QUANTIFICATION OF ENVIRONMENTAL IMPACTS FOR THE MALAYSIAN RUBBER INDUSTRY USING LIFE CYCLE ASSESSMENT

ZAMERI BIN MOHAMED

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

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ZAMERI BIN MOHAMED

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QUANTIFICATION OF ENVIRONMENTAL IMPACTS FOR THE MALAYSIAN RUBBER INDUSTRY USING LIFE CYCLE ASSESSMENT

ABSTRACT

Over the last 10 years, the Malaysian rubber industry's contribution to Malaysia export earnings has increased significantly from RM 15.5 billion in 2003 to RM 33.7 billion in 2013. Due to its importance, the Malaysian Rubber Industry is included in the Malaysia National Key Economic Area as it is forecasted to contribute RM 52.9 billion in Malaysia Gross Nation Income by 2020. The main aim of this study is to provide a comprehensive inventory and detailed quantification of the environmental impact and greenhouse gases emission (GHGs) for the major part of the Malaysian rubber industry comprising the cultivation of rubber tree from cradle to grave and its three independents components (nursey, immature rubber and mature rubber), and standard Malaysian rubber (SMR) production from cradle to gate. The research methodologies used were questionnaire surveys with the objective to create a very comprehensive life cycle inventories tables representing the actual activities in the Malaysian rubber industry. The quantification of the environmental impact for this study was evaluated using Simapro software version 7.3.3 with Eco-indicator 99 as the default methodology while the quantification of GHGs emission was evaluated based on the global warming potential from the Intergovernmental Panel on Climate Change 2007 fourth assessment report using the same software. The results from the questionnaire survey indicate that the average annual consumption of ammonium sulphate and potassium chloride fertilizers in the cultivation of rubber trees from cradle to grave in Malaysia is estimated at 9.3% from total Malaysia consumption for 2014. The environmental impact from the average annual activities in the cultivation of rubber trees from cradle to grave in Malaysia represent 0.083% of the human health impact, 0.006% of the ecosystem quality impact and 0.111% of the resource depletion impact in Malaysia based on normalization procedure and these normalization results can be interpreted as representing 0.058% of the Malaysian environmental impact based on weighting procedure. The GHGs emission from the average annual activities in the cultivation of rubber trees from cradle to grave in Malaysia is 315.54 GgCO_2eq and it represents 0.11% from the 2011 Malaysia GHGs emission. For the SMR production from cradle to gate, the environmental impact from the average annual production in Malaysia is 0.046% of the human health impact, 0.003% of the ecosystem quality impact and 0.176% of the resource depletion impact in Malaysia based on normalization procedure and can be summarized as representing 0.055% of the Malaysian environmental impact based on weighting procedure. The average annual GHGs emission from the production of SMR in Malaysia in this study is 229.41 GgCO_2eq and it represent 72.7% from the average annual GHGs emission from the cultivation of rubber trees from cradle to grave in Malaysia for this study. The most significant aspect of this study is that this is the first LCA study ever carried out in Malaysia for the rubber industry.

Keywords: life cycle assessment; greenhouse gases emission; Malaysian rubber industry

KUANTIFIKASI KESAN ALAM SEKITAR UNTUK INDUSTRI GETAH MALAYSIA MENGGUNAKAN PENILAIAN KITAR HAYAT

ABSTRAK

Sepanjang 10 tahun yang lepas, sumbangan industri getah Malaysia kepada pendapatan eksport Malaysia telah meningkat dengan nyata dari RM 15.5 bilion pada 2003 kepada RM 33.7 bilion pada 2013. Disebabkan oleh kepentingannya, industri getah Malaysia telah disenaraikan sebagai sebahagian dari bidang utama ekonomi negara dan diramalkan bakal menyumbang RM 52.9 bilion kepada pendapatan kasar Malaysia menjelang tahun 2020. Tujuan utama kajian ini adalah untuk menyediakan satu inventori komprehensif dan kuantifikasi lengkap kesan alam sekitar dan pelepasan gas rumah hijau untuk sebahagian besar industri getah Malaysia merangkumi penanaman pokok getah bermula dari peringkat semaian sehinggalah penebangan pokok getah tua dan tiga komponennya (nurseri, pokok muda dan pokok matang), dan pengeluaran getah mutu Malaysia (SMR).Metodologi penyelidikan yang digunakan adalah dalam bentuk kajian soal selidik bagi mewakili aktiviti-aktiviti sebenar didalam industri getah Malaysia.Kuantifikasi kesan alam sekitar untuk kajian ini telah dijalankan menggunakan perisian Simapro versi 7.3.3 dengan Eco-indicator 99 sebagai kaedah yang ditetapkan manakala kuantifikasi gas rumah hijau dinilai berdasarkan potensi pemanasan global bersumberkan laporan dari panel antara-kerajaan mengenai perubahan iklim 2007 menggunakan perisian yang sama. Keputusan dari kajian soal selidik menunjukkan bahawa purata penggunaan tahunan baja ammonium sulfat dan kalium klorida dalam penanaman pokok getah dari peringkat semaian sehinggalah penebangan pokok getah tua dianggarkan pada 9.3% dari jumlah penggunaan Malaysia untuk tahun 2014. Kesan alam sekitar dari purata aktiviti tahunan dalam penanaman pokok getah dari peringkat semaian sehinggalah penebangan pokok getah tua di Malaysia mewakili 0.083% daripada kesan kesihatan manusia, 0.006% daripada kesan kualiti ekosistem dan 0.111% daripada kesan kesusutan sumber di Malaysia berdasarkan prosedur penormalan dan penormalan ini boleh ditafsirkan sebagai mewakili 0.058% daripada kesan alam sekitar Malaysia berdasarkan prosedur pemberatan.Pelepasan gas rumah hijau dari purata aktiviti tahunan dalam penanaman pokok getah dari peringkat semaian sehinggalah penebangan pokok getah tua di Malaysia ialah 315.54 GgCO2eq dan ini mewakili 0.11% dari jumlah pelepasan gas rumah hijau Malaysia untuk tahun 2011.Untuk pengeluaran SMR, kesan alam sekitar dari purata pengeluaran tahunan di Malaysia ialah 0.046% daripada kesan kesihatan manusia, 0.003% daripada kesan kualiti ekosistem dan 0.176% daripada kesan kesusutan sumber di Malaysia berdasarkan prosedur penormalan dan dapat dirumuskan sebagai mewakili 0.055% daripada kesan alam sekitar Malaysia berdasarkan prosedur pemberatan. Pelepasan gas rumah hijau dari purata tahunan pengeluaran SMR di Malaysia bagi kajian ini ialah 229.41 GgCO2eq dan ini mewakili 72.7% dari jumlah pelepasan gas rumah hijau dari purata tahunan aktiviti penanaman pokok getah dari peringkat semaian sehinggalah penebangan pokok getah tua di Malaysia. Kajian ini merupakan kajian yang pertama kali dilakukan di Malaysia untuk industri getah.

Kata kunci: penilaian kitar hayat; pelepasan gas rumah hijau; industri getah Malaysia

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1NRS	: One Nation Rubber Strategy
APEC	: Asia Pacific Economic Cooperation
AR4	: IPCC 2007 fourth assessment report
BLIC	: European Association of the Rubber Industry
BOD	: Biological Oxygen Demand
CH_4	: Methane
CO_2	: Carbon Dioxide
CO_2eq	: Carbon Dioxide Equivalent
COD	: Chemical Oxygen Demand
COP 15	: 15th Conference of the Parties
DALY	: Disability Adjusted Life Years
DOE	: Department of Environment Malaysia
DOS	: Department of Statistic
DRC	: Dry Rubber Content
EIA	: Environmental Impact Assessment
EQA	: Environmental Quality Act
ERTMA	: European Tyre and Rubber Manufacturers' Association
ETP	: Economic Transformation Programme
FAO	: Food and Agriculture Organization
FELCRA	: Federal Land Consolidation and Rehabilitation Authority
FELDA	: Federal Land Development Authority
GDP	: Gross Domestic Product
GEN	: Global Ecolabelling Network
Gg	: Gigagram

GGP	: Government Green Procurement
GHGs	: Greenhouse Gases
GNI	: Gross National Income
GRG	: General Rubber Goods
GWh	: Gigawatt hour
GWP	: Global Warming Potential
ha	: Hectare
HDPE	: High Density Polyethylene
HG	: House-grade Block Rubber
IPCC	: Intergovernmental Panel on Climate Change
IRG	: Industrial Rubber Goods
ISO	: International Organization for Standardization
JEMAI	: Japan Environmental Management Association for Industry
KADA	: Kemubu Agriculture Development Authority
LCA	: Life Cycle Assessment
LCI	: Life Cycle Inventory
LCIA	: Life Cycle Impact Assessment
LDPE	: Low Density Polyethylene
LTAP	: Long-term Action Plan
LULUCF	: Land use, Land use Change and Forestry
MRB	: Malaysian Rubber Board
MYLCID	: Malaysia Life Cycle Inventory Database
N_20	:Nitrous Oxide
NKEA	: National Key Economic Area
PAFs	: Potentially Affected Fractions
PDF	: Potentially Disappeared Fraction

POO	: Probability of Occurrence
RISDA	: Rubber Industry Smallholders Development Authority
RM	: Ringgit Malaysia (Malaysian currency)
RRIM	: Rubber Research Institute of Malaysia
SCP	: Sustainable Consumption and Production
SDGs	: Sustainability Development goals
SETAC	: Society for Environmental Toxicology and Chemistry
SMR	: Standard Malaysian Rubber
TWYBP	: Two Whorl Young Budding in the Polybag
UNCED	: United Nations Conference on Environment and Development
UNDP	: United Nations Development Program
UNEP	: United Nations Environmental Protection
UNFCCC	: United Nations Framework Convention on Climate Change

CHAPTER 1: INTRODUCTION

1.1 Background of Study

The history of rubber cultivation in Malaya started in the late 1877 when nine seedlings from the batch of about 2700 germinated seeds at Kew Botanic Gardens near London were despatched and planted in Kuala Kangsar, Perak (Chan et al., 2000). Since the establishment of the first rubber plantation in Malaya in 1896, the rubber industry has grown tremendously into the present Malaysia. There were 218,900 hectares of rubber planted area in Malaya in 1910 (Chan et al., 2000) as compared to 1.066 million hectares of rubber planted area in Malaysia in 2014 (Malaysian Rubber Board, 2016b).

Over the last 10 years, the Malaysian rubber industry contribution to Malaysia export earnings has increased significantly from RM 15.5 billion in 2003 to RM 33.7 billion in 2013 (Malaysian Rubber Board, 2014c). Malaysia is the world fifth largest producer of natural rubber with the production of 0.67 million tonnes in 2014 (Malaysian Rubber Board, 2016b). Due to its importance, the Malaysian Rubber Industry is included in the Malaysia National Key Economic Area (NKEA)(Sumormo, 2012). NKEA is an important driver of economic activities that has the potential to directly contribute to the Malaysian Economic Growth measurable by the Gross National Income (GNI) indicator and will help Malaysia achieved a high income status by 2020 (KADA, 2017; Sumormo, 2012).

As part of Malaysia NKEA, the Malaysian Rubber Industry is being prioritised in getting the government support as compared to the non NKEA based industry (PEMANDU, 2017).The Malaysian rubber industry is expected to contribute RM 52.9 billion in GNI by 2020 (Ahmad, 2013).

1.2 Environmental Management in the Malaysian Rubber Industry

As one of the Malaysian industries that contribute significantly to the economic development of the country, the Malaysian Rubber Industry also generated a significant amount of waste (Verasamy et al., 2003). These wastes are subjected to various regulations under the Malaysian Environmental Quality Act 1974. The open burning of rubber plantation wastes in the form of rubber tree stumps after land clearing are governed under the Environmental Quality (Clean Air) Regulations 1978 Part III (Burning of wastes). The practice of open burning are only allowed for specific cases after obtaining special permission from Department of Environment Malaysia (DOE) (Kheong, 1998).

The Malaysian government also gazetted the Environmental Quality (Prescribed Premises)(Raw Natural Rubber) Regulations (1978) in making sure that all the raw effluents from the raw rubber processing activities in Malaysia are treated and meet the legal discharge standard before they are allowed to be discharged into the watercourse. The rubber products manufacturing factories in Malaysia are subjected to Environmental Quality (Sewage and Industrial wastes) Regulations (1979) and Environmental Quality (Scheduled Waste) Regulations (1989) (Isa, 2004).

1.2.1 Upstream Rubber Industry

Zero burning practice is widely adopted by the upstream rubber industry in Malaysia at present due to strict enforcement by the authorities involved in maintaining the environmental regulation in Malaysia. Rubber Industry Smallholders Development Authority (RISDA), one of the main government agencies in Malaysia which is responsible in supervising and managing the rubber plots owned by the rubber smallholders also adopted the zero burning practices in their management as announced by the RISDA director general during the National Rubber Economic Conference 2013 (Mohamad, 2013).

For special cases, where the burning of biomass is necessary, the rubber plantation management must inform the DOE at least a week before the burning and the burning must be carried out with strict regulations as imposed by the DOE (Kheong, 1998). In special cases such as in the rubber planted area suspected of having root disease or in certain areas where it is difficult to stack the biomass from the land clearing process, the light and selective burning of the plant debris is still allowed to be carried out (Ali, 2005; Verasamy et al., 2003). In the case of the rubber planted area suspected of having root disease, the burning of the plant debris is considered as necessary in order to get rid of this disease before the land is replanted with new batch of rubber planting materials.

In the zero burning practice, the plant debris from the fallen old rubber trees is stacked in the field to allow for natural decomposition process to take place (Verasamy et al., 2003). Through this process, nutrients locked up in the plant debris stack in the field can be returned to the soil and increase the soil fertility when this plant debris started to decay (Kheong, 1998). According to Ali (2005), the zero burning practice of stacking the plant biomass also has the benefits of reducing soil erosion from the newly cleared rubber planted area.

1.2.2 Midstream Rubber Industry

The raw rubber processing in Malaysia consumes large volume of water. The average water consumption for block rubber processing in Malaysia is 19.5 L/kg dry rubber content (DRC) while latex concentrate processing average water consumption is 10.5 L/kg DRC (Isa, 1993). Isa (2008) estimated the raw rubber processing in Malaysia discharge around 55 million liters of effluent daily. The effluents from the raw rubber processing contain high amount of biological oxygen demand (BOD) and chemical oxygen demand (COD) (Verasamy et al., 2013).

Under the Environmental Quality (Prescribed Premises) (Raw Natural Rubber) Regulations, 1978, the raw rubber processing factories must obtain licence from DOE before they are allowed to operate (Isa et al., 2008). In order to get the license, the raw rubber processing factories must establish a proper effluent treatment system so that the treated effluent from the factories can comply with the regulatory standards before it is allowed to be discharged to public watercourse (Isa et al., 2008). The regulatory standard for watercourse discharge of raw rubber processing effluent is given in Table 1.1.

Table 1.1: Effluent discharge limits for raw rubber processing factories

Parameter	Types of Raw Rubber Processing Factory	
	SMR & Conventional Grade (Since 1.4.81)	Latex Concentrate (Since 1.4.83)
pH	6-9	6-9
BOD_3	100	100
COD	250	400
Suspended Solids	150	150
Ammoniacal Nitrogen	40*	300
Total Nitrogen	60*	300

(All value, excepts pH are expressed in mg/L, * Filtered sample) ;Source:(Anitha et al., 2007).

The majority of wastewater effluent treatment system employed by the raw rubber processing in Malaysia is end of pipe treatment system and according to Verasamy and Nor (2011) this might be due to the availability of abundant supply of fresh water in Malaysia. The types of effluent treatment system adopted by the raw rubber processing factories in Malaysia and its characteristics are summarized in Table 1.2.

Table 1.2: Current effluent treatment systems adopted by the raw rubber processing factories in Malaysia

Effluent Treatment System	Characteristics
Anaerobic/Facultative Ponding System	• Relatively simple and low cost • Low maintenance cost • Require a very large land area • Consists of an aerobic pond and one or more facultative connected in series.
Aerobic System	• This system includes oxidation ditch, aerated lagoon, activated sludge and submerged aeration. • Small land requirement • Require high operating cost
Enclosed Anaerobic System	• High rate system capable of high organic loading rates. • Suitable as a pre-treatment and requires subsequent facultative or aerobic systems.

Source: (Isa, 2008; Nor, Verasamy, Karim, & Isa, 2005).

Anaerobic facultative ponding system is the most popularly adopted effluent treatment system by the raw rubber processing factories in Malaysia due to its treatment efficiency, easy to maintain and did not require sophisticated equipment (Isa et al., 2008). A survey carried out in 2008 indicate that 43 Standard Malaysian Rubber (SMR) factories representing 75% from the total SMR factories in Malaysia are using this anaerobic/facultative ponding system to treat their effluent (Isa, 2009a).

According to Isa (2008), this anaerobic /facultative ponding system is not suitable for factories located in the urban area where land is a premium or factories in the vicinity of residential areas as it causes malodour problems. The average performance of the anaerobic/facultative ponding system in the treatment of effluent from the raw rubber processing industry in Malaysia is summarized in Table 1.3.

Table 1.3: Performance of the anaerobic/facultative ponding system based on average values

Parameter	SMR Block Rubber processing			Latex Concentrate processing		
	Raw Effluent	Treated Effluent	Removal (%)	Raw Effluent	Treated Effluent	Removal (%)
pH	5.5	7.5	-	4.8	7.8	-
Suspended solids	322	125	61	818	359	56
COD	2899	230	92	4849	529	89
BOD	1769	59	97	3524	153	96
Total Nitrogen	141	55	61	602	202	66
Ammoniacal Nitrogen	68	42	38	466	134	71

(All value, excepts pH are expressed in mg/L) ;Source: (Verasamy & Nor, 2011)

Membrane bioreactor (MBR) which consist of biological activated sludge process combined with membrane filtration has been given much attention in recent years as it provide solution to the problems faced by the conventional treatment system (Pretibaa et al., 2008). In the MBR system, the clarifier in a conventional aerobic system is being substitutes with microfiltration or ultrafiltration membrane modules (Sulaiman et al., 2010). According to Stephenson et al. in (Pretibaa et al., 2008), MBR required lower footprint compared to the conventional systems and this system provides treated wastewater with a recycling option. The high sludge retention time in the MBR system is also capable in providing better support for the growth of the slow-growing nitrifying bacteria as compared to the conventional activated sludge system (Pretibaa et al., 2008).

Based on the study by Sulaiman et al. (2010), the wastewater from latex concentrate processing factory had the potential to be treated with MBR as its performance are better than the current system of oxidation ditch (Table 1.4).

Table 1.4: Removal efficiency for oxidation ditch system and MBR process

Parameters	Oxidation ditch system (%)	MBR process (%)
BOD_3	96.03	96.78
COD	96.62	96.99
Suspended solids	75.56	77.91
Total Nitrogen	59.14	65.17
Ammoniacal Nitrogen	49.46	61.35

Pretibaa et al. (2008) conducted a study on the potential of MBR system coupled with anoxic treatment in treating the effluent from rubber examination glove factory as compared to the conventional activated sludge system currently being used in the industry and the results indicate that the average removal efficiency for COD and ammoniacal nitrogen from MBR system is better as shown in Table 1.5.

Table 1.5: Removal efficiency for activated sludge and MBR process for selected parameter

Parameters	Activated sludge system (%)	MBR process plus anoxic treatment (%)
COD	85.7	90.1
Ammoniacal Nitrogen	94.8	99.0

Based on the studies above, the MBR is showing positive results and has great potential to be used in treating the wastewater for the Malaysian rubber industry especially with its better removal efficiency, shorter hydraulic retention time and less sludge production as highlighted by Sulaiman et al. (2010). However the MBR also has its own setbacks that need to be overcome in the form of relatively higher capital cost and operating cost as mentioned by (Pretibaa et al., 2008).

According to Yusoff (2010), the raw rubber processing industry compliance to the Environmental Quality (Prescribed Premises) (Raw Natural Rubber) Regulations 1978 for 2010 is at 94% as compared to the Malaysian Department of Environment target of 100%. The raw rubber processing industry in Malaysia has also been identified as one of the major contributors to the malodour problem in Malaysia (Isa, 2005). The sources of malodour from raw rubber processing factories are hydrogen sulphide gas which is released from the anaerobic ponds that treated effluents from latex concentrate processing factories and the dryer exhaust gas from SMR processing factories (Isa, 2005).

These dryer exhaust gases contain volatile fatty acids and other volatile organic compounds originated from the drying process of SMR block rubber in the dryer of SMR factories (Verasamy et al., 2013; Verasamy et al., 2003). The water scrubber system is widely used by SMR processing factories in Malaysia to control the malodour from the dryer exhaust gases (Verasamy et al., 2013). The use of water scrubber system by the SMR processing factories was found to reduce the odour concentrations in the dryer exhaust gases by average of about 77% and the performance of the water scrubber system in controlling malodour from SMR processing factories is shown in Table 1.6 (Isa, 2008).

Table 1.6: Performance of the water scrubber systems in controlling malodour from SMR processing factories

Odour source	Odour concentration (ou/m^3)				Reduction in odour concentration (%)
	Before treatment		After treatment		
	Range	Mean	Range	Mean	
Dryer 1	9350-20805	15672	3014-4858	3644	76.7
Dryer 2	9244-21031	15958	2849-4858	3611	78.0

1.2.3 Downstream Rubber Industry

The rubber products manufacturing industry in Malaysia discharges around 30 million litres of effluent daily (Isa, 2004). Chemical flocculation process is used to remove zinc from the effluent to form the chemical sludge (Verasamy et al., 2003). The chemical flocculation process used during the treatment of the effluent from the rubber product manufacturing industry in Malaysia is important as the final effluent discharge from this industry must not contain more than 2.0 mg/L of zinc as required under the existing environmental regulation (Isa, 2004).

The rubber products manufacturing industry produce 6000 tonne of chemical sludge per year (Nor, 2009). The chemical sludge from this effluent treatment plant is classified as scheduled waste and is subjected to Environmental Quality (Scheduled Waste) Regulations (1989) and must only be disposed at the designated Integrated Scheduled Waste Management System at Bukit Nenas, Negeri Sembilan (Isa, 2004).

The most popular effluent treatment system adopted by the rubber products manufacturing industry in Malaysia is the flocculation/activated sludge system (Verasamy & Nor, 2011). The performance of the flocculation/ activated sludge system in treating the effluent from a rubber glove manufacturing factory is shown in Table 1.7.

Table 1.7: Performance of flocculation/activated sludge system in the treatment of effluent from glove manufacturing factories

Parameter	Factory A	Factory B
Glove production (pieces/day)	25000	25000
Actual effluent flow rate (m^3/day)	15	20
BOD in raw effluent (mg/L)	305-4030	56-284
BOD in treated effluent (mg/L)	1-76	1-146
Average BOD removal (%)	98.0	77.0
COD in raw effluent (mg/L)	594-4598	235-3000
COD in treated effluent (mg/L)	53-113	31-461
Average COD removal (%)	95.8	79.8
Suspended solids in raw effluent (mg/L)	120-424	16-260
Suspended solids in treated effluent (mg/L)	16-84	4-220
Average suspended solids removal (%)	82.0	61.0
Zinc in raw effluent (mg/L)	3-126	0.5-5.0
Zinc in treated effluent (mg/L)	0.5-9.0	0.5-3.0
Average Zinc removal (%)	90.0	60.0

Source: (Verasamy & Nor, 2011).

1.3 Climate Change and Malaysia Greenhouse Gases Emission

Climate is an integral part of environment and climate change in more ways than one is a measure of abuse and mismanagement of this environment through time (Sani, 2009). According to IPCC (2014), human influence on the climate change is clear and the more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts on human and natural system.

Malaysia had formulated two policies i.e. The National Policy on Climate Change and the National Green Technology Policy to collectively guide the nation towards addressing climate change holistically, ensuring climate-resilient development, developing a low carbon economy and promoting green technologies (Ministry of Natural Resources and Environment Malaysia, 2011). According to Al-Amin and Filho (2011), low carbon economy is one of the key initiatives proposed by the Malaysian government in the fight against the issue of global warming and climate change.

Malaysia ratified the United Nation Framework Convention on Climate Change (UNFCCC) on 13 July 1994 and the Kyoto Protocol on 4 September 2002 (UNDP, 2015). As part of the obligations under Article 4 of the UNFCCC, the Government of Malaysia submitted its Initial National Communication in July 2000 and the Second National Communication was submitted in January 2011 (Ministry of Natural Resources and Environment Malaysia, 2015; Sani, 2009). Malaysia greenhouse gases (GHGs) emission for the year 2011 was 290.230 million tonnes CO_2eq and the removal was 262.946 million tonnes CO_2eq with a net sink of 27.284 million tonnes CO_2eq (Table 1.8).

Table 1.8: Malaysia GHGs inventory for 2011

Sector	Emissions (Million tonne CO2eq)	Sink (Million tonne CO2eq)
Energy	218.914	
Industrial Processes	18.166	
Agriculture	15.775	
LULUCF	2.490	-262.946
Waste	34.885	
Total	290.230	-262.946
Net Total (after subtracting sink)	-27.284	

Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Malaysia emissions per gross domestic product (GDP) for the year 2000 is 0.62 t CO_2eq/thousand RM (Ministry of Natural Resources and Environment Malaysia, 2011). Malaysia's commitment to addressing the GHGs emission in the context of sustainable development was announced by the Prime Minister during the 15th Conference of the Parties (COP 15) to the UNFCC on 17th December 2009 (Ministry of Natural Resources and Environment Malaysia, 2015; Theseira, 2013). At the COP 15, the Prime Minister had announced Malaysia's voluntary reduction of up to 40% in terms of carbon emission intensity of GDP by the year 2020 compared to year 2005 conditional on receiving the transfer of technology and finance support from developed countries (Ministry of Natural Resources and Environment Malaysia, 2015).

Malaysian Rubber Industry as a whole can play a role in contributing to this reduction pledge. Among the possible initiatives the Malaysian Rubber Industry can adopt to help in achieving this reduction are through better management of fertilizers usage in the upstream rubber industry, persuading the midstream rubber industry processing factories to use a fully aerobic effluent treatment system to treat their raw effluents and more efficient energy usage in the downstream rubber industry.

1.4 Life Cycle Assessment

Life Cycle Assessment (LCA) is an environmental management tool that enables quantification of environmental burdens and their potential impacts over the whole life cycle of a product, process or activity (Azapagic, 1999). According to Yusoff (2006), LCA has been introduced primarily for use in product manufacturing for the purpose of tracing the direct impacts as well as impacts associated with a product throughout the entire life cycle from cradle to grave in order to get a holistic overview of the environmental burden associated with the products.

LCA is a systematic environmental assessment tool that can be used as marketing tool for the product or service (The Green House, 2017). LCA is also a very useful tool for developing and implementing strategies towards overall process optimisation, environmental labels and design for environment (Nor, 2010).

1.4.1 LCA Study for the Malaysian Rubber Industry

In the Malaysian context, LCA methodology is relatively a new approach. A majority of the LCA studies in Malaysia at present are carried out to highlight the environmental sustainability of the oil palm industry. The LCA studies on the oil palm industry in Malaysia covered all the sectors within the industry starting from the planting material production up to the biodiesel and other oil palm based products. All the LCA studies from the oil palm industry in Malaysia has one common objective i.e. to dispel the misinterpretation of the oil palm industry as a very unsustainable industry by international non-governmental organization.

LCA methodology is the most suitable environmental management tool to measure the environmental impact and quantify the greenhouse gas emission from the Malaysian rubber industry. The LCA study conducted for the Malaysian Rubber Industry will no doubt be a very useful source to identify the environmental hotspots in the Malaysian Rubber Industry and help in finding solutions to reduce these hotspots for the betterment of the Malaysian Rubber Industry.

Certain recommendations, policy or standard operating procedures may be introduced by Malaysian Rubber Board (MRB) based on the findings of the LCA study from the Malaysian Rubber Industry. The findings from the LCA study for Malaysian Rubber Industry will also be very beneficial for decision makers across the whole chain of the Malaysian Rubber Industry.

This LCA study for the Malaysian Rubber Industry is the first study of its kind carried out in Malaysia. Prior to this study, there was an earlier LCA study for the production of natural rubber latex concentrate and skim block rubber in North Sumatera, Indonesia involving two latex concentrate factories by Maulina (2014). The objectives of the study by Maulina (2014) is not only confined to produce life cycle inventories and environmental impact data from the life cycle impact assessment stage, but the objective was further expanded to include the assessment on the level of eco-efficiency for the production of natural rubber latex concentrate and skim block rubber by utilizing the values obtain from the life cycle impact assessment analysis based on Eco-Indicator 99 methodology (Maulina, 2014).

Other than the studies as mentioned above, there were some ongoing study in Thailand related to LCA but majority of these studies focuses solely on the quantification of GHGs emission related to their local natural rubber industry.

1.5 Problem Statement

1.5.1 Lack of Data on the Rubber Cultivation in Malaysia from Cradle to Grave Perspective

The rubber cultivation in Malaysian can be divided into 3 main stages that are operating concurrently i.e. the rubber nursery operation, the immature rubber operation and the mature rubber operation. These three stages have their own standard operating procedures in meeting their specific objectives. The activities of these three stages are monitored and recorded by the rubber related agencies in Malaysia but the record sharing among these agencies are known to be very poor due to some overlapping jobs scope and sibling rivalry.

MRB had conducted a very comprehensive survey in 2011/2012 for the immature and mature rubber stages from the individual rubber smallholders in Malaysia based on social and economic theme involving 0.338 million hectares of rubber planted area. The survey did include some agronomic practices questionnaire but unfortunately it did not fully capture the agronomic practices from the cradle to grave perspective for these two stages.

The work to quantify the inventories of these three stages in the rubber cultivation activities in Malaysia from various stakeholders and to combine it into a single set of database for rubber cultivation activities in Malaysia from cradle to grave perspective is very important to fill the information gap as mentioned above. The established inventories database for the rubber cultivation activities in Malaysia from cradle to grave perspective will no doubt represent the actual activities of rubber cultivation in Malaysia. The established inventories database for the rubber cultivation activities in Malaysia from cradle to grave perspective will be a very important element to measure the environmental impacts and quantify the GHGs emission for the Malaysian Rubber Industry as a whole.

1.5.2 Projection of Demand for Environmental Certification of SMR and other Malaysian Based Rubber Products

The overall goal of environmental certification in the form of environmental labels and declarations is to communicate verifiable and accurate information on the environmental aspects of products and services(ISO 14020, 2000). Environmental labels and declarations are considered to be a good tool for marketing the green image of products and services (SIRIM & ITC, 2007).

In the developed countries, the number of environmental labelling scheme has been growing exponentially and through the use of the environmental labels, consumers can differentiate between products that are less harmful to human and the environment from other products in the market (Thannimalay, 2013). The current business trend especially in the developed countries put great emphasis on the green credential of the products in their market through strict product regulations. These product regulations are not only applied to the locally manufactured products but also included the products imported into their market.

With the global environmental consciousness among the ordinary consumers worldwide and especially consumers with high purchasing power in the developed countries, it just a matter of time before the Malaysian based rubber products manufacturers are expected by their customers to disclose the environmental information of their products. This trend is already evident as in the case of SMR block rubber where the international tyres manufacturers which are the main buyers of the SMR block rubber are pressing the SMR block rubber processors in Malaysia for more detailed information on the energy and chemicals usage, list and quantity of emissions during the production of SMR block rubber.

Conducting LCA study for the natural rubber cuplump production and SMR block rubber production is the right step towards providing support to the Malaysian SMR block rubber industry in the form of providing details and transparent information regarding the environmental impacts and the GHGs emission in the production of SMR block rubber from cradle to gate approach. The information from this study on LCA for the production of SMR block rubber will be very valuable for the international tyres manufacturers especially in Europe to incorporate it as the verified background data in their LCA study for the tyre production from cradle to grave approach.

The detailed information on the GHGs emissions from the LCA study for the production of SMR block rubber will also be very useful in assisting the Malaysian based rubber products to get certified by the newly launched SIRIM Environmental Declaration Carbon Footprint Type III. The SIRIM Environmental Declaration Carbon Footprint Type III is part of the MyHIJAU Mark and is eligible for Malaysian Government Green Procurement Programme.

1.5.3 Lack of Detailed Information on GHGs Emission and the Possibility of Setting up Voluntary Carbon Trading for Malaysian Rubber Industry

From the literature search, there is not much information available on the figures related to the GHGs emission from the Malaysian rubber Industry. Nor (2010) listed a profile on the possible sources and types of GHGs emission from the Malaysian Rubber Industry but there were no values attached to it reflecting the difficulties in getting the values or whether the values are available at present. There are also studies discussing the benefits of zero burning technique in the rubber upstream industry in order to avoid the release of GHGs emission from the burning of biomass during land clearing as reported in Verasamy et al. (2003) and Kheong (1998), yet there were also no values attached to this GHGs emission avoidance technique.

In summary, it is timely that the GHGs emission related to the Malaysian Rubber Industry is properly studied and documented extensively for the benefits of the Malaysian Rubber Industry and Malaysia as whole. The results from the quantification of GHGs emission work for the Malaysian Rubber Industry using LCA approach will greatly help in filling the information gap as described above. The results from this LCA study on the GHGs emission for the Malaysian Rubber Industry can also be used to project the environmental sustainability of the rubber planting activities in Malaysia as compared to other two major crops in Malaysia i.e. the planting of oil palm and paddy cultivation.

According to Malaysian Rubber Board (2017), the rubber trees in the rubber plantations have the potential to sequester carbon dioxide from the atmosphere at a rate comparable to, if not better than the natural forest. In theory, by comparing the GHGs emission from the Malaysian Rubber Industry to its upstream sequestration potential, it can be positively projected that the Malaysian Rubber Industry is indeed a very environmentally sustainable industry from the perspective of carbon accounting. MRB as the custodian of the Malaysian Rubber Industry in Malaysia is in the initial planning stage to create a domestic voluntary carbon trading purely confined to the Malaysian Rubber Industry.

This proposal however, is still at the infancy level and may need to get approval from the Malaysian Attorney General Department before it can be implemented. The opinions from various stakeholders in the Malaysian Rubber Industry will also need to be consulted first. The proposal is basically looking to create a mechanism where producers of the rubber based products from the midstream and downstream of the Malaysian Rubber Industry had to make certain payment to the rubber smallholders for keeping their rubber trees as the source of carbon sink. The results from the quantification of GHGs emission for the Malaysian Rubber Industry using LCA approach will definitely be very useful in convincing the various stakeholders in the Malaysian Rubber Industry to support this proposal in order to enhance and gave a very positive sustainability image of the Malaysian Rubber Industry.

1.6 Challenges in Implementing LCA in Malaysian Rubber Industry

Implementing the LCA study for the Malaysian rubber industry requires commitments from all parties involved and this is a huge task with a lot of challenges. Among the major challenges anticipated in conducting the LCA for the Malaysian rubber industry are the difficulties in data collection and verification. This is due to the perception of certain parties in the Malaysian rubber industry that the LCA study will only risk the exposure of their sensitive operational data. These parties need to be convinced on the benefits of producing products with clear and verifiable environmental information. The cooperation from Greentech Malaysia through MyHIJAU SME and Entrepreneur programme may be needed to run awareness program and training session for these parties on the benefits of producing Ecolabel certified product.

Another challenge in implementing LCA study in Malaysia is the lack of Malaysian background data. This is not something new but had been reported by the previous LCA practitioner before. According to Norliyana Z.Z et al, Onn &Yusof, Yusoff & Hansen and Vijaya as reported by Thannimalay (2013), most of the LCA studies conducted in Malaysia were using European background data due to the lack of Malaysian background data. Apart from the works initiated by SIRIM, the Institutes of Higher Learning in Malaysia can also play a role to speed up the process of producing more

Malaysian based background data for LCA studies conducted in Malaysia through collaboration with the industry.

1.7 Objectives of the Study

The main aim of the study is to provide comprehensive inventories, detailed quantification of the environmental impact and GHGs emission for the cultivation of rubber tree from cradle to grave in Malaysia and SMR block rubber production from cradle to gate in Malaysia and recommended strategies for improvement. In order to achieve the main purpose as stated above, the objectives as listed below must be achieved:

The objectives of this study are:

1. To review the current practice and quantify a comprehensive Life Cycle Inventory (LCI) for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components i.e. nursery, immature rubber and mature rubber stages.
2. To quantify a LCI for the production of natural rubber cuplump from cradle to gate in Malaysia based on the mass allocation ratio from literature.
3. To review the current practice and quantify a comprehensive LCI for the production of SMR block rubber from cradle to gate in Malaysia.
4. To quantify the environmental impact in the form of Life Cycle Impact Assessment (LCIA) and recommended strategies for improvement based on the individual LCI for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components i.e. nursery, immature rubber and mature rubber stages, production of natural rubber cuplump from cradle to gate in Malaysia and production of SMR block rubber from cradle to gate in Malaysia.

5. To quantify the GHGs emission and recommended strategies for improvement based on the individual LCI for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components i.e. nursery, immature rubber and mature rubber stages, production of natural rubber cuplump from cradle to gate in Malaysia and production of SMR block rubber from cradle to gate in Malaysia.

1.8 Scope of the Study

The scope of the study started from the production of the rubber planting materials in the form of two whorl young budding in the polybag , the planting of rubber planting materials in the rubber smallholders holding and the maintaining of these immature rubber trees until it is mature and ready for tapping, the process of maintaining the growing of mature rubber trees and extraction of natural rubber cuplump from the mature rubber trees through tapping until the mature rubber trees are fell down. The scope of the study also covered the production of SMR block rubber using natural rubber cuplump as the raw materials input.

For objectives 1,2 and 3, the scope of the study is divided into 4 parts of survey works. In the first part, detailed questionnaire surveys on the production of two whorl young budding in the polybag were sent to licensed rubber nursery operators in Malaysia. The questionnaire covered the process starting from seeds germination until the young budding in the polybag is ready to be planted in the rubber smallholdings.

