruit bunches (from 'Mother Palm')	Plantation to seed producer	51	1 unit of germinated seed	9.89×10^{-4}	9.00×10^{-4}	101.03

Germinated Seeds	Seed Producer to nursery	86	1 unit of seedling	5.32×10^{-3}	5.08×10^{-3}	157.7
Seedlings	Nursery to plantation	70	1 tonne of FFB	8.36×10^{-2}	8.12×10^{-2}	7,808.30
Plantation						
Fresh fruit bunches	Plantation to mill	31	1 tonne of CPO	20.90	19.9	382,407.53
Palm Oil Mill						
Crude Palm Oil	Mill to refinery	164	1 tonne of RBD PO	20.86	19.89	294,725.44
Palm Oil Refinery						
Refined oils for export						
RBD Palm Oil	Refinery to ports	67	1 tonne of RBD PO	Electricity: 0.45 kWh	7.02	11,417.48

				(0.31 kg) Diesel: 7.37 kg Total (7.68 kg CO_2eq.)		

RBD Palm Olein	Refinery to ports	21	1 tonne of RBD PO	Electricity: 0.47 kWh (0.32 kg) Diesel: 2.14 kg Total (2.46 kg CO_2eq.)	2.02	17,889.32
RBD Palm Stearin	Refinery to ports	18	1 tonne of RBD PO	Electricity: 0.46 kWh (0.32 kg) Diesel: 1.93 kg Total (2.25 kg CO_2eq.)	1.84	2,976,70
Refined oils for retailers						
RBD Palm Oil	Refinery to retailers	44	1 tonne of RBD PO	4.78	4.55	528.79

RBD Palm Olein	Refinery to retailers	53	1 tonne of RBD PO	6.80	6.48	11,714.74
RBD Palm Stearin	Refinery to retailers	63	1 tonne of RBD PO	8.50	8.10	9,820
Total						**736,570.33**

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The increased awareness of the importance of environmental protection, and the possible impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts. One of the techniques being developed for this purpose is life cycle assessment (LCA).

LCA can assist in

- identifying opportunities to improve the environmental performance of products at various points in their life cycle,
- informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign),
- the selection of relevant indicators of environmental performance, including measurement techniques, and
- marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration).

For practitioners of LCA, ISO 14044 details the requirements for conducting an LCA.

LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave).

5.2 Conclusions based on the objectives of the study

The aim of this study is to use the LCA approach to identify at which stage of the palm oil supply chain that transportation contributes the most to the environmental performance within the boundary of the study.

The study has met with this objective as the results of the life cycle inventory (LCI) for the overall energy consumption for the different stages of the palm oil supply chain based on the production of one tonne RBD palm oil indicated that transportation of the fresh fruit bunches from plantation to palm oil mill and crude palm oil from mill to refinery were the main contributors. The study projected the diesel consumption for the transportation of the oil palm products along the palm oil supply chain based on the actual production of the oil palm products for the whole year. Based on the data from the study, the diesel consumption by the oil palm industry for the transportation of the bunches (from 'mother palm') to the transportation of the RBD palm oil, RBD palm olein and RBD palm stearin was 185,031,617.67 L per year or about 0.18 billion L per year of which the transportation of FFB and CPO contributed 54.3% and 33.8% respectively.

The diesel consumption from the transport of RBD palm oil, RBD palm olein and RBD palm stearin from refineries to ports contributed 0.28%, 3.98% and 0.52% repectively while the contribution from the transport of RBD palm oil, RBD palm olein and RBD palm stearin from refineries to retailers contributed 0.13%, 5.2% and 1.69% respectively.

The contribution from the transportation of the fruit bunch, germinated seed and seedlings were not significant as they contributed only 0.03%, 0.01% and 0.01% to the overall diesel consumption respectively.

The total diesel consumption from the transportation process along the palm oil supply chain contributed only 0.51% from the total diesel consumption from petroleum in the country which was about 36.1 billion L per year.

The study also met with its objective in determining the GHG emissions from the transportation of oil palm products along the palm oil supply chain and to compare its performance for the whole oil palm industry to the overall GHG emission from transportation in the country. From the study, the GHG emission by the oil palm industry was 779,858.80 tonne CO_2 eq per year with the highest emission came from transport of the FFB and the CPO at 401,623.99 CO_2 eq per year (51.5 %) and 309,098.68 CO_2 eq per year (39.63%). The contribution from the others sectors along the palm oil supply chain were 0.01%, 0.02%, 1.03%, 1.60%, 2.77%, 0.47%, 0.07%, 1.58% and 1.32% for the transport of the fruit bunches (from 'mother palm'), germinated seeds, seedlings, RBD palm oil, RBD palm olein and RBD palm stearin to the ports and retailers respectively.

The total GHG emission for the transportation of the palm oil industry along the supply chain contributed 3.54% to the 22 million tonne CO_2 eq per year for the overall GHG emission from transportation in the country from the combustion of fuel for all transport activity in the country (regardless of the sector, except for international marine bunkers and international aviation).

The weighted results of the life cycle impact assessment (LCIA) showed that the most significant environmental impacts from this study were contributed by the impact categories in the following order: fossil fuel, respiratory in-organics, acidification/eutrophication and climate change. This study showed that consistent with the findings from the LCI analysis, the environmental impacts were highest during the transportation of the fresh fruit bunches from the oil palm plantations to palm oil mills followed by the transportation of crude palm oil from the mills to refineries. The impact came from the use of fossil fuel to transport the FFB to plantations and the CPO from mills to refineries.

The study also found that when compared to different vehicle sizes, the transportation using 28 tonne vehicle consumed relatively higher energy and generated higher GHG emissions compared to 40 tonne vehicles. The higher energy consumption was because more fuel was needed for more trips to transport the materials. The emission factors were also smaller for the bigger capacity vehicles. The environmental impact was also found to be higher in the 28 tonne vehicles compared to 40t vehicles.

In comparison between transportation and the production along the palm oil supply chain, from previous LCA studies, it was found that transportation was not significant in the production of germinated seeds and seedlings. However, transportation contributed significantly during the production of the FFB, CPO and the refined palm oil.

From the total amount of GHG emissions (tonnes of CO_2 eq.) based on the production of materials in 2013, the reduction in terms of GHG emissions savings from the use of B5 blends was 43,288.47 CO_2 eq. per year or 5.55% savings of the GHG emissions per year. This savings would be greater when the blends incorporated higher amounts of biodiesel.

5.3 Recommendations for improvement options from current practises by stakeholders

Based on the above findings, improvements in the handling and transportation practices of the oil palm products along the palm oil supply chain are therefore recommended to all stakeholders concerned towards a sustainable development of the Malaysian Oil Palm Industry. In view of the fact that transportation of FFB from plantation to mill is one of the main contributors to GHG emissions, this sector of the oil palm industry can play a significant role to reduce transportation emissions in the country. As the GHG emissions are influenced by vehicle capacity, the plantations are recommended to use bigger capacity lorry i.e. 40t and 28t rather than the 16t lorry. It is noted that this recommendation may not be possible for the in-field collections as the roads in the plantations are not wide enough for bigger vehicles and it also does not apply to some plantations that are very close to the mills where FFB are sent immediately to mills after collection using tractors. This recommendation can be considered, for other plantations with loading ramps or collection centres where lorries collect the bunches from these collection centres for transportation to the mills. For plantations close to mills and with suitable terrain, one could also consider the use of a rail system with cages rather than tractors. As large amounts of the FFB are being transported and processed annually to produce CPO, improvement from this sector can have a very significant impact on the overall environmental performance of the oil palm industry.

For the transportation of CPO and its refined products, the use of other mode of transport should be explored in view of the long distances involved transporting these products. The use of rail transport as another alternative could be considered especially when mills or refineries are near railway stations. The emissions for CO_2 using rail transport is 3146 g CO_2/kg diesel (Spielmann et. al., 2004). In comparison, the CO_2 emission to transport CPO in a 30t capacity lorry tanker by road, based on this study, is 5237 g CO_2/kg diesel (1 L is equal to 0.84 kg diesel (Spielmann et. al., 2004). However, the savings in terms of diesel consumption from the use of rail transport is even greater at 0.68 g/tkm (Spielmann et. al., 2004) as compared to 21.58 g/tkm when using road transport. This is based on the assumption that the CPO was transported in a 30t capacity lorry tanker over an average distance of 170 km to the refinery, and consumed 38.6 L/100km of diesel (including the empty return trip). The lower diesel consumption in rail transport is due to the fact that the train is able to carry a much bigger load than the road tanker at any one time.