For the second part, detailed questionnaire survey on the agronomic practices during the process of growing the immature rubber trees started from the first day planting of rubber planting materials until the rubber trees are ready for tapping were sent to government agencies in Malaysia which are responsible in helping the organized rubber smallholders to maintain their land.

In the third part, detailed questionnaire surveys on the agronomic practices during the process of maintaining the growth of mature rubber trees and extraction of natural rubber cuplump were sent to government agencies in Malaysia which are responsible in helping the organized rubber smallholders to maintain their land.

For the last part in meeting the scope of objective 1,2 and 3, detailed questionnaire survey on the production of SMR block rubber were sent to five SMR block rubber factories who had agreed to provide information for this study. The questionnaire covered the whole process of SMR block rubber production starting from the purchase of natural rubber cuplump until the SMR block rubber are ready to be exported.

The environmental impacts and hotspots identification for the study was conducted using SIMAPRO software version 7.3.3 developed by Pre Consultants B.V. Eco-indicator 99 was selected as the impact assessment methodology to represent the scope for the objective 4 of this study.

The scope for objective 5 of this study on the quantification of GHGs emission and hotspots identification was conducted based on global warming potential (GWP) 100 year time horizon from the Intergovernmental Panel on Climate Change (IPCC) 2007 fourth assessment report (AR4).

1.9 Organization of the Thesis

This thesis has been divided into five chapters as follows. Chapter one describes the general overview of the Malaysian Rubber Industry. This chapter also explained the importance of conducting LCA for the Malaysian Rubber Industry. Problem statement, objectives and scope of the study are also presented in this chapter.

Chapter two focuses on the literature review related to the study area. This chapter describes in detail the overview of the Malaysian Rubber Industry. This chapter also discussed the concept of climate change, the relationship between climate change and sustainable development, sustainable consumption and production, environmental labels and declarations, green procurement and government green procurement, and environmental management in Malaysia and its related policies. Lastly this chapter discusses the concept of LCA, application of LCA and LCA developments at international and national level.

Chapter three describes in details the methodology that was used to conduct this study based on ISO 14040:2006 and ISO14044: 2006 procedures. This chapter described in detail the four survey exercises that had been conducted for this study to produce 6 corresponding LCI table. For each of the individual LCI table, the goal and scope of the study, functional unit, system boundary, exclusion, assumption and fix value used are also explained in details. Various photos are also included in this chapter to help in visualizing the actual process for these 6 LCI table. The Eco-indicator 99 impact assessment and the GWP from the IPCC 2007 fourth assessment report (AR4) which are the selected methodologies in this study are also explained in detail in this chapter.

Chapter four presents the results and discussion. The results from the LCI tables for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components i.e. nursery, immature rubber and mature rubber stages, production of natural rubber cuplump from cradle to gate in Malaysia and production of SMR block rubber from cradle to gate in Malaysia are discussed in great details.

Chapter five summarizes and concludes the findings from this study. This chapter also offer possible suggestions and recommendations for future studies.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview of the Malaysian Rubber Industry

The Malaysian rubber industry can be divided into three main streams i.e. upstream, midstream and downstream. The upstream rubber industry activities cover the cultivation of rubber trees from the rubber seeds germination process until the mature rubber trees are fell down for replanting. The upstream activities can be further divided into 3 main segments i.e. the rubber nursery stage, the immature rubber stage and the mature rubber stage.

The rubber midstream covers all the processing activities that fully utilize the local natural rubber produced by the upstream rubber industry in the form of natural rubber cuplump and natural rubber latex. The downstream activities cover the rubber product manufacturing in Malaysia. The downstream activities can be further classified into 2 main segments i.e. manufacturing of latex based products like gloves and condoms and the manufacturing of dry rubber based products like general rubber goods (GRG), industrial rubber goods (IRG), footwear components, tyres and tube.

The Malaysian rubber industry has always been regarded as an environmentally sustainable industry. The rubber trees have the potential to sequester carbon dioxide from the atmosphere at a rate comparable to if not better than the natural forest (Malaysian Rubber Board, 2017). The rubber trees after the process of falling down are converted into renewable rubber wood for furniture based industry. The term renewable or environmentally friendly associated with the rubber wood arises from the fact that the rubber wood represents a relatively sustainable alternative as compared to the tropical woods extracted from natural forest (Usubharatana et al., 2013).The midstream rubber processing activities produce renewable source of materials in the form of block rubbers and latex concentrate as compared to their non-renewable petroleum based competitors in the form of synthetic block rubber and synthetic latex.

In 2010, the Malaysian government decided to place the rubber industry under the Economic Transformation Programme (ETP) by listing the rubber industry as one of the 12 National Key Economic Areas (NKEA). In order to improve the competitiveness of the Malaysian Rubber Industry and meeting the NKEA objectives, Malaysian Rubber Board (MRB) had launched the One Nation Rubber Strategy (1NRS) in 2014 with proposed strategies to be implemented by the Malaysian Rubber industry (Malaysian Rubber Board, 2016a).

Among the strategies proposed in the INRS are as follow:

1) Strategy to increase the local supply of raw materials by the rubber upstream through:
   - Increasing and maintaining 1.2 million hectares of rubber areas through replanting and new planting
   - Increasing the productivity of the rubber smallholdings to 2 tonnes/hectare/year through the usage of better quality planting materials, implementing good agronomic practices and adopting cluster management for the individual rubber smallholders
2) Strategy to enhance the competitiveness of Standard Malaysia Rubber (SMR) block rubber through reduction of production cost. The production cost is expected to be lower if the SMR block rubber processing line fully utilizes the optimum capacity, provided enough local supply of raw materials are available. The supply of good quality local raw materials from the rubber upstream industry will also contribute to the cost reduction of the SMR block rubber production.

3) Strategy to attain market advantage for rubber trees sequestration potential through the establishment of voluntary carbon trading specifically for Malaysian rubber industry. By quantifying the greenhouse gases (GHGs) emission for various sectors in the Malaysian rubber industry using life cycle assessment (LCA) methodology, the information from these studies will be used as a basis to establish carbon trading with voluntary partners within the Malaysian rubber industry. The Malaysian rubber industry as a whole is expected to gain the benefits from this proposed strategy.

(Malaysian Rubber Board, 2014c)

2.1.1 Upstream Rubber Industry

The planting materials for the rubber industry in Malaysia are produced in the rubber nurseries before they are transplanted into the rubber plantation. The rubber nurseries in Malaysia in general can be classified into two general categories i.e. the ground nursery and the polybag nursery depending on their standard operating procedures. In ground nursery, the planting materials are planted on the ground, whereas in a polybag nursery, the planting materials are planted in the polybag arranged in designated rows (Malaysian Rubber Board, 2009). The commonly produced planting materials by the rubber nurseries in Malaysia are in the form of young budding in the polybag, bare root budded stump, budded stump in the polybag and green budstick (Sulaiman et al., 2009).

In 2011, 19.367 million polybag units of planting materials were produced from rubber nurseries operator in Malaysia (Osman & Nasir, 2012). Young budding in the polybag is the most popular form representing 69.8% from the total production of planting materials in the polybag (Table 2.1). As of March 2011, there are 166 licensed rubber nurseries in Malaysia and 110 of these licensed rubber nurseries are actively producing the planting material with the total combined area of 1431.6 hectare (Osman & Nasir, 2012).

Table 2.1: Malaysia production of planting materials in the polybag for 2011

State	Young budding in Polybag	Budded Stump in Polybag	Matured budding in Polybag
Kedah	5,408,311	2,098,074	60,370
Perlis	394,437	71,410	-
Perak	541,061	313,169	153,973
Selangor	98,740	61,940	-
Negeri Sembilan	273,178	260,457	-
Melaka	665,311	730,938	122,205
Johor	645,305	529,670	6,810
Pahang	791,672	398,647	2,170
Kelantan	1,345,141	249,130	12,219
Terengganu	478,111	47,899	-
Sabah	428,819	-	-
Sarawak	2,450,004	728,116	-
Total	**13,520,090**	**5,489,450**	**357,747**

Source: (Osman & Nasir, 2012).

The rubber plantation sector in Malaysia consisting of immature rubber stage and mature rubber stage is responsible for supplying the raw materials for the midstream rubber sector. Rubber plantation is the second largest agricultural crops in Malaysia after oil palm plantation in terms of planted area (Table 2.2).

Table 2.2: Planted area ('000 ha) for major agricultural crops in Malaysia

Crop \ Year	2011	2012	2013
Rubber	1027.04	1041.19	1057.27
Oil palm	5000.11	5076.93	5229.74
Cocoa	20.85	11.75	13.73
Paddy*	687.94	684.55	671.70

Source: Statistics on commodities 2013, Ministry of Primary Industries and Commodities in (Ministry of Natural Resources and Environment Malaysia, 2015). *Agrofood statistics 2014, Ministry of Agriculture and Agro-Based Industry in (Ministry of Natural Resources and Environment Malaysia, 2015).

During the early stages of the rubber cultivation in this country, the estate based plantation was a major driving force in the rubber upstream sector (Said, 2003). Over the last two decades, there was a significant change in the rubber upstream sector as it gradually changes from estate based plantation to smallholding based plantation (Table 2.3). Malaysian natural rubber production also showed a declining pattern in the last two decades (Table 2.3). Malaysian natural rubber production in 1990 was 1.29 million tonnes as compared to 0.67 million tonnes in 2014 (Malaysian Rubber Board, 2015a, 2016b).

Table 2.3: Malaysian natural rubber production showing a decline in the output from the estate

Year	Production ('000 Tonnes)		Total Production ('000 Tonnes)	% Estate
	Estate	Smallholdings		
1990	396.61	894.36	1,291.50	30.71
1995	242.31	847.06	1,089.37	22.24
1996	237.93	844.54	1,082.47	21.98
1997	215.93	755.15	971.08	22.24
1998	198.87	686.83	885.70	22.45
1999	183.06	585.81	768.87	23.81
2000	128.13	799.47	927.61	13.81
2001	99.53	782.53	882.07	11.28
2002	84.88	804.95	889.83	9.54
2003	76.36	909.29	985.65	7.75
2004	71.23	1,097.50	1,168.74	6.10
2005	65.29	1,060.73	1,126.02	5.80
2006	68.40	1,215.23	1,283.63	5.33
2007	66.80	1,132.80	1,199.55	5.57
2008	59.59	1,012.77	1,072.36	5.56
2009	56.23	800.79	857.02	6.56
2010	55.98	883.26	939.24	5.96
2011	53.01	943.19	996.21	5.32
2012	58.76	864.04	922.80	6.37
2013	57.40	769.02	826.42	6.95
2014	55.77	612.84	668.61	8.3

Note: Yield for estate: 1990-2006: Based on DOS; 2007-2009: Based on survey conducted by MRB ;Source: Department of Statistics (DOS); Malaysian Rubber Board (MRB) in (Malaysian Rubber Board, 2015a, 2016b).

In terms of land planted with rubber, the trend shows a gradual decline over the last two decades with 1.06 million of hectares were planted with rubber in 2014 as compared to 1.84 million hectares in 1990 (Table 2.4).

Table 2.4: Natural rubber planted area in Malaysia

Year	('000 hectares)		
	Peninsular Malaysia	East Malaysia	Total
1990	1,536.33	300.37	1,836.70
1995	1,422.45	266.36	1,688.80
1996	1,377.20	267.14	1,644.34
1997	1,348.01	268.49	1,616.50
1998	1,283.11	260.51	1,543.62
1999	1,212.36	252.39	1,464.75
2000	1,184.95	245.73	1,430.68
2001	1,152.42	236.90	1,389.32
2002	1,139.14	209.67	1,348.81
2003	1,104.99	220.61	1,325.60
2004	1,057.33	221.50	1,278.83
2005	1,048.98	222.32	1,271.30
2006	1,042.59	221.00	1,263.59
2007	1,019.78	228.26	1,248.04
2008	1,018.77	228.26	1,247.03
2009	789.02	239.22	1,028.24
2010	772.65	247.73	1,020.38
2011	776.87	250.17	1,027.04
2012	771.60	269.59	1,041.19
2013	771.86	285.41	1,057.27
2014	775.54	290.06	1,065.60

Source: The data for total rubber planted are in Malaysia are provided by DOS in (Malaysian Rubber Board, 2015a, 2016b).

The decline in the natural rubber production and rubber planted area in Malaysia as shown in Table 2.3-2.4 was due to the prolonged low natural rubber prices in the 1990s which saw many rubber estates and smallholdings rubber area converted into oil palm and other lucrative economic activities (Sumormo, 2011). According to (Ang, 2010), the prolonged low price of natural rubber after 1997 and coupled with the Asian currency crisis were making the work to tap the rubber trees uneconomical leading to the shortage of rubber tappers.

In order to fulfil the strategy to increase the local supply of raw material as listed in 1NRS, a policy to replant 40,000 hectares per year and a new planting of 30,000 hectares per year for 5 years had been implemented since 2012 (Ahmad, 2013). This policy aims to make sure that the target of 1.2 million hectares of rubber planted area in Malaysia by 2020 is achievable (Ahmad, 2013). Under the same strategy to increase the local supply of raw material, rubber smallholders will also be supplied with high quality planting materials during the replanting and new planting program under the RITES^{TM} system (Ahmad, 2013).

RITES^{TM} is the acronym for Rubber Information and Traceability System which was launched by MRB in 2010. RITES^{TM} allows enforcement officers from MRB to detect and monitor the source of planting materials produced by rubber nurseries through the usage of barcode attached at each of the planting material produced (Sulaiman & Ghani, 2012). With the implementation of RITES^{TM} only quality planting materials from selected clone are supplied to the rubber smallholders to ensure better tree productivity and subsequently achieving the target of 2 tonne/hectare/year by 2020 (Osman & Nasir, 2012).

2.1.2 Midstream Rubber Industry

The midstream rubber industry in Malaysia can be divided into 2 main segments i.e. the processing of latex concentrate and the processing of block rubber. The processing of latex concentrate from rubber midstream industry only represents around 15% from the Malaysian rubber midstream total factory output as shown in Table 2.5 due to the problem of getting enough supply of the natural rubber latex.

In Malaysia, the most popular method of processing latex concentrate is through the process of centrifugation although lately there are newer technologies being tried out by industry. Sime Darby Malaysia Berhad and Sime Darby Plantation Sdn Bhd in collaboration with Department of Chemical Engineering University of Malaya have file patents for processes related to the use of membrane treatment to concentrate the natural rubber latex with international publication number W0 2013/055201 A1 (A method of recovering rubber from skim natural rubber latex), WO 2014/069979 A1 (An improved method of recovering rubber from skim natural rubber latex) and WO 2016/204601 A1(A process and system for concentrating epoxidized natural rubber latex into epoxidized natural rubber latex concentrate)(MyIPO, 2018).

Block rubber processing is the most dominant segment in the midstream rubber industry in Malaysia due to the majority of the local raw materials produced is in the form of natural rubber cuplump. For 2012 to 2014, the natural rubber cuplump represents an average of 90.8% from the total natural rubber production by the Malaysian rubber upstream industry (Malaysian Rubber Board, 2016b). Block rubber processing represent more than 85% of the total factory output from the rubber midstream processing industry in Malaysia for the year 2000-2003 (Table 2.5).

Table 2.5: Rubber midstream industry output

Year	Production in Dry Weight (Tonnes)			Percentage of Block Rubber (%)
	Block Rubber	Latex Concentrate	Total	
2000	876,128	153,741	1,029,869	85.1
2001	787,933	141,726	929,659	84.8
2002	839,285	141,915	981,200	85.5
2003	948,885	114,344	1,063,229	89.2

Source: (Goh et al., 2004).

Block rubber processing in Malaysia produces two types of similar products i.e. Standard Malaysian Rubber (SMR) block rubber and house-grade block rubber (HG). These two products are normally produced using the same raw material and processing line. The difference between the SMR block rubber and HG block rubber is that the SMR block rubber are governed by various regulations and quality control system imposed by MRB while the HG block rubber quality is only guaranteed by their respective processors. For 2000-2003, SMR block rubber represents an average 85.6% from the total block rubber production in Malaysia as shown in Table 2.6. The SMR block rubber production in Malaysia based on individual grades for 2010-2012 is shown in Table 2.7.

Table 2.6: Malaysia block rubber production details for 2000-2003

Year	Production (Tonnes)		Percentage of SMR (%)
	Block Rubber	SMR	
2000	876,128	792,208	90.4
2001	787,933	678,736	86.1
2002	839,285	700,908	83.5
2003	948,885	780,273	82.2

Source: (Goh et al., 2004; Malaysian Rubber Board, 2004)

Table 2.7: Production of SMR block rubber in Malaysia for 2010 to 2012 based on individual grade

SMR Grade	Production (Tonnes)		
	2010	2011	2012
SMRCV50	782	358	408
SMRCV60	4,852	2,650	3,232
SMR L	1,891	1,741	1,439
SMR 5	2,266	3,799	4,748
SMR GP	47,940	42,426	45,912
SMR10CV	856	1,827	1,615
SMR 10	211,420	223,260	214,614
SMR20CV	6,141	2,677	2,398
SMR20	421,999	356,088	344,420
Total	698,147	635,126	618,786

Source: (Malaysian Rubber Board, 2014a).

The natural rubber cuplump based SMR block rubber (SMR 10, SMR 20, SMR 10CV and SMR 20CV) is the most dominant SMR grades and represent 92.0%, 92.0% and 91.0% respectively from the total SMR production in Malaysia for 2010 -2012 (Table 2.7).

The SMR block rubber processing in Malaysian is an export oriented based industry. For 2012, 97.6% from the total SMR block rubber production in Malaysia was exported to over sea market (Malaysian Rubber Board, 2014a). The SMR block rubber is exported to 59 countries around the world with China being the major export destination (Table 2.8).

Table 2.8: SMR block rubber export destination for 2012

Country exported	Tonnes	Percentage of total production (%)
China	237,364	38.4
Germany	96,633	15.6
United State of America	28,494	4.6
Rest of the world (Representing 56 countries)	241,597	39.0

Source: (Malaysian Rubber Board, 2014a)

2.1.3 Downstream Rubber Industry

The Malaysian downstream rubber industry profile comprises six main products sectors is summarized in Table 2.9.

Table 2.9: Profile of Malaysian downstream rubber industry for 2012-2014

Product sector		Number of companies			Export (Value in RM Million)
		2012	2013	2014	2014
Latex Products	Glove	59	59	54	12,197.19
	Condom	13	13	14	
	Catheters	7	7	6	
	Latex thread	2	2	2	
	Other	44	45	41	
	Sector Total	125	126	117	
General rubber goods		152	152	138	1,069.22
Industrial rubber goods		32	32	31	594.82
Footwear and components		17	17	13	315.14
Tyres		12	12	9	982.83
Inner Tube		11	11	8	15.13
Industry Total		**349**	**350**	**316**	**15,174.33**

Source: MRB except for export value which is from DOS in (Malaysian Rubber Board, 2015a).

The latex products manufacturing sector is the single biggest contributor to the Malaysian export value of rubber downstream industry at 80.4% from the total rubber downstream industry export value for 2014 (Table 2.9). Based on data from Department of Statistic Malaysia, the gloves manufacturing industry contributes RM 10533.5 million of export value for 2014 representing 86.4% from the total export value for latex products sector of RM 12197.19 (MREPC, 2015). Malaysia currently supply up to 60% of the world consumption for the examination gloves (Yazid & Yatim, 2014). For 2012, Malaysia exported 100 billion pieces of rubber gloves which is around 63% of the world's supply to 180 countries (Rubber Journal Asia, 2015).

The GRG and IRG manufacturing sector contribute 11% from the total Malaysian export value of rubber products for 2014 with the total value of RM 1664.04 million (Malaysian Rubber Board, 2015a). The GRG and IRG manufacturing sector produce a wide range of rubber products such as hoses, rubber boots, engine mounting and beltings. According to Shah (2012), 77% from the total of 187 GRG/IRG manufacturers in Malaysia is categorized as a small and medium enterprise (SME).

2.1.4 Challenges Facing the Malaysian Rubber industry

Rubber smallholders are the backbone of the Malaysian rubber upstream industry as it contributes an average of 92.8% from the total Malaysia natural rubber production for 2012- 2014 (Malaysian Rubber Board, 2016b). Any unresolved issues related to rubber smallholders will definitely affect the country natural rubber production. At present, the production of natural rubber by the upstream rubber industry dominated by the rubber smallholders is still not sufficient to cater for the demand from the rubber midstream industry.

Among the challenges facing the rubber upstream industry are the uneconomical size of holdings, low individual tree productivity and aged rubber smallholders which contribute to the relatively lower natural rubber productivity in Malaysia measured in kg/Ha/Year as compared with other natural rubber producing countries (Malaysian Rubber Board, 2014c). Other factors that contribute to the low productivity in the production of natural rubber in Malaysia are the usage of poor planting materials during replanting process, no fertilizer application or fertilizer application not according to the recommendations and significant portion of the rubber trees in the rubber smallholders areas are old (Ahmad, 2013).

For the midstream rubber industry, the challenges facing the SMR block rubber processors are inadequate supply of local raw materials, environmental related problems, dependency on foreign labour as locals are not interested to work due to uncomfortable conditions in the factories, escalating costs of major components such as diesel, electricity, transport and shipping, contamination of raw materials and price volatility of the SMR block rubber (Kin, 2010).

For the rubber downstream industry, the latex based products manufacturing sector is facing the problem of inadequate supply of locally produced latex concentrate. In 2013, the latex product manufacturing sector required about 379,300 tons of latex concentrate with only 72,900 tonnes being produced locally (Malaysian Rubber Board, 2014c). The importation of the latex concentrate for rubber glove manufacturers in Malaysia exposed the industry to the risk of the rising cost in raw materials purchase and its subsequent production cost (Yazid & Yatim, 2014). The rubber glove manufacturers in Malaysia are also facing the challenges in the form of dependency on foreign labour, lacking in continuous skilled workforce and high cost associated with using of conventional energy sources (Yazid & Yatim, 2014).

For the dry rubber based product manufacturing sector in Malaysia, among the challenges facing the industry are labour shortage, increasing cost of raw material and competition from low cost countries such as China, Thailand, Indonesia and India which also produced the same product (Shah, 2012).

2.2 Climate Change and Sustainable Development

Climate change is summarized by Harris (2000) as the extraordinary warming of the Earth from increased concentrations of greenhouse gases (GHGs). The current anthropogenic emission of GHGs are the highest in history and are driven largely by human activities through infrastructure development, industries, agriculture and motor vehicles (IPCC, 2014; Sani, 2009). The atmospheric concentrations of carbon dioxide, methane and nitrous oxide at present are unprecedented at least for the last 800,000 years (IPCC, 2014). According to Van der et al., in (de Blécourt et al., 2013), it is estimated that 12-15% of the global anthropogenic carbon dioxide emissions is originated from the deforestation and forest degradation.

Climate change is more than just a warming trend as the increasing temperature through continued emission of GHGs will cause further warming and long lasting changes in all components of the climate system (IPCC, 2014; Sani, 2009). The consequences of the climate change are likely to be harmful to humans and natural environment in the form of changes in major wind patterns, amount and intensity of precipitation and increased frequency of severe storms and weather extremes (Harris, 2000; Sani, 2009).

Climate change affects most significantly in agriculture as compared to other economic sectors due to its strong linkage and dependence on the climate and the environmental factors as suggested by Mad Nasir et.al in Al-Amin et al. (2011). Among the climatic factors that can influence the agricultural productivity are increase in temperature, changes in sowing and harvesting dates, water availability and rainfall patterns (Ahmed et al., 2015). According to Baharuddin in (Al-Amin et al., 2011), an increase in rainfall is prejudicial for rubber plantations which suffer losses in the form of loss of tapping days and crop washouts.

Climate change is a threat to sustainable development and this threat can be reduced and managed through mitigation and adaptation strategies (IPCC, 2014). The adaptation and mitigation strategies to overcome the challenge of climate change however must be fully compatible with the wider objectives for economic growth and human progress (WTO, 2015). Mitigation approach works on limiting the climate change by reducing the GHGs or enhancing their sink (Füssel, 2007). According to Lal, Van Noordwijk et al., and Don et.al., in (Guillaume et al., 2015), improvement on the carbon sink through the reduction of deforestation is important as loss of soil organic carbon which is a key mitigation in climate change is a well-known consequence of converting natural forest to agricultural land. Among mitigations measures that can be adopted to reduce the risk of climate change are more efficient use of energy, greater use of low carbon and life style and behaviour changes (IPCC, 2014). According to McCarthy et al. in Füssel (2007), adaption means actions targeted at the vulnerable system in response to actual or expected climate change with the objective of moderating harm from climate change or exploiting opportunities.

Sustainable development term was popularized in *Our Common Future*, a report published by the World Commission on Environment and Development in 1987 which is also known as the Brundtland report (Drexhage & Murphy, 2010). The Brundtland report defined sustainable development as "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). Sustainable development can be described as the requirements for effective environmental protection and conservation of resources with economic development (Nor, 2010). Sustainable development in general poses two fundamental challenges i.e. to promote informed decisions that are conductive to sustainability and to integrate conservation with the need for economic development (Yusoff, 2006).

The Brundtland commission's work provided the basis for the 1992 United Nation Conference on Environment and Development (UNCED) also known as Earth Summit where it was formally agreed that sustainable development needs to be a balance of the three dimensions i.e. environmental protection, economic growth and social development (Cook, 2010; Nor, 2010). One of the most important achievements during the 1992 Earth Summit is the signing of the United Nations Framework Convention on Climate Change (UNFCCC) by 165 states (Sani, 2009). The UNFCCC set an overall framework for intergovernmental efforts to tackle the challenges posed by climate change (Cook, 2010).The ultimate goal of the UNFCCC is to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate change" (Sani, 2009).

2.3 Sustainable Development Goal

The sustainability development goals (SDGs) which were adopted by world leaders at 2015 UN Sustainable Development Summit officially came into force on 1st of January 2016 (UNITED NATION, 2017). The SDGs form part of the 2030 Agenda for Sustainable Development after negotiations and consultations processes at the intergovernmental level that lasted nearly three years (Barclay et al., 2015). This 2030 Agenda entitled 'Transforming our world: the 2030 Agenda for Sustainable Development' is a very important political consensus by UN Member States to work collectively in achieving people-centred sustainable development (Barclay et al., 2015).

A total of 193 countries in the UN General Assembly adopted the 2030 Agenda on September 2015 (UNDP, 2017).The uniqueness of the SDGs is that it calls for action by all countries regardless whether the countries are poor, rich or in the middle income group to promote prosperity while protecting the planet (UNITED NATION, 2017). The SDGs are a basically a framework of 17 goals across social, economic and environmental areas of sustainable development which UN Member States committed to making reality over the next 15 years beginning in 2016 (Barclay et al., 2015).

2.3.1 Sustainable Consumption and Production

At the 1992 Earth Summit, Sustainable Consumption and Production (SCP) was given global endorsement and was recognized as an overarching theme to link environmental and development changes (UNEP, 2010, 2011). The 1992 Earth Summit final report, Agenda 21 states that the unsustainable patterns of consumption and production are the main cause of the continued deterioration of the global environment

(UNEP, 2010). The unsustainable patterns of consumption and production have resulted in a very serious impact to the environmental sustainability in terms of over exploitation of natural resources, generation of wastes and environmental pollution and these problems are becoming more crucial because of the rapid economic growth and increase in the population (Adham et al., 2013).

SCP has been defined as 'the use of services and related products for basic needs and for a better quality of life at the minimum usage of resources, toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generation' at the Sustainable Consumption Symposium in Oslo, Norway on 19-20 January 1994 (UNEP, 2011). SCP can be summarized as a practice to do 'more and better with less' through the reduction in the environmental degradation that can have adverse effect to the peoples' quality of life and well-being (Adham et al., 2013). SCP is a holistic approach that focus on the sustainable and efficient management of resources, encourages the development of processes that use and generate less materials, less hazardous substances and less waste (UNEP, 2011).

SCP links economic processes to the environment and natural resources and at present is seen as a fundamental instrument for mitigation of environmental degradation and resource depletion (Bizikova et al., 2015). SCP provides policy instruments and tools to encourage cleaner production and responsible consumption (Bizikova et al., 2015). Responsible consumption and production is one of the listed SDGs under the 2030 Agenda for Sustainable Development to support the shift towards sustainable patterns of production and consumption.

The shift towards the SCP patterns will result in reduced environmental impacts and waste due to the more efficient use of resource (Bizikova et al., 2015). Effective policies and engagement of governments are very important in the shift towards SCP patterns in order to protect the rich resources that nature provides as well as to improve the lives of some of the world's poorest (UNEP, 2011).

Malaysia has been advocating the SCP concept since 1992 Earth Summit with the acknowledgement that the current resource intensive practices of production and consumption patterns will give negative impact on the quality of life of the present and future generation if it remains unabated (Adham et al., 2013). Malaysia sees SCP as the best approach to enhance the quality of life and standard of living for the present and future generations and is making extensive efforts and commitments in the implementation of SCP related policies (Adham et al., 2013). Malaysia is also considered as one of the four most progressive economies in sustainable development in South East Asia but unfortunately a holistic plan on SCP in Malaysia has yet to be developed (Adham et al., 2013).

The European Union through its EU-Switch funding is helping Malaysia to strengthen the institutional frameworks and policy in order to promote a shifting towards patterns of sustainable consumption and production (Hezri, 2015). Consultations and studies are being carried out by a secretariat based in the Economic Planning Unit of the Prime Minister's Department with the aim to incorporate elements of SCP into the preparation of the 11th Malaysian Plan 2016-2020 (Hezri, 2015). Apart from incorporating the elements of SPC into the 11th Malaysian Plan, the long-term target is for Malaysia to have its own SCP Policy Blueprint to guide the nation along the principles of SCP (Adham et al., 2013).

2.4 Environmental Labels and Declarations

Environmental labels and declarations are one of the environmental management tools with the most obvious means of marketing the green image of products or services and have the tendency to favour the SCP patterns (ISO 14020, 2000; SIRIM & ITC, 2007). Environmental labels and declarations are labels which identify overall, proven environmental preference of a product or service within a specific product/service category (GEN, 2015). Environmental labels and declarations can be applied in various forms such as statement, symbol and graphic (SIRIM & ITC, 2007). The objectives of the environmental labels and declarations are:

- To communicate a verifiable and accurate information on the environmental aspects of products and services
- To encourage the demand and supply of products and services that cause less stress to the environment
- To stimulate the potential for market-driven continuous environmental improvement.

(ISO 14020, 2000)

Ecolabelling is a voluntary programme of environmental performance labelling that is practices around the world and is used by manufacturers or retailers to help consumers identify products and services that have reduced environmental impacts (GEN, 2015; Reader, 2006). Following the growing global concern for environmental issues, many ecolabelling programmes have been developed around the world where most of it is run at national level with the objectives to increase the demand and supply of products and services that cause less stress to the environment (Reader, 2006).

The objectives of the ecolabelling programmes are to reduce the environmental impact of products, to help consumers make an informed choice and to promote sustainable consumption through encouraging consumers to choose products and services considered to be environmentally preferable (Ramasamy, 2008). Ecolabelling or environmental labelling programmes can be classified into three types as defined below:

- Type I Environmental Labelling Programme

Type I environmental labelling programme is a voluntary, multi criteria based third party programme that awards a license which authorizes the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations (ISO 14024, 1999).

- Type II Environmental Labelling Programme

Type II environmental labelling programme is a self-declared environmental claim that is made without independent third-party certification by manufacturers, importers, distributors or anyone else likely to benefit from such a claim (ISO 14021, 1999).

- Type III Environmental Declarations Programme

Type III environmental declaration is a voluntary programme that provide quantified environmental data of a product under pre-set categories of parameters set by a qualified third party and based on life cycle assessment, and verified by that or another qualified third party (GEN, 2015).

The Type I environmental labelling programmes are the world's first and also the most established environmental labelling and declaration in the world (IGPN, 2010). In the Asian region, there are at least 12 Type I environmental labelling programmes in operation in 10 countries excluding Malaysia (IGPN, 2010).Malaysia introduced its own SIRIM Type I environmental labelling programme in 2004. Malaysia also introduce MyHIJAU mark as Malaysia's official green labelling scheme that brings together certified green products and services that meet local and international environmental standards under one single mark (MGTC, 2017). A total of 281 products from 14 different Type I environmental labelling scheme had been awarded the MyHIJAU Mark label as of December 2016 (MGTC, 2017). SIRIM Type I environmental labelling scheme is the biggest contributor with 140 products from 33 companies (MGTC, 2017).

The SIRIM Type 1 Environmental Labelling programme was launched in 2004 and had been upgraded as Malaysia National Environmental Labelling programme in 2011 (Thannimalay, 2013). The SIRIM Type 1 Environmental Labelling programme is owned by SIRIM QAS International Sdn Bhd a subsidiary of SIRIM Berhad which is the largest and oldest certification, inspection and testing body in Malaysia (GEN, 2011). The SIRIM Type 1 Environmental Labelling programme complies with ISO 14024 and awards successful licensees the right to use the mark of the SIRIM Ecolabel on their products (SIRIM 2011). With the acceptance of SIRIM QAS International as a full member in Global Ecolabelling Network (GEN), the SIRIM Ecolabelling scheme has become an internationally recognized standard and puts it on par with the ecolabelling schemes of other member countries (SIRIM 2011).

There are far fewer Type III environmental labelling programmes globally as compared to type I environmental labelling programmes as reported by SIRIM and ITC (2007). The same trend was also observed in Malaysia where only 6 products under the Type III environmental labelling programmes are awarded the MyHIJAU Mark label as of December 2016 (MGTC, 2017). One of the main reasons is due to the fact that type III environmental labels required a significant amount of data that must be carried out using LCA approach. The Type III environmental labelling programme is also relatively new in Malaysia as compared to the Type I environmental labelling programmes. SIRIM Carbon Footprint certification scheme was only launched in 2014.

SIRIM Carbon Footprint Certification Scheme is a type III environmental declarations programme that present quantified GHGs profile for the life cycle of a product to enable comparisons between products fulfilling the same function as defined under ISO 14025:2006 and ISO/TS 14067:2013 (Ang, 2015). The SIRIM Carbon Footprint Certification scheme is operated within Malaysia but can be applied to all products that are manufactured within or outside Malaysia (Ang, 2015).

2.5 Green Procurement

Green procurement is the procurement of products or services that have a reduced environmental impact as compared with other products or services that serve the same purpose (Mosgaard, 2015). Lambert and Cooper in Eltayeb et al. (2011) defined the green procurement as the procurement process that consider the issue of sustainability in addition to the traditional procurement criteria such as cost, quality and delivery while Large and Thomsen in Appolloni et al. (2014) defined green procurement as an integration of environmental considerations into purchasing policies, programmes and action. In most cases, ecolabels, avoidance of environmentally hazardous substances and used of recycled materials are some of the keywords that linked green procurement to the procurement of products or components as suggested by Nagel in (Mosgaard, 2015).

Green procurement has gained wide acceptance in Europe, United States of America, Australia and New Zealand and it is being actively promoted in Japan, the Republic of Korea, Taiwan, China and Thailand while it is a relatively new concept in many parts of

Asia (IGPN, 2010). The environmental initiative to embark on green procurement in most of the developed countries is driven by their own governments (Thannimalay, 2013). In Malaysia, the government is actively involved in promoting the sourcing as well as purchasing of products and services that are environmental friendly through the setting up of MyHIJAU programme (Standards Malaysia, 2015).

2.5.1 Malaysia MyHIJAU Programme

Malaysia MyHIJAU Programme is a national initiative towards adopting the SCP concept under the 11th Malaysia Plan (Gee, 2015). MyHIJAU programme is implemented by Malaysia Green Technology Corporation (Green Tech Malaysia), an organization under the Ministry of Energy, Green Technology and Water tasked with catalysing green technology development in line with the Malaysian Green Technology Policy (MAGIC, 2017; Standards Malaysia, 2015).

The objectives of the MyHIJAU programme are as follow:

- To coordinate and consolidate government initiatives in green products and services development in Malaysia.
- To increase awareness and knowledge to the public sector, private sector and society in conserving the environment through SCP
- To develop guidelines and procedures to the industries for producing local green products and services.
- To build capacity, skill and expert for competitive green production to the industries.

(Atan, 2013)

There are 4 sub-programmes in MyHIJAU programme representing sustainable consumption and sustainable production components. MYHIJAU Procurement and

MYHIJAU Directory were grouped under the sustainable consumption component while MYHIJAU Mark and MYHIJAU Industry & SMEs were grouped under the sustainable production (Gee, 2015).

MYHIJAU Procurement

MYHIJAU procurement is part of the government initiative towards the development of green procurement in Malaysia and covers among others the promotion activities, public awareness and capacity building (Atan, 2013).

MyHIJAU Directory

MYHIJAU Directory is a comprehensive guide to a wide range of green products and services that are categorized systematically for ease of consumer reference (Standards Malaysia, 2015). MYHIJAU Directory had been in operation since January 2011 and up to August 2013, there are 108 companies listed in this directory with a majority being in the energy and building materials and maintenance sector (Adham et al., 2013; Atan, 2013). For the product or service to be listed in the MYHIJAU Directory, it must contribute to environmental sustainability such as resource minimization, lower carbon dioxide emission and efficient energy use (Adham et al., 2013). The directory is available both in electronic and printed format (Standards Malaysia, 2015).

MyHIJAU Mark

MyHIJAU Mark is the official label that recognises certified green products, equipment, system as well as services that have been certified by Green Tech Malaysia as meeting local and international environmental standard (Atan, 2015). The products, equipment, system or services must meet the following criteria in order to be accorded the MyHIJAU Mark label:

- Minimise the degradation of the environment or reduce greenhouse gas emissions
- Promote health and/or improve the environment
- Conserve the use of energy, water and/or other forms of natural resources, or promote the use of renewable energy, or recyclable material.

(Atan, 2015)

A verification body plays an important role in the MyHIJAU Mark and only products and services certified by a verification body recognised by Green Tech Malaysia are eligible to be awarded with MyHIJAU mark label. The type of green labels certification accepted by the Green Tech Malaysia and awarded with MyHIJAU Mark is shown in Table 2.10. Products with MyHIJAU Mark label give assurance to the consumers that the internationally recognised environmental and ecological standards are met during the manufacturing of the products (Standards Malaysia, 2015).