Vehicles should be well maintained to reduce emissions to the environment. Policies for vehicles used in the transportation sector could be set to limit the life spent so as to avoid the continued use of old vehicles which are inefficient and may add to the environmental load particularly with regard to emissions. As a big portion of the transportation along the palm oil supply chain is also contracted to external transportation companies, these companies too have their role in ensuring a greener environment. Investments in vehicles with modern and more energy efficient will reduce diesel consumption and reduce emissions.

During the study, it was also observed that many of the oil palm plantations were still having laterite/soil road and gravel road surface. These types of road systems are less efficient in transporting the FFB to mills as compared to a tarmack road where the road surfaces are covered by tar and bitumen. As the road conditions were less favourable to transport FFB, there may be more trips needed as vehicles speeds are slowered due to uneven and hilly roads. Plantations are therefore recommended to invest in tarmack road systems or alternatively using a soil sealant to improve the conditions of the road as this will eventually results in reduced diesel consumption.

In view of the high GHG emissions resulting from the long distance to transport the RBD PO from refineries to ports that are located inland, the establishment of mini ports nearer to these refineries could be considered to minimize the transport by road to existing ports. The development of new ports or the upgrading of existing ports involved in the transportation of refined palm oil, palm olein and palm stearin should include priority to infrastructures like pipelines to reduce road transport from refineries to ports. This move is supported by results from this study which showed that the GHG emissions from electricity to pump the products along the pipelines were much lower than the emissions generated by road transport.

The implementation of the B5 programme by the Malaysian government requires the mandatory blending of 5% biodiesel with petroleum diesel. This move is in line with the National Biofuel Policy to reduce dependency on petroleum diesel especially in the transport sector. The use of higher percentage of biodiesel in diesel blends should be encouraged to further reduce the emissions.

5.4 Recommendations for future works

In view that the findings from this study were based on data gathered though questionnaires from the relevant stakeholders of the Malaysian Oil Palm Industry i.e. nurseries, oil palm plantations, mills and refineries, future studies are recommended with increased sampling size. This will verify the findings of this study as some of the sectors such as the nursery were limited in the sampling number due to the difficulty in getting verified information.

The system boundary for this study is from 'cradle-to-gate' along the palm oil supply chain i.e from the transportation of the fruit bunches (from 'mother palm') right through to the transportation of the RBD palm oil, RBD palm olein and RBD palm stearin to ports and retailers. Future studies are therefore recommended to expand the system boundary to 'cradle-to-grave' on LCA study on the handling and transportation of the RBD palm oil, RBD palm olein and RBD palm stearin during shipment until the products arrived at the manufacturing plants or the consumer's doorstep in selected overseas countries.

Data on the GHG emissions for palm oil products from ships may also be required in view that international organization such as the International Maritime Organization (IMO) is currently considering efforts to reduce GHG emissions from ships currently under discussions by the Marine Environment Protection Committee (IMO, 2014). The Committee is to identify and develop mechanisms to limit or reduce GHG emissions from international shipping and in doing so, may establish a GHG emission baseline during shipment. If such a requirement becomes necessary, such data on the carbon footprint will be benefial to the Malaysian Oil Palm Industry in our efforts to ensure palm oil products remain competitive and to promote palm oil products in the global market.

Modelling on the transportation of the oil palm products based on some of the recommendations made from this study may be conducted to determine the reduction in the energy consumption and the savings in GHG emissions by the Malaysian Oil Palm Industry and to promote for such policies to be implemented.

In addition, modelling on the transportation of the oil palm products using the rail system may also be done to evaluate the GHG saving to the Malaysian oil palm industry particularly during the transportation of the FFB to mills and the transportation of the CPO to refineries.

REFERENCES

1 Ahmad, M. N. (2009). LCI for electricity for Malaysia. Paper presented at the Seminar on Life Cycle Assessment for the Petrochemical and Plastics Industry, Nov. 2009, Kuala Lumpur, Malaysia.

2 André M., Hammarström U. and Reynaud I. (1999) Driving statistics for the assessment of pollutant emissions from road transportation. INRETS report (3) LTE 9906. European Community DG VII.

3 Beer, T.; Grant, T and Cambell, P. K. (2007). The greenhouse and air quality emissions of biodiesel blends in Australia. *Report for Caltex Australia Limited*. Report number KS54C/1/F2.28.

4 Bento, A. M. Klotz, R. (2014). Climate policy decisions require policy-based Life Cycle Analysis. *Environ Sci Technol* vol. 48(10), p. 5379-5387

5 BERNAMA (2009). Malaysia announces conditional 40 percent cut in emissions. http://ww2.utusan.com.my/utusan/special.asp?pr=theMesssenger&y=2009&dt=1218&pub=theMessenger&sec=Home_News&pg=hn_09.htm. Retrieved on 16 June 2016.

6 BERNAMA (2016). Implementation of B10, B7 Programmes deferred to a later date. Retrieved on 13 December 2016 from http://www.bernama.com/bernama/v8/bu/newsbusiness.php?id=1302235

7 Bezergianni, S. and Dimitriadis, A. (2013). Comparison between different types of renewable diesel. *Renewable and Sustainable Energy Reviews*, vol. 21 p. 110-116

8 Biofuels (2014). Third Generation Biofuels. Retrieved on 16 September 2014 from http://biofuels.org.uk/third-generation-biofuels.html.

9 Bloomberg (2014). Malaysia delays full implementation of B5 Biodiesel mandate. Retrieved on 6 August 2014 from mobile.bloomberg.com/new.

10 Boonrod, B.; Prapainainar, C.; Narataruksa, P.; Kantama, A.; Saibautrong, W.; Sudsakorn K. and Mungcharoen, T. (2017). Evaluating the environmental impacts of bio-hydrogenated diesel production from palm oil and fatty acid methyl esters through life cycle assessment, *Journal of Cleaner Production*, vol. 142, p. 1210-1221

11 BTCE (1995). Greenhouse Gas Emissions from Australian Transport, Long Term Projections, Report 88, Bureau of Transport and Communications Economics, Canberra, Australia.

12 BTRE (2002). Greenhouse Gas Emissions from Transport, Australians Trends to 2020, Report 107, Bureau of Transport and Regional Economics, Canberra, Australia.

13 BTRE (2003). Greenhouse Gas Emissions from Transport, A macro Modelling Approach, Bureau of Transport and Regional Economics, Canberra, Australia.

14 Cadle S. H.; Mulawa P.; Groblicki P.; Laroo C.; Ragazzi R. A.; Nelson K.; Gallagher G. and Zielinska B. (2001) In-use light-duty gasoline vehicle particulate matter emissions on three driving cycles. *In: Environmental Science & Technology*, vol. 35(1), pp. 26-32

15 Choo, Y.M. and Goh, S. H. (1987). Esterification of carboxylic acids/glyceride mixtures. United Kingdom patent No. GB 2148897.

16 Choo, Y.M. and Ong, S. H. (1989). Carboxylic acid esterification. United Kingdom patent No. GB 2161809.

17 Choo, Y.M. and Ong, S. H.; Cheah, K. Y. and Abu Bakar, S. N. (1992). Production of alkyl esters from oils and fats. Australian patent No. AU 626014.

18 Choo, Y.M.; Ma, A. N. and Yusof, B. (1995). Production and evaluation of palm oil methyl esters as diesel substitute, *Elaeis Special Issue*, p. 5-25

19 Choo, Y.M.; Harrison, L. L. N.; Ma, A. N.; Lim, W. S. and Mohd Basri, W. (2009). Greenfuel for Climate Change Mitigation-2nd Generation Biofuels. Paper presented at the 2009 International Conference on Oil Palm and the Environment, 14-15 August 2009, Malaysian Agro Exposition Park, Serdang.