MyHIJAU SME and Entrepreneur

MyHIJAU SME and Entrepreneur objective is to encourage the local SMEs to adopt green practices and produce local green products and services (Atan, 2015). MyHIJAU SME and Entrepreneur also aims to facilitate the successful incorporation of best green practices and applications in the SMES' operations (Atan, 2015).

Table 2.10: Type of green labels certification accepted for MyHIJAU Mark

Category	Certification scheme	Sector	Example of verification body logo accepted by Green Tech Malaysia
ISO 14024	Type I Ecolabelling Scheme	Manufacturing and services	
ISO 14025	Carbon Footprint Labelling Scheme	Manufacturing and services	
Other Type I Voluntary Sustainable Scheme	Energy Efficiency Rating and Labelling Scheme	Energy	
	Water Efficient Products Labelling Scheme	Water	
	Timber Certification Scheme	Forestry	

Source: (Atan, 2015)

2.6 Government Green Procurement in Malaysia

Bouwer et al. in Michelsen and de Boer (2009) defined Government Green Procurement (GGP) as the approach by public authorities in integrating environmental criteria into all stages of their procurement process and thus encouraging the spread of environmental technologies and development of sound products through seeking and choosing the outcomes and solutions that have the least possible environmental impact throughout their whole life cycle. In the Malaysian context, GGP refers to the acquisition of products, services and work in the public sector that takes into consideration environmental criteria and standards in conserving the environment and resources, which minimises and reduces the negative impacts of human activities (Kahlenborn et al., 2013).

GGP is an indicator of the government commitment to sustain the environment and has been recognized as an effective tool in minimizing the environmental impacts (Musa et al., 2013). By implementing GGP, the government plays an important role in creating the demand for environmentally products and persuading the business to take part in environmentally friendly activities (Musa et al., 2013). In the case of Malaysia, government procurement represent about 12-15 % of GDP (Kahlenborn et al., 2014).

GGP is a very new concept in Malaysia and had only been outlined in 10th Malaysia Plan 2011-2015 (Musa et al., 2013). According to Adham and Siwar (2012), the implementation of GGP will help Malaysia to achieve the target reduction in carbon emission intensity by 40 percent of GDP by 2020. The selection of products and service for the implementation of Malaysia GGP are based on the following criteria:

- Availability of standards: MyHIJAU mark on the products and services can be easily recognized

- Readiness of local suppliers: GGP for the relevant product group or service category helps local manufacturers to become more competitive in international markets.
- Environmental impact: New green products or services that can significantly reduce the carbon footprint, water and energy consumption or the emission of toxic substances.
- Budgetary considerations: The products and services are frequently used in the government sector and the amount spent is significant.

(Kahlenborn et al., 2014)

As GGP needs to be introduced in a step-by step and systematic way, the Malaysian government has endorsed a GGP short-term action plan as an initial step towards Malaysia's long-term GGP implementation strategy in Malaysia (Kahlenborn et al., 2013). Malaysia GGP short-term action plan cover the period from July 2013 to December 2014 (Kahlenborn et al., 2013).The Malaysia GGP short-term action plan target and achievements are shown in Table 2.11 with the overall green procurement cost is RM 352 million (SCP Malaysia).

Table 2.11: Target and achievements under GGP short-term action plan

Target	Achievement
Selection of 2 products/services group	6 products/services group • Paint/Coating • Cement • EE Lightings • ICT • Cleaning Services • Paper
Selection of 2 pilot implementers	5 Ministries: • Economic Planning Unit • Ministry of Energy, Green Technology and Water • Ministry of Education • Ministry of Home Affairs • Ministry of Health

Source: (SCP Malaysia)

With the expiry of the Malaysia GGP short-term action plan in December 2014, the implementation of the GGP in Malaysia is being continued through Malaysian GGP Long-Term Action Plan (LTAP) that will cover the period from 2015 to 2025 (Kahlenborn et al., 2014). Through LTAP, the GGP will be expanded to all Government ministries and agencies including the regional and local government with more products and services group will also be included (Kahlenborn et al., 2014). For 2016, 12 selected products and services group had been identified and by 2020, the target is to have at least 30 products and services group that are ready in the market to fulfill the demand of government agencies in Malaysia (SCP Malaysia).

2.7 Environmental Management in Malaysia

Environmental Quality Act 1974, National Environment Policy and Climate Change Policy form the basis of environmental management in Malaysia (Ministry of Natural Resources and Environment Malaysia, 2015). The environmental management in Malaysia had evolved through at least three stages with each of the stages was landmarked by an important policy shift as reflected in the legislation (Sani, 2009).

According to Sani (2009), the early stage covers the earlier period up until the Environmental Quality Act (EQA) was enacted. The EQA was enacted in 1974 and provides a legal framework at the federal level and is enforceable throughout Malaysia with the focus on pollution control (Hezri & Hasan, 2006). With the passage of the EQA 1974, the Division of the Environment was created in 1975 and later upgraded to Department of Environment (DOE) in 1983 (Hezri & Hasan, 2006).

The second stage covers the period between 1974 and 1987 where in 1987 the Environmental Impact Assessment (EIA) Order was introduced signifying a serious attempt at preventive measures as compared to the curative measured which appear to be the order of the day before that (Sani, 2009). Following the introduction of the EIA order, the EIA procedure has been made mandatory in 1988 with the intention to assess the overall environmental impact on the environment for new developments projects or the expansion of existing projects involving 19 prescribed activities (Vun & Latiff, 1999). A total of 1705 projects subjected to EIA were monitored by the DOE between 1988 and 1995 with the highest number was related to resort and recreational development (19%), followed closely by quarry (18%), infrastructure (12%), housing (10%) and industry (9%) as reported by DOE in (Vun & Latiff, 1999).

The third stage of the evolution covers the period after 1987 where trade and environment take the centre issues and this stage also witnesses the ugly tussles between ruthless lopsided economic activities and environmental conservation at the expense of long term sustainability (Sani, 2009).

In the twenty-first century, international environmental thinking especially on sustainable development has started to influence the development of environmental management related policies in Malaysia (Hezri, 2015).The government agencies have also started using consultation approach with civil societies and business in an attempt to accommodate their concerns in the proposed policies related to environmental management (Hezri, 2015).The approaches as described above has resulted in broad agreement on the direction of sustainable development in Malaysia as expressed in policies such as National Policy on the Environment and National Climate Change Policy (Hezri, 2015).

2.7.1 National Policy on Environment

National Policy on Environment was approved by the Cabinet on 20nd of October 2002 with the policy statement for continuous economic, social and cultural progress and enhancement of the quality of life of Malaysians through environmentally sound and sustainable development (Ministry of Science Technology and the Environment Malaysia, 2002). The policy seeks to integrate environmental considerations into all related decision making involving development activities in order to foster long term economic growth, human development and protection and enhancement of the environment (Ministry of Science Technology and the Environment Malaysia, 2002). The objectives of this policy are to ensure Malaysia achieve:

- A clean, safe, healthy and productive environment for present and future generations.
- Conservation of the country's unique and diverse cultural and natural heritage with effective participation by all sectors of society
- Sustainable lifestyles and patterns of consumption and production.

(Ministry of Science Technology and the Environment Malaysia, 2002)

2.7.2 National Policy on Climate Change

National Policy on Climate Change was approved by the Cabinet on 20th November 2009 with the policy statement to ensure climate resilient development to fulfil national aspirations for sustainability (Ministry of Natural Resources and Environment Malaysia, 2010) . The National Policy on Climate Change provides the framework to mobilize and guide government agencies, industry, communities as well as other stakeholders and major groups in addressing the challenges of climate change in an effective and holistic manner (Ministry of Natural Resources and Environment Malaysia, 2011). The objectives of the National Policy on Climate Change are:

- Mainstreaming climate change through wise management of resources and enhanced environmental conservation resulting in strengthened economic competitiveness and improved quality of life.
- Integration of responses into national policies plans and programmes to strengthen the resilience of development from arising and potential impacts of climate change.
- Strengthening of institutional and implementation capacity to better harness opportunities to reduce negative impacts of climate change.

(Ministry of Natural Resources and Environment Malaysia, 2010)

2.7.3 Malaysian Green Technology Policy

The Malaysian National Green Technology Policy was officially launched on 24 July 2009 with policy statement ‘Green technology shall be a driver to accelerate the national economy and promote sustainable development (MGTC, 2015; Ministry of Energy Green Technology and Water Malaysia, 2009).

The Malaysian National Green Technology Policy seeks to promote low carbon technology and ensure sustainable development while conserving the natural environment and resources (Ministry of Natural Resources and Environment Malaysia, 2011). The national goals of the Malaysian National Green Technology Policy is to provide directions and motivations for Malaysians to continuously enjoy good quality living and a healthy living (Ministry of Energy Green Technology and Water Malaysia, 2009). From the perspective of the green procurement, the goals for the Malaysian National Green Technology Policy can be classified into short- term, mid-term and long-term as below:

- Short-term goal (10th Malaysia Plan 2011-2015): to spread the availability and recognition of green technology for products and services in the local market through labelling programmes, standards and rating
- Mid-term goal (11th Malaysia Plan 2016-2020): to ensure green technology becomes the preferred choice in procurement of products and services
- Long-term goal (12th Malaysia Plan 2021-2025 and beyond):
    a) Inculcation of green technology in Malaysian culture
    b) Malaysian becomes a major producer of green technology in the global market.
    c) The reduction of overall resources consumption while sustaining national economic growth through widespread adoption of green technology

(Ministry of Energy Green Technology and Water Malaysia, 2009)

The criteria for green technology for products and services as defined in the Malaysian National Green Technology Policy are as follow:

- It minimize the degradation of the environment
- It has a zero or low GHGs emission
- It is safe for use and promotes healthy and improved environment for all forms of life
- It conserves the use of energy and natural resources
- It promotes the use of renewable resources

(Ministry of Energy Green Technology and Water Malaysia, 2009)

2.8 Life Cycle Assessment

In the ISO 14040 (2006), life cycle assessment (LCA) is defined as the process of compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. The term product in the (ISO 14040, 2006) refers to both goods and services. LCA is an important decision making tool in environmental management due to its holistic approach to system analysis (Azapagic & Clift, 1999). The main advantage of LCA over other methods of environmental analysis is because LCA methodology includes all burdens and impacts in the life cycle of a product or process and not focussing solely on the emissions and wastes generated by the manufacturing site only (Azapagic & Clift, 1999). LCA can assist in:

- Identifying opportunities to improve the environmental performances of products at various points in their life cycle.
- Informing decision makers in any organizations in terms of strategic planning, priority setting, products design or redesign
- Selection of relevant indicators of environmental performance
- Making an environmental claim, producing an environmental product declaration or implementing an ecolabelling scheme

(ISO 14040, 2006)

There are four phases in LCA studies namely goal and scope definition, inventory analysis, impact assessment and interpretation. The relationship between the phases is illustrated in Figure 2.1 (ISO 14040, 2006).

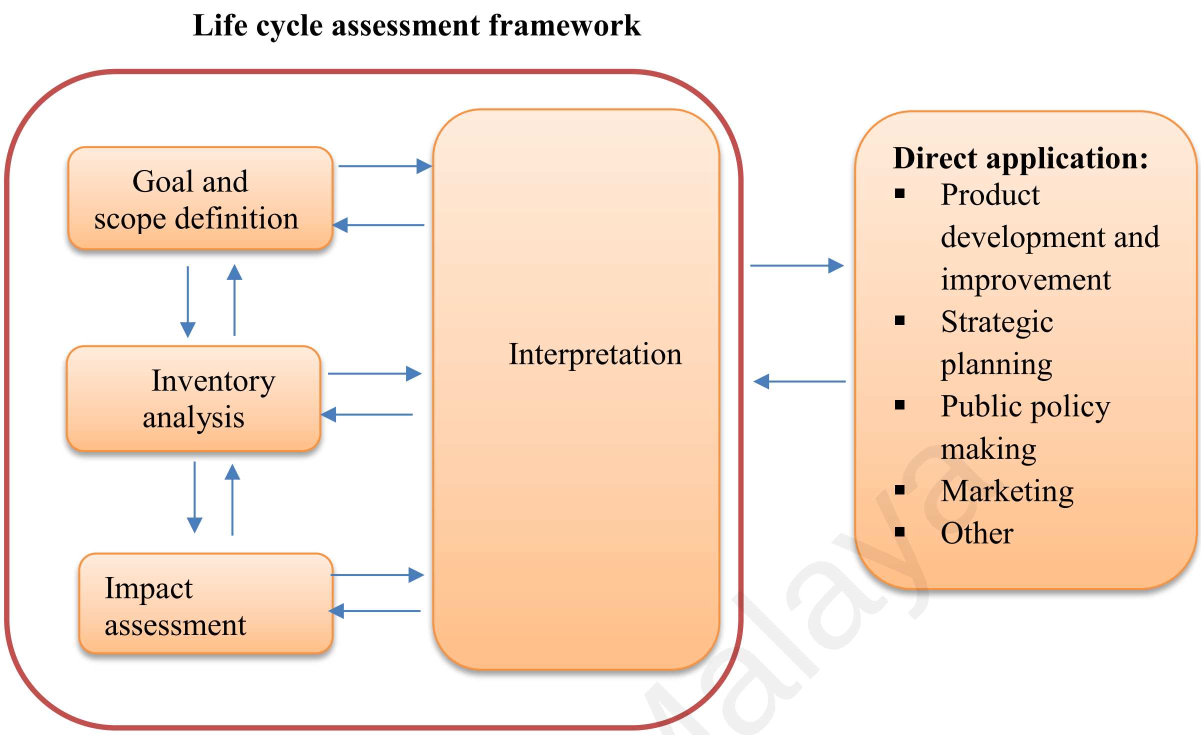

Figure 2.1: Stages of an LCA

2.8.1 Goal and Scope Definition

This is the first phase of any LCA study and according to ISO 14040 (2006) the goal must clearly mentioned the intended application, the reasons for carrying out the study and the intended audience. The scope of any LCA study should be sufficiently well defined to ensure that the breadth, depth and the details in which the study is conducted are both compatible and sufficient to address the stated goals (ISO 14040, 2006). The functional unit, system boundary, allocation procedures, assumptions and limitation are parts of the scope.

The functional unit provide a reference to which the inputs and outputs are related and in any LCA study it must be clearly define, measurable and consistent with goal and scope of the study (ISO 14040, 2006; ISO 14044, 2006). One of the primary purposes of a functional unit is to provide a reference to which the input and output are normalized in a mathematical sense (ISO 14044, 2006). The system boundary determines the unit processes that should be included within the LCA study and the criteria used in setting the system boundary are important for the degree of confidence in the result of any LCA study (ISO 14040, 2006; ISO 14044, 2006).

2.8.2 Inventory Analysis

The life cycle inventory (LCI) phase is the second phase of any LCA study. Inventory analysis involves data collection and calculation procedures within the system boundary for inclusion in the inventory as relevant inputs and outputs of a product system (ISO 14040, 2006; ISO 14044, 2006). According to Svoboda (1995), LCI can be defined as an objective, data-based process of quantifying energy and raw materials requirements, air emissions, waterborne effluents, solid waste, and other environmental releases incurred throughout the life cycle of a product, process, or activity.

All calculation procedures in the inventory analysis for any LCA study must be transparently documented and the assumptions used must be clearly stated and explain (ISO 14044, 2006). In general there are two types of inventory data i.e. the foreground data that have to be collected independently according to the purpose of carrying out LCA analysis and the background data which are usually collected from literatures and software (Narita, 2005a). Data validity check must be conducted during the process of data collection for inventory analysis to make sure that the data quality requirements have been fulfilled (ISO 14044, 2006). For the data collected from public sources, the sources must be referenced (ISO 14044, 2006).

2.8.3 Impact Assessment

The life cycle impact assessment phase (LCIA) is the third phase of LCA and its purpose is to evaluate the significance of potential environmental impacts based on the LCI results (ISO 14040, 2006). The LCIA phase is important in providing the information for the life cycle interpretation phase (ISO 14040, 2006). The LCIA phase consists of mandatory and optional elements. The mandatory elements in the LCIA phase are:

- Selection of impact categories, category indicators and characterization models
- Classification – Assigning of LCI results to the selected impact categories
- Characterization – The process of calculating the category indicator results

The optional elements in the LCIA phase are:

- Normalization- The process of calculating the magnitude of category indicator results as compared to reference information
- Grouping - Sorting and possibly ranking of the impact categories
- Weighting – Converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choice

(ISO 14044, 2006)

2.8.3.1 Eco-Indicator 99 Methodology for LCIA

The Eco-indicator 99 methodology consists of two parts i.e. modelling of damages that are inflicted on the environment and a valuation procedure to establish the seriousness of these damages (Goedkoop & Spriensma, 2001). In the Eco-indicator 99 methodology, the environment is defined as a set of biological, physical and chemical parameters influenced by man, that are conditions to the functioning of man and nature (Goedkoop & Spriensma, 2001). There are basically three damage categories in the Eco-indicator 99 methodology:

- Human Health - Contains the idea that all human beings should be free from environmentally transmitted illness, disabilities or premature deaths in present and future.
- Ecosystem Quality – Contains the idea that non-human species should not suffer from disruptive changes of their populations and geographical distribution.
- Resources – Contains the idea that the nature's supply of non-living goods, which are essential to the human society, should also be available for future generations.

(Goedkoop & Spriensma, 2001)

In the Eco-indicator 99 methodology, four different procedures were used to establish the link between the inventory table and potential damages as summarized in Table 2.12.

The damage category to Human Health

The health of human being in present or future generation may be damaged either by reducing its duration of life by a premature death or by causing a temporary or permanent reduction of body functions (Goedkoop & Spriensma, 2001). Among the most important damages caused by the emissions from products system to the human health are as follow:

- Infectious disease, cardiovascular and respiratory disease, as well as force displacement due to climate change.
- Cancer as a result of ionising radiation
- Cancer and eye damages due to ozone layer depletion

Table 2.12: Steps linking inventory table to damage categories

Damage category	Steps involved
Human Health modelling	1. Fate analysis - linking an emission to a temporary change in concentration 2. Exposure analysis – linking this temporary concentration to a dose 3. Effect analysis – linking the dose to a number of health effects e.g. number and types of cancer 4. Damage analysis – links health effect to the number of years lives disabled and years of life loss
Ecosystem Quality modelling	a) Toxic emissions and emissions that change acidity and nutrients levels modelling 1. Fate analysis - linking emissions to concentrations 2. Effect analysis – linking concentrations to toxic stress or increased nutrient or acidity levels 3. Damage analysis – linking these effects to the increased potentially disappeared fraction for plants b) Land use and land transformation is modelled on the basis of empirical data on the quality ecosystems as a function of the land use type and the area size
Resource modelling	1. Resource analysis – linking an extraction of resource to a decrease of the resource concentration 2. Damage analysis – linking lower concentration to the increased efforts to extract the resource in the future

Source:(Goedkoop & Spriensma, 2001)

- Respiratory disease and cancer due to toxic chemicals in air, drinking water and food.

The unit for the human health damage category is DALY (Disability Adjusted Life Years)

(Goedkoop & Spriensma, 2001)

The damage category to Ecosystem Quality

It will be very difficult to determine all damages inflicted to the ecosystems as the ecosystems are very complex (Goedkoop & Spriensma, 2001). The species diversity is used as an indicator for Ecosystem Quality damage category in the Eco-indicator 99 methodology. (Goedkoop & Spriensma, 2001) defined the species diversity as a percentage of species that are threatened or disappear from a given area during a certain time. Two different approaches are used for modelling the Ecosystem Quality as described below:

a) Toxic emissions and emissions that change acidity and nutrients level

Ecotoxicity impact category:

In this method, the Potentially Affected Fractions (PAFs) of species in relation to the concentration of toxic substances are determined on the basis of toxicity data for terrestrial and aquatic organisms (Goedkoop & Spriensma, 2001). The PAF expresses the percentage of species that is exposed to a concentration above the No Observed Effect Concentration (NOEC) (Goedkoop & Spriensma, 2001). PAF in the context of ecotoxicity should be interpreted as toxic stress and not a measure to model disappearance or extinction of species(Goedkoop & Spriensma, 2001).

Acidification and eutrophication impact category:

The PAF concept cannot be use directly in this impact category as damage from acidification and eutrophication is caused by an entirely different and complex biochemical mechanism (Goedkoop & Spriensma, 2001). The method in acidification and eutrophication look at the observed effects from acidification and eutrophication on plants and from these observations, the probability that a plant species still occurs in an area can be determined (Goedkoop & Spriensma, 2001). Wiertz et al. in Goedkoop and Spriensma (2001) called this as Probability of Occurrence (POO) which is translated into PDF (Potentially Disappeared Fraction) indicator where;

$$PDF = 1\text{-}POO$$

(Goedkoop & Spriensma, 2001)

The PDF indicator use target species approach. According to Bal et al. in Goedkoop and Spriensma (2001), the target species are the species that should occur on a specific type of ecosystem if there is no man made changes in the nutrient level or acidity. The fate and damage modelling for NO_x, SO_x and NH_3 depositions in this methodology contains a very detailed grid with an exact description of the type of ecosystem and the associated set of target species (Goedkoop & Spriensma, 2001).The damage model calculates to what extent the number of target species increase or decrease if an additional deposition is added to the background (Goedkoop & Spriensma, 2001). The acidification and eutrophication are combined as a single impact category because it is not possible to determine whether a damage is caused by changes in nutrient level or the acidity (Goedkoop & Spriensma, 2001).

b) Land use

For land use impact category, the PDF based on all species is used as an indicator incorporating four different models;

- The local effect of land occupation
- The local effect of land conversion
- The regional effect of land occupation
- The regional effect of land conversion

(Goedkoop & Spriensma, 2001)

The local effect refers to the change in species numbers occurring on the occupied or converted land itself while the regional effect refers to the changes on natural areas outside the occupied or converted area (Goedkoop & Spriensma, 2001). The unit for the land use impact category is PDF.m^2.yr indicating that the damages increase with an increase in area size, an increase in occupation time or an increase in restoration time for a formerly converted area (Goedkoop & Spriensma, 2001).

The Ecosystem Quality is the most problematic damage category as compared to Human health and Resources as it is not completely homogeneous (Goedkoop & Spriensma, 2001). A temporary solution is to combined the Potentially Affected Fraction (PAF) and Potentially Disappeared Fraction (PDF) indicators in the Ecosystem Quality damage category (Goedkoop & Spriensma, 2001).

The damage category to Resources

In the Eco-indicator 99 methodology, only mineral and fossil fuels impact categories are model for Resources damage category (Goedkoop & Spriensma, 2001). Eco-indicator 99 methodology does not consider the quantity of resources but emphasis on the qualitative of the resources with resources concentration as the main element of resources quality (Goedkoop & Spriensma, 2001). Market forces assure that the deposits with the highest concentrations of resources are depleted first, leaving future generations to deal with lower concentrations and this decreasing concentration is the basis for the resources analysis (Goedkoop & Spriensma, 2001).

The resource analysis modelled the decrease of the concentration of resources (Goedkoop & Spriensma, 2001). An assessment procedure for the seriousness of resources depletion based on the energy needed to extract a mineral in relation to the concentration has been developed by Chapman and Roberts as cited in Goedkoop and Spriensma (2001). Based on this assessment, as more minerals are extracted, the energy requirements for future mining will increase and the damage is the energy needed to extract the mineral in the future (Goedkoop & Spriensma, 2001). The fossil fuels impact category also use the same concept of surplus energy like mineral impact category and much of the data for fossil fuel is supplied by Muller-wenk as cited in Goedkoop and Spriensma (2001). The unit of the Resources damage category is the surplus energy in the form of MJ per kg extracted materials (Goedkoop & Spriensma, 2001).

2.8.3.2 ReCiPe 2016 Methodology for LCIA

ReCiPe 2016 is currently the most updated version of LCIA methodology and the report on ReCiPe 2016 was release on 15th December 2016 (RIVM, 2018). ReCiPe 2016 is a state-of-the-art methodology in converting life cycle inventories to a limited number of life cycle impact scores on midpoint and endpoint level (Huijbregts et al., 2017).The ReCiPe 2016 is focussed on:

- Providing characterization factors that are representative for the global scale, while maintaining the possibility for a number of impact categories to implement characterization factors at a country and continental scale.
- Improving the methods applied to model midpoint-to-endpoint factors.

(Huijbregts et al., 2017)

In line with the global nature of many product life cycles, ReCiPe 2016 is equipped with 17 midpoint impact categories and 3 endpoint categories and the overview of the impact categories and their relation to the areas of protection is shown in Figure 2.2 while the overview of the midpoint impact categories is shown in in Table 2.13 (Huijbregts et al., 2017).

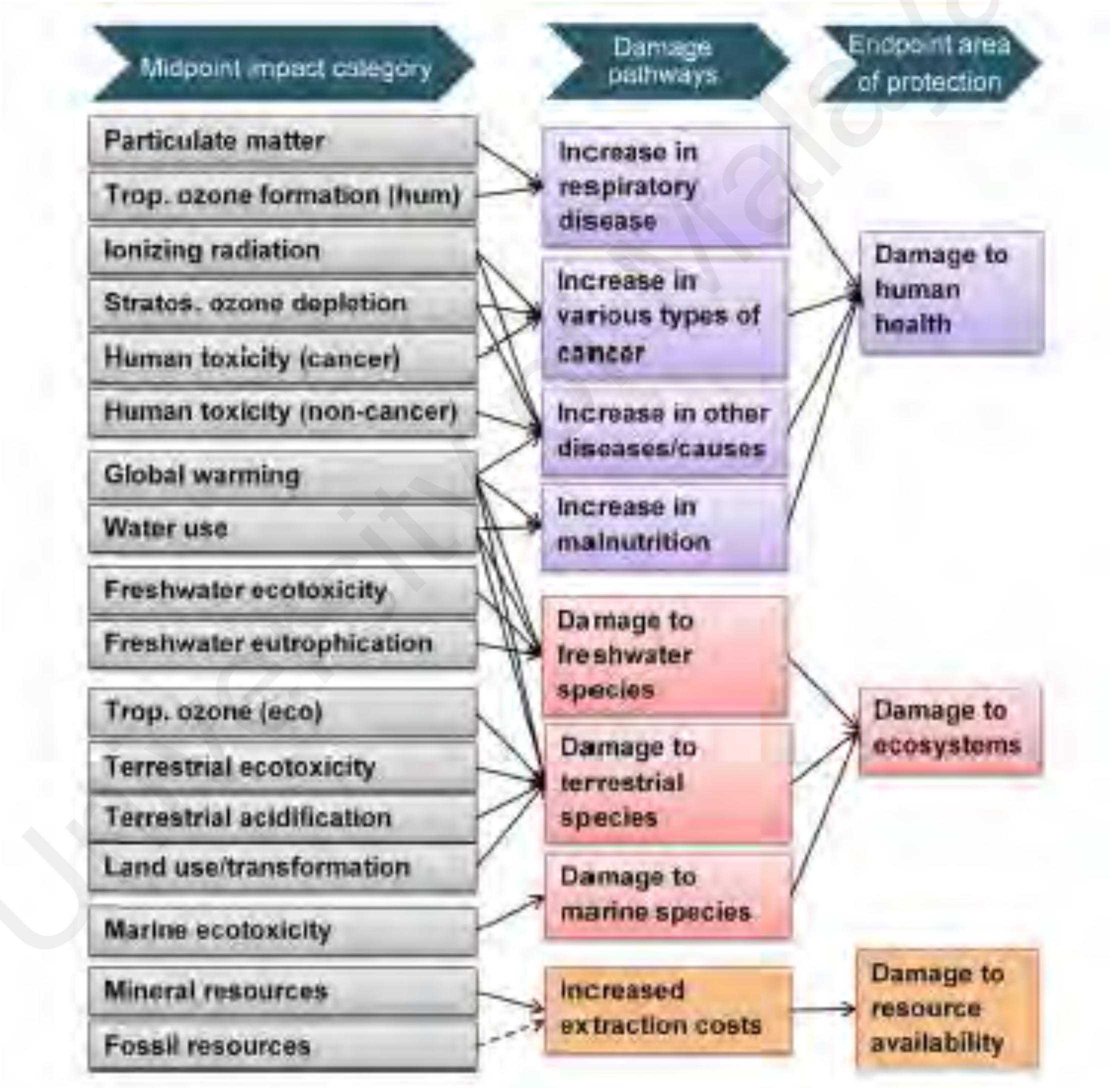

Figure 2.2: Overview of the impact categories and their relation to the endpoint categories in the ReCiPe 2016

Table 2.13: Overview of the ReCiPe 2016 midpoint impact categories

Midpoint impact category	Indicator	Midpoint characterization factor	Unit
Climate change	Infrared radiative forcing increase	Global warming potential (GWP)	kg CO_2-eq to air
Ozone depletion	Stratospheric ozone decrease	Ozone depletion potential (ODP)	kg CFC-11-eq to air
Ionising radiation	Absorbed dose increase	Ionising radiation potential (IRP)	kBq Co-60-eq to air
Fine particulate matter formation	PM2.5 population intake increase	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air
Photochemical oxidant formation: terrestrial ecosystems	Tropospheric ozone increase	Photochemical oxidant formation potential: ecosystems (EOFP)	kg NOx-eq to air
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase	Photochemical oxidant formation potential: humans (HOFP)	kg NOx-eq to air
Terrestrial acidification	Proton increase in natural soils	Terrestrial acidification potential (TAP)	kg SO_2-eq to air
Freshwater eutrophication	Phosphorus increase in freshwater	Freshwater eutrophication potential (FEP)	kg P-eq to freshwater
Human toxicity: cancer	Risk increase of cancer disease incidence	Human toxicity potential (HTPc)	kg 1,4-DCB-eq to urban air
Human toxicity: non-cancer	Risk increase of non-cancer disease	Human toxicity potential (HTPnc)	kg 1,4-DCB-eq to urban air
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	Terrestrial ecotoxicity potential (TETP)	kg 1,4-DCB-eq to industrial soil
Freshwater ecotoxicicity	Hazard-weighted increase in freshwaters	Freshwater ecotoxicity potential (FETP)	kg 1,4-DCB-eq to freshwater
Marine ecotoxicity	Hazard-weighted increase in marine water	Marine ecotoxicity potential (METP)	kg 1,4-DCB-eq to marine water
Land use	Occupation and time-integrated land transformation	Agricultural land potential (LOP)	m^2 x yr annual cropland-eq
Water use	Increase of water consumed	Water consumption potential (WCP)	m^3 water-eq consumed
Mineral resource scarcity	Increase of ore extracted	Surplus ore potential (SOP)	kg Cu-eq
Fossil resource scarcity	Upper heating value	Fossil fuel potential (FFP)	kg oil-eq

The endpoints are related to the three areas of protection where damage representations are as follow:

- Human health- Represent the years that are lost or that a person is disabled due to disease or accident
- Natural environment- Represent the local species loss integrated over time
- Resource scarcity –Represent the extra costs involved for future mineral and fossil resource extraction

(Huijbregts et al., 2016)

The overview of the endpoint categories for ReCiPe 2016 is shown in Table 2.14.

Table 2.14: Overview of the ReCiPe 2016 endpoint categories

Area of protection	Endpoint	Name	Unit
Human health	damage to human health	disability-adjusted loss of life years	year
Natural environment	damage to ecosystem quality	time-integrated species loss	species x yr
Resource scarcity	damage to resource availability	surplus cost	Dollar

Source: (Huijbregts et al., 2016)

2.8.4 Interpretation

Life cycle interpretation is the final phase of the LCA procedure. The interpretation phase of an LCA or an LCI study comprises three elements as follows:

- Identification of the significant issues based on the results of the LCI and LCIA phases of LCA
- An evaluation that considers completeness, sensitivity and consistency checks

- Conclusions, limitations and recommendations

(ISO 14044, 2006)

2.8.5 Limitations in LCA

According to Narita (2005b), among the limitations identified in the LCA study are;

- The nature of choices and assumptions made in LCA may be subjective as for example the system boundary settings, selection of data sources and impact categories.
- Models used for inventory analysis or to assess environmental impacts are limited by their assumptions and may not be available for all impacts or applications.
- Results of LCA studies focussed on global and regional issues may not be appropriate for local applications.
- The accuracy of LCA studies may be limited by accessibility of relevant data or data quality.

2.8.6 Key Features of an LCA

Some of the key features of the LCA methodology as explained in the ISO 14040 (2006) are :

- The environmental aspects and impacts of product systems starting from raw material acquisition up to final disposal are assessed in a systematic way in accordance with the stated goal and scope through the usage of LCA methodology.
- LCA methodology is open to the inclusion of new scientific findings

- LCA methodology is based on a functional unit and it is different from other environmental techniques such as environmental impact assessment or risk assessment but the information from other environmental techniques had the potential to be used in LCA
- LCA addresses potential environmental impacts and does not predict precise impacts due to reasoning such as the inherent uncertainty in modelling of environmental impacts and the fact that some possible environmental impacts are clearly future impacts.

2.9 Application of LCA

LCA is an environmental management tool with the prime objective to provide a picture of the interactions of an activity with the environment (Azapagic, 1999). Udor et al. in Yusoff (2006) defined LCA as a tool to access the environmental impacts and resources used throughout a product's life from raw material acquisition through production use and disposal. LCA has two main applications as follow:

- Helping decision makers choose among alternatives based on the environmental performances of a product or a process.
- Providing a basis for assessing potential improvements in the environmental performance of the system. This is particularly important as it can suggest ways to modify or design a system with decrease overall environmental impacts.

(Azapagic, 1999)

Through the application of LCA, critical environmental hotspots along the entire product value chain will be outline and prioritize for improvement. LCA also plays a central role by linking environmental considerations to procurement decisions, product development processes and design choices. According to Baumann and Tilmann

(2004), the strength of LCA is that it studies a whole product system. The list of possible LCA application is summarized in Table 2.15.

Table 2.15: LCA applications

Area	Applications
Decision making	Product design and development Process design and development Purchasing Support for regulatory measures and policy instruments
Learning/exploration	Characterization of production systems Identification of improvements possibilities Selection of environmental performance indicators
Communications	LCA based eco-labelling Environmental product declarations Benchmarking

Source: (Baumann & Tilmann, 2004)

2.10 LCA Development

LCA has been increasingly used to support the policy and business in the European Union (Recchioni et al., 2015). According to Cook (2010), LCA is a cornerstone of the European Integrated Product Policy, the Thematic Strategies on Waste Prevention and Recycling and on the Sustainable Use of Natural Resources. In the European Commission's Integrated Product Policy, LCA is specifically defined as the best framework to assess the potential environmental impacts of products (Recchioni et al., 2015).

LCA is also the most common tool used by the European tyre industry to assess the potential environmental impacts of their products. Continental conducted LCA study for car passenger tyre in 1999 with conclusion that major environmental impact of the tyre life cycle occur during the use stage (Krömer et al., 1999). European Association of the Rubber Industry (BLIC), predecessor to European Tyre and Rubber Manufacturers' Association (ERTMA) had authorized a study on LCA of an average European car tyre in year 2000/2001 (BLIC, 2001).This study has been recognized as a standard reference for European tyre industry due to its high quality of data sources directly from the Europe tyre manufacturer (BLIC, 2001).

At the international stage, a network of information sharing and exchanges of experiences led by several North American and Western European countries has speed up the development process of LCA (Roy et al., 2009). In Western Europe, 'the power house' of LCA since the late 1980's, many different databases have been developed over the years which characterize particular industrial sectors and products groups (Norris & Notten, 2002).

Researchers from different international organizations that are closely involved in the development process of LCA such as the International Organization for Standardization (ISO) and Society for Environmental Toxicology and Chemistry (SETAC) are working towards developing and disseminating practical tools to evaluate the opportunities, risks and trade-offs associated with products and services over their entire life cycle (Roy et al., 2009). The list of major research organizations working on LCA and their activities are shown in Table 2.16 (Roy et al., 2009).

The initial moves towards developing a public LCA database with data applicable to the Asia Pacific region had been driven largely by Japan (Norris & Notten, 2002). In 2000, the Japan Environmental Management Association for Industry (JEMAI) had launched a project with Korea, Chinese Taipei, Malaysia and Thailand with the objective to develop LCI data in cooperation with these countries on energy and a few basic materials as reported by Franklin Associated in Norris and Notten (2002). The summary of LCI database and LCIA methodology development among the Asia Pacific Economic Cooperation (APEC) countries carried out in 2002 is shown in Table 2.17.

Table 2.16: Major research organizations and their LCA activities

Name of Organization/Institute	Activities
International Standard Organisation (ISO)	Developed the Environmental Management Standard ISO14000 series as part of the international standard on LCA
United Nations Environmental Protection (UNEP)	Established the best available practices for LCA through partnership with other international organizations, government authorities, business and industry , and non-govermental organization
Australia Life Cycle Assessment Society Inc.	Promote and foster the development and application of LCA methodology in Australia and internationally for ecological sustainable development
LCA Center, Denmark	Promote product oriented environmental strategies in private and public companies by assisting them in implementing life cycle thinking
Society for the Promotion of LCA development, Belgium	Involved in the development of LCA and for the necessary restructuring of company policies toward sustainable development
IVF, Swedish Institute for Production Engineering Research	IVF has a large research program on LCAs and studies the possibility of including industrial hygiene into its LCAs.
LCA Center, Tsukuba, Japan	Development of LCA software LIME (Japanese version of LCIA method based on endpoint modelling), LCA database and dissemination of LCA methodology.
Global Alliance of LCA Centers (GALAC)	GALAC is a new international coalition formed by the following institutions to bring together National-level or higher organizations to promote the use of life cycle approaches. The institutions are: American Center for Life Cycle Assessment, Canadian Interuniversity Reference Center for Life Cycle Assessment, Forschungszentrum Karlsruhe, Gemany, LCA Center, Denmark, Research Center for LCA, Japan.
European Commission (European Platform on Life Cycle Assessment)	Support life cycle thinking in the development of goods and services with reference data and recommended methods.
The Directorate for Food Fisheries and Agri-Business, Denmark	Support a project on life cycle assessment of basic food(2000-2003). It also supports LCA Food database (www.lcafood.dk) and the data can be exported and used for free (Nielson et al.,2003)

Table 2.17: LCI and LCIA methodology development among APEC countries

	LCI Database development	LCIA Methodology Development
Australia	Yes	Yes
Canada	Yes	Yes
Chile	Yes*	Yes
China	Yes*	Yes
Chinese Taipei	Yes	Yes
Indonesia	Yes	No
Japan	Yes	Yes
Korea	Yes	Yes
Malaysia	Yes	No
Mexico	No	No
Papua New Guinea	No	No
Philippines	Not Available	No
Singapore	Yes	No
Thailand	Yes	No
USA	Yes*	Not Available

* Source: (Sagisaka & Chiu, 2008) except for* which is source from (Norris & Notten, 2002).