20 Choo, Y. M.; Halimah, M.; Zulkifli, H.; Vijaya, S.; Puah, C. W.; Tan, Y. A. (2011) Determination of GHG contributions by subsystems in the oil palm supply chain using LCA approach. *International Journal of Life Cycle Assessment*, vol.16. p. 670-681

21 Corley, R. H. V. and Tinker, P. B. (2016). Seed Germination and Nurseries. *The Oil Palm*, Fifth Edition. Wiley Blackwell UK, pp 225-239

22 Curran, M. A. (2013). Life Cycle Assessment: a review of the methodology and its application to sustainability. Current Opinion in Chemical Engineering, vol. 2, p. 273-277

23 Economy and Industrial Development Division, Malaysian Palm Oil Board (MPOB), Ministry of Plantation Industries and Commodities, 2014

24 Energy measurements and Conversions (2010). Retrieved in January 2010 from http://www.extension.iastate.edu/agdm/wholefarm/pdf/c6-87.pdf.

25 European Commission (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

26 European Commission (2009). Renewable Energy Directive. Retrieved on 13 December 2015 from https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

27 Finnveden, G.; Hauschild M. Z.; Ekval, T.; Guinee, J.; Heijungs, R.; Hellweg, S.; Koehler, A.; Pennington, D. and Suh, S. (2009). Recent developments in Life Cycle Assessment. Journal of Environmental Management, vol. 91, p. 1-21

28 Finnveden, G.; Hofstetner, P.; Bare, J.; Bassoon, L.; Ciroth, A.;Mettier, T.; Seppala, J.; Johansson, J.; Norris, G. and Volkwein, S. (2002). Normalization, grouping and weighting in life cycle impact assessment. In: Udo de Haes et al. (Eds.), Life Cycle Impact Assessment: Striving towards Best Practise, SETAC Press, Pensacola, FL, p. p. 177-208

29 Freedman, B.; Pryde, E. H. and Mounts, T. L. (1984). Variables affecting the yields of fatty esters from transesterified vegetable oil. *J. Amer. Oil Chem Soc.*, vol. 61 (10), p. 1638-1643

30 Frischnecht, R (2010). Personal communication. ESU-services, Uster, Switzerland.

31 Goedkoop, M.and Spriensma, R. (2000). The eco-indicator 99- A Damage-oriented Method for Life Cycle Impact Assessment. Methodology Report, second ed. 17-4-2000, Pre Consultants, B.V. Amersfoort, the Netherlands.
32 Goedkoop, M.; Schryver, A. D. and Oele, M. (2007). SimaPro Version 7.1, Introduction to LCA with SIMAPRO, Pre Consultants, Amersfoort, Netherlands.

33 Halimah, M.; Zulkifli, H.; Vijaya, S.; Tan, Y. A.; Puah, C. W. and Choo, Y. M. (2010). Life Cycle Assessment of Oil Palm Seedling Production (Part 1). *Journal of Oil Palm Research* vol. 22. December 2010 p. 878-886

34 Halimah, M.; Tan, Y. A.; Nik Shasha, K. K.; Mohd Din, A. and Choo, Y. M. (2014). Life Cycle Assessment for the production of oil palm seeds. *Tropical Life Sciences Research*, vol. 25 (2), p. 41-51

35 Harrison, R. M.; Shi, J. and Mark, D. (2000). Characterisation of particles from a current technology heavy duty vehicle engine. *In: Environ. Science and Technology*, vol. 34(5), pp. 748-755

36 Hassel D., Jost P., Dursbeck F., Brosthaus J. and Sonnborn K. (1987) Das Abgas-Emissionsverhalten von Personenkraftwagen in derBundesrepublik Deutschland im Bezugsjahr 1985. 7/87. Umwelt Bundesamt (UBA), Berlin

37 Hilbers, T. J.; Sprakel, L. M. J.; van den Enk, L. B. J.; Zaalberg, B.; van den Berg, H. and van der Ham, L. G. J. (2015). Green diesel from hydrotreated vegetable oil process design study. *Chem. Eng. Technol*. Vol. 38, p. 651-657
38 Hoffstetter, P.; Braunschweig, A.; Mettier, M.; MÜller-Wenk, R.; Tietje, O. (1999). Dominance Analysis in the Mixing Triangle, A Graphical Decision Support Tool for Product Comparisons. *Journal of Industrial Ecology*.
39 Houghton, J. (2002). In: *Global Warming. The Complete Briefing.* 3rd Edition, Cambridge University Press.
40 IMO (2014). Reduction of GHG Emissions from Ships, Marine Environment Protection Committee, International Marine Organization, 1 July 2014
41 ISO (2006). ISO 14040- Environmental Management- Life Cycle Assessment - Principles and Framework, International Organization for Standardization, Geneva, Switzerland.
42 ISO (2006). ISO 14044- Environmental Management- Life Cycle Assessment – Requirements and Guidelines, International Organization for Standardization, Geneva, Switzerland.
43 IPCC (2006). Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD?IEA, Paris, France
44 IPCC (2007). 4th Report of the Assessment of the IPCC on Climate Change, Intergovernmental Panel on Climate Change. Retrieved in November 2009 from www.ipcc.ch/.../publications_ipcc_fourth_assessment_report_synthesis_
45 INFRAS (2000) Aktualisierung der Emissions- und Verkehrsgrundlagen. Infras Arbeitsunterlagen 15, Berlin
46 Keller, M.; Evéquoz, R.; Heldstab, J. and Kessler, H. (1995). Luftschadstoffemissionen des Strassenverkehrs 1950-2010. Nr. 255. Bundesamt für Umwelt, Wald und Landschaft (BUWAL), Bern.

47 Koch, M. (2000) Airborne fine particulates in the environment: A review of health effect studies, monitoring data and emission inventories. IR-00-004. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.
48 KKR (2007). Road Transport Act 1987 (Act 333) & Commercial Vehicles Licensing Board Act 1987 (Act 334), Ministry of Works, Malaysia.
49 Kiatkittipong, W.; Phimsen, S.; Kiatkittipong, K.; Wongsakulphasatch, S.; Laosiripojana, N. and Assabumrungrat, S. (2013). Diesel-like hydrocarbon production from hydroprocessing of relevant refining palm oil. *Fuel Process Technol*. Vol 16, p. 16-26
50 Kushairi, A. and Rajanaidu, N. (2000). Breeding Populations, Seed Production and Nursery Management. Advances in Oil Palm Research Vol 1, MPOB, Bangi, p. 39-96
51 Kushairi, A. (2013). Introduction to MPOB and the Malaysian Palm Oil Industry. In: *Selected Readings*, 33rd Palm Oil Familiarization Programme, MPOB, Bangi.
52 Latiff, A. (2000). The Biology of the Genus *Elaeis.* Advances in Oil Palm Research Vol 1. MPOB, Bangi, p. 19-38
53 Lükewille, A.; Bertok, I.; Amann, M.; Cofala, J.; Gyarfas, F.; Heyes, C.; Karvosenoja, N.; Klimont, Z. and Schöpp, W. (2001). A framework to estimate the potential and costs for the control of fine particulate emissions in Europe. IR-01-023. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.
54 McManus, M. C. and Taylor, C. M. (2015). The changing nature of Life Cycle Assessment. *Biomass and Bioenergy*, vol. 82, p. 13-26
55 Metric Conversions (2014). US Barrels (Oil) to Litre. Retrieved on 6 September 2014 from http://www. Metric-conversions.org/volume/us-oil-barrels-to-liters.htm
56 Mohammad, M.; Kandaramath Hari, T.; Yaakob, Z.; Chandra Sharma, Y. and Sopian, K. (2013). Overview on the production of paraffin based-biofuels via catalytic hydrodeoxygenation. *Renewable and Sustainable Energy Reviews*, vol. 22, p. 121-132
57 Morawska, L.; Bofinger, N. and Kocis, L. (1998). Submicrometer particles from diesel vehicle emissions. *In: Environmental. Science and Technology*, vol. 32(14), p. 2033-2042
58 MPOB (2016). Malaysian Oil Palm 2015 Statistics, Malaysian Palm Oil Board, Ministry of Plantation Industries and Commodities, Malaysia.
59 Minister of Primary Industries, Malaysia (2000). Message from the Minister of Primary Industries Malaysia. Advances in Oil Palm Research Vol 1, MPOB, Bangi, p. iv-v
60 MPIC (2006). The National Biofuel Policy, Ministry of Plantation Industry and Commodities, Malaysia.
61 Noorazah, Z.; Yusoff, S.; Vijaya, S.; Zulina, A. M.; Zailan, A. B.; Razmah, G. and Hazimah, A. H. (2014). Evaluation of environmental impacts and GHG of palm polyol production using Life Cycle Assessment. *Journal of Oil Palm Research*, vol. 27(2), p. 144-155
62 Oil World Annual (2015). Oilseeds & Oils/Fats Annual Stocks/Usage Ratios. ISTA Mielke GmbH, Hamburg, Germany.