There is also an increasing recognition from the developed countries that LCI databases for the products and services from the developing countries need to be developed as these countries supply resources to them (Norris & Notten, 2002). Among the challenges facing these developing countries in developing the LCI databases are low LCA capacity and low interest from the government and the industry (Norris & Notten, 2002).

2.10.1 LCA Development in Malaysia

The government of Malaysia in its Ninth Malaysia Plan (2006-2010) had recognized the importance of LCA in promoting the greater use of environmentally sound technologies (Economic Planning Unit, 2006). A National Life Cycle Assessment Project Structure was established with SIRIM acting as the project coordinator with the specific objectives as follow:

i. To develop the national life cycle inventory database

ii. To develop a critical mass of local LCA practitioners

iii. To develop ecolabelling criteria documents for the National Ecolabelling Program

iv. To create awareness among industry and consumer groups on the importance of LCA in today's manufacturing and purchasing practice.

(Chen, 2008)

One of the outputs from this project is the establishment of the Malaysia Life Cycle Inventory Database (MYLCID) with a total of 166 LCI datasets available on the website (SIRIM, 2015). Under the Ninth Malaysia Plan there are 41 LCA projects undertaken by SIRIM as shown in Table 2.18 (Chen & Ismail, 2010). Other than SIRIM, the institute of higher learning in Malaysia are also involved in the LCA study and the list of LCA studies involved are listed in Table 2.19.

Table 2.18: LCA projects under Ninth Malaysia Plan undertaken by SIRIM

Category	Number of Project
Database & Impact Assessment	2
Agro Industry	3
Petroleum, Petrochemical and Plastic	9
Electrical and Electronic	3
Chemical	4
Heavy Industry	7
Utilities and Services	3
General Consumer Goods	9
Waste Management	1

Table 2.19: LCA studies by Malaysian institute of higher learning

Category	Projects
Agro Industry	1. LCA on the production of biodiesel from palm oil and Jatropha oil 2. LCA on crude palm oil production in Malaysia
Electrical and Electronic	3. LCA in E&E in Malaysia; A case study of ballast
General Consumer Goods	4. LCA on food and beverages of selected food outlet 5.LCA in portable water production 6.LCA in the water treatment process in Malaysia: An environmental impact comparison between water source quality and climate
Waste Management	7. Assessment of solid waste management in Malaysia using LCA 8. LCA on plastic recycling; comparison between raw and recycled plastic materials. 9. LCA of waste management (A case study of refuse derived fuel)
Transportation	10. LCA for transportation sector; A comparison of Perodua and Proton vehicles.

Source: (Chen & Ismail, 2010)

2.11 Summary

Climate change is a threat to sustainable development and Malaysia had formulated National Policy on Climate Change and National Green Technology Policy to address the issues of climate change holistically. Malaysia also showed a serious commitment in tackling the climate change through the pledge to voluntarily reduce up to 40% carbon emission intensity of GDP by the year 2020 as compared to the 2005 level.

Malaysia is currently the fifth largest producer of natural rubber in the world and rubber is the Malaysia second largest agricultural crops planted area. Malaysian rubber industry is included in the NKEA and is forecasted to contribute RM 52.9 billion in GNI by 2020. As one of the main contributor to the development of the country, the Malaysian rubber industry also generated a significant environmental impact in the form of wastes and emissions that are subjected to various regulations under the Malaysian Environmental Quality Act 1974. A number of initiatives have already being implemented to reduce the environmental impact from the Malaysian rubber industry and the initiative to implement the LCA methodology for the Malaysian Rubber Industry is part of the continuous effort in meeting sustainability goal in the Malaysian rubber industry and stringent environmental market regulations worldwide.

LCA is an environmental management tool that has gained worldwide recognition and is increasingly used to support the government policies and business especially in the European Union. In the context of the rubber based industry, LCA is also the most common tool used by the European tyre industry to assess the potential environmental impacts of their products.

The issues on the lack of available data for the rubber cultivation activities in Malaysia from cradle to grave perspective, the need to prepare for the anticipated demand in SMR environmental certification and the lacking on the details information regarding the GHGs emissions from the Malaysian rubber industry are the three main areas identified as the missing information gap in the literature review that this study needs to overcome through implementing the LCA study for the Malaysian Rubber Industry.

CHAPTER 3: METHODOLOGY

In this chapter, the methodology used to conduct the study is described. The methodology for this study was carried out according to ISO 14040:2006 and ISO 14044:2006 procedures.

The first objective of the study is to review the current practice and quantify a comprehensive Life Cycle Inventory (LCI) for the cultivation of rubber trees from cradle to grave in Malaysia and its three components i.e. nursery stage, immature rubber stage and mature rubber stages. Three series of surveys were conducted to achieve this objective. These three surveys are the survey on the production of two whorl young budding in the polybag by the rubber nursery operators in Malaysia, the survey on the process of maintaining the healthy growth of immature rubber trees during the immature rubber stage by the organized rubber smallholders management in Malaysia and the survey on the process of maintaining the healthy growth of mature rubber trees during the mature rubber stage until the rubber trees are ready to be fell down for replanting by the organized rubber smallholders management in Malaysia.

The second objective is to quantify LCI for the production of natural rubber cuplump from cradle to gate in Malaysia based on the mass allocation ratio from literature. This objective was achieved by applying the mass allocation ratio from the combination of literature source from Yew et al. in Rahaman and Amu (2002) and Rahaman and Amu (2002) based on rubber cultivation scenario in Malaysia to the LCI table for the cultivation of rubber trees from cradle to grave in this study.

The third objective is to review the current practice and quantify a comprehensive LCI for the production of SMR block rubber from cradle to gate in Malaysia. A survey on the production of SMR block rubber by the SMR block rubber processors in Malaysia was conducted to achieve this objective.

The fourth objective is to quantify the environmental impact in the form of Life Cycle Impact Assessment (LCIA) based on the LCI table for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components, the production of natural rubber cuplump from cradle to gate in Malaysia and the production of SMR block rubber from cradle to gate in Malaysia and recommended strategies for improvement. This objective was achieved by analysing these 6 individual LCI table using Simapro software version 7.3.3 with Eco-indicator 99 as the default methodology for LCIA quantification and environmental hotspot identification. The recommended strategies for improvement based on the LCIA hotspot reduction for these 6 individual LCIA results are also explained in details to fulfil this objective.

The final objective of this study is to quantify the greenhouse gases (GHGs) emission and recommended strategies for improvement based on the LCI for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components, the production of natural rubber cuplump from cradle to gate in Malaysia and the production of SMR block rubber from cradle to gate in Malaysia. This objective was achieved by analysing these 6 individual LCI table based on Intergovernmental Panel on climate change (IPCC) 2007 fourth assessment report (AR4) global warming potential for 100 year-time horizon using Simapro 7.3.3 software developed by Pre Consultants. The recommended strategies for improvement based on the GHGs emission hotspot reduction for these 6 individual GHGs emission results were also explained in details to fulfil this objective.

The list of the 6 individual LCI tables in this study and its corresponding survey works is summarized in Table 3.1 while Figure 3.1 illustrates the scope of this 6 individual LCI tables in relation to the whole natural rubber industry from cradle to grave perspective.

Table 3.1: List of LCI tables and its corresponding survey works

LCI Table	Survey conducted
Production of two whorl young budding in the polybag	Production of two whorl young budding in the polybag by the rubber nurseries operators in Malaysia
Production of mature rubber trees	Process to maintain the healthy growth of immature rubber trees by the organized rubber smallholders in Malaysia
Process to maintain the healthy growth of mature rubber trees	Process to maintain the healthy growth of mature rubber trees by the organized rubber smallholders in Malaysia
Cultivation of rubber trees from cradle to grave	No survey was conducted. The LCI table was based on the combination of surveys from the production of two whorl young budding in the polybag, process to maintain the healthy growth of immature rubber trees and the process to maintain the healthy growth of mature rubber trees.
Production of natural rubber cuplump	No survey was conducted. The LCI table was based on the applying mass allocation rules to the LCI table for the cultivation of rubber trees from cradle to grave.
Production of SMR block rubber	Production of SMR block rubber by the SMR block rubber processors in Malaysia

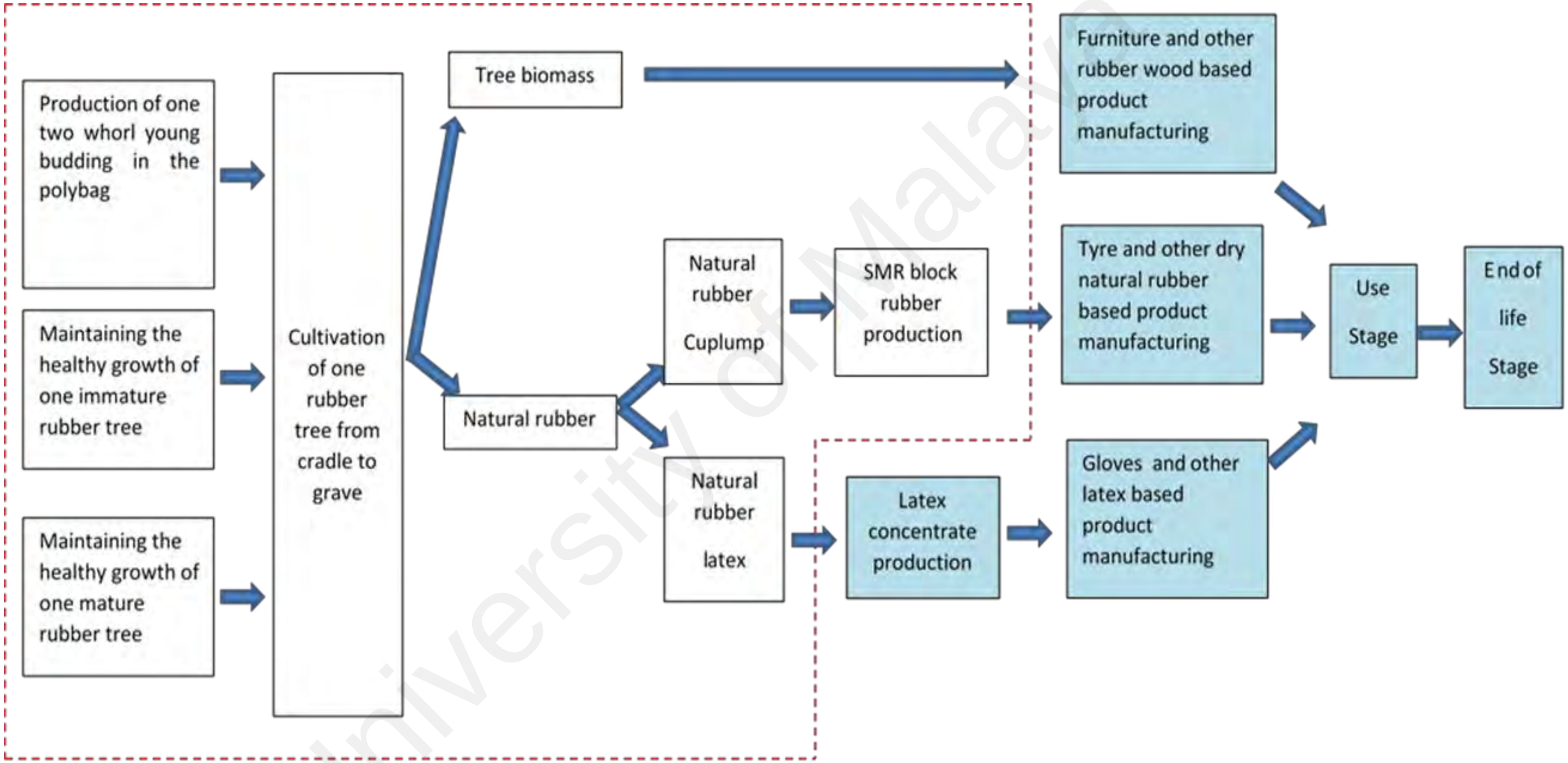

Figure 3.1: The scope of this study in relation to the whole natural rubber industry from cradle to grave perspective

3.1 The Study on the Production of Two Whorl Young Budding in the Polybag by the Rubber Nursery Industry in Malaysia

Survey form for the study on the production of two whorl young budding in the polybag was distributed to 39 licensed rubber nurseries operators in Malaysia. These 39 licensed rubber nurseries were selected based on the criteria that they produce the rubber planting material in the form of two whorl young budding based on information in the *E-semaian*, an online database containing detail information of the entire licensed rubber nurseries operators in Malaysia managed by the Malaysian Rubber Board (Malaysian Rubber Board, 2014b).

The two whorl young budding was selected to represent the type of planting material produce by the rubber nurseries operators in Malaysia as it represents 71.0% from the total production of rubber planting materials in Malaysia for 2013 (Malaysian Rubber Board, 2014b). From the total of 39 survey forms distributed, 30 of these licensed rubber nurseries responded to this study. Two unlicensed rubber nurseries operated by a private plantation group in Malaysia also agreed to participate in this study. In general, it was noted that all the rubber nurseries that took part in this study adopted almost the same standard operation procedures in producing two whorl young budding in the polybag as recommended by Malaysian Rubber Board (MRB).

3.1.1 Goal and Scope of the Study

The goal of this study is to review the current practice and quantify a comprehensive LCI table for the production of two whorl young budding in the polybag in Malaysia. The scope of this study is to perform a cradle to gate LCI study started from the arrival of the rubber seeds to the rubber nurseries until the young budding in the polybag is ready to be transported and planted in the smallholders plot.

3.1.1.1 Functional Unit

The functional unit for this study i.e. the quantified performance of a product system for used as a reference unit as defined by (ISO 14040, 2006) is based on the quantity of one two whorl young budding in polybag produced by the rubber nurseries ready to be planted at smallholders plot. For this study, it was assumed that there was no significant quality differences of the two whorl young budding in polybag produced from all the respondents in this study.

3.1.1.2 System Boundary

The system boundary for this study is defined as a cradle to gate approach as illustrated in Figure 3.2 while the main process involved in the production of two whorl young budding in the polybag is summarized in Figure 3.3 to 3.10.

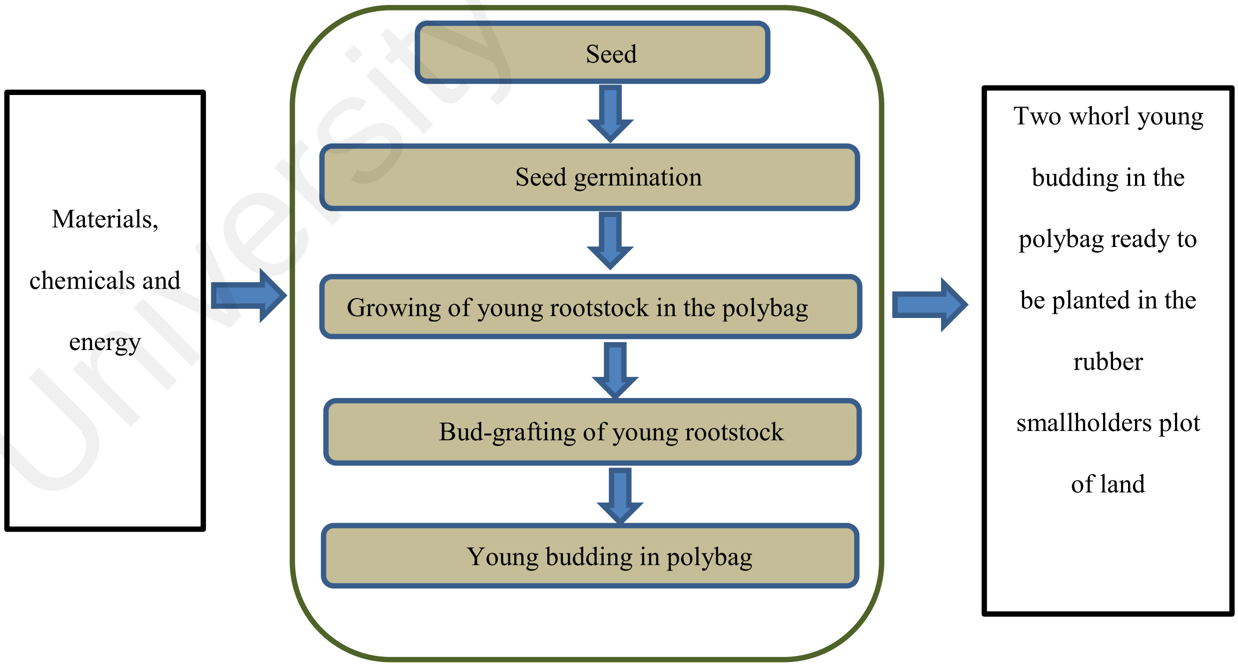

Figure 3.2: System boundary for the production of two whorl young budding in the polybag

Figure 3.3: Germination of rubber seeds in the germination bed

Figure 3.4: Top soil in the polybag where germinated rubber seeds will be planted

Figure 3.5: Growing of young rootstock in the polybag

Figure 3.6: Materials used in the bud-grafted process

Figure 3.7: The successful grafted young rootstock in the polybag

Figure 3.8: A typical source of water for the rubber nurseries sprinkler water system

Figure 3.9: Diesel engine used to run the water sprinkler system.

Figure 3.10: Transportation of two whorl young budding in the polybag from a rubber nursery

3.1.1.3 Exclusion, Fixed value and Assumptions

Some of the activities which were part of the defined cradle to gate system boundary but difficult to obtain the data and are assumed not to be a significant contributor to the environmental impact for this study are excluded and listed in the Table 3.2. A set of fix values used in this study is explained in Table 3.3.

Table 3.2: List of activities excluded from the study

Activities	Reasons for exclusion
Land clearing for nursery establishment	i) It is a one-off activity involving some elements of fuel through the use of machineries but difficult to quantify the amount. ii) The amount of fuel used is insignificant as only one time land clearing needed and the nurseries can be used as many years as possible by the rubber nurseries operators ii) Consider as capital good as defined by Yusoff (2006).
Construction of rubber germination bed	i) The construction of germination beds consist of a very simple and basic structure containing layer of sawdust on top of a layer of sand and it can be reused for many times. ii) Consider as capital good as defined by Yusoff (2006).
Extraction of top soil to fill up the polybag	i) Difficult to obtain data and considered as outside the scope of this study ii) Considered as an environmentally insignificant as it can be translated as a process of transferring the top soil from the source to the rubber nurseries and finally the top soil is moved from the rubber nurseries and buried permanently in the hole at smallholders plots together with the young budding.
Air emissions from diesel combustion in engine use to run water sprinkler system in the nurseries	i)Difficult to obtain data due to unavailability and inaccessibility of specific equipment during the study and the amount is predicted to be insignificant towards environmental impact based on literature data of oil palm seedling by Halimah et al. (2013)
The production of bud patch used in the bud grafting process	i)The weight of bud patch was less than 0.05% from the total weight of young rootstock and cut off criteria was applied for the bud patch used in the bud grafting process of young rootstock as allowed in ISO 14044 (2006).
The production of transparent polyethylene tape used to wrap up bud patches to young rootstocks in the bud grafting process	i) The weight of transparent polyethylene tape was less than 0.05% from the total weight of young rootstock and cut off criteria was applied for the transparent polyethylene used in the bud grafting process of young rootstock as allowed in ISO 14044 (2006)

Table 3.3: Fix value used in the study for the production of two whorl young budding in the polybag.

Parameter	Value	Reasons
The average weight of one piece of polybag	0.01 kg	There are variations in the weight of polybag depending on the size of the polybag used and it will be a very laborious and tedious process to measure the weight of individual polybag from all the rubber nurseries in this study. The average weight for 7 x 15 inch polybag supplied by one of the rubber nurseries in this study is 0.01 kg based on the measurement in the laboratory.
The average rainy days per month from January to December.	Various (Please refer to Table 3.4)	In the rubber nursery standard operation procedure, the water sprinkler system will not be operated on rainy days. All the rubber nurseries operators in this study did not have proper record on the numbers of days their water sprinkler system did not operate. The number of days water sprinkler system operating per month is very important to estimate the diesel usage. A simple model was developed using the purchased Meteorology Department of Malaysia data to estimate number of days water sprinkler system was not used throughout the life cycle of the two whorl young budding in the polybag.

Table 3.4: Average number of rainy days per month for water sprinkler system substitution

Weather monitoring station	Average number of days per month with rainfall of more than 4mm* in 2013	Coverage for Nurseries location in;
Alor Setar	8	Kedah
Chuping	7.5	Perlis
Gong Kedak	9.4	Northern of Terengganu
Kluang	7.7	Johor
Kuala Krai	8.9	East of Kelantan
Kuala Terengganu	9.9	Middle of Terengganu
Melaka	6.6	Melaka and Negeri Sembilan

*Based on email communication with Norjana Jamal from Meteorology Department of Malaysia on 28th of February 2014, 4mm/hr is considered as heavy rain and it was decided that for cumulative rainfall of more than 4mm per day, is sufficient to water the plant thus no water sprinkler system was needed on that particular day.

In this study, a set of assumptions were also used and these assumptions are listed as below:

- Zero mortality assumed from the process of transferring germinated seed from germination bed into a polybag to be grown as young rootstock in polybag
- Zero mortality assumed from the young rootstock in polybag until it is transformed into two whorl young budding in the polybag through bud-grafting process.
- The young rootstock in polybag that failed the bud-grafting process will be left together with the young budding in the polybag. This unsuccessful bud-grafted of young rootstock will still indirectly receiving fungicide protection during spraying operation and water from the water sprinkler system due to their close proximity with the young budding in the polybag. The unsuccessful bud-grafted of young rootstock were only discarded from the nursery during the process of transporting two whorl young budding in polybag for replanting process.

3.1.2 Life Cycle Inventory

The methodology used to come out with a comprehensive LCI table for the production of two whorl young budding in the polybag by the rubber nursery industry in Malaysia is simplified in Figure 3.11.

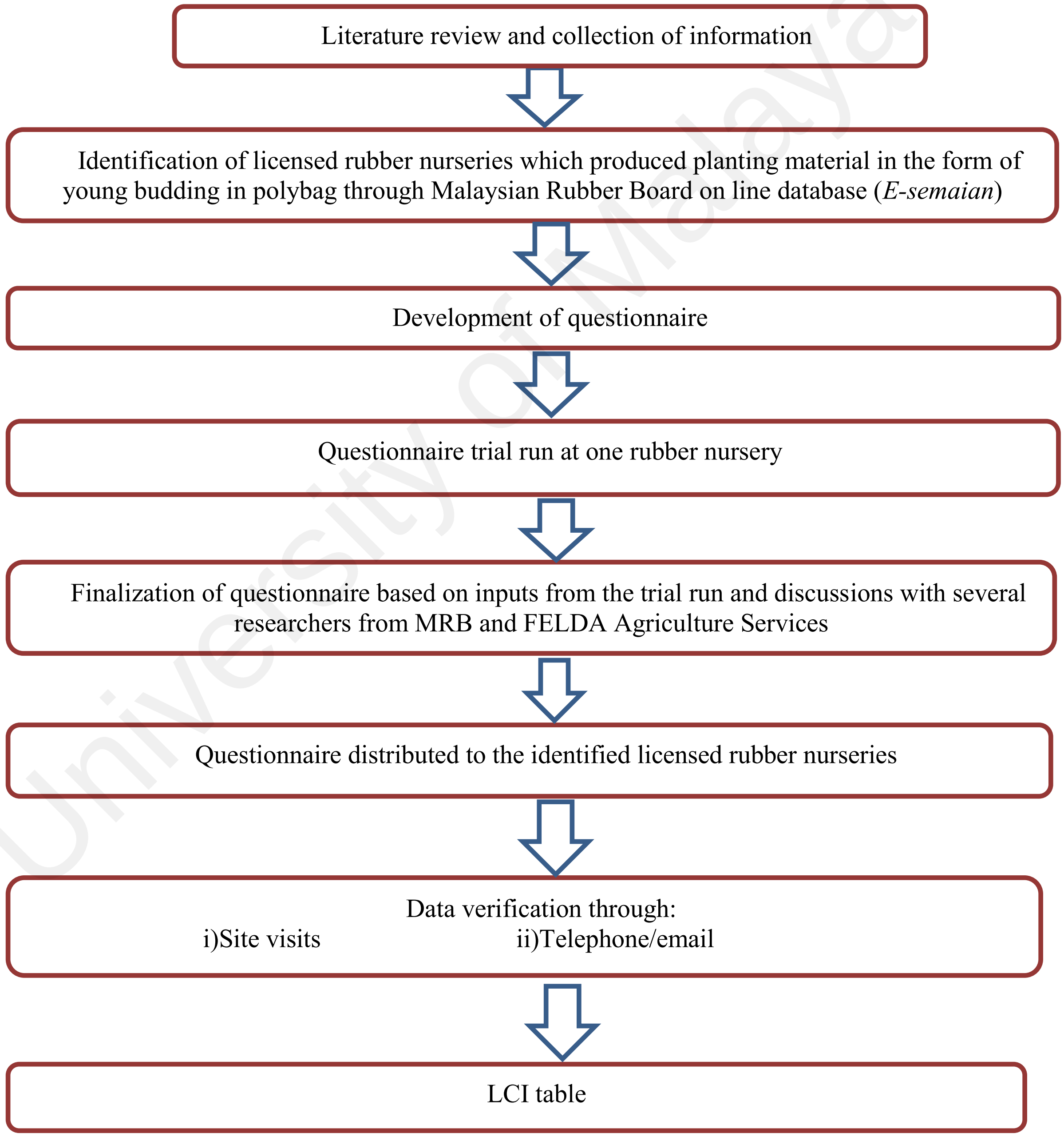

Figure 3.11: Methodology used for the development of LCI table in the study for the production of two whorl young budding in the polybag

3.1.2.1 The Details of the Questionnaire

The questionnaire in general was divided into 4 components and is summarized in Table 3.5.

Table 3.5: Summary on the components of the questionnaire for rubber nurseries operators

Components	Information requested from the respondent
General information	1). Rubber Nursery name, address, person in charge contact details and license number. 2). Average duration for one complete cycle of young budding in the polybag production 2). Distance of the rubber seeds source from the nursery 3) Germination rate of rubber seedlings 4) Polybag size used and the town where it was purchased 5). The average age of young rootstock ready for bud-grafting process. 6). The average success rate of bud-grafting process 7). The ratio for rock phosphate fertilizer and top soil mixing
Watering operation	1). Average daily consumption of water for a plant 2). Source of water for watering the plant 3). Diesel consumption for water sprinkler system 4) Water pump capacity 5) Average number of polybag per one sprinkler
Fertilizer application	1) Type of fertilizer used 2) Amount of fertilizer used 3) Frequency of fertilizer used 4) The town where the fertilizer was purchased
Chemical applications	1) Fungicide brand name 2) Amount of fungicide used 3) Frequency of fungicide used 4) The town where the fungicide was purchased

3.2 The Study on the Production of Mature Rubber Tree from Immature Rubber Stage in Malaysia

The majority of the rubber planted area in Malaysia is owned by the rubber smallholders. In 2014, rubber smallholders own 92.5% from the total rubber planted area in Malaysia of 1.066 million hectares (Malaysian Rubber Board, 2016b). The rubber smallholders can be divided into two broad categories i.e. organized rubber smallholders under the supervision of rubber related agencies in Malaysia and individual rubber smallholders. For this study, it was decided that only the immature rubber planted area owned by the organized rubber smallholders will be included. Individual rubber smallholders are excluded from this study as there are great difficulties in getting verified information from this group on their agronomic practices as these individual rubber smallholders normally did not have any proper written record on their agronomic practices.

There are three main government agencies in Malaysia which are responsible in helping the organized rubber smallholders to maintain their small plot of land namely Rubber Industry Smallholders Development Authority (RISDA), Federal Land Development Authority (FELDA) and Federal Land Consolidation and Rehabilitation Authority (FELCRA). The approach and level of involvement from each of this rubber related agencies is quite different but they do share the same objective to increase the production of natural rubber by rubber smallholders in Malaysia.

Survey form for the study on the production of mature rubber tree from immature rubber stage was distributed to 34 FELDA Schemes and 34 FELCRA Projects that are currently in the immature stage in Malaysia based on information from (FELCRA, 2015; Ghani, 2015) and follow up phone call to the respective FELDA scheme and FELCRA projects for final confirmation. A total of 10 FELDA Schemes and 7

FELCRA projects responded to this study. Two private rubber estates with 6 batch of planting also agreed to participate in this study. It is also important to note that RISDA did not allow this study be conducted for their rubber smallholders.

3.2.1 Goal and Scope of the Study

The objective of this study is to review the current practice and quantify a comprehensive LCI table for the production of mature rubber tree from immature rubber stage in Malaysia. The scope of this study is to perform a gate to gate LCI study starting with the planting of rubber planting materials into the rubber smallholders plot until the rubber planting materials are mature and ready for tapping.

3.2.1.1 Functional Unit

The functional unit for this study i.e. the quantified performance of a product system for used as a reference unit as defined by (ISO 14040, 2006) was based on the quantity of one mature rubber tree that is ready for tapping. For this study, it was assumed that there were no significant quality differences of the mature trees ready for tapping from all the respondents in this study.

3.2.1.2 System Boundary

The system boundary for this study was defined as a gate to gate approach as illustrated in Figure 3.12 while Figure 3.13-3.14 show a typical immature rubber trees holding.

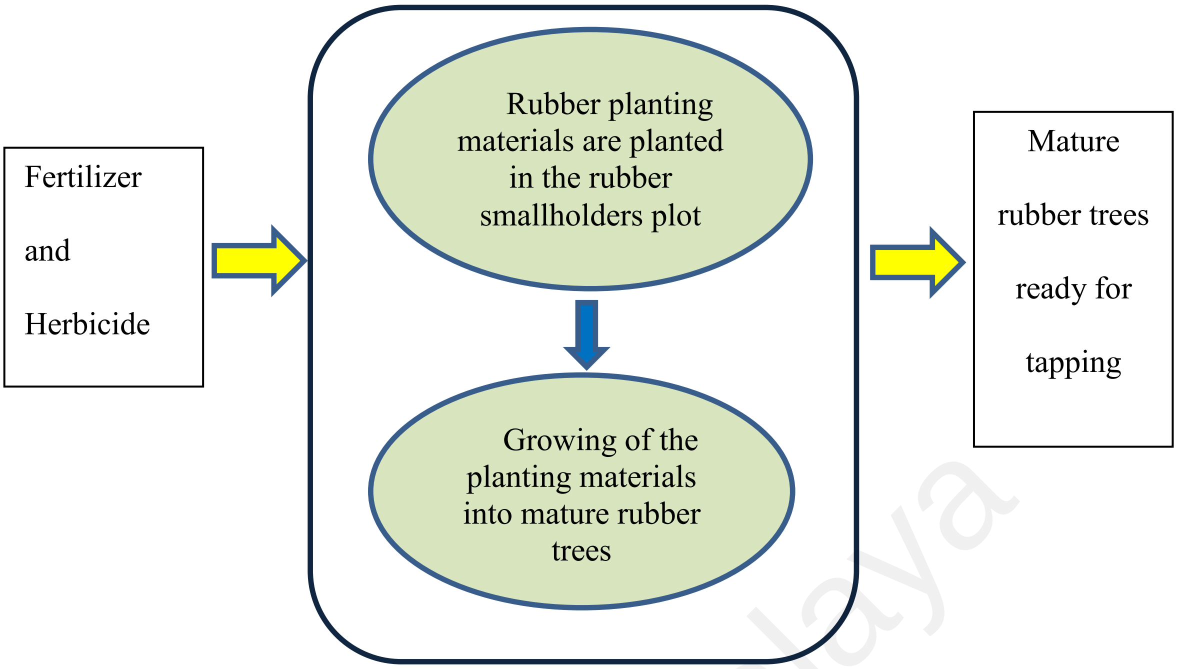

Figure 3.12: System boundary for the production of mature rubber trees ready for tapping

Figure 3.13: Newly planted young budding (Source: Khairul, FGV Laka Selatan)

Figure 3.14: Immature rubber trees almost ready for tapping

3.2.1.3 Exclusion

Some of the activities which were part of the defined gate to gate system boundary but very difficult to obtain data and assumed not to be a significant contributor to the environmental impact for this study were excluded and listed in the Table 3.6.

Table 3.6: List of activities excluded from the study

Activities	Reasons for exclusion
Land clearing for replanting	i) It is a one-off activity involving some elements of fuel through the use of machineries but difficult to quantify. The amount of fuel used is considered as insignificant as the process will only be repeated for next 31-32 years. ii) It was noted that no open burning was carried out in the land clearing process for replanting as informed by FELDA/FELCRA management.
Fertilizer loss through run-off and leaching	i) Difficult to obtain data and the FELDA/FELCRA management did not record this kind of data. ii) The amount is predicted to be insignificant towards the environmental impact based on discussions with FELD/FELCRA managements as fertilizer application is normally conducted during the non-rainy seasons iii) According to Ismail (1979), ammonium sulphate loses due to leaching and volatilisation are low.

3.2.2 Life Cycle Inventory

The methodology used to come out with a comprehensive LCI table for the production of mature rubber trees from immature rubber stage by the organized rubber smallholders in Malaysia is simplified in Figure 3.15.

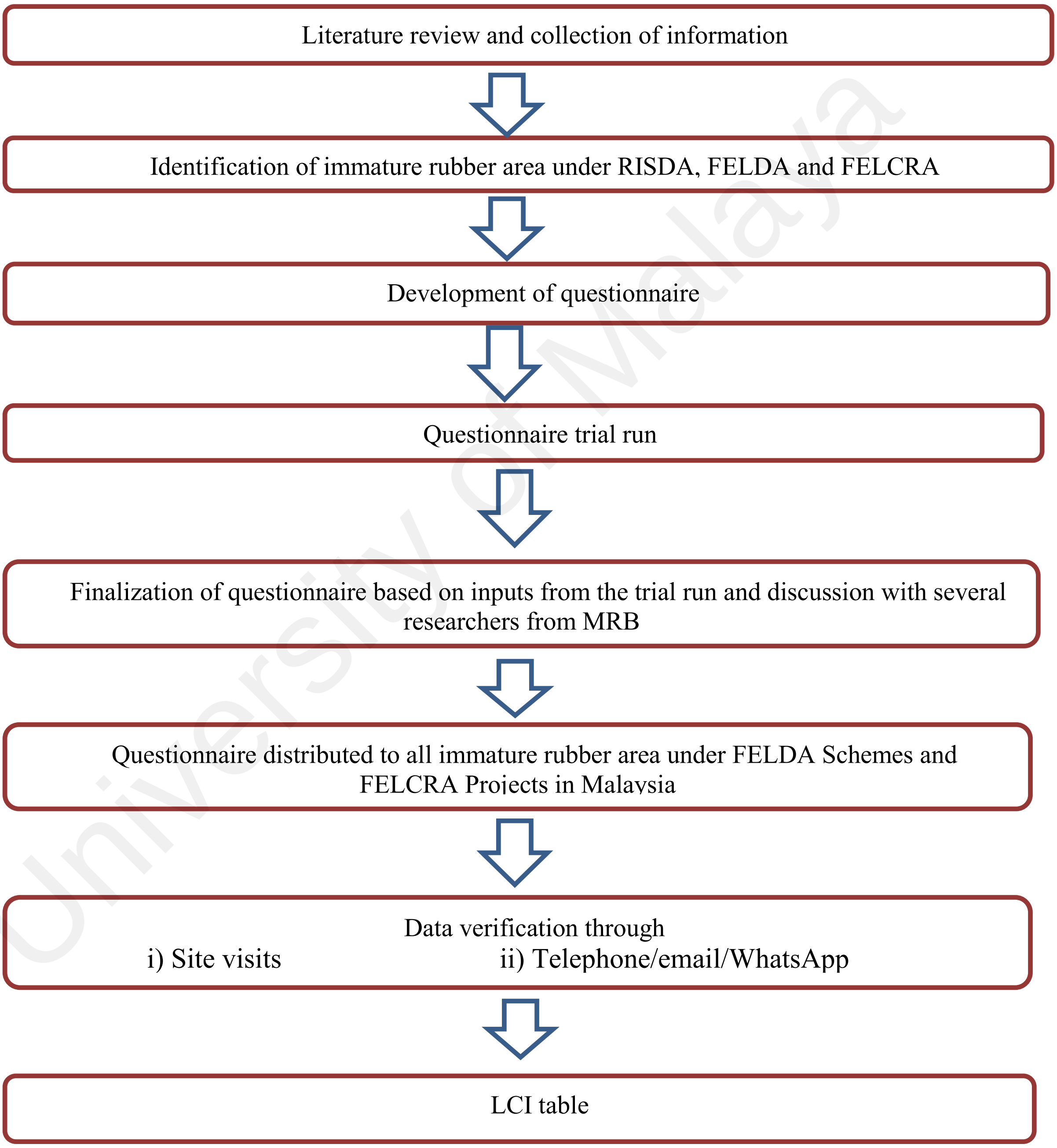

Figure 3.15: Methodology used for the development of LCI table in the study for the production of mature rubber trees from immature rubber stage

3.2.2.1 The Details of the Questionnaire

The questionnaire in general was divided into 3 components and summarized in Table 3.7.