63 PE-International (2014). A Brief History of Life Cycle Assessment. Retrieved on 17 September 2014 from http://www.pe-international.com/malaysia/company/newsroom/news-detail/article/a-brief-history-of-life- cycle-assessment-lca/

64 Puah, C. W.; Choo, Y. M. and Ma, A. N. (2010). Life Cycle Assessment for the production and use of palm biodiesel (Part 5). *Journal of Oil Palm Research*, vol. 22, p. 927-933

65 Rajanaidu, N. (1994). Oil Palm Cultivation and FFB Production. *In Selected Readings- Palm Oil Familiarization Programme*, MPOB, Bangi, p. 11-23.

66 Reichhardt, T. (1995) Weighing the Health Risks of Airborne Particulates. *In: Environmental Science and Technology*, 29(360 A).

67 Ristovski Z., Morawska L., Bofinger N. D. and Hitchins J. (1998) Submicrometer particulate emissions from spark ignition vehicles. *In: Environmental Science and Technology*, vol. 32(24), p. 3845-3852

68 Sanchez, S.; Woods, J.; Akhurst, M.; Brander, M.; O'Hare, M.; Dawson, T. P. (2012). Accounting for indirect land use change in the Life Cycle Assessment of biofuel supply chains. *J R Soc Interphase*, vol. 9(71), p. 1105-1119.

69 Sandin, G.; Royne, F.; Berlin, J. and Peters, G. M. (2015). Allocation in LCAs of biorefinery products: implications for results and decision-making. *Journal of Cleaner Production*, vol. 93, p.213-221.

70 Sivasothy, K. (2000). Palm Oil Milling Technology. Advances in Oil Palm Research Vol 1. MPOB, Bangi, p. 744-782

71 Singh, K. K. (2008). In: *Global Warming in 21st Century. Causes, Effect and future*. MD Publications, New Delhi, India.

72 Spielmann M, Kägi T, Stadler P, Tietje O (2004) Life Cycle Inventories of Transport Services, Ecoinvent Report No 14, Swiss Federal Institute of Technology, Department of Environmental Sciences, Zürich www.ecoinvent.ch

73 Tan, Y. A.; Chow, M. C.; Halimah, M.; Zulkifli, H.; Vijaya, S.; Puah,C. W.; Putri, N. F.; Neo, Y. P.; Noorlin, H.; Chong, C. L.; Ma, A. N.; Choo, Y. M. and Mohd Basri, W. (2009). Life Cycle Assessment (LCA) for Food: Refined Palm Oil and Its Fractions. Paper presented at the 2009 International Conference on Oil Palm and the Environment, 14-15 August 2009, Malaysian Agro Exposition Park, Serdang, Selangor, Malaysia.

74 Tan Y. A.; Halimah, M.; Zulkifli, H.; Vijaya, S.; Puah, C. W.; Chong, C. L., Ma, A. N. and Choo, Y. M. (2010) Life Cycle Assessment of Refined Palm Oil Production and Fractionation (Part 4). *Journal of Oil Palm Research*, vol. 22. p. 913-926

75 Tan, K. T.; Lee, K. T.; Mohamed, A. R. and Bhatia, S. (2009). Palm Oil: Addressing issues and towards sustainable development. *Renewable and Sustainable Energy Reviews*, vol. 3, p. 420-427

76 Taylor, C. M. and McManus, M. C. (2013). The evolving role of LCA in bioenergy policy. *Bioenergy Connection*. vol. 3 (2), p. S1-4

77 The Borneo Post (2015). B7 biodiesel to be sold in Sarawak, Sabah, Labuan from end of January 2015. Retrieved on 13 December 2016 from

http://www.theborneopost.com/2015/01/17/b7-biodiesel-to-be-sold-in-sarawak-sabah-labuan-from-end-of-january/

78 The Star (2014). Palm Oil Biodiesel Programme to cover all of Malaysia by July. Retrieved on 6 August 2014 from www.thestar.com.my

79 UNFCCC (2008). Kyoto Protocol, Negotiating the Protocol, United Nation Framework Convention on Climate Change (UNFCC). Retrieved on 15 April 2008, from http://unfccc.int/essential_background/kyoto_protocol/items/2830.php

80 UNFCCC (2009). Issues- A brief history of the climate change process, United Nation Framework Convention on Climate Change (UNFCC). Retrieved in November 2009 from http://unfccc.int/cop7/issues/briefhistory.html

81 UNFCCC (2014). Kyoto Protocol, United Nation Framework Convention on Climate Change (UNFCC). Retrieved on 14 June 2014 from http://unfccc.int/kyoto_protocol/items/2830.php

82 US EIA (2014). International Energy Statistics, U.S Energy Information Administration. Retrieved on 6 September 2014 from http://www.eia.gov/countries-data.cfm

83 US EIA (2014). Emissions of Greenhouse Gases in the U.S., U.S. Energy Information Administration. Retrieved on 17 September 2014 from http://www.eia.gov/environment/emissions/ghg_report/ghg_carbon.cfm

84 US EPA (1993). Life Cycle Assessment: Inventory Guidelines and Principles, US Environmental Protection Agency.

85 United States Congress (2007). US Energy Independence and Security Act of 2007, 110th United States Congress**,** www.govtract.us/congress/bills/110/hr6**.**

86 US EPA (2016). Overview for renewable fuel standard programme. Retrieved on 13 December 2016 from https://www.epa.gov/renewable-fuel-standard-program/program-overview-renewable-fuel-standard-program

87 Uusitalo, V.; Vaisanen, S.; Havukainen, J.; Havukainen, M.; Suokka, R. and Louranen, M. (2014). Carbon footprint of renewable diesel from palm oil, jatropha oil and rapeseed oil, *Renewable Energy*, vol. 69, p. 103-113

88 Vijaya, S.; Choo, Y. M.; Halimah, M.; Zulkifli, H.; Tan, Y. A. and Puah, C. W. (2010). Life Cycle Assessment of the production of crude palm oil (Part 3). *Journal of Oil Palm Research*, vol. 22, p. 895-.903

89 Whitmore, T.C. (1973). The Palms of Malaya. Longmans, Malaysia. p. 56-58

90 World Development Indicators (2014). World Development Indicators. Retrieved on 6 August 2014 from http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=World-Development-Indicators

91 Yusof, B. (1995). Palm Oil Industry in Malaysia – a Success Story. APPARI Publication 1995/2 FAO Bangkok. p. 26

92 Yusof, B. (2000). Future Developments in the Malaysian Oil Palm Industry. Advances in Oil Palm Research Vol II. MPOB, Bangi, p. 1494-1507

93 Yusof B. and Chan, K. W. (2004). The Oil Palm and its Sustainability. *Journal of Oil Palm Research*, vol.16 (1), 1-10

94 Yusoff, S. and Hansen, S. B. (2007). Feasibility Study of Performing a Life Cycle Assessment on Crude Palm Oil Production in Malaysia. *International Journal of Life Cycle Assessment*, vol.12 (1). p. 50-58

95 Zamagni, A.; Guinee, J.; Heijungs, R.; Masoni, P.; Raggi, A. (2012). Lights and shadows in consequential LCA. *International Journal of Life Cycle Assessment*, vol.17 (7), p. 904-918

96 Zulkifli, H.; Halimah, M.; Chan, K. W.; Choo, Y. M. and Mohd Basri, W. (2010). Life Cycle Assessment for Oil Palm Fresh Fruit Bunch Production (Part 3). *Journal of Oil Palm Research*, vol. 22. p. 887-894