Table 3.7: Summary on the components of the questionnaire for the immature rubber smallholdings management

Components	Information requested from the respondent
General information	1). Name of Felda Scheme/Felcra Project, address and person in charge contact details 2). The immature rubber planting area in Hectare 3) The number of participating rubber smallholders 4) The year the rubber trees was planted and its stand per hectare 5) The stand per hectare of the rubber tree during the survey 6) The year the immature rubber trees are expected ready for tapping
Fertilizer application	1) Type of fertilizer used. 2) Fertilizer formulation for the used fertilizer 3) Amount of fertilizer used per hectare 4) Frequency of fertilizer used per year
Chemical applications	1) Type of herbicide used (Brand name) 2) Amount of herbicide used per hectare 3) Frequency of herbicide used per year

3.3 The Study for the Mature Rubber Stage

The background on the rubber planted area in Malaysia has been described in details in the section 3.2 and will not be repeated in this section. Survey form for the study on the agronomic practices by the organized rubber smallholders in maintaining the healthy growth of their mature rubber trees was distributed to 21 FELDA Schemes and 274 FELCRA Projects that are currently in the mature stage in Malaysia based on information from (FELCRA, 2015; Ghani, 2015) and follow up phone call to the respective FELDA schemes and FELCRA projects for final confirmation. A total of 9 FELDA Schemes and 33 FELCRA Projects responded to this study. Two private rubber estates also agreed to participate in this study.

3.3.1 Goal and Scope of the Study

The objective of this study is to review the current practice and quantify a comprehensive LCI table in maintaining the healthy growth of mature rubber trees in Malaysia. The scope of this study is to perform a gate to gate LCI study started from the mature rubber trees first tapping until the mature rubber trees is ready to be fell down for replanting.

3.3.1.1 Functional Unit

The functional unit for this LCI study i.e. the quantified performance of a product system for used as a reference unit as defined by (ISO 14040, 2006) was based on the quantity of one mature rubber tree in the mature rubber stage. For this study it was assumed that there were no significant quality differences between the mature rubber trees from all the respondents in this study.

3.3.1.2 System Boundary

The system boundary for this study was defined as a gate to gate approach as illustrated in Figure 3.16 while Figure 3.17-3.18 shown mature rubber trees holding at different age.

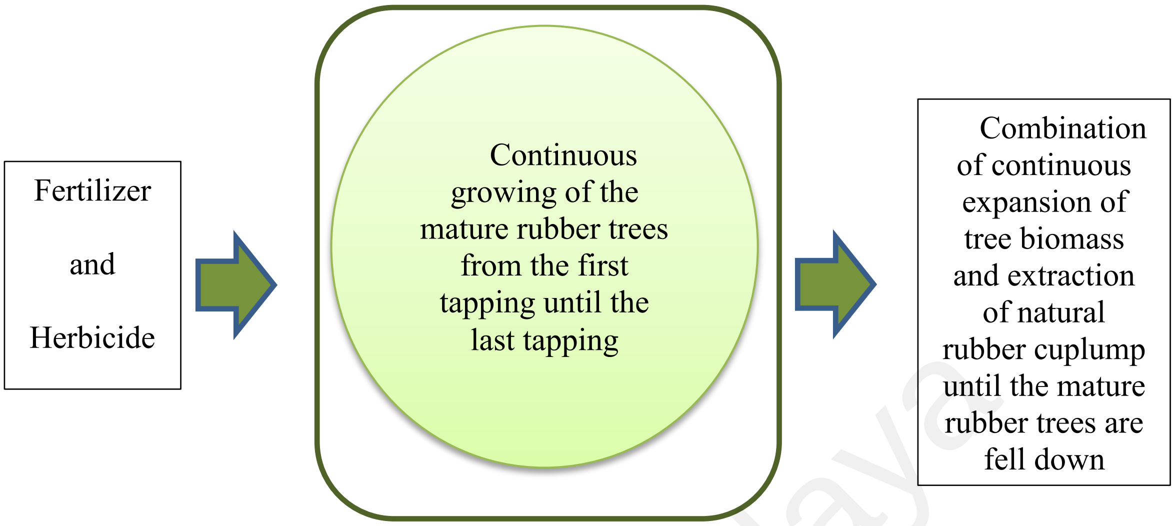

Figure 3.16: System boundary to maintain the healthy growth of mature rubber trees in the mature rubber stage

Figure 3.17: First year tapping of mature rubber trees (Source: Khairul,FGV Laka Selatan)

Figure 3.18: Four years tapping of mature rubber trees

3.3.1.3 Exclusion and Assumption

Some of the activity which were part of the defined gate to gate system boundary but very difficult to obtain data and is assumed not to be a significant contributor to environmental impact for this study were excluded and listed in Table 3.8.

Table 3.8: List of activities excluded from the study

Activities	Reasons for exclusion
Fertilizer loss through run-off and leaching	i) Difficult to obtain data and the FELDA/FELCRA management did not record this kind of data. ii) The amount is predicted to be insignificant towards environmental impact based on discussions with FELD/FELCRA managements as fertilizer application is normally conducted during non-rainy seasons. iii) According to Ismail (1979), ammonium sulphate loses due to leaching and volatilisation are low.

3.3.2 Life Cycle Inventory

The methodology used to come out with a comprehensive LCI table to maintain the healthy growth of the mature rubber trees from the respondents in this study is simplified in Figure 3.19.

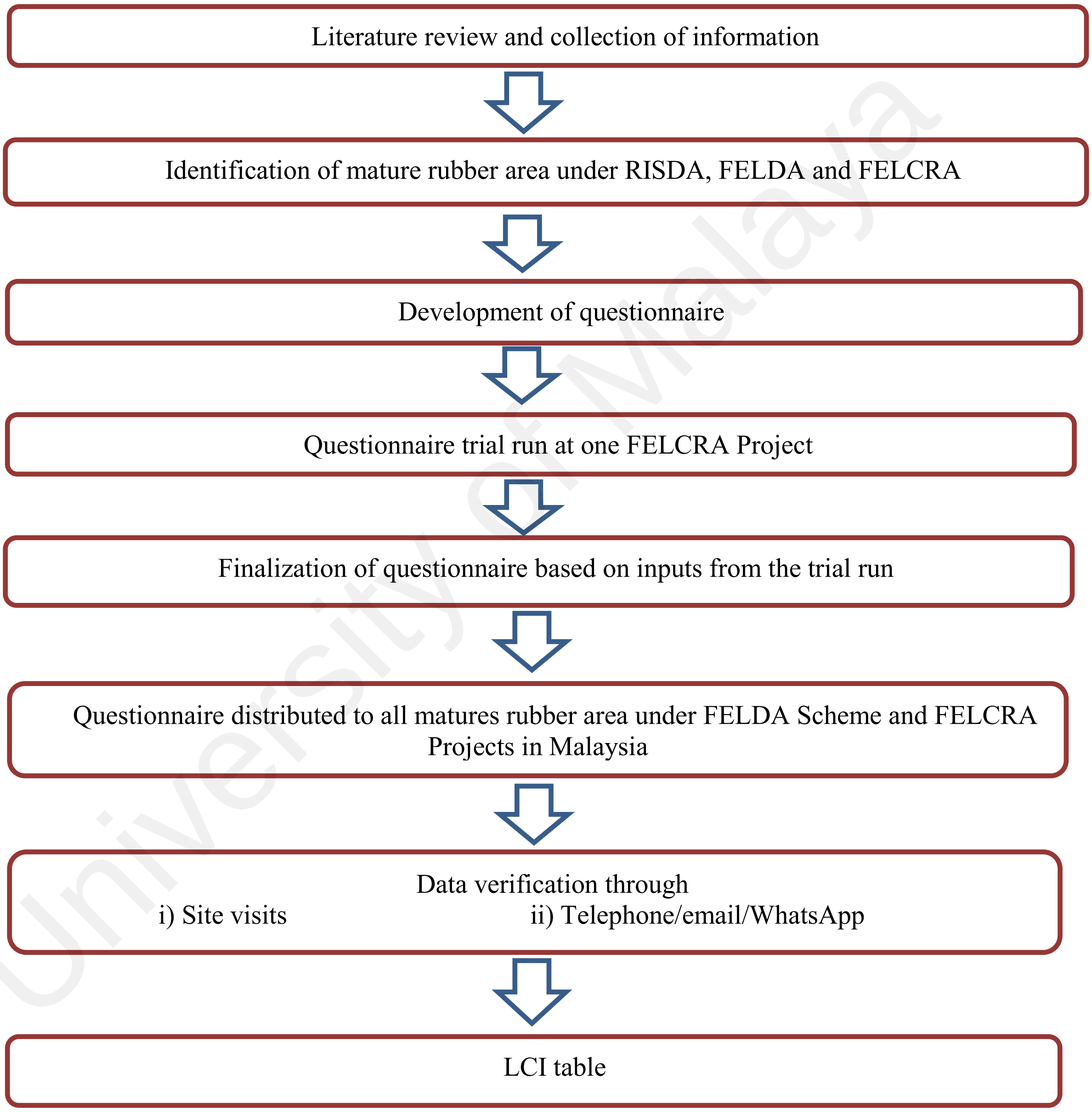

Figure 3.19: Methodology used for the development of LCI table in maintaining the healthy growth of mature rubber trees

3.3.2.1 The Details of the Questionnaire

The questionnaire in general was divided into 3 components and summarized in Table 3.9.

Table 3.9: Summary on the components of the questionnaire for the mature rubber smallholdings management

Components	Information requested from the respondent
General information	1). Name of Felda Scheme/Felcra Project, address and person in charge contact details 2). The mature rubber planting area in Hectare 3) The number of participating smallholders 4) The year the rubber trees was planted and its stand per hectare 5) The stand per hectare of the rubber tree during the survey 6) The year the mature rubber trees started been tap
Fertilizer application	1) Type of fertilizer used. 2) Fertilizer formulation for the used fertilizer 3) Amount of fertilizer used per hectare 4) Frequency of fertilizer used per year
Natural rubber cuplump extraction	1) Amount of natural rubber cuplump extracted based on kg/Hectare/Year 2) Average Dry Rubber Content of the natural rubber cuplump
Chemical applications	1) Type of herbicide used (Brand name) 2) Amount of herbicide used per hectare 3) Frequency of herbicide used per year

3.4 The Study on the Production of SMR Block Rubber in Malaysia

At present, there are 43 standard Malaysian rubber (SMR) block rubber factories in Malaysia and 40 of these factories produce SMR block rubber using natural rubber cuplump as their raw material (Malaysian Rubber Board, 2015b). Most of these SMR rubber factories are very reluctant to participate in this study as they consider the questionnaire used in this study is very sensitive in nature and had the potential to be reverse calculate to estimate their production cost. They are also worried about the possibility the information given by them through the questionnaire will accidentally be leaked to their competitors' event though confidentiality agreement was offered. Through the assistance from the Director of Technology and Engineering division of the Malaysian Rubber Board, finally 5 SMR rubber factories agreed to participate in this study after non-disclosure agreement was made.

3.4.1 Goal and Scope of the Study

The objective of this study is to review the current practice and quantify a comprehensive LCI table for the production of SMR block rubber in Malaysia. The scope of this study is to perform a gate to gate LCI study started from the transportation of natural rubber cuplump to the SMR block rubber factories until the SMR block rubber is ready to be transported out of the factories to their potential buyers.

3.4.1.1 Functional Unit

The functional unit for this study i.e. the quantified performance of a product system for used as a reference unit as defined by (ISO 14040, 2006) was based on the quantity of one kg SMR block rubber produced from the SMR block rubber factories. For this study, it was assumed that there was no significant quality differences between the SMR block rubbers produced from all the five factories that took part in this study.

3.4.1.2 System Boundary

The system boundary for this study was defined as a cradle to gate approach as illustrated in Figure 3.20 while Figures 3.21 - 3.30 show various processing stages in the production of SMR block rubber.

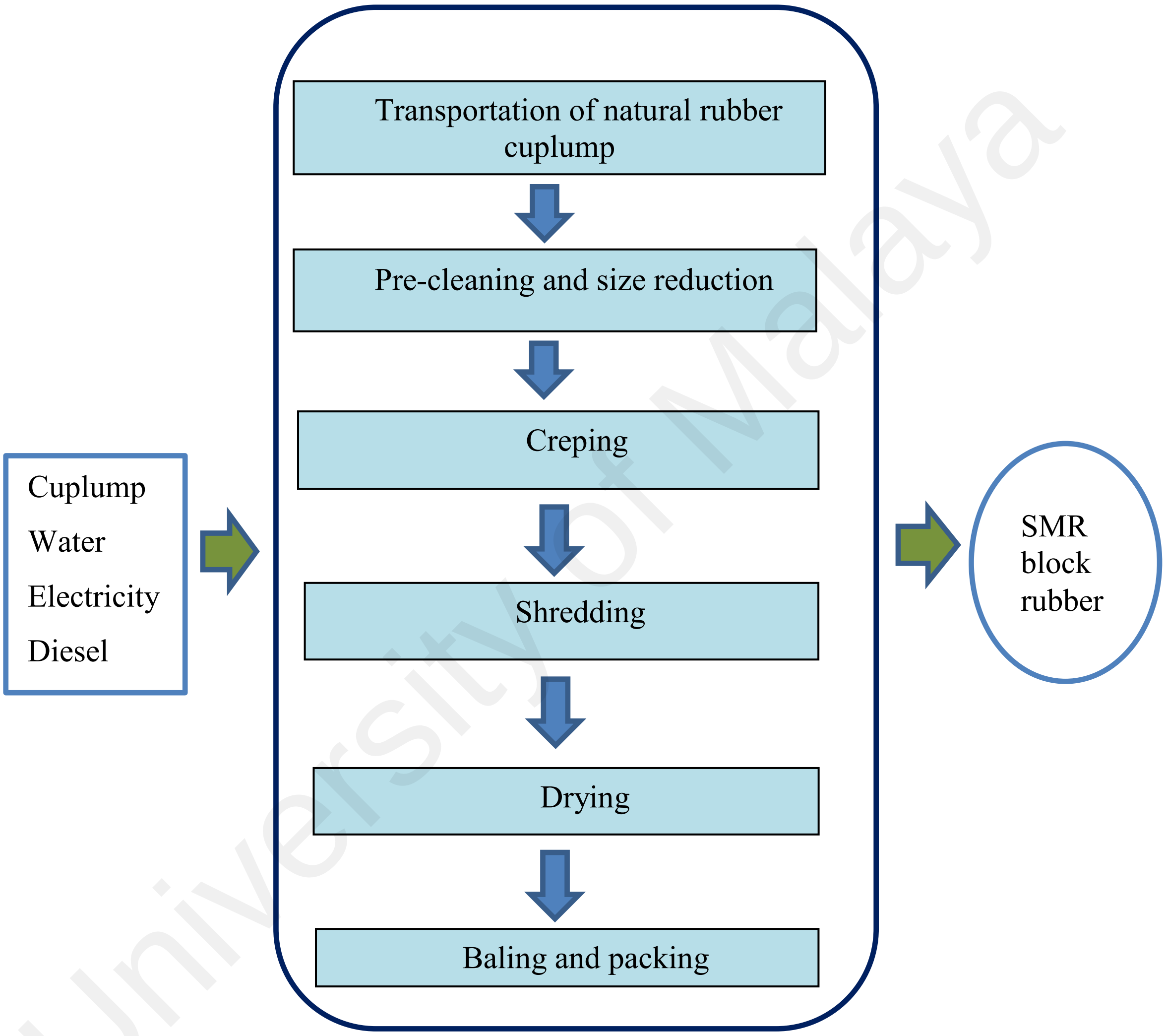

Figure 3.20: System boundary for SMR block rubber production

Figure 3.21: Natural rubber cuplump transported to SMR block rubber factory

Figure 3.22: Pre-cleaning and size reduction process (Source: Tan,MRB).

Figure 3.23: Creping process (Source: Tan, MRB).

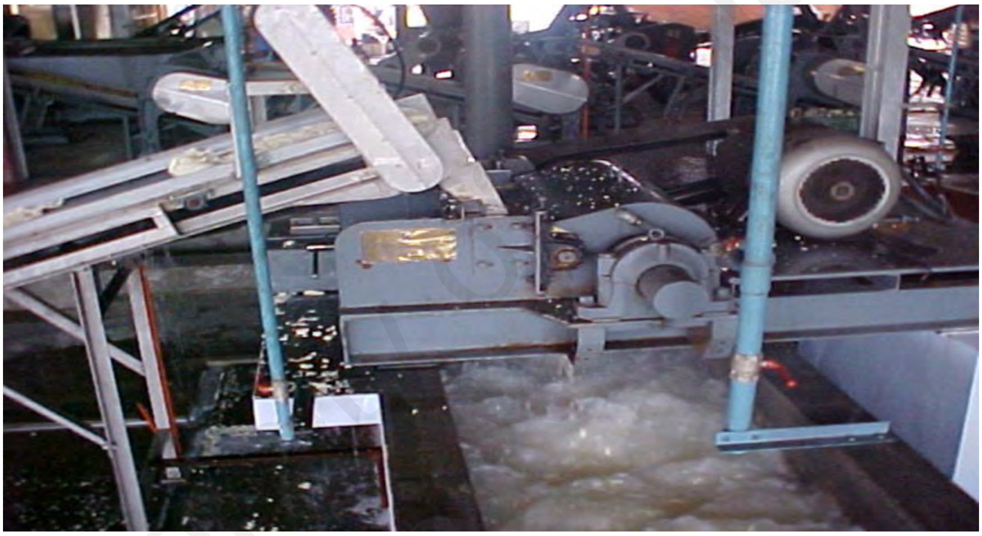

Figure 3.24: Shredding process

Figure 3.25: Wet rubber crumbs are transformed into dried rubber after drying

Figure 3.26: Baling and packing process

Figure 3.27: Raw effluent after passing the rubber trap and before entering the anaerobic pond

Figure 3.28: A typical anaerobic pond

Figure 3.29: Final discharge point of treated effluent to waterbody and subjected to Environmental Quality Regulations 1978

3.4.1.3 Fixed Value Used in the Study

A set of fixed value used in this study are listed in Table 3.10.

Table 3.10: Fixed value used in the study for the SMR block rubber production

Parameter	Value	Source
The density of LDPE film use to wrap the block rubber	0.921 g/cm^3	As different factories may have different supplier for this LDPE film and since its contribution in terms of weight over weight of block rubber is less than 0.1%, it was decided that the value of 0.921 gram/cm3 was used based on the source from http://www.blueridgefilms.com/ldpe_physical.html (Access date: 28 November 2014 at 9.22am)
Ratio of BOD3/BOD5	BOD3/BOD5=1.2	The ratio of BOD3/BOD5=1.2 was based on the works by Lee and Meng (1975)
Diesel density	0.84	Based on Petronas Euro 2M diesel specifications
Methane gas release in the anaerobic pond	0.37m^3 methane/ kg COD	Based on works by Bakti et al. (1981)
Amount of COD removed after discharging from anaerobic pond	70%	Based on Isa (2009b)

3.4.2 Life Cycle Inventory

The methodology used to come out with a comprehensive LCI table for the production of SMR block rubber is simplified in Figure 3.30.

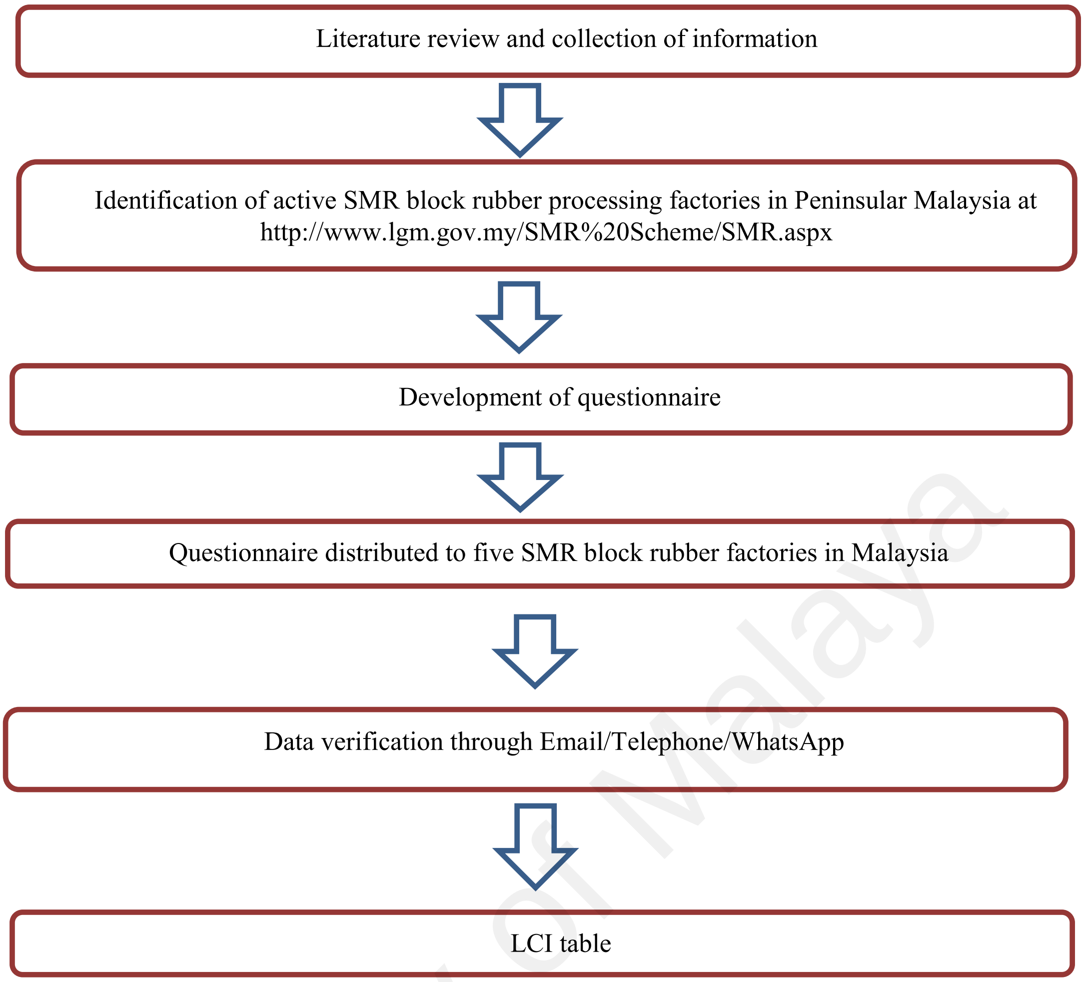

Figure 3.30: Methodology used for the development of LCI table in the study for the production of SMR block rubber

3.4.2.1 The Details of the Questionnaire

The questionnaire in general was divided into 7 components and summarized in Table 3.11.

Table 3.11: Summary on the components of the questionnaire for the SMR block rubber processors

Components	Information requested from the respondent
General information	1) Name of Factory, address and person in charge contact details 2) Average processing line capacity 3) Design processing line capacity 4) Number of shift per day 5) Number of working days per week 6) Individual rubber bale weight

Table 3.11, continued

Components	Information requested from the respondent
Production	1) Total annual production for 2010,2011 and 2012 2) Total annual export for 2010,2011 and 2012 3) Export destination and port of embarkment
Machineries details	1) List of all the machines and its horse power (hp) in the factory processing line 2) Dryer capacity, dryer dwell time, dryer wet end temperature, and dryer dry end temperature
Source of raw material	1) Amount of cuplump purchased for 2011 and 2012 2) Average distance from purchased cuplump source to the factory 3) Amount of imported raw material for 2011 and 2012 4) Average distance from the imported raw material source to the factory
Packaging	1) Type of packaging used
Utilities	1) Factory annual electricity consumption for 2011 and 2012 2) Factory annual water consumption for 2011 and 2012 3)Factory annual diesel consumption for 2011 and 2012
Effluent Treatment System	1) Type of effluent treatment system 2) Average effluent final discharge characteristics per month for 2011 and 2012 (Exact replicate data the SMR block rubber factories must submit to Department of Environment under Environmental Quality Regulations 1978)

3.5 Life Cycle Assessment Software

SimaPro software developed by PRe Consultants is selected to be used in this study as it has an extensive databases and a large number of standard impact assessments (Yusoff, 2006). According to Herrmann and Moltesen (2015), SimaPro software is also one of the leading software program used for LCA studies worldwide.

3.5.1 Life Cycle Impact Assessment Methodology

Most LCA experts do not develop impact assessment methodologies and prefer to select one that has already been published (Goedkoop, Schryer, et al., 2010). Eco-indicator 99 had been selected as the default impact assessment methodology in this study. Eco-indicator 99 methodology uses individualist, egalitarian and hierarchist perspectives to come out with three version of damaged model as shown in Table 3.12.

Table 3.12: Main characteristics of the Eco-indicator 99 perspectives

Perspective	Main characteristic
Egalitarian: Long time perspective	Even a minimum of scientific proof justifies inclusion
Individualist: Short time perspective	Only proven effects are included
Hierarchist: Balance time perspective	Consensus among scientists determine inclusion of effects

Source: (Yusoff, 2006)

The hierarchist perspective of the Eco-indicator 99 methodology is used as the default version in this study as suggested by Goedkoop and Spriensma (2001).There are five types of impact assessment results based on Eco-indicator 99 used in this study and are explained below:

Characterization

Classification and characterization are mandatory steps in the life cycle impact assessment (ISO 14040, 2006). In the classification step, all inventory data will be sorted into impact categories according to the effects they have on the environment while in the characterization step, the inventory data within each category will be multiplied by a characterization factor to differentiate the substances based on their severity (Onn & Yusoff, 2010). In the Eco-indicator 99, damaged factor is used as the default characterization factor to calculate characterization results as this methodology use the damage oriented approach or end point approach (Goedkoop & Spriensma, 2001). The characterization impact assessment parameters and its description in the Eco-indicator 99 are listed in the Table 3.13.

Table 3.13: Eco-indicator 99 characterization impact assessment parameters

Damage category	Impact category	Characterization	Impact category description
Human Health	Carcinogens	DALY/kg emission	Carcinogenic effects on human due to emissions of carcinogenic substance to air, water and soil
Human Health	Respiratory organics	DALY/kg emission	Respiratory effects on human due to emission of organic substances to air
Human Health	Respiratory inorganics	DALY/kg emission	Respiratory effects on human due to emission of inorganic substances (dust, sulphur and nitrogen oxide) to air
Human Health	Climate change	DALY/kg emission	Infectious diseases, cardiovascular and respiratory diseases, as well as force displacement caused by climate change
Human Health	Radiation	DALY/kg emission	Effects caused by radioactive radiation on human
Human Health	Ozone layer	DALY/kg emission	Effects caused by ozone layer depletion on human due to increase UV radiation to the earth surface as a result of ozone layer depleting substance emissions to air
Ecosystem Quality	Ecotoxicity	PAF*m^2*year/kg emission	Damage to ecosystem quality as a result of emission of ecotoxic substances to air, water and soil
Ecosystem Quality	Acidification/ Eutrophication	PDF*m^2*year/kg emission	Damage to ecosystem quality as a result of emission of acidifying substances to air (The effect of phosphate and other eutrophication emissions to water still unable to be included in this impact category)
Ecosystem Quality	Land use	PDF*m^2*year/m2 PDF*m^2*year/m2a	Damage as a result of either: • Land conversion • Land occupation
Resources	Minerals	MJ surplus	Damage in the form of extra energy that future generations must use to extract the ore as a results of decreasing ore grades
Resources	Fossil fuels	MJ surplus	Damage in the form of extra energy that future generations must use to extract the fossil fuels as a results of lower quality fossil fuels

DALY: Disability Adjusted Life Years (Years of disable living or years of life lost due to the impact); PAF: Potentially Affected Fraction ;PDF: Potentially Disappeared Fraction (Plant species disappeared as results of the impact) ;MJ surplus: Extra energy that future generation must use to excavate scarce resources ;Source: (Goedkoop, Oele, et al., 2010; Goedkoop & Spriensma, 2001)

Damage assessment

In the damage assessment, the impact categories from characterization can be group into three damage categories i.e. human health, ecosystem quality and resources. This is made possible by converting the PAF value in ecotoxicity impact category to PDF value. In the SimaPro, the formula for converting PAF value to PDF value is as follow:

PDF*m2yr= (PAF*m2yr/10)

For the details information on the conversion from PAF value to PDF value, please refer to Goedkoop and Spriensma (2001).

Normalization

Normalization is an optional step in in the life cycle impact assessment (ISO 14040, 2006). Normalization is required in order to gain a better understanding of the relative size of each impact categories (Onn & Yusoff, 2010). Normalization is done to compare the most significant potential impact through assessing which of the potential impacts are large and which are small by placing them in relation to the impacts for an average person and the normalized impact potentials are express in person equivalents (PE) (Subramaniam et al., 2008).

In the normalization procedure, the damage values will be held against values of a reference scenario. The reference scenario used is most often the total impacts from a country or a region in one year divided by the number of inhabitant (Yusoff, 2006).In the Eco-indicator 99, normalization is performed on damage category level based on European scenario. The Eco-indicator 99 normalization factors and values used in this study are shown in Table 3.14.

Table 3.14: Eco-indicator 99 (H) V2.08/Europe EI 99 H/A Normalization factors and values

Damage category	Normalization factor	Normalization value [Damage category unit/(Person.Year)]
Human Health	1.14E+02	8.77E-03
Ecosystem Quality	1.75E-04	5.71E+03
Resources	1.33E-04	7.52E+03

The normalization formula used in the SimaPro 7.3.3 is as follow:

Normalization = Damage assessment*Normalization factor

Where;

Normalization factor= 1/Normalization value

Weighting

Weighting is the procedure of assigning relative importance of the normalized value by multiplying it with the weighting factor. In the Eco-indicator 99, the weighting was conducted based on the panel approach through sending out questionnaire to 365 members of the Swiss discussion platform on LCA (Goedkoop & Spriensma, 2001). The weighting factor in Eco-indicator 99 as shown in Table 3.15 were based on the feedback from 82 members of the Swiss discussion platform on LCA who assigned 40% importance to human health, 40% importance to ecosystem quality and 20% importance to resources (Goedkoop & Spriensma, 2001).

Table 3.15: Eco-indicator 99 (H) V2.08/Europe EI 99 H/A Weighting factors

Damage category	Weighting factor
Human Health	400
Ecosystem Quality	400
Resources	200

After multiplication of normalized value with the weighting factors for the three damage category, all the weighting impact categories and damage categories values will be assigned with a standardized Eco-indicator point (Pt) and these weighting impact categories and damage categories values can be directly compared. The value of 1 Pt in weighting impact assessment represent one thousandth of the yearly load of one average European inhabitant or (1/1000)PE (PRe Consultants, 2000).

Single score

Single score impact assessment is basically an alternative presentation of the weighting impact assessment results. Single score impact assessment and weighting impact assessment represent the same identical values for each of the damage categories and impact categories. By using single score impact assessment, it will be easier to identify the dominant process involved.

3.5.2 Greenhouse Gases Emission Quantification Methodology

All the GHGs emission from this study is quantified in the carbon dioxide equivalent (CO_2eq) value using global warming potential (GWP) for 100 year-time horizon based on IPCC 2007 fourth assessment report (AR4).   According to Gillenwater (2015), the IPCC 2007 AR4 values is adopted by UNFCCC for international reporting and the 100 year-time horizon GWP values is the most universally used values.

The formula for the conversion of the GHGs value in this study to CO_2eq is as follow;

$$\text{GHGs emission in } CO_2\text{eq} = \Sigma \text{ (Mass of GHGi) x (GWPi)}$$

Nitrous oxide emissions for this study were calculated using the formula from IPCC (2006) as below:

1) N_20 direct emission from fertilizer use in kg = (N in kg)*0.01*(44/28)

2) N_20 indirect emission after emission of fertilizer N as NOx and NH_3 in kg=

(N in kg)*0.001*(44/28)

3) N20 indirect emission after N leaching and run-off in kg =

(N in kg)*0.00225*(44/28)

3.6 Life Cycle Interpretation

The results for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components, production of natural rubber cuplump from cradle to gate in Malaysia based on the mass allocation ratio from literature and the production of SMR block rubber from cradle to gate in Malaysia were interpreted according to their goal and scope of the study as described in the ISO 14044:2006 procedures.

3.7 Data sources for LCI, LCIA and GHGs Emission Quantification

Two types of data were used to quantify the LCI, LCIA and GHGs emission in the study for the cultivation of rubber trees from cradle to grave in Malaysia and its three components, production of natural rubber cuplump from cradle to gate in Malaysia and production of SMR block rubber from cradle to gate in Malaysia. These two types of data are known as foreground data and background data. The foreground data in this study were collected directly from the details questionnaire received from the respondents involved.

Background data in this study were sourced from Ecoinvent database, Industrial Data 2.0 database, and LCA Food DK database which is embedded within the Simapro software version 7.3.3. The background data for this study were also sourced from online databases and literature. The list of all the background data used in this study is show in Table 3.16.

Table 3.16: List of background data sources used in the study

Data information	
Process	Data source
Production of N fertilizer	LCA Food Database by (Nielsen, Nielsen, Weidema, Dalgaard, & Halberg, 2003)
Production of P205 fertilizer	LCA Food Database by (Nielsen et al., 2003)
Production of K20 fertilizer	LCA Food Database by (Nielsen et al., 2003)
HDPE Resin E production	Industrial data 2.O by (Boustead Consulting, 2007)
Production of Magnesium oxide at plant	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Active ingredients for the fungicide/insecticide and its percentage	Publicly access government database by(Pesticide Board Malaysia, 2013) .
Production of mancozeb, at regional storage /RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of chlorothalonil, at regional storage /RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of insecticide, at regional storage /RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of diesel, at regional storage /RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Percentage of Ammonium sulphate in RRIM mixture magnesium X	(Malaysian Rubber Board, 2009)
Percentage of rock phosphate in RRIM mixture magnesium X	(Malaysian Rubber Board, 2009)
Percentage of potassium chloride in RRIM mixture magnesium X	(Malaysian Rubber Board, 2009)
Percentage of magnesium sulphate in RRIM mixture magnesium X	(Malaysian Rubber Board, 2009)
Percentage of Ammonium sulphate in RRIM mixture magnesium Y	(Malaysian Rubber Board, 2009)
Percentage of rock phosphate in RRIM mixture magnesium Y	(Malaysian Rubber Board, 2009)
Percentage of potassium chloride in RRIM mixture magnesium Y	(Malaysian Rubber Board, 2009)
Percentage of magnesium sulphate in RRIM mixture magnesium Y	(Malaysian Rubber Board, 2009)

Table 3.16, continued

Data information	
Process	Data source
Percentage of Ammonium sulphate in RRIM mixture Y	(Malaysian Rubber Board, 2009)
Percentage of rock phosphate in RRIM mixture Y	(Malaysian Rubber Board, 2009)
Percentage of potassium chloride in RRIM mixture Y	(Malaysian Rubber Board, 2009)
Production of Ammonium sulphate as N at regional storehouse / RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of Phosphate rock, as P205, beneficiated, dry at plant /MA U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of Potassium chloride as K20 at regional storehouse / RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of Magnesium sulphate, at plant /RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Production of Glyphosate at regional storehouse /RER U	Ecoinvent database version 2.2 by (Ecoinvent, 2010)
Active ingredients for the herbicide and its percentage	Publicly access government data base by Publicly access government database by (Pesticide Board Malaysia, 2013)
Percentage of P205 in rock phosphate fertilizer	(Malaysian Rubber Board, 2009)
Percentage of MgO in magnesium sulphate fertilizer	(Malaysian Rubber Board, 2009)
Percentage of Ammonium sulphate in RRIM mixture J fertilizer	(Malaysian Rubber Board, 2009)
Percentage of rock phosphate RRIM mixture J fertilizer	(Malaysian Rubber Board, 2009)
Percentage of potassium chloride in RRIM mixture J fertilizer	(Malaysian Rubber Board, 2009)
Percentage of Ammonium sulphate in RRIM mixture Magnesium J fertilizer	(Malaysian Rubber Board, 2009)

CHAPTER 4: RESULTS AND DISCUSSION

The results and discussion for this study are divided into 5 main components as listed below:

- The life cycle inventory (LCI), life cycle impact assessment (LCIA) and greenhouse gases (GHGs) emission quantification for the cultivation of rubber tree from cradle to grave in Malaysia.
- The LCI, LCIA and GHGs emission quantification for the production of young budding in the polybag from cradle to gate in Malaysia.
- The LCI, LCIA and GHGs emission quantification in the production of mature rubber trees from gate to gate in Malaysia.
- The LCI, LCIA and GHGs emission quantification in maintaining the growth of mature rubber trees from gate to gate in Malaysia.
- The LCI, LCIA and GHGs emission quantification for the production of natural rubber cuplump from cradle to gate in Malaysia.
- The LCI, LCIA and GHGs emission quantification for the production of SMR block rubber from cradle to gate in Malaysia.

All the objectives for this study are successfully fulfilled as summarized below:

- The first objective of this study is to review the current practice and quantify a comprehensive LCI for the cultivation of rubber trees from cradle to grave and its three components i.e. nursery, immature rubber and mature rubber stages. All the inputs and outputs involved in the cultivation of one rubber tree from cradle to grave in 31.75 years average life span has successfully been reviewed and compiled in the form of LCI input-output table. The inputs and outputs involving the production of one two whorl young budding in the rubber nursery for an average of 9 month, the production of one mature rubber tree for an average of 6 years in the immature stage and the process to maintain the healthy growth of one mature rubber tree in the mature rubber stage for an average of 25 years were also successfully reviewed and compiled in the form of their respective LCI input-output table

- The second objective of this study is to quantify a LCI for the production of natural rubber cuplump from cradle to gate in Malaysia based on the mass allocation ratio from literature. This objective was successfully achieved through the establishment of LCI input-output table for the production of one kg natural rubber cuplump (56%DRC) from cradle to gate. This LCI input-output table was generated by applying the mass allocation ratio from the combination of literature source from Yew et al. in Rahaman and Amu (2002) and Rahaman and Amu (2002) to the LCI table for the cultivation of one rubber tree from cradle to grave in this study.
- The third objective of this study is to review the current practice and quantify a comprehensive LCI for the production of SMR block rubber from cradle to gate in Malaysia. All the inputs and outputs involved in the production of one kg SMR block rubber has successfully been reviewed and compiled in the form of LCI input-output table.
- The fourth objective of this study is to quantify the environmental impact in the form of LCIA based on the LCI tables for the cultivation of rubber trees from cradle to grave in Malaysia and its three components, the production of natural rubber cuplump from cradle to gate in Malaysia and the production of SMR block rubber from cradle to gate in Malaysia and recommended strategies for

improvement. The fourth objective of this study has successfully been achieved and is described in details in this chapter.

- The fifth and final objective of this study is to quantify the GHGs emission and recommended strategies for improvement based on the LCI for the cultivation of rubber trees from cradle to grave in Malaysia and its three independent components, the production of natural rubber cuplump from cradle to gate in Malaysia and the production of SMR block rubber from cradle to gate in Malaysia. The fifth objective of this study has successfully been achieved and is described in details in this chapter.

4.1 LCA Study for the Cultivation of Rubber Tree from Cradle to Grave in Malaysia

The cultivation of rubber tree from cradle to grave in this study is represented by 3 boundaries. These 3 boundaries are:

- The production of rubber planting material in the form of young budding in the polybag (nursery boundary).
- The process of maintaining the growth of the newly transplanted young budding until the young rubber trees are mature and ready for tapping (immature rubber boundary).
- The process of maintaining the growth of the mature rubber trees and extraction of natural rubber in the form of cuplump from the mature rubber trees until the end of life of the mature rubber trees (mature rubber boundary).

The defined system boundary for the cultivation of rubber tree from cradle to grave in this study is simplified in Figure 4.1. For ease of the study, zero mortality scenarios is used with the assumption that all the young budding in the polybag grow until it reaches its end of life stage at the age of 31.75 years with 25 years of tapping period (Figure 4.1).

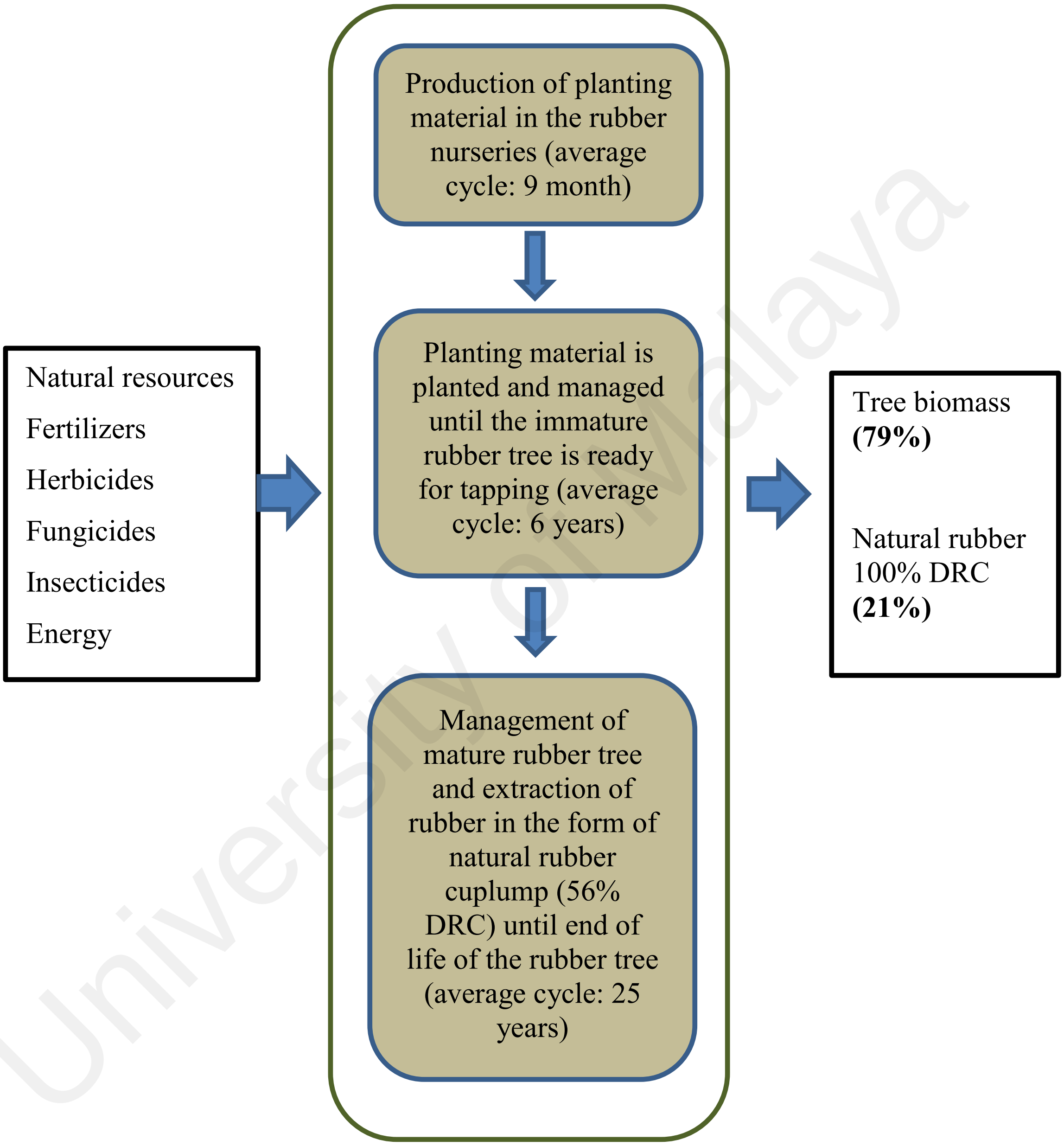

Figure 4.1: The defined system boundary for the cultivation of one rubber tree from cradle to grave.

In this study, allocation is made for the outputs from the cultivation of one rubber tree from cradle to grave. The tree biomass accumulated at the end of life of a rubber tree is allocated 79% and the dry natural rubber with 100% dry rubber content (DRC) extracted from the entire life of a rubber tree is allocated 21% (Figure 4.1).

The basis for this allocation ratio is based on combination of data by Yew et al. in Rahaman and Amu (2002) and data from Rahaman and Amu (2002) for the rubber trees cut down at the age of 30 years with 25 years of tapping period (Table 4.1).

Table 4.1: Allocation ratio based on the output for the cultivation of one rubber tree from cradle to grave

Age of rubber tree	Output	
	Tree biomass (kg/Tree)	Natural rubber (100%DRC) (kg/Tree)
30 years (25 years tapping)	602.7	160
Output allocation ratio	**79%**	**21%**

4.1.1 Life Cycle Inventory

The inventory data for this study was obtained through 3 series of surveys carried out in Peninsular Malaysia involving 32 rubber nurseries operators, 23 immature rubber management holdings and 44 mature rubber management holdings as described in Chapter 3. The LCI input- output table for the cultivation of one rubber tree from cradle to grave is shown in Table 4.2.

Table 4.2: LCI table for the cultivation of one rubber tree from cradle to grave

Input	Unit	Average value	Cradle to grave boundary		
Nursery boundary (9 month)			**Products**		
			Output	**Unit**	**Average value**
			Tree biomass	kg	403.91
Polybag	kg	0.0130	Natural rubber (100%DRC)	kg	107.37
Fertilizer N	kg	0.0042	**Emission**		
Fertilizer P205	kg	0.0042	Nitrous oxide	kg	0.0815
Fertilizer K20	kg	0.0039			
Rock phosphate fertilizer	kg	0.0790			
Magnesium oxide	kg	0.0010			
Fungicide (80% w/w mancozeb)	kg	0.0009			
Fungicide (50% w/w chlorothalonil)	kg	0.0002			
Insecticides (various active ingredients)	kg	0.0003			
River water	m^3	0.2227			
Diesel	L	0.0399			
Immature rubber boundary (6 years)					
Ammonium sulphate fertilizer	kg	2.579			
Rock phosphate fertilizer	kg	2.192			
Potassium chloride fertilizer	kg	0.706			
Magnesium sulphate fertilizer	kg	0.497			
Herbicide with 41% glyphosate	L	0.238			
Herbicide with 13% paraquat dichloride	L	0.096			
Mature rubber boundary (25 years)					
Ammonium sulphate fertilizer	kg	16.036			
Rock phosphate fertilizer	kg	9.389			
Potassium chloride fertilizer	kg	11.21			
Magnesium sulphate fertilizer	kg	2.328			
Herbicide with 41% glyphosate	L	0.367			
Herbicide with 13% paraquat dichloride	L	0.476			
Herbicide with 32.1% triclopyr butotyl	L	0.285			
Herbicide with 20% metsulfuron methyl	L	0.026			

4.1.1.1 Fertilizer Usage in the Rubber Cultivation from Cradle to Grave

The fertilizer inputs from the rubber nursery stage are very small and insignificant from a cradle to grave perspective and will not be discussed in details. The summary of the fertilizer usage during the immature and mature stage in the cultivation of one rubber tree from cradle to grave is summarized in Table 4.3.

Table 4.3: Quantity of fertilizer used in the cultivation of one rubber tree from cradle to grave

Fertilizer	Quantity used (kg/Tree/31 year)	Quantity used (kg/Tree/ year)
Ammonium sulphate	18.61	0.60
Rock phosphate	11.58	0.37
Potassium chloride	11.92	0.38
Magnesium sulphate	2.83	0.09
Total	44.94	1.45

Based on the Table 4.3, ammonium sulphate recorded the highest usage at 41.4% from the total amount of fertilizer used followed by potassium chloride (26.5%) and rock phosphate (25.8%). Magnesium sulphate fertilizer recorded the lowest usage at 6.3% from the total amount of fertilizers used.

Ammonium sulphate is the source of nitrogen and largely used in the rubber plantation in Malaysia as majority of the rubber plantation in Malaysia are grown in inland soil. According to Ismail (1979), ammonium sulphate is largely used for rubber grown in inland soils due to its loses to leaching and volatilisation are low as compared to urea which has a high volatilisation losses. Another source of nitrogen fertilizer that can be used for inland soils is ammonium nitrate but because of its high water solubility, extra precautions have to be taken during its use in order to reduce leaching during wet days or on wet soils (Ismail, 1979).

In this study, all the rubber trees are planted in inland soil and this explains why majority of the respondents used ammonium sulphate as the source of nitrogen for their fertilizer. All respondents from this study are using fertilizers based on the recommended dosage that suit their soil and other physical conditions.

Rubber is the second most important crop in Malaysia after oil palm representing 15.2% from the total planted area of major agriculture crops in Malaysia (Ministry of Natural Resources and Environment Malaysia, 2015). In 2014, there are 1.066 million hectares of rubber planted area in Malaysia (Malaysian Rubber Board, 2016b). In 2014, rubber smallholders own 92.5% of the rubber planted area in Malaysia (Malaysian Rubber Board, 2016b). For 2011, 0.963 million hectares of rubber planted area in Malaysia are owned by the rubber smallholders representing 93.7% from the total rubber planted area in Malaysia (Malaysian Rubber Board, 2016b). From this 0.963 million hectares of rubber planted areas in Malaysia, it is estimated that 0.193 million hectares are owned by the rubber smallholders under the management of rubber related agencies in Malaysia while the balance of 80% are owned by the individual rubber smallholders (Malaysian Rubber Board, 2012). There are great difficulties in getting verified information from the individual rubber smallholders on their agronomic practices as these smallholders normally did not have any proper written record on their agronomic practices and some of them are even illiterate.

The survey carried out by the MRB through face to face interview with individual rubber smallholders representing 0.338 million hectares of rubber planted area in Malaysia from March 2011 to March 2012 did gave some insight information on the agronomic practices by the individual rubber smallholders involved but not at the full disclosure level as the objectives of the survey is more towards the creating of demographic, social and regulation related based individual rubber smallholders database (Malaysian Rubber Board, 2012). Based on this survey, 41.7% of the planted rubber areas receive fertilizers at the recommended dosage, 19.2% of the planted rubber areas receive fertilizers lower than the recommended dosage while the remaining 39.1% of the planted rubber areas did not receive any fertilizer for the past one year (Malaysian Rubber Board, 2012).

Due to the unavailability of the accurate information regarding the agronomic practices by the individual rubber smallholders from cradle to grave perspective, it is proposed that an estimation of 51.3% from the total rubber planted area in Malaysia receives fertilizers at the recommended dosage. The basis for this estimation is as below:

- The percentage of the rubber planted area that received fertilizers at the recommended dosage for the past one year in (Malaysian Rubber Board, 2012) represent the percentage of the rubber planted area in Malaysia that received fertilizers at the recommended dosage from cradle to grave
- From the total percentage of the rubber planted area that receive fertilizers lower than the recommended dosage for the past one year in(Malaysian Rubber Board, 2012), half of it is considered as receiving fertilizers at the recommended dosage from cradle to grave

Based on 51.3% of the planted rubber area in Malaysia is fertilized at the recommended dosage and with the average stand of 410 rubber trees per hectare from this study, the estimated fertilizer consumption for the cultivation of rubber trees in Malaysia from cradle to grave is summarized in Table 4.4.

Table 4.4: Estimated fertilizer consumption for the cultivation of rubber trees in Malaysia from cradle to grave

Fertilizer	Quantity use (Tonne)	
	31 years	1 year
Ammonium sulphate	4,172,581	134,599.4
Potassium chloride	2,596,372	83,753.95
Rock phosphate	2,672,604	86,213.05
Magnesium sulphate	634,519.3	20,468.37
Total	10,076,077	325,034.8

The average for one year consumption of ammonium sulphate and potassium chloride for the cultivation of rubber trees in Malaysia from cradle to grave as shown in Table 4.4 represent 17% and 5.4% respectively from the Malaysian ammonium sulphate and potassium chloride consumption in 2014 (FAO, 2017). The average for one year total consumption of ammonium sulphate and potassium chloride in the cultivation of rubber trees in Malaysia from cradle to grave is estimated at 9.3% from the total Malaysia consumption for 2014 (FAO, 2017).

Based on this study, the consumption of fertilizers in the cultivation of rubber trees from cradle to grave is quite low if considering that rubber planted area is the second largest planted areas of major agriculture crops in Malaysia as reported in Ministry of Natural Resources and Environment Malaysia (2015).

This finding however is not a surprise as according to Liri (2015), the estimated total consumption of fertilizers by the rubber cultivation sector in Malaysia is the lowest at 3.1% as compared to the oil palm cultivation at 88.3% and rice cultivation at 8.6% in 2013. From Liri (2015) data, it is apparent that the lower consumption of fertilizer by the rubber cultivation sector is partly due to some percentage of the rubber individual smallholders did not use fertilizers at the recommended dosage or in the worst case scenario did not use fertilizers at all as explained before. If we take into account all the rubber planted area in Malaysia used fertilizer at the recommended dosage, the annual consumption of fertilizers by the rubber cultivation sector in Malaysia will definitely be higher than the reported figure of 3.1%.

The supplies of nutrients needed by the rubber tree through application of fertilizer are very important in the rubber cultivation in order to ensure the healthy growth of the rubber tree that can produce maximum yield. The nutrients consumption in the cultivation of one rubber tree from cradle to grave in this study is shown in Table 4.5.

Table 4.5: Nutrients consumption in the cultivation of one rubber tree from cradle to grave

Fertilizer	Nutrient type	Nutrient content (%)	Nutrient quantity used	
			(kg/Tree/ 31years)	(kg/Tree/ year)
Ammonium sulphate	N	21	3.91	0.13
Rock phosphate	P2O5	36	4.17	0.13
Potassium chloride	K2O	61	7.27	0.23
Magnesium sulphate	MgO	26	0.74	0.02

K20 nutrient recorded the highest used in the cultivation of one rubber tree from cradle to grave while N and P2O5 nutrients are equally recorded as the second highest (Table 4.5). K20 nutrient supply the rubber tree with potassium which is an important element as it is involved in most of the physiological processes in the rubber trees like photosynthesis, protein and carbohydrate synthesis and translocation of metabolites (Daud, 2013). The inadequate supply of K20 nutrient will inhibit the growth, height, girth size and number of leaves which can lead to the rubber tree being stunted (Daud, 2013).

Using the estimation that 51.3% of the planted rubber area in Malaysia is fertilized at the recommended dosage as the basis of calculation and with the average stand of 410 rubber trees per hectare, the estimated fertilizers consumption in the form of nutrients for the cultivation of rubber trees in Malaysia from cradle to grave are summarized in Table 4.6.

Table 4.6: Estimated nutrients consumption for the cultivation of rubber trees in Malaysia from cradle to grave

Nutrient	Quantity use (Tonne)	
	31 years	One year
N	876,668.1	28,279.6
P2O5	934,963.1	301,60.1
K2O	1,630,019.6	52,581.3
Total Nutrient	3,441,650.8	111,021.0

The average for one year consumption of N, P205 and K20 nutrients for the cultivation of rubber trees in Malaysia from cradle to grave represent 5.6%, 6.6 and 5.3% respectively from the total Malaysian consumption of these three nutrients in 2014 (FAO,2017).

According to Sabri (2009), the estimated consumption of N, P205 and K20 nutrients from rubber cultivation sector in Malaysia based on the official recommended rate of fertilizer used is at 9.9%, 11.3% and 8.1% respectively from the estimated Malaysian N, P205 and K20 nutrients consumption in 2008. If it is considered that the actual consumption of the N, P205 and K20 nutrients is at 51.3% from the official recommended rate of fertilizer used in the rubber cultivation from Sabri (2009) data, the estimated consumption of N, P205 and K20 nutrients from rubber cultivation sector in Malaysia will be 5.1%, 5.8% and 4.1% respectively. Hence these figures concur and are almost identical with the value from the average one year consumption of N, K20 and P205 nutrients for the cultivation of rubber trees in Malaysia from cradle to grave based on this study.

Combination of oil palm cultivation, rubber cultivation and rice cultivation consume 89.6% of the total fertilizer consumption in Malaysia in 2013 (Liri, 2015). Oil palm cultivation sector is the single biggest user of fertilizers representing 78.2% from the total of N, P205 and K20 nutrients consumption in Malaysia for 2010-2010/11 (Heffer, 2013). Even though rice cultivation is the third largest planted areas of major agriculture crops in Malaysia, rice cultivation represent the second biggest usage of fertilizers at 9.5% from the total N, P205 and K20 nutrients consumption in Malaysia for 2010-2010/11 (Heffer, 2013).

In the Heffer (2013) report, the rubber cultivation N, P205 and K20 nutrients consumption is combined with other crops such as cocoa, tobacco, coffee and tea and represent 9.5% from the total N, P205 and K20 nutrients consumption in Malaysia for 2010-2010/11. The relatively lower consumption of N, P205 and K20 nutrients by the rubber cultivation sector in Malaysia as reflected in estimation from this study and in line with the reporting by Heffer (2013), Sabri (2009) and Liri (2015) actually is a positive sign that the rubber cultivation sector in Malaysia is more environmentally sustainable from the perspective of fertilizer utilization as compared to the other two main crops in Malaysia i.e. oil palm and rice cultivation.

4.1.1.2 Herbicide Usage in the Rubber Cultivation from Cradle to Grave

Weed control in Malaysian plantations has for a long time depended on herbicides and herbicides application still remains the major strategy for weed control in Malaysia (Ooi, 1992; Seng & Ismail Sahid, 2010). Herbicides represent 71.6% from the total value of pesticides consumed for crops vigilance in Malaysia for 2007 as reported by Agriquest Sdn Bhd in Othman and Jafari (2014).

Herbicides usage in Malaysia for 2004 represents 67.49% from the total Malaysian pesticide used as reported by anonymous and Malaysian crop care and public health association in Wibawa et al. (2007). The summary of the herbicide usage in the cultivation of one rubber tree from cradle to grave is summarized in Table 4.7.

Table 4.7: Quantity of herbicides used in the cultivation of one rubber tree from cradle to grave

Herbicide	Amount of Herbicide used	
	(L/tree/31.75 years)	(L/tree/year)
Herbicide with 41% glyphosate	0.605	0.019
Herbicide with 13% paraquat dichloride	0.572	0.018
Herbicide with 32.1% triclopyr butotyl	0.285	0.009
Herbicide with 20% metsulfuron methyl	0.026	0.001

Glyphosate based herbicide is widely used by the respondents from the immature stage in this study. For the mature stage in this study, glyphosate based herbicide is still widely used by the respondents but in combination with either triclopyr butotyl or mestsulfuron methyl based herbicides. Paraquat dichloride based herbicide is still used in the cultivation of rubber trees from cradle to grave by the respondents in this study despite its controversial health effect.

According Rosmawati and Shaari (2007), paraquat is one of the most dangerous herbicides in the world and farmers around the world who are regularly exposed to the paraquat experiences serious problems with their health. The government of Malaysia has banned the use of the paraquat on 22 August 2002 for the reasons of toxicity and hazard to human but the ban was lifted in 2006 (Rosmawati & Shaari, 2007; Tan, Ramanathan, Choy, Raman, & Lim, 2013; Wibawa et al., 2010).The numbers of respondents using the paraquat dichloride based herbicide as the sole herbicide however is relatively small representing only 3.3% from the total respondents.

The active ingredients in the form of chemical components in the herbicide is responsible for the eradication of weed (Rutherford et al., 2009). There are numerous herbicides active ingredients manufactured by a range of companies marketed throughout the world and these actives ingredients are registered and authorised on a regional or national basis (Rutherford et al., 2009).

In Malaysia, all pesticides active ingredients which include herbicides active ingredients must be registered with Pesticide Control Division, Department of Agriculture Malaysia before they can be used. The herbicides consumption in the form of active ingredients for the cultivation of one rubber tree from cradle to grave is shown in Table 4.8.

Table 4.8: Herbicide active ingredients consumption for the cultivation of one rubber tree from cradle to grave

Herbicide	Herbicide active ingredient	Amount of active ingredients used	
		(kg/Tree/31.75 years)	(kg/Tree/ year)
Herbicide with 41% glyphosate	glyphosate	0.248	0.00781
Herbicide with 32.1% triclopyr butotyl	triclopyr butotyl	0.091	0.00287
Herbicide with 13% paraquat dichloride	paraquat dichloride	0.074	0.00233
Herbicide with 20% metsulfuron methyl	metsulfuron methyl	0.005	0.00016

Glyphosate is a broad-spectrum and nonselective systemic herbicide and is utilized extensively for control of plants including broad leaved weeds and grasses (Nourouzi et al., 2011). From Table 4.8, glyphosate herbicide recorded the highest consumption in the cultivation of one rubber tree from cradle to grave. This finding is in tandem with the statement by Morshed, Omar, Mohamad, and Wahed (2011) that glyphosate is the most predominant herbicide used in Malaysia.

Based on survey by MRB involving 0.338 million hectares of rubber planted area in Malaysia owned by the individual rubber smallholders, the weeds control in 65.9% of this rubber planted area is carried out by using herbicides (Malaysian Rubber Board, 2012). Due to the limited information available, the figures from the MRB survey will be used as the basis of calculation in this study in order to estimate the herbicides consumption during the cultivation of rubber tree stage from cradle to grave.

Assuming that the weed control in 65.9% of all the planted rubber area in Malaysia is carried out by using herbicides at the recommended frequency as the basis of calculation and with the average stand of 410 rubber trees per hectare, the estimated consumption of herbicides active ingredients for the cultivation of rubber trees in Malaysia from cradle to grave based on 1.066 million hectares of rubber planted area in Malaysia are summarized in Table 4.9.

Table 4.9: Estimated herbicides active ingredients consumption for the cultivation of rubber trees in Malaysia from cradle to grave

Herbicide active ingredient	Quantity use (Tonne)	
	31.75 years	One year
Glyphosate	71,429.6	2,249.8
Triclopyr butotyl	26,210.1	825.5
Paraquat dichloride	21,313.7	671.3
Metsulfuron methyl	1,440.1	45.4
Total	120,393.4	3,791.9

The average yearly consumption of herbicide active ingredients for the cultivation of rubber trees in Malaysia from cradle to grave represents 9.2% from the total herbicide active ingredients consumption in Malaysia of 41061 tonnes in 2014 (FAO, 2017). This estimation reflected the relatively lower consumption of herbicides active ingredients in the cultivation of rubber trees in Malaysia as the rubber planted area is the second largest planted areas of major agriculture crops in Malaysia.

4.1.2 LCIA for the Cultivation of Rubber Tree from Cradle to Grave

SimaPro software version 7.3.3 developed by PRe Consultants is used in this study as it has extensive databases and allow for manual addition of process that are not included in it databases (Yusoff, 2006). SimaPro software is also one of the leading software program used for LCA studies worldwide (Herrmann & Moltesen, 2015).

Characterization

The characterization result for the cultivation of one rubber tree from cradle to grave is shown in Figure 4.2. This characterization result illustrates the relative impact contribution from all the processes in the cultivation of one rubber tree from cradle to grave towards each of the characterization impact categories. The values for this characterization result are represented by Table 4.10

Ammonium sulphate production is the main contributor to 7 impact categories i.e. carcinogens, respiratory organics, respiratory inorganics, ecotoxicity, acidification/eutrophication, minerals and fossil fuels with contribution of 44.8%, 46.3%, 32.0%, 50.6%, 41.1%, 50.8% and 55.3% respectively towards their respective impact categories (Figure 4.2). Ammonium sulphate production also contributed significantly towards climate change, radiation, ozone layer and land use impact categories at 22.2%, 21.6%, 30.6% and 26.7% respectively (Figure 4.2).

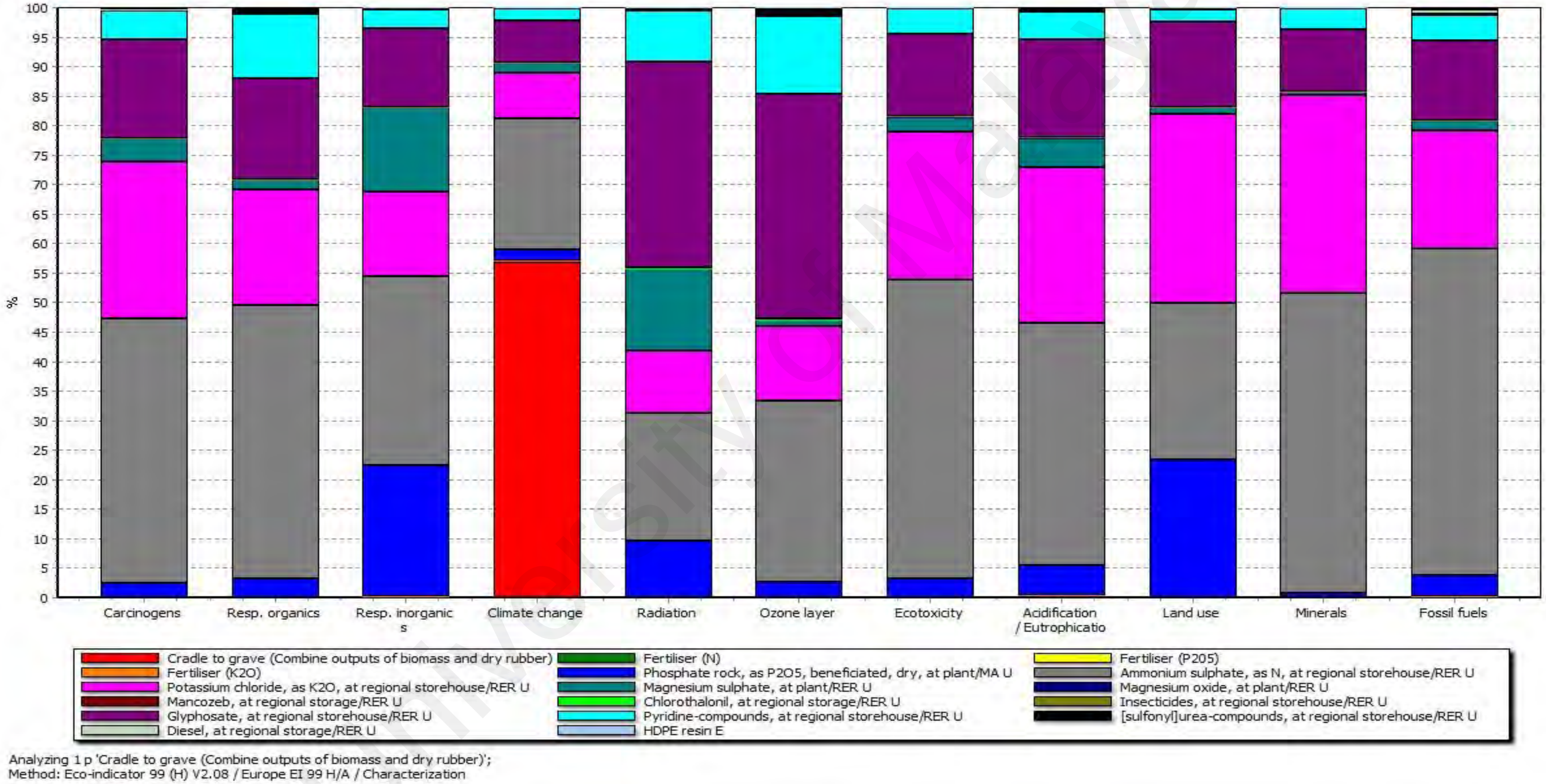

Figure 4.2: Characterization for the cultivation of one rubber tree from cradle to grave based on impact categories

Table 4.10: Characterization values for the cultivation of one rubber tree from cradle to grave

Impact category	Unit	Total	Ammonium sulphate application	Fertiliser (N)	Fertiliser (P205)	Fertiliser (K2O)	Phosphate rock	Ammonium sulphate	Potassium chloride	Magnesium sulphate	Magnesium oxide	Mancozeb	Chlorothalonil	Insecticides	Glyphosate	Pyridine-compounds	[sulfonyl]urea-compounds	Diesel	HDPE resin E
Carcinogens	DALY	7.4E-06	0E+00	1E-12	4E-13	2E-13	2E-07	3E-06	2E-06	3E-07	3E-09	3E-09	1E-10	1E-09	1E-06	4E-07	2E-08	2E-09	3E-08
Resp. organics	DALY	1.6E-08	0E+00	3E-12	3E-12	7E-13	5E-10	8E-09	3E-09	3E-10	2E-13	3E-12	5E-13	4E-12	3E-09	2E-09	6E-11	6E-11	8E-11
Resp. inorganics	DALY	1.5E-05	0E+00	1E-08	7E-09	8E-10	3E-06	5E-06	2E-06	2E-06	1E-09	8E-09	2E-10	3E-09	2E-06	5E-07	4E-08	2E-08	1E-08
Climate change	DALY	9.9E-06	6E-06	9E-09	1E-09	5E-10	2E-07	2E-06	8E-07	2E-07	2E-10	8E-10	8E-11	9E-10	7E-07	2E-07	1E-08	4E-09	5E-09
Radiation	DALY	9.5E-08	0E+00	0E+00	0E+00	0E+00	9E-09	2E-08	1E-08	1E-08	2E-12	3E-11	3E-12	4E-11	3E-08	8E-09	4E-10	5E-11	0E+00
Ozone layer	DALY	3.8E-09	0E+00	0E+00	0E+00	0E+00	1E-10	1E-09	5E-10	4E-11	9E-15	1E-12	2E-13	9E-13	1E-09	5E-10	4E-11	2E-11	0E+00
Ecotoxicity	PAF*m2yr	8.5E+00	0E+00	1E-08	8E-09	3E-09	3E-01	4E+00	2E+00	2E-01	5E-04	1E-02	2E-04	1E-03	1E+00	4E-01	2E-02	4E-03	9E-05
Acidification/ Eutrophication	PDF*m2yr	2.7E-01	0E+00	9E-04	3E-04	3E-05	1E-02	1E-01	7E-02	1E-02	6E-06	2E-04	5E-06	7E-05	4E-02	1E-02	1E-03	5E-04	3E-04
Land use	PDF*m2yr	4.4E-01	0E+00	0E+00	0E+00	0E+00	1E-01	1E-01	1E-01	5E-03	1E-06	5E-05	3E-06	4E-05	6E-02	9E-03	5E-04	1E-03	0E+00
Minerals	MJ surplus	1.6E+00	0E+00	0E+00	0E+00	0E+00	1E-02	8E-01	5E-01	7E-03	2E-06	3E-04	2E-05	1E-04	2E-01	6E-02	3E-03	2E-04	1E-06
Fossil fuels	MJ surplus	3.6E+01	0E+00	3E-02	9E-03	5E-03	1E+00	2E+01	7E+00	6E-01	1E-04	6E-03	7E-04	7E-03	5E+00	2E+00	9E-02	2E-01	1E-01

Glyphosate production is the main contributor to radiation and ozone layer impact categories at 35.0% and 38.1% respectively while potassium chloride production is the main contributor to land use impact category at 31.9% (Figure 4.2).

Direct and indirect nitrous oxide emission from the application of ammonium sulphate recorded the highest contribution at 56.9% from the total value of climate change impact category (Figure 4.2).

Damage Assessment

The damage assessment result is shown in Figure 4.3. For human health damage category, ammonium sulphate production is the highest contributor at 31.9%, followed by nitrous oxide direct and indirect emission from the application of ammonium sulphate at 17.3% (Figure 4.3). For ecosystem quality damage category, ammonium sulphate production is the highest contributor at 42.2% followed by the production of potassium chloride at 27.2% (Figure 4.3).

For resources damage category, ammonium sulphate production is the biggest contributor at 55.1% followed by potassium chloride production at 20.6% (Figure 4.3). The damage assessment results for the three damage categories are non-comparable between them as they only show relative distribution within their respective damage categories. The damage assessment results however give a strong indication that ammonium sulphate production is the most polluting process in the cultivation of one rubber tree from cradle to grave.

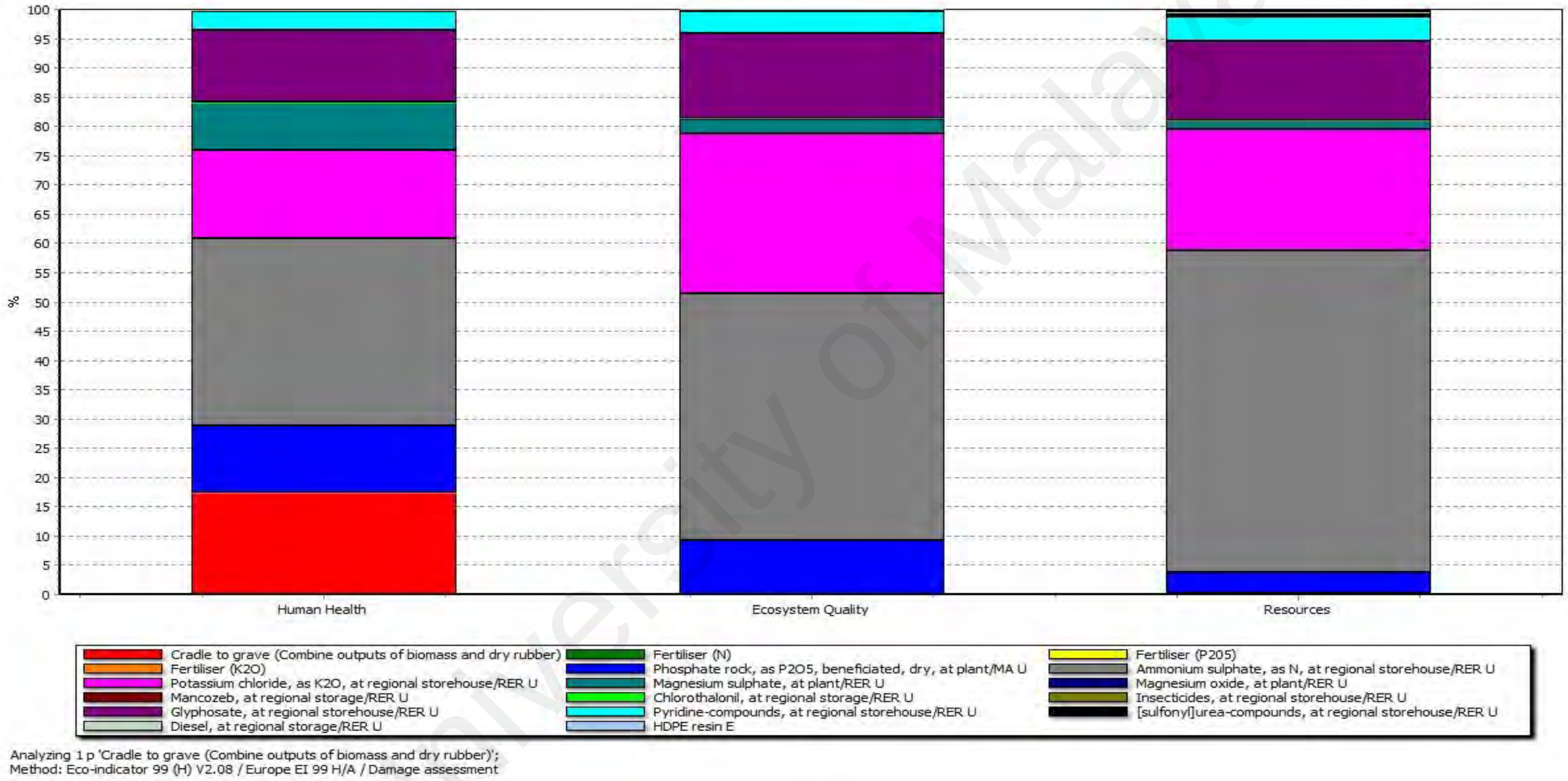

Figure 4.3: Damage assessment for the cultivation of one rubber tree from cradle to grave based on damage categories

Normalization

The normalization result for the cultivation of one rubber tree from cradle to grave is summarized in Table 4.11 and Figure 4.4 in the form of person equivalent (PE).

Table 4.11: Normalization values for the cultivation of one rubber tree from cradle to grave based on damage categories

Damage category	Normalization value (PE)
Human health	3.71 E-03
Ecosystem quality	2.74E-04
Resources	4.99E-03

For normalization results based on impact categories, it is a very clear indication that fossil fuels impact category is the most dominant (Figure 4.4). Ammonium sulphate production is the single main contributor at 55.3% followed by potassium chloride production at 20.0% towards the total value of fossil fuels impact category (Figure 4.4).

Respiratory inorganics, climate change and carcinogens play minor role while the rest of the impact categories are considered as insignificant. According to Onn and Yusoff (2010), even though normalization substantially improves insight into the results, no final judgement can be made as not all impact categories are considered to be equal importance.

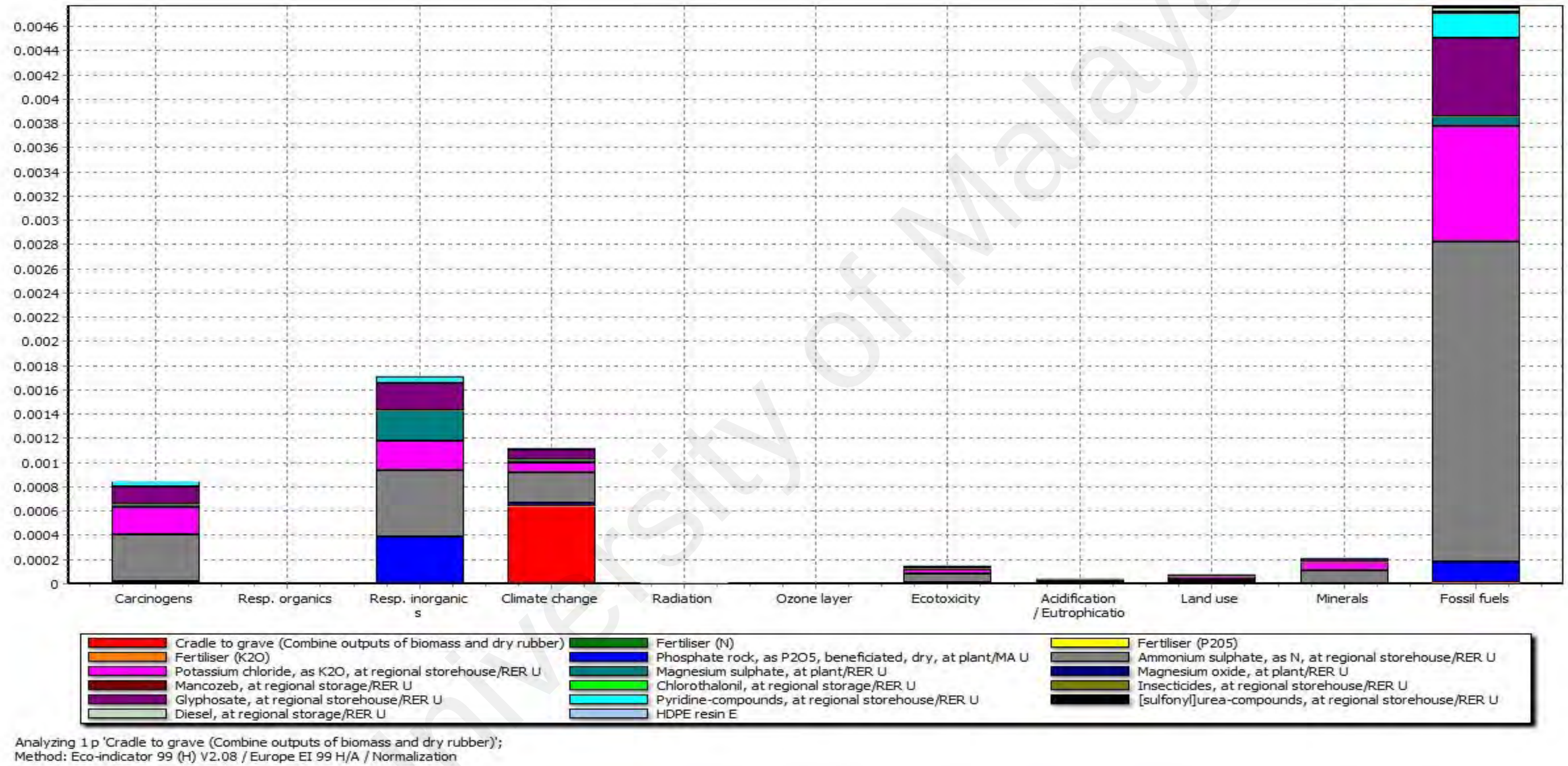

Figure 4.4: Normalization for the cultivation of one rubber tree from cradle to grave based on impact categories

Using the assumption that 51.3% of all planted rubber area in Malaysia is fertilized at the recommended dosage as the basis of calculation and the average stand of 410 rubber trees per hectare, the estimated impact towards the damage categories from the cultivation of the rubber trees in Malaysia from cradle to grave based on 1.066 million hectares is summarized in Table 4.12.

Based on Table 4.12, the cultivation of rubber trees in Malaysia from cradle to grave in 31.75 years contributes to:

- 2.6% of the human health impact in Malaysia
- 0.2% of the ecosystem quality impact in Malaysia
- 3.5% of the resource depletion impact in Malaysia

If we look on the impact based on yearly average in the Table 4.12, the estimated impact from the cultivation of the rubber trees in Malaysia for a year will be as follows:

- 0.083% of the human health impact in Malaysia
- 0.006% of the ecosystem quality impact in Malaysia
- 0.111% of the resource depletion impact in Malaysia

Table 4.12: Estimated impact for the cultivation of rubber trees from cradle to grave in Malaysia based on damage categories

Damage category	Normalization value (PE)		Malaysian population 2016# (Million)	Impact to Malaysia (%)	
	Based on 31.75 years	Based on 1 Year		Based on 31.75 years	Based on 1 year
Human health	8.31E+05	2.62E+04	31.7	2.62	0.083
Ecosystem quality	6.13E+04	1.93E+03	31.7	0.19	0.006
Resources	1.12E+06	3.52E+04	31.7	3.53	0.111

Source: (Department of Statistic Malaysia, 2016)

The impact from the cultivation of rubber tree from cradle to grave based on a year average is compared with the production of crude palm oil in Malaysia in order to explain the impact into a clearer perspective as according to Zawawi (2012), Malaysian crude palm oil production in 2009 is the second highest in the world at 39.0% from the world's total production of crude oil palm. The comparison results are shown in Table 4.13.

Based on Table 4.13, the environmental impact from the cultivation of rubber trees from cradle to grave for a year basis is relatively very low and can be considered as insignificant when compared to the Malaysia production of crude palm oil in 2015. Human health damage category, ecosystem quality damage category and resource depletion damage category values for the cultivation of rubber trees from cradle to grave for a year basis only represent 1.56%, 1.03% and 1.37% respectively from the Malaysian crude palm oil production impact in 2015 (Table 4.13).

In the absence of Malaysia's own finalizes normalization values, LCA practitioners in Malaysia had no choice but to depend on the available normalization values such as the European normalization value in the Eco-indicator 99 methodology to conduct their LCIA study. The preliminary works towards the creation of Malaysian own normalization value was carried out by Onn and Yusoff (2010) which reported that normalization values for Malaysia in average are four time higher compared to the European value but there are no continuation of the study as recommended by them in term of using better collection of more recent data and comparing with different type of software and different type of methodology. Normalization values must be weighted in order to compare the values from each of the impact categories.

Table 4.13: Damage categories for the cultivation of rubber trees from cradle to grave as compared to the crude palm oil production in Malaysia

Damage category	Normalization value for the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (PE)	Normalization value for the production of 1 tonne crude palm oil from cradle to gate in Malaysia[#] (PE)	Production of crude palm oil from cradle to gate in Malaysia equivalent to the normalization value for the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (Tonne)	Malaysia crude palm oil production for 2015* (Tonne)
Human Health	2.62E+04	0.0841	311533.9	19,961,581.0
Ecosystem quality	1.93E+03	0.0094	205976.5	19,961,581.0
Resources	3.52E+04	0.1290	272868.2	19,961,581.0

Source:[#] (Yusoff, 2006) * (MPOB, 2017)

Weighting

The weighting result for the cultivation of one rubber tree from cradle to grave is shown in Figure 4.5 and Table 4.14.

Table 4.14: Weighting values for the cultivation of one rubber tree from cradle to grave

Damage category	Impact category	Unit	Impact category value	Damage category value
Human Health	Carcinogens	Pt	3.39E-01	
Human Health	Resp. organics	Pt	7.51E-04	
Human Health	Resp. inorganics	Pt	6.87E-01	
Human Health	Climate change	Pt	4.51E-01	
Human Health	Radiation	Pt	4.35E-03	
Human Health	Ozone layer	Pt	1.74E-04	
Total Human Health		Pt		1.48E+00
Ecosystem Quality	Ecotoxicity	Pt	5.96E-02	
Ecosystem Quality	Acidification/ Eutrophication	Pt	1.89E-02	
Ecosystem Quality	Land use	Pt	3.08E-02	
Total Ecosystem Quality		Pt		1.09E-01
Resources	Minerals	Pt	4.27E-02	
Resources	Fossil fuels	Pt	9.55E-01	
Total Resources		Pt		9.97E-01
Total		Pt	2.59E+00	2.59E+00

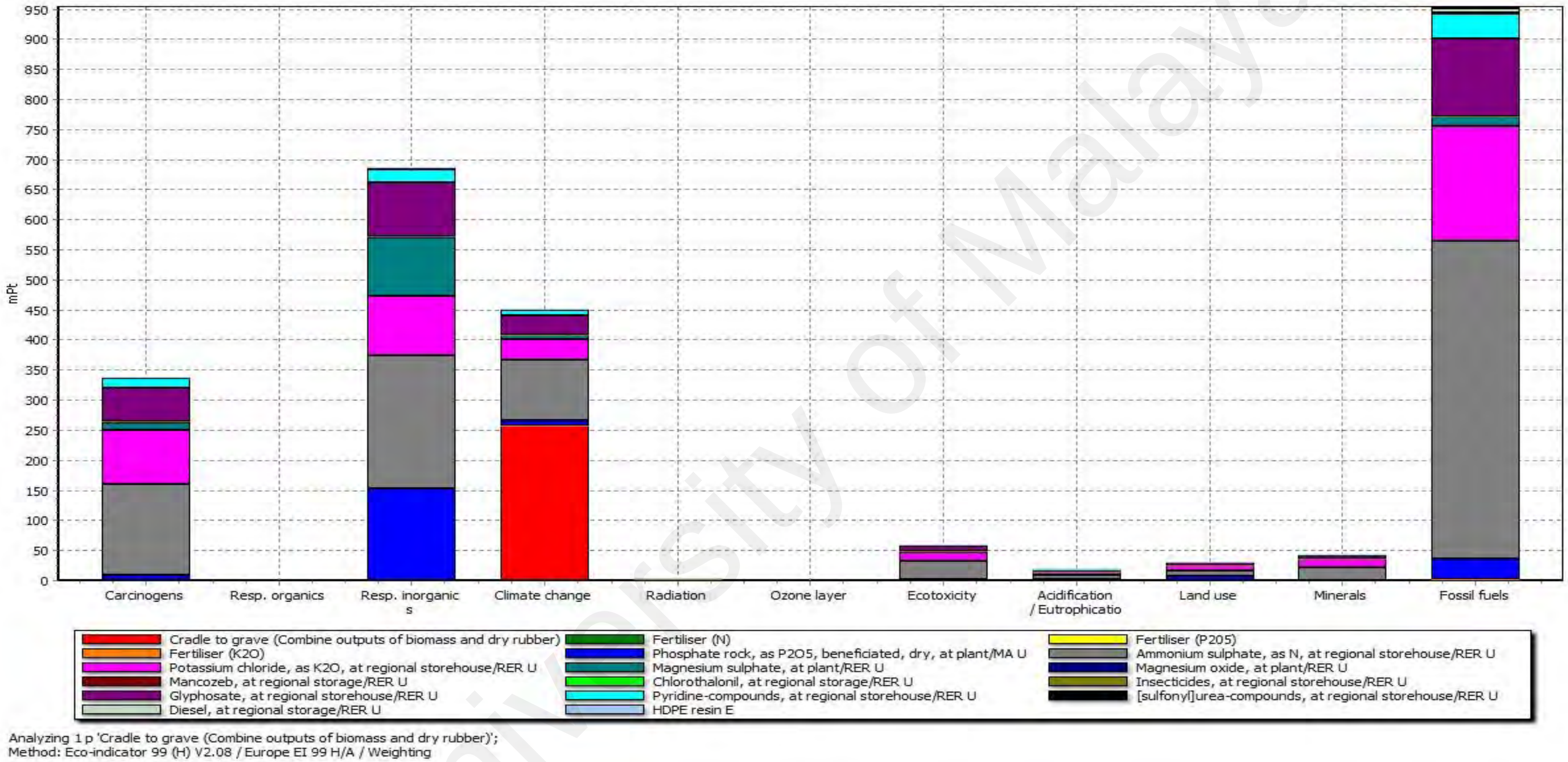

Figure 4.5: Weighting for the cultivation of one rubber tree from cradle to grave based on impact categories

Fossil fuels impact category is the most dominant representing 36.9% from the total value of 11 weighting impact categories in the cultivation of one rubber tree from cradle to grave (Figure 4.5 and Table 4.14). The other 3 dominant impact categories which are lower than fossil fuels are respiratory inorganics, climate change and carcinogens representing 26.5%, 17.4% and 13.1% respectively from the total weighted value in the cultivation of one rubber tree from cradle to grave (Figure 4.5 and Table 4.14).

The remaining 7 impact categories only represent a total of 6.1% from the total value of 11 impact categories in the cultivation of one rubber tree from cradle to grave and are considered as insignificant impact categories contributors (Figure 4.5 and Table 4.14).

For fossil fuels impact category, ammonium sulphate production is the single biggest contributor at 55.2% from the total value of 0.95 Pt (Figure 4.5). The contribution of ammonium sulphate production toward the total value of fossil fuels impact category in the production of one rubber tree from cradle to grave is through the usage of fossil fuels in in the form of natural gas, crude oil and hard coal as feed materials in the industrial furnaces to supply the needed heat during the ammonium sulphate production process (Ecoinvent, 2010).

For respiratory inorganics impact category, ammonium sulphate production is the highest contributor at 32.0% and follow by phosphate rock production at 22.2% from the total value of 0.69Pt (Figure 4.5). The emission to the air of inorganics substances in the form of PM 2.5 and PM 10 particulates, nitrogen oxide, sulphur dioxide, sulphate, sulphur trioxide and ammonia during the production of ammonium sulphate and phosphate rock as reported by Ecoinvent (2010) is responsible in contributing to the total value of respiratory inorganics impact category in the production of one rubber tree from cradle to grave.

For climate change impact category, the application of ammonium sulphate as the source of nitrogen in the cultivation of rubber trees during the immature and mature stage is the single highest contributor at 56.9% from the total value of 0.45Pt (Figure 4.5).

The application of ammonium sulphate to the rubber trees resulted in the direct and indirect emission of nitrous oxide as clearly formulated in IPCC (2006). Nitrous oxide is a greenhouse gas with global warming potential of 298 based on fourth assessment report (AR4) of (IPCC, 2007) is responsible in contributing to the total value of climate change impact category in the production of one rubber tree from cradle to grave.

The second highest contributor to the climate change impact category is ammonium sulphate production with contribution of 22.2% from the total value of climate change impact category (Figure 4.5). GHGs emission in the form of carbon dioxide, chloroform, methane, nitrous oxide and other types of GHGs release during the production of ammonium sulphate as reported in Ecoinvent (2010) is responsible in contributing to the total value of climate change impact category in the production of one rubber tree from cradle to grave.

Using the estimation that 51.3% of all planted rubber area in Malaysia is fertilized at the recommended dosage as the basis of calculation and the average stand of 410 rubber trees per hectare, the estimated impact for the cultivation of the rubber trees in Malaysia from cradle to grave based on 1.066 million hectares towards the three main weighting impact categories are summarized in Table 4.15.

Table 4.15: Estimated impact for the cultivation of the rubber trees in Malaysia from cradle to grave towards three main weighting impact categories

Impact category	Weighting value for the cultivation of rubber trees from cradle to grave in Malaysia (Pt)	
	based on 31.75 years	based on 1 year
Fossil fuels*	214,030,323	6,741,112.5
Respiratory inorganics*	154,026,094	4,851,215.6
Climate change*	101,118,168	3,184,824.2

Note: *Represent 80.8% from the total value of 11 weighting impact categories for the cultivation of rubber trees in Malaysia from cradle to grave (See Table 4.14).

In order to better understand the impact of these three main weighting impact categories for the cultivation of rubber trees in Malaysia from cradle to grave, the weighing values of these three main impact categories based on one year average is compared with the impact from the production of crude palm oil in Malaysia as summarized in Table 4.16.

Based on Table 4.16, the environmental impact from the cultivation of rubber trees from cradle to grave for a year basis is relatively very low as compared to the Malaysia production of crude palm oil in 2015.

Table 4.16: Weighting main impact categories for the cultivation of rubber trees from cradle to grave based on one year average as compared to the crude palm oil production in Malaysia

Impact category	Weighting value for the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (Pt)	Weighting value for the production of 1 tonne crude palm oil from cradle to gate in Malaysia# (Pt)	Production of crude palm oil in Malaysia equivalent to the weighting value for the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (Tonne)	Malaysia crude palm oil production for 2015* (Tonne)
Fossil fuels	6,741,112.5	23.77	283,597	19,961,581.0
Respiratory inorganics	4,851,215.6	29.8	162,792	19,961,581.0
Climate change	3,184,824.2	3.215	990,614	19,961,581.0

Source:# (Yusoff, 2006) , *(MPOB, 2017)

Damage in the form of extra energy that future generations must use to extract the fossil fuels as a results of lower quality fossil fuels due to the cultivation of rubber trees in Malaysia from cradle to grave based on one year average is equal to the fossil fuels damage value from the production of 283,597 tonnes of crude palm oil (Table 4.16).

For the respiratory effects on mankind due to the emission of inorganics substances to the air from the cultivation of rubber trees in Malaysia from cradle to grave based on one year average, its impact is equal to the respiratory inorganics damage value from the production of 162,792 tonnes of crude palm oil(Table 4.16).

In the case of climate change impact on humans in the form of an increase in diseases and death, the climate impact from the cultivation of rubber tree in Malaysia from cradle to grave based on one year average is equal to the climate change damage value from the production of 990,614 tonnes of crude palm oil (Table 4.16).

The impact from the cultivation of rubber trees in Malaysia from cradle to grave based on a year average are equal to 1.42%,0.82% and 4.96% from the fossil fuels, respiratory inorganics and climate change impact categories of the crude palm oil production in Malaysia for 2015 (Table 4.16).

The differences in these percentage is due to the ranking of fossil fuels, respiratory inorganics and climate change impact categories in the cultivation of rubber tree from cradle to grave is not the same as the ranking of these three impact categories in the production of crude palm oil. In the production of crude oil palm in Malaysia as reported by Yusoff (2006), respiratory inorganics is the highest contributor at 48.7% while climate change is the fourth contributor at 5.3% from the total value of 11 weighting impact categories.

Nevertheless the important points that can be derived from this comparison is that the impact from these three main impact categories during the cultivation of rubber trees in Malaysia from cradle to grave based on a year average is very low as compared to the same impact based on the production of crude palm oil in Malaysia. To explain it further from the perspective of Malaysian environmental impact for the cultivation of rubber trees from cradle to grave in Malaysia, the total weighted value from the 11 weighting impact categories in the cultivation of one rubber tree from cradle to grave in Malaysia is used as the basis of the calculation.

The total weighted value from the 11 weighting impact categories in the cultivation of one rubber tree from cradle to grave is 2.59 Pt which is equal to 0.00259 PE as explained by PRe Consultants (2000)(Table 4.14).

Relating this total weighted value of 0.00259 PE to 1.066 million hectares of land planted with rubber in Malaysia at the average stand of 410 rubber trees per hectare from this study and with 51.3% of this rubber planted area is fertilized at the recommended dosage and the population of 31.7 million people in Malaysia, the impact from the total cultivation of the rubber trees in Malaysia from cradle to grave in 31.75 year is responsible for 1.83% of the Malaysian environmental impacts.

If we look on the impact from a year average perspective, the impact from the total cultivation of the rubber trees in Malaysia from cradle to grave for a year is responsible for only 0.058% of the Malaysian environmental impacts. This is relatively lower as compared to the production of crude palm oil in Malaysia in 2015 which contribute to 3.8% of the Malaysian environmental impacts.

Single Score

In the cultivation of one rubber tree from cradle to grave, health effects to the human and resources depletion are the two greatest concerns that need to be addressed properly by the current management of rubber smallholdings and may need special attention in the future replanting program (Table 4.17 and Figure 4.6).

Table 4.17: Cultivation of one rubber tree from cradle to grave based on damage categories

Damage category	Unit	Total	Percentage (%)
Human Health	Pt	1.48	57.3
Ecosystem Quality	Pt	0.11	4.2
Resources	Pt	1.00	38.5
Total	Pt	2.59	100.0

Human health damage category contributes 57.3% while resource damage category contributes 38.5% toward the total value of the three damage categories (Table 4.17 and Figure 4.6). Ecosystem quality damage category recorded the lowest impact at 4.2% from the total value of the three damage categories in the cultivation of one rubber tree from cradle to grave (Table 4.17 and Figure 4.6).

For the cultivation of one rubber tree from cradle to grave based on process, it is a clear evident that ammonium sulphate production is the single highest process contributor representing 41.3% from the total value of the three damage categories (Figure 4.6)

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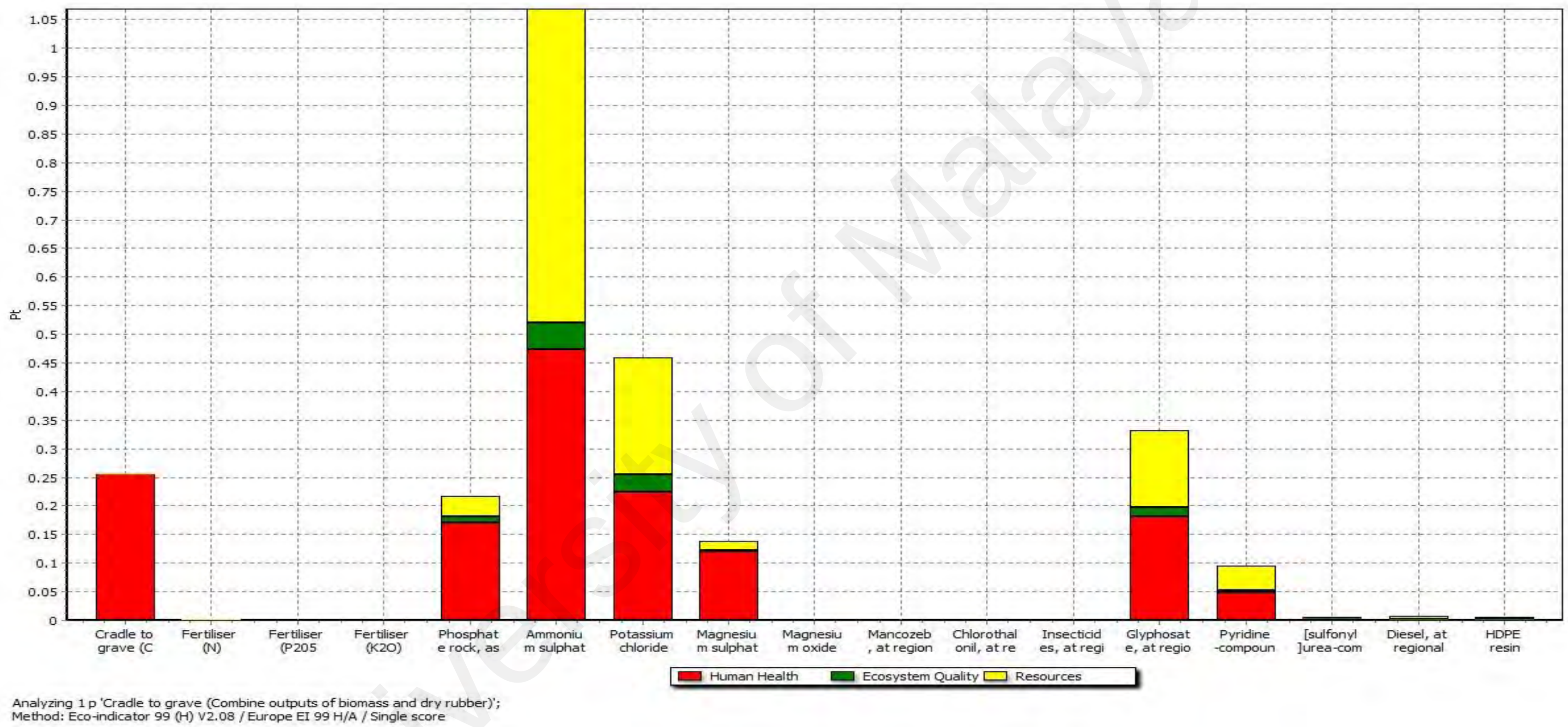

Figure 4.6: Single score for the cultivation of one rubber tree from cradle to grave based on damage categories

For ammonium sulphate production, fossil fuels impact category is the biggest concern as it represents 49.4% from the total impact in the production of ammonium sulphate (Figure 4.7). This is followed by respiratory inorganics, carcinogens and climate change impact categories with contribution of 20.6%, 14.2% and 9.4% respectively towards the total impact from the production of ammonium sulphate (Figure 4.7). The remaining 7 impact categories are considered insignificant contributors towards the environmental impact in the production of ammonium sulphate (Figure 4.7).

As ammonium sulphate input is very important in the cultivation of rubber trees from cradle to grave, the environmental impact from the usage of this fertilizer is unavoidable. In order to achieve the sustainability in the rubber cultivation there is a need to do a check and balance approach between supplying the adequate amount of ammonium sulphate to the rubber trees and at the same time preventing excessive application of this fertilizer. The adequate amount of ammonium sulphate is needed in order to maintain the healthy growth of the rubber trees and to maximize its yield capacity. An excessive usage of ammonium sulphate is not only increasing the cost in maintaining the rubber trees but it also can lead to a greater environmental impact.

The optimum usage of ammonium sulphate during the mature rubber stage is one of the possible strategies to avoid the excessive usage of this fertilizer that can be detrimental to the environment in the cultivation of rubber trees from cradle to grave in Malaysia. This is important as the mature rubber stage represent on average 78.7% from the total life cycle of the rubber trees from cradle to grave.

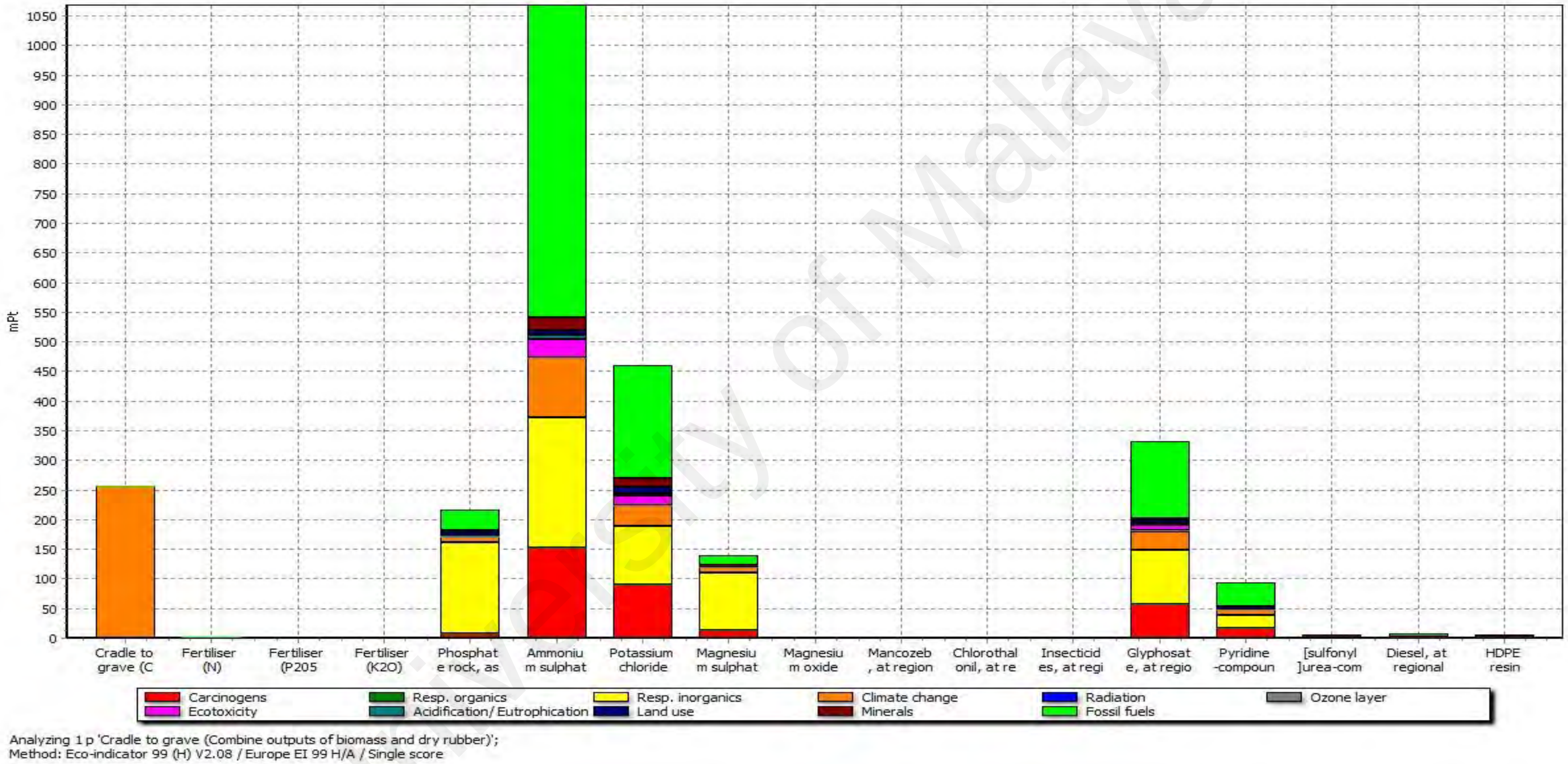

Figure 4.7: Single score results in the cultivation of one rubber tree from cradle to grave based on impact categories

According to Malaysian Rubber Board (2009), the uptake of nitrogen is most active at the commencement of refoliation up to five months thereafter. The application of ammonium sulphate during this period will definitely optimize the utilization of nitrogen by the rubber trees. The management of rubber smallholders needs to ensure a proper planning in procurement and delivery of the fertilizer to the smallholders so that the application of the ammonium sulphate fertilizer can be done within the recommended period without difficulties.

4.1.3 LCIA on GHGs Emission for the Cultivation of Rubber Tree from Cradle to Grave

The total GHGs emission value for the cultivation of one rubber tree from cradle to grave based on this study is 44.68 kgCO_2eq (Figure 4.8 and Table 4.19). Direct and indirect nitrous oxide (N_2O) emission from the application of ammonium sulphate at 24.28 kg$C0_2$eq is the single highest contributor representing 54.34% from the total GHGs emission in the cultivation of one rubber tree from cradle to grave (Figure 4.8).

The second highest contributor to the total GHGs emission in the cultivation of one rubber tree from cradle to grave is the ammonium sulphate production at 23.54% while potassium chloride recorded the third highest contribution at 8.09% from the total GHGs emission in the cultivation of one rubber tree from cradle to grave (Figure 4.8).

Glyphosate production recorded 7.51% while the remaining 13 processes are considered as insignificant contributors towards the total value of GHGs emission in the cultivation of one rubber tree from cradle to grave (Figure 4.8).

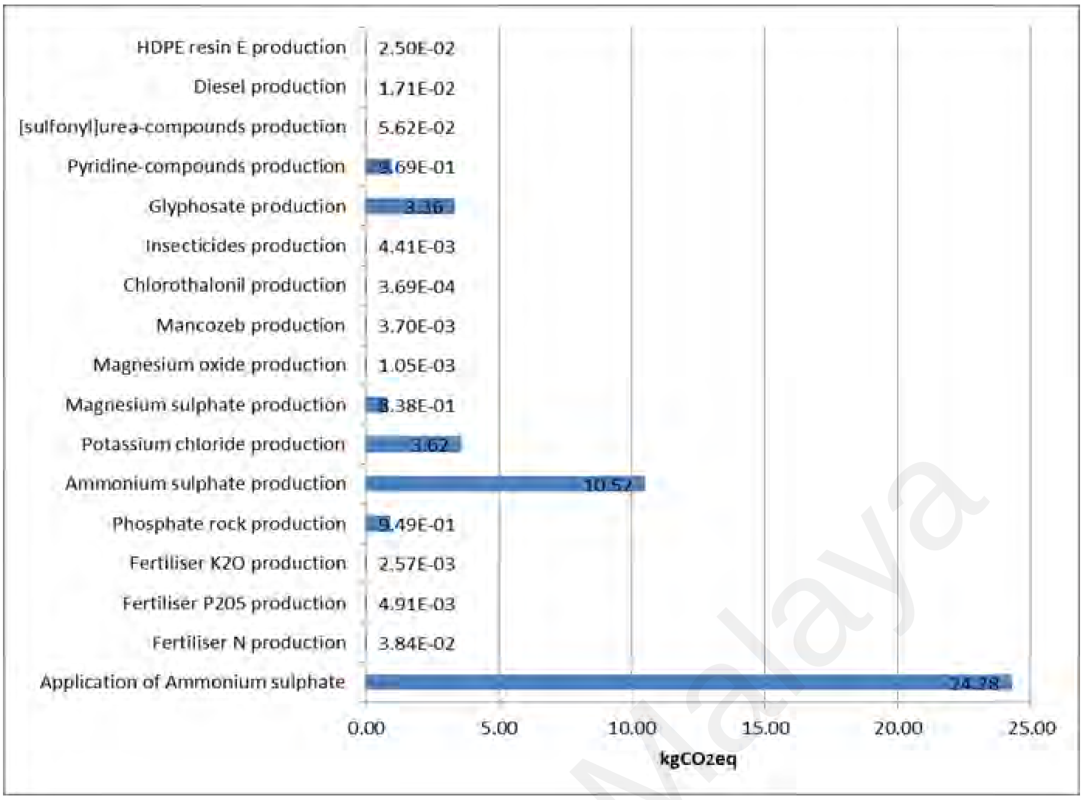

Figure 4.8: GHGs emission for the cultivation of one rubber tree from cradle to grave

From Figure 4.8, it is obvious that production and usage of ammonium sulphate are the two major processes responsible for 77.9% from the total GHGs emission in the cultivation of one rubber tree from cradle to grave. The reduction in the usage of ammonium sulphate will definitely reduce the GHGs emission from the cultivation of one rubber tree from cradle to grave. Among the possible strategy to reduce the amount of ammonium sulphate usage is through the optimum utilization of ammonium sulphate during the mature rubber stage as explained in details in the section 4.1.2.

The GHGs emission for the cultivation of rubber trees from cradle to grave in Malaysia based on estimation that 51.3% of the 1.066 million hectares rubber planted area with the average stand of 410 rubber trees per hectare is fertilized at the recommended dosage is summarized in Table 4.18.

Table 4.18: GHGs emission for the cultivation of rubber trees in Malaysia from cradle to grave

	Cradle to grave (31.75 Years)	Average one year for cradle to grave
GHGs emission ($GgCO_2eq$)	10,018.39	315.54
Percentage from Malaysia 2011 GHGs emission (%)*	3.45	0.11
Percentage from agriculture sector in Malaysia 2011 GHGs emission (%)*	63.51	2.0

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on Table 4.18, the GHGs emission value for the 31.75 years cradle to grave cultivation of rubber trees in Malaysia is very low and only represent 3.45% from the Malaysian 2011 GHGs emission of 290,230 GgCO2eq (Ministry of Natural Resources and Environment Malaysia, 2015).

The GHGs emission value based on the average one year cradle to grave cultivation of rubber trees in Malaysia at 315.54 $GgCO_2eq$ only represent 0.11% from the Malaysian 2011 GHGs emission and is considered as insignificant as compared to the Malaysian 2011 GHGs emission (Table 4.18).

The GHGs emission value of 10018.39 $GgCO_2eq$ for the 31.75 years cradle to grave cultivation of rubber trees in Malaysia is very significant and represent 63.5% from the 2011 Malaysian agricultural sector GHGs emission of 15775 GgCO2eq (Table 4.18).

The GHGs emission value based on the average one year cradle to grave cultivation of rubber trees in Malaysia at 315.54 GgCO2eq only represent 2% from the 2011 Malaysian agricultural sector GHGs and is considered as relatively very low (Table 4.18).

The list of GHGs emission and its corresponding values in contributing to the total GHGs emission value for the cultivation of one rubber tree from cradle to grave is shown in Table 4.19

Table 4.19: GHGs emission profile for the cultivation of one rubber tree from cradle to grave

GHGs	Weight in $kgCO_2eq$
Carbon dioxide	18.98
Chloroform	6.47E-07
Nitrous oxide	24.47
Ethane, 1,1-difluoro-, HFC-152a	5.23E-07
Ethane, 1,1,1-trichloro-, HCFC-140	2.69E-09
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	0.001922
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	6.22E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	5.84E-04
Ethane, hexafluoro-, HFC-116	6.27E-03
Methane	1.18
Methane, bromo-, Halon 1001	1.36E-15
Methane, bromochlorodifluoro-, Halon 1211	4.49E-04
Methane, bromotrifluoro-, Halon 1301	4.10E-04
Methane, chlorodifluoro-, HCFC-22	1.60E-03
Methane, dichloro-, HCC-30	5.55E-06
Methane, dichlorodifluoro-, CFC-12	2.70E-04
Methane, dichlorofluoro-, HCFC-21	1.01E-09
Methane, monochloro-, R-40	6.98E-09
Methane, tetrachloro-, CFC-10	1.90E-03
Methane, tetrafluoro-, CFC-14	2.95E-02
Methane, trichlorofluoro-, CFC-11	5.15E-08
Methane, trifluoro-, HFC-23	3.14E-05
Sulfur hexafluoride	1.60E-02
Total GHGs Emission	44.68

Nitrous oxide and carbon dioxide (CO_2) are the two major GHGs that contribute 97.3% from the total GHGs emission value for the cultivation of one rubber tree from cradle to grave (Table 4.19). Only carbon dioxide and nitrous oxide emission will be discussed in details as other GHGs emission are considered as insignificant contributors towards the total GHGs emission value for the cultivation of one rubber tree from cradle to grave (Table 4.19).

Carbon dioxide emission

Carbon dioxide emission contribute 42.5% from the total GHGs emission value for the cultivation of one rubber tree from cradle to grave (Table 4.19).The values of the carbon dioxide emission for the cultivation of one rubber tree from cradle to grave based on process involved is shown in Table 4.20.

Table 4.20: Carbon dioxide emission values based on process involved for the cultivation of one rubber tree from cradle to grave

Process	CO_2 (kg)
Ammonium sulphate production	9.94
Potassium chloride production	3.21
Glyphosate production	3.12
Phosphate rock production	9.07E-01
Pyridine-compounds production	8.96E-01
Magnesium sulphate production	7.93E-01
[sulfonyl]urea-compounds production	4.90E-02
HDPE resin E production	2.04E-02
Diesel production	1.55E-02
Fertilizer N production	1.28E-02
Fertilizer P205 production	4.65E-03
Insecticides production	4.03E-03
Mancozeb production	3.47E-03
Fertilizer K2O production	2.38E-03
Magnesium oxide production	1.04E-03
Chlorothalonil production	3.39E-04
Total CO_2 Emission	18.98

Ammonium sulphate production is the single major carbon dioxide emission contributor representing 52.4% from the total carbon dioxide emission for the cultivation of one rubber tree from cradle to grave (Table 4.20). The chemical production of synthetic fertilizer such as ammonium sulphate is an energy intensive process that releases a relatively high emission of carbon dioxide (Jawjit et al., 2010).

According to (Mathews & Ardiyanto, 2015), ammonium sulphate production had the lowest emission of carbon dioxide among the nitrogenous fertilizers with a value of 0.42kg CO_2 per kg of ammonium sulphate. In this study, 0.534 kg CO_2 is release per kg of ammonium sulphate production and this represent 94.5% from the total GHGs emission for the production of 1 kg ammonium sulphate (Ecoinvent, 2010).

The second and third highest contributor to the total carbon dioxide emission for the cultivation of one rubber tree from cradle to grave is potassium chloride and glyphosate productions at 16.9% and 16.4% respectively (Table 4.20).

In this study, production of 1kg of potassium chloride release 0.27 kg CO_2 and this represent 88.8% from the total GHGs emission for the production of 1 kg potassium chloride (Ecoinvent, 2010). The carbon dioxide emission value in this study is slightly lower than the average carbon dioxide emission value of 0.37 kg CO_2 per kg of potassium chloride from the various study as reported in (Mathews & Ardiyanto, 2015).

Other than ammonium sulphate, potassium chloride and glyphosate productions, the rest of the processes involved are considered as insignificant contributors towards the total value of the carbon dioxide emission for the cultivation of one rubber tree from cradle to grave (Table 4.20).

The carbon dioxide emission for the cultivation of one rubber tree from cradle to grave is 18.98 $kgC0_2$ (Table 4.20). Relating this figure to the total rubber planted area in Malaysia of 1.066 million hectares with the estimation that 51.3% of the rubber planted area is fertilized at the recommended dosage and the average stand of 410 rubber trees per hectare, the estimated carbon dioxide emission for the cultivation of rubber trees in Malaysia is summarized in Table 4.21.

Table 4.21: Estimated carbon dioxide emission for the cultivation of rubber trees in Malaysia from cradle to grave

	Cradle to grave (31.75 Years)	Average one year for cradle to grave
Carbon dioxide emission ($GgCO_2$)	4,256.1	134.05
Percentage from Malaysia 2011 carbon dioxide emission (%)*	2.04	0.06

*Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on Table 4.21, carbon dioxide emission for an average one year cultivation of the rubber trees in Malaysia from cradle to grave perspective at 134.05 $GgCO_2$ is considered as insignificant as compared to the reported Malaysian 2011 carbon dioxide emission value of 208,258 $GgCO_2$(Ministry of Natural Resources and Environment Malaysia, 2015).

Nitrous oxide emission

Nitrous oxide emission represents 54.8% from the total GHGs emission value in the cultivation of one rubber tree from cradle to grave (Table 4.19).

The values of the nitrous oxide emission for the cultivation of one rubber tree from cradle to grave based on process involved are shown in Table 4.22.

Table 4.22: Nitrous oxide (N_20) emission values based on process for the cultivation of one rubber tree from cradle to grave

Parameter	N_20 (kg)
Ammonium sulphate production	1.21E-04
Potassium chloride production	2.65E-04
Glyphosate production	7.31E-05
Phosphate rock production	2.78E-05
Pyridine-compounds production	1.84E-05
Magnesium sulphate production	2.67E-05
[sulfonyl]urea-compounds production	8.81E-06
HDPE resin E production	1.03E-14
Diesel production	2.95E-07
Fertilizer N production	8.07E-05
Fertilizer P205 production	1.58E-07
Insecticides production	3.41E-07
Mancozeb production	8.60E-08
Fertilizer K2O production	1.89E-07
Magnesium oxide production	5.51E-09
Chlorothalonil production	6.65E-09
Ammonium sulphate application	8.15E-02
Total N_20 Emission	8.21E-02

Nitrous oxide in the form of direct and indirect emissions from the application of ammonium sulphate to the soil is the single most important source of nitrous oxide emission representing 99.2% from the total nitrous oxide emission value for the cultivation of one rubber tree from cradle to grave (Table 4.22).

Nitrous oxide is produced naturally in soil through the processes of nitrification and denitrification (IPCC, 2006). The emission of nitrous oxide from the soil can be increased through application of nitrogen fertilizer to the soil in the direct emission process (Jawjit et al., 2010).

According to Kramer *et al*. in Zawawi (2012), the application of nitrogen fertilizers contributed to direct emission of nitrous oxide as a results of denitrification. Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification that leaks from microbial cell into soils and ultimately into atmosphere and one of the main controlling factors in this reaction is the availability of inorganic nitrogen in the soil (IPCC, 2006). The indirect nitrous oxide emission are emissions that are induced by the nitrogen fertilizer use, but taking place elsewhere after nitrogen loses from the fertilized fields (Jawjit et al., 2010). These losses include nitrogen leaching and runoff, and emissions of nitrogen fertilizer as nitrogen oxides (NOx) or ammonia (NH_3)(Jawjit et al., 2010).

Nitrous oxide emission value for the cultivation of one rubber tree from cradle to grave is 24.47 kgC0_2eq based on its global warming potential of 298 (IPCC, 2007). Relating this to the total rubber planted area in Malaysia of 1.066 million hectares with estimation that 51.3% of the rubber planted area is fertilized at the recommended dosage and the average stand of 410 rubber trees per hectare, the estimated nitrous oxide emission for the cultivation of rubber trees in Malaysia is summarized in Table 4.23.

Table 4.23: Estimated nitrous oxide emission for the cultivation of rubber trees in Malaysia from cradle to grave

	Cradle to grave (31.75 Years)	Average one year for cradle to grave
Nitrous oxide emission (GgCO_2eq)	5,485.5	172.8
Percentage from Malaysia 2011 Nitrous oxide emission (%)*	40.41	1.27

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on Table 4.23, nitrous oxide emission for an average one year cultivation of the rubber trees in Malaysia from cradle to grave perspective at 172.8 GgCO_2eq is considered as very low as compared to the reported Malaysia 2011 nitrous oxide emission value of 13,574 $GgCO_2eq$ (Ministry of Natural Resources and Environment Malaysia, 2015).

4.2 Completeness, Sensitivity and Consistency

Completeness check, sensitivity check and consistency check are the three techniques that should be considered as part of the evaluation in the interpretation phase that must be carried out in order to establish confidence in the results of LCA (ISO 14044, 2006; Thannimalay, 2013).

4.2.1 Completeness Check

The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete (ISO 14044, 2006). In this study, all the data from each of the boundaries have been described comprehensively and data source are described thoroughly in the chapter 3. The list of exclusions and its justification are also being described thoroughly in the chapter 3. All the relevant information and data used in this study is viewed as sufficient to reach conclusion in accordance with the goal and scope definition.

4.2.2. Sensitivity Check

The objective of the sensitivity check is to assess the reliability of the results and how they are affected by uncertainties in data, LCIA methods and assumption (Thannimalay, 2013). Sensitivity analysis tries to determine the influence of variations in assumption, method and data on the results (ISO 14044, 2006). Sensitivity analysis is a comparison of the results obtained using certain given assumptions, methods or data with the results obtained using altered assumptions, methods or data (ISO 14044, 2006).

4.2.2.1 Sensitivity Analysis of Ammonium Sulphate Usage in Mature Boundary

In this study, ammonium sulphate usage from the mature rubber boundary was found to represent 86.1% from the total usage of ammonium sulphate in the cultivation of one rubber tree from cradle to grave. A sensitivity analysis was done to evaluate the environmental impacts from the usage of ammonium sulphate from the mature rubber boundary in this study as compared to the recommended value of ammonium sulphate usage in the mature rubber boundary from the literature. The summary of the comparison is shown in Table 4.24.

Table 4.24: Comparison of ammonium sulphate usage in the mature rubber boundary for sensitivity analysis

Parameter	Lowest value*	This study	Highest value*
Ammonium sulphate usage (kg/Tree/25 Years)	12.50	16.04	20.10

*Source: (Malaysian Rubber Board, 2009)

According to (Malaysian Rubber Board, 2009), the lowest recommended value of 0.50 kg/tree/year of ammonium sulphate can only be applied to the mature rubber trees that had received adequate fertilizers during their immature period. If the mature rubber trees during their immaturity period did not received adequate fertilizers, the highest value of 0.804 kg/tree/year of ammonium sulphate is recommended to be applied to the mature rubber trees (Malaysian Rubber Board, 2009).

Weighting

The results for this sensitivity analysis study are shown in Figure 4.9 and Table 4.25

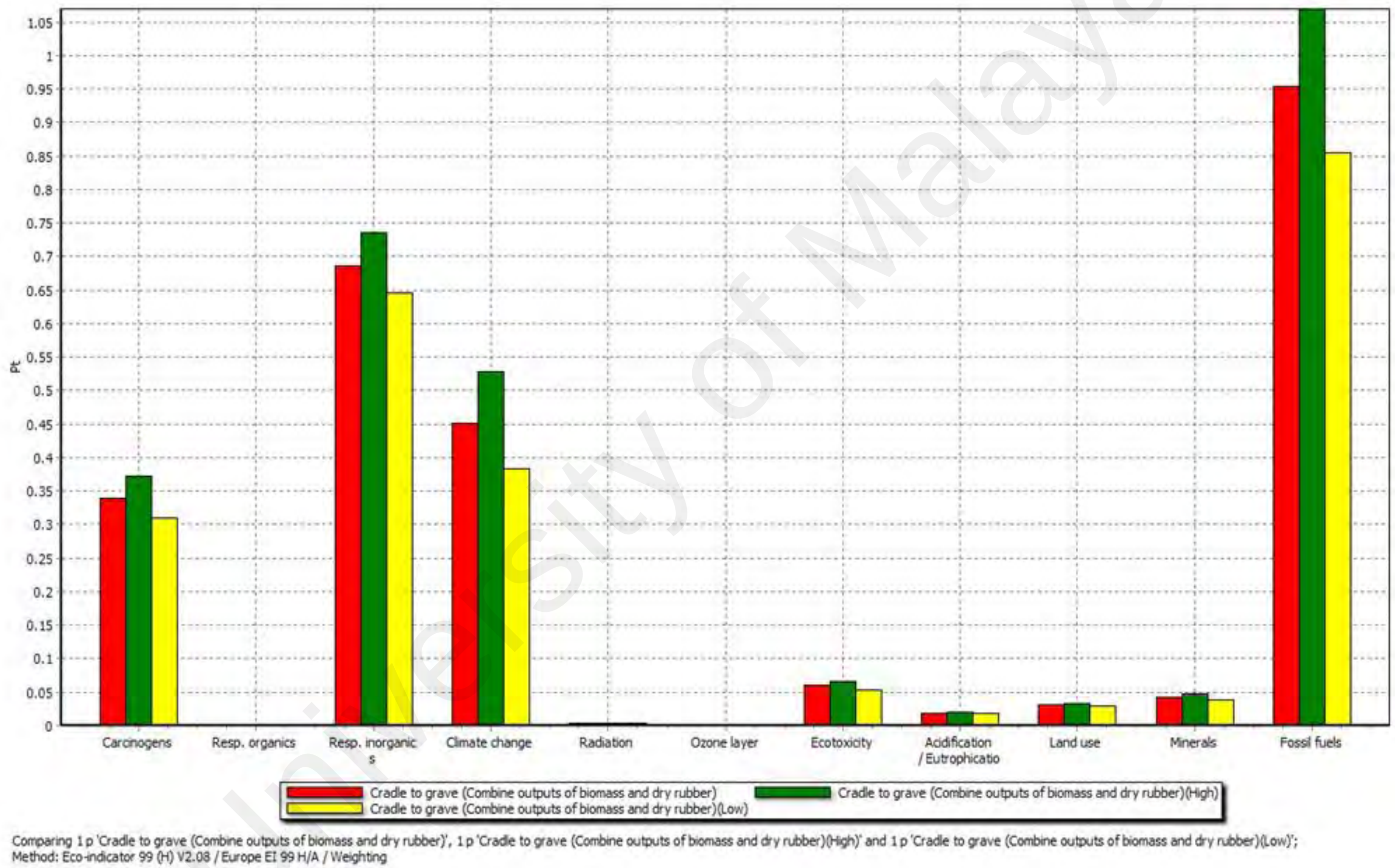

Figure 4.9: LCIA weighting for different ammonium sulphate usage rate in the mature rubber boundary

Table 4.25: Weighting values based on different ammonium sulphate usage rate for the cultivation of one rubber tree from cradle to grave

Impact category	Unit	Ammonium sulphate usage		
		Lowest value	This study	Highest value
Total	Pt	2.337	2.589	2.877
Carcinogens	Pt	0.310	0.339	0.372
Resp. organics	Pt	0.001	0.001	0.001
Resp. inorganics	Pt	0.645	0.687	0.735
Climate change	Pt	0.383	0.451	0.529
Radiation	Pt	0.004	0.004	0.005
Ozone layer	Pt	0.000	0.000	0.000
Ecotoxicity	Pt	0.054	0.060	0.066
Acidification/ Eutrophication	Pt	0.017	0.019	0.021
Land use	Pt	0.029	0.031	0.033
Minerals	Pt	0.039	0.043	0.047
Fossil fuels	Pt	0.854	0.955	1.069

This sensitivity analysis results obviously show that the increase in the ammonium sulphate usage is directly responsible for the increase in the environmental impact for the cultivation of one rubber tree from cradle to grave (Figure 4.9 and Table 4.25). The total weighting value from the usage of ammonium sulphate from this study is 9.7% higher than the lowest recommended value of ammonium sulphate usage for mature rubber boundary (Table 4.25). The total weighting value from the highest recommended value of ammonium sulphate usage is 10.0% higher than the total weighting value from the usage of ammonium sulphate from this study (Table 4.25).

There are four main impact categories that are directly affected by the cultivation of one rubber tree from cradle to grave while the rest of the impact categories are considered as insignificant (Figure 4.9 and Table 4.25). These four impact categories are fossil fuels, respiratory inorganics, climate change and carcinogens.

Greenhouse gases emission

The GHGs emission value for the cultivation of one rubber tree from cradle to grave based on varied values of ammonium sulphate usage rate in this sensitivity analysis is shown in Table 4.26.

Table 4.26: GHGs emission based on different amount of ammonium sulphate usage rate in the mature rubber boundary

Parameter	Ammonium sulphate usage in mature rubber boundary for the cultivation of one rubber tree from cradle to grave		
	Lowest value	This study	Highest value
GHGs emission ($kgCO_2eq$)	38.08	44.68	52.26

The GHGs emission value for the cultivation of one rubber tree from this study is 14.8% higher than the GHGs emission value from the lowest recommended value of ammonium sulphate usage (Table 4.26).The GHGs emission value for the cultivation of one rubber tree from the highest recommended value is 14.5% higher than GHGs emission value from this study (Table 4.26).

Ammonium sulphate application which resulted in the direct and indirect emission of nitrous oxide and the production of ammonium sulphate contribute 77.8% from the total GHGs emission value for the cultivation of one rubber tree from this study. As ammonium sulphate usage from the mature rubber boundary represent 86.1% from the total usage of ammonium sulphate in the cultivation of one rubber tree from cradle to grave, the increase in the usage of ammonium sulphate in the mature rubber boundary will definitely increase the GHGs emission value for the cultivation of one rubber tree from cradle to grave.

As conclusion, the increase in the amount of ammonium sulphate usage from mature rubber boundary in the cultivation of one rubber tree from cradle to grave will definitely increase the total LCIA weighting value and GHGs emission associated with it.

The total LCIA weighting value and GHGs emission value for the cultivation of rubber trees from cradle to grave has the potential to be reduced if the rubber trees during their immature stage are fertilized adequately according to the recommended value.

Based on this finding, it is important for the rubber related agencies in Malaysia to educate the rubber smallholders on the important of fertilizing their immature rubber trees adequately so that the amount of fertilizers required in the future up keeping of the rubber trees are relatively lower.

This practice is not only beneficial in terms of lowering the cost of future fertilizers requirement during the mature rubber boundary but what is also equal important is the overall potential reduction of the environmental impact associated with the rubber cultivation from cradle to grave in Malaysia.

4.2.3 Consistency Check

The objective of the consistency check is to determine whether the assumptions, methods and data are consistent with the goal and scope definition (ISO 14044, 2006). In this study, the assumptions and data are consistently applied in accordance with the goal and scope definition before conclusions are made.

4.3 Critical Process and Alternative Scenario

From the results of the LCA for the cultivation of one rubber tree from cradle to grave, it was clear that the main polluting processes are ammonium sulphate production and ammonium sulphate application. Alterations will be made on these processes in order to visualize the environmental impact and GHGs emission based on the alternative scenario.

In this alternative scenario, the environmental impact and GHGs emission from the usage of ammonium nitrate is compared to the usage of ammonium sulphate for the cultivation of one rubber tree from cradle to grave. Ammonium sulphate contains 21% N while ammonium nitrate contains 35% N.

In this alternative scenario, the comparison is made based on the same amount of N i.e. 3.91 kg N/tree/ life cycle regardless of the initial weight of both fertilizers. In order to use this scenario, both of the fertilizers must be applied during the dry season as the losses due to leaching from ammonium nitrate is very low during the dry season and therefore it is comparable with ammonium sulphate characteristic of low leaching loss.

Characterization

All impact categories in the characterization impact assessment with the exception of respiratory organics show an increase in the value from the usage of ammonium nitrate as the source of N for the cultivation of one rubber tree from cradle to grave (Figure 4.10). Respiratory organics impact category value from the usage of ammonium nitrate recorded 4.9% lower as compared to the usage of ammonium sulphate in the cultivation of one rubber tree from cradle to grave (Figure 4.10).

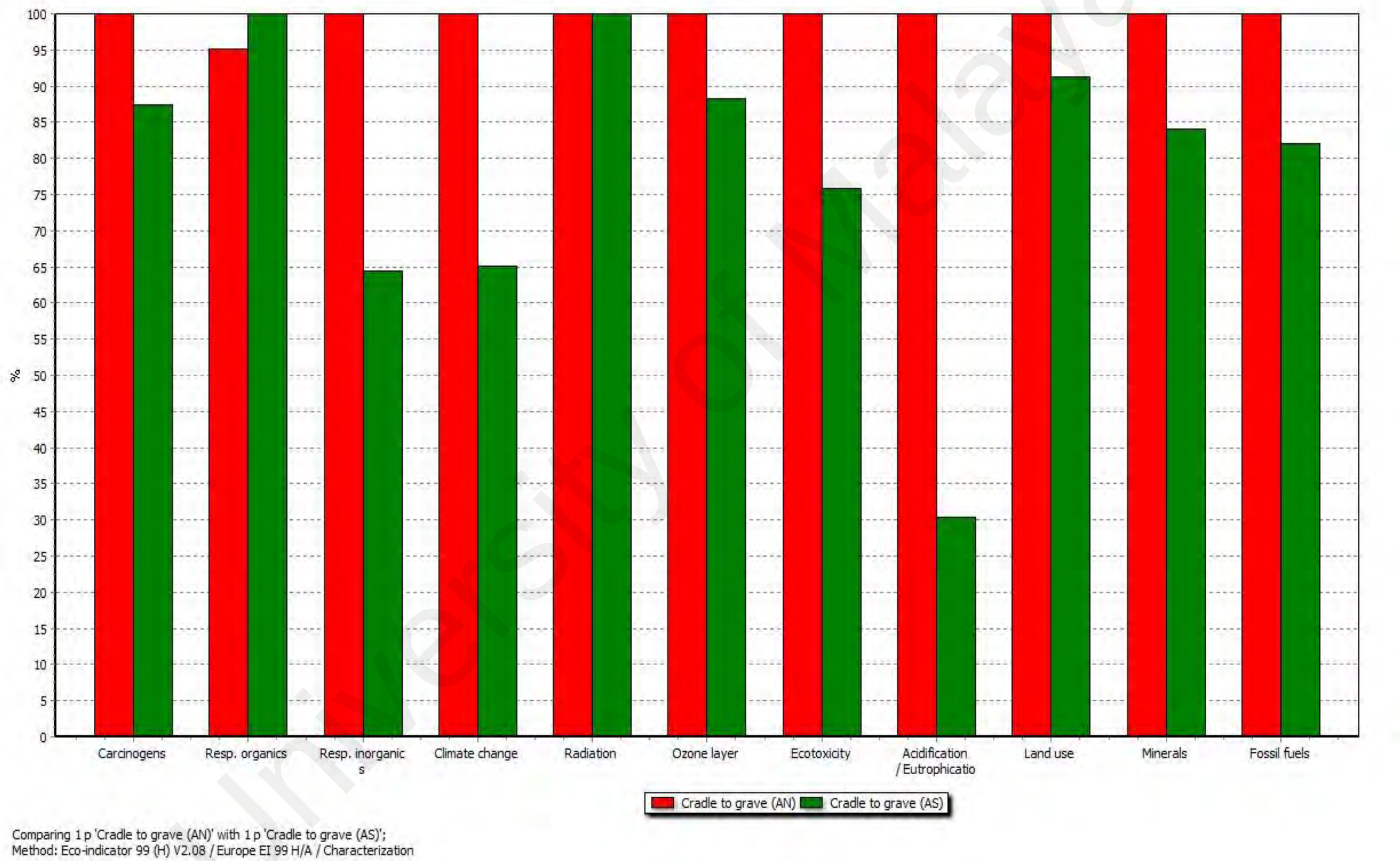

Figure 4.10: LCIA characterization results based on different types of N fertilizers

The relatively higher value of respiratory organics impact category from the usage of ammonium sulphate is due to the 17.7% higher emission of non-methane volatile organic compound from the production of ammonium sulphate as compared to emission of non-methane volatile organic compound from the production of ammonium nitrate based on the same amount of N (Ecoinvent, 2010). Non-methane volatile organic compound is the single main emission that contribute 78.3% and 85.2% respectively towards the total value of respiratory organic impact category in the production of ammonium nitrate and ammonium sulphate based on the same amount of N (Ecoinvent, 2010).

Acidification/Eutrophication impact category value recorded the highest difference between the usages of these two types of N fertilizers (Figure 4.10). Acidification/Eutrophication value from the usage of ammonium nitrate recorded 69.7% higher than the usage of ammonium sulphate (Figure 4.10). The obviously higher value of Acidification/Eutrophication impact category from the usage of ammonium nitrate is due to emission of ammonia and nitrogen oxides from the production of ammonium nitrate which are 99.3% and 73.9% higher as compared to the emission of the same gases from the production of ammonium sulphate based on the same amount of N (Ecoinvent, 2010). These two gases represent 96.9% and 80.0% from the total value of Acidification/Eutrophication impact category in the production of ammonium nitrate and ammonium sulphate based on the same amount of N (Ecoinvent, 2010).

Weighting

The weighting result for this alternative scenario study is shown in Table 4.27 and Figure 4.11. The total value of weighting impact assessment from the usage of ammonium nitrate at 3.54Pt is 26.9% higher as compare to the total weighting value from the usage of ammonium sulphate for the cultivation of one rubber tree from cradle to grave (Table 4.27).

Table 4.27: Weighting value based on different types of N fertilizers

Impact category	Unit	Type of N fertilizer	
		Ammonium nitrate	Ammonium sulphate
Total	Pt	3.54050	2.58872
Carcinogens	Pt	0.38791	0.33881
Resp. organics	Pt	0.00072	0.00075
Resp. inorganics	Pt	1.06597	0.68697
Climate change	Pt	0.69211	0.45099
Radiation	Pt	0.00436	0.00435
Ozone layer	Pt	0.00020	0.00017
Ecotoxicity	Pt	0.07871	0.05964
Acidification/ Eutrophication	Pt	0.06245	0.01895
Land use	Pt	0.03375	0.03082
Minerals	Pt	0.05075	0.04267
Fossil fuels	Pt	1.16358	0.95459

Fossil fuels, respiratory inorganics, climate change and carcinogens are the four main weighting impact categories contributors to the total value of weighting impact assessment for both fertilizers while the remaining impact categories are considered as insignificant contributors (Figure 4.11).

These four main impact categories represent 93.5% and 93.9% respectively towards the total value of weighting impact assessment for ammonium nitrate and ammonium sulphate usage based on the same amount of N for the cultivation of one rubber tree from cradle to grave (Table 4.27). The values for these four significant impact categories i.e. fossil fuels, respiratory inorganics, climate change and carcinogens recorded 18.0%, 35.6%, 34.8% and 12.7% higher from the usage of ammonium nitrate as compared to the usage of ammonium sulphate (Figure 4.11).

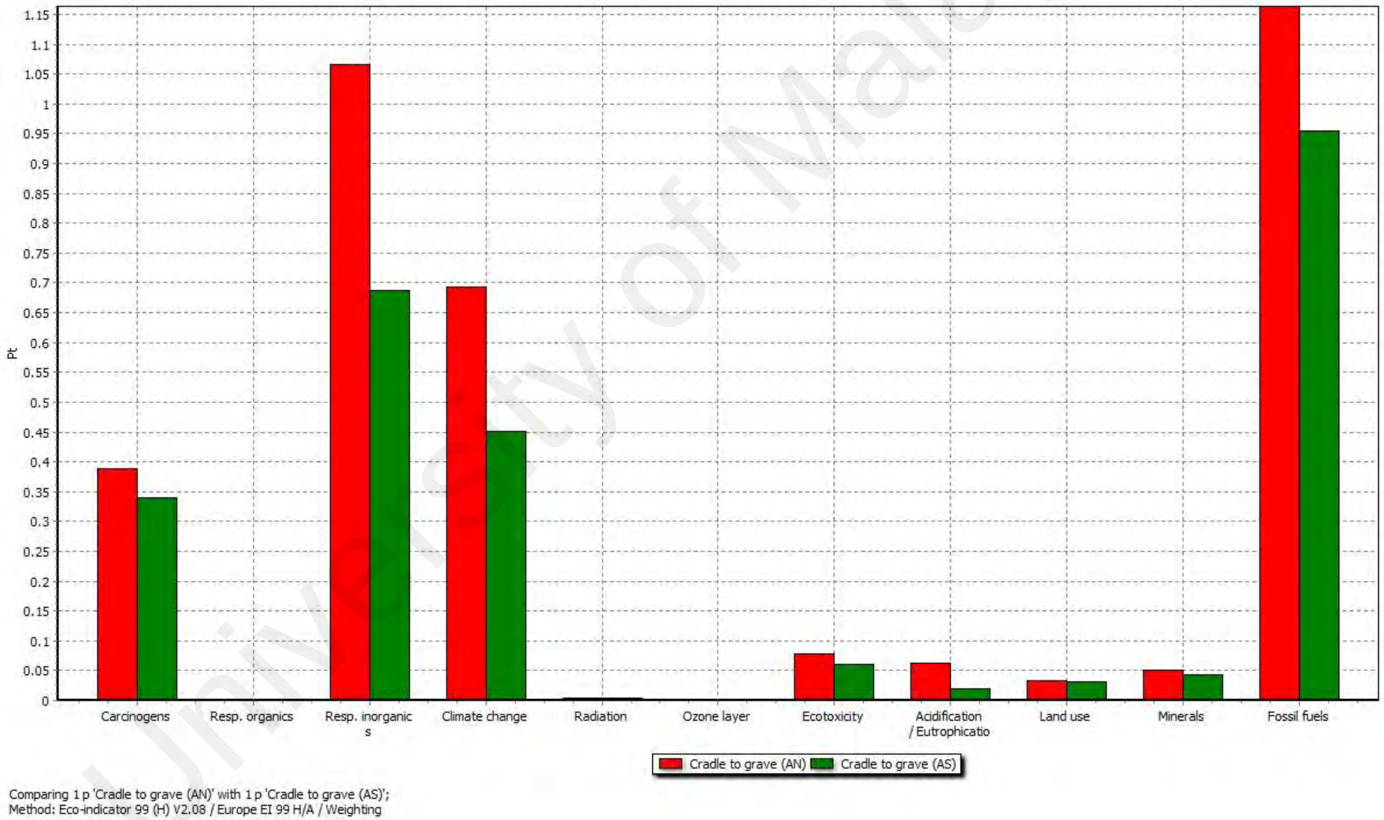

Figure 4.11: LCIA weighting results based on different types of N fertilizers

Greenhouse gases emission

The GHGs emission for this alternative scenario of using ammonium nitrate as the source of N in the cultivation of one rubber tree from cradle to grave as compared to the usage of ammonium sulphate is shown in Table 4.28.

Table 4.28: GHGs emission from different types of N fertilizers for the cultivation of one rubber tree from cradle to grave

GHGs	Weight in $kgCO_2eq$	
	Ammonium nitrate	Ammonium sulphate
Carbon dioxide	19.828	18.982
Nitrous oxide	46.474	24.466
Other GHGs emissions (Insignificant)	1.288	1.232
Total GHGs Emission	67.59	44.68

Nitrous oxide and carbon dioxide are the two main GHGs that contribute to the total GHGs emission value for the cultivation of one rubber tree from cradle to grave based on the usage of ammonium nitrate and ammonium sulphate at 3.91 kg N/tree/ life cycle (Table 4.28). The remaining GHGs emission is considered as insignificant contributor towards the total GHGs value in the cultivation of one rubber tree from cradle to grave (Table 4.28).

Carbon dioxide and nitrous oxide contribute 98.1% and 97.2% respectively towards the total GHGs emission value for the cultivation of one rubber tree from cradle to grave for ammonium nitrate and ammonium sulphate (Table 4.28). Carbon dioxide emission value of 19.83 $kgCO_2eq$ from the usage of ammonium nitrate is only 4.3% higher that carbon dioxide emission value from the usage of ammonium sulphate at 18.98 $kgCO_2eq$ based on the same amount of N (Table 4.28).

Nitrous oxide emission value from the usage of ammonium nitrate at 46.47 $kgCO_2eq$ is 47.4% higher than the nitrous oxide emission value from the usage of ammonium sulphate based on the same amount of N (Table 4.28). Nitrous oxide emission contribute 65.9% from the total GHGs emission value for the production of ammonium nitrate while in the production of ammonium sulphate, nitrous oxide only contribute 0.3% from the total GHGs emission (Table 4.29).

Table 4.29: Comparison of GHGs emission value between production of ammonium nitrate and ammonium sulphate

	Unit	N fertilizer	
		Ammonium nitrate	Ammonium sulphate
GHGs emission for 1 kg fertilizer	$kgCO_2eq$	2.993	0.565
Percentage of N in the fertilizer	%	35	21
GHGs emission for 1 kg N	$kgCO_2eq$	8.551	2.690
Nitrous oxide emission for 1 kg N	$kgCO_2eq$	5.639	0.009

Source: (Ecoinvent, 2010)

The total GHGs emission value from the usage of ammonium nitrate in the cultivation of one rubber tree from cradle to grave at 67.59 $kgCO_2eq$ is 33.9% higher than the GHGs emission from the usage of ammonium sulphate (Table 4.28). This is due to the total GHGs emission from the production of ammonium nitrate is higher than the total GHGs emission from the production of ammonium sulphate (Table 4.29).

This alternative scenario managed to show that the environmental impact from the usage of ammonium nitrate as the source of N in the cultivation of rubber tree from cradle to grave will lead to the relatively higher environmental impact and GHGs emission value as compared to the usage of ammonium sulphate. As conclusion, from the sustainability and environmental perspective, it is better to maintain the use of ammonium sulphate as the source of N in the cultivation of rubber trees from cradle to grave as compared to the usage of ammonium nitrate.

4.4 Comparison with other Studies

The study on the quantification of environmental impact and greenhouse gases (GHGs) emission for the cultivation of rubber tree from cradle to grave is the first study ever conducted in Malaysia, one of the world's major natural rubber producers. The study on the quantification of environmental impact for the cultivation of rubber tree from cradle to grave perspective using Eco-indicator 99 methodology is also probably the first study of its kind internationally.

According to Petsri et al. (2013), the available information on the GHGs emission for rubber tree cultivation is very limited. From literature search, a few studies that focused on the GHGs emission from the cultivation of rubber trees in Thailand were found and the findings from these studies are used to compare with our study.

A comparison is made between this study and the study by Petsri et al. (2013) and Phungrussami and Usubharatana (2015). The summary of the comparison is shown in Table 4.30.

From this comparison study, the GHGs emission value in the cultivation of rubber tree from cradle to grave from Petsri et al. (2013) is the highest and followed by the GHGs emission value reported by Phungrussami and Usubharatana (2015)(Table 4.30). The GHGs emission value in the cultivation of rubber tree from cradle to grave from this study is the lowest among these 3 GHGs figures (Table 4.30).

Table 4.30: Comparison with other studies on the GHGs emission for the cultivation of rubber tree from cradle to grave

	This study	**(Phungrussami & Usubharatana, 2015)**	**(Petsri et al., 2013)**
Tree life cycle (Years)	31.75	25-30	25
GHGs emission from land clearing and soil preparation before planting	Excluded	Included	Included
GHGs emission from biomass burning during land preparation	Excluded due to zero burning practice	Excluded due to zero burning practice	Included
GHGs emission from the operation of felling down the rubber trees at the end of life	Excluded	Excluded	Included
Nursery stage	Included	Information not available	Included
Immature stage	Included	Included	Included
Mature stage	Included	Included	Included
GHGs global warming potential value	100 year GWP Fourth assessment report (IPCC, 2007)	GWP Fourth assessment report (IPCC, 2007)	100 year GWP Second assessment report (IPCC, 1996)
GHGs emission /ha/Life cycle (TonCO2eq/ha/life cycle)	18.32	22.07	31.75
Average number of tree /ha	410	Information not available	418.99
Average GHGs emission/Tree/Life cycle ($kgCO_2eq$/Tree/life cycle)	44.68	52.68*	75.77

* Due to no information available on the average number of tree per hectare (ha),(Petsri et al., 2013) data of 418.99 Tree/ha was used to estimate the GHGs emission based on a single tree in the (Phungrussami & Usubharatana, 2015) study as both paper represent Thailand rubber cultivation scenario.

The possible reasons why the GHGs emission value from Petsri et al. (2013) is the highest reported value are listed below:

- The GHGs emission value reported by Petsri et al. (2013) included the GHGs emission from the diesel used in the operation during felling and cutting of the rubber trees and transporting of the rubber logs at the end of their life. The GHGs emission from this process represents 7.1% from the total GHGs emission value as reported by Petsri et al. (2013). Petsri et al. (2013) did not give the breakdown percentage between the GHGs emission from the diesel used for transportation of the rubber logs and diesel used in the chain saw during the operation of felling and cutting of rubber trees. In the Phungrussami and Usubharatana (2015) study, 86.5% of the diesel consumption during the felling, cutting and transporting of the fallen rubber trees is used for transportation and only the remaining 13.5% is used for chain saw operation. Phungrussami and Usubharatana (2015) study did not include the GHGs emission from the diesel used in the operation during felling, cutting and transporting of the rubber logs at the end of their life in the plantation boundary but assigned it to felling boundary. In this study, the GHGs emission from the diesel used in the operation during felling and cutting of the rubber trees and transporting of the rubber logs from the plantation were also excluded due to unavailability of data. Even if the GHGs emissions data from the diesel used in the operation during felling and cutting of the rubber trees and transporting of the rubber logs from the plantation were available, this study will only include the GHGs emission from the diesel usage from the chain saw. Hence, it is more appropriate that the GHGs emission value from the diesel usage for the transportation of rubber logs from the plantation should be covered under the rubber furniture manufacturing GHGs emission scope rather than rubber cultivation from cradle to grave scope.

- The GHGs value reported by Petsri et al. (2013) included the GHGs emission from biomass burning during land preparation. The burning of biomass (leaves, branches, roots) represent 11.0% from the total GHGs value as reported by Petsri et al. (2013). This study and Phungrussami and Usubharatana (2015) study did not take into account the GHGs emission from biomass burning during land preparation as this study and Phungrussami and Usubharatana (2015) study were in the opinion that zero burning practices were applied during the land preparation.

- The GHGs value reported by Petsri et al. (2013) was based on the 100 year GWP from the IPCC second assessment report (IPCC, 1996) while for this study and Phungrussami and Usubharatana (2015) study, the reported GHGs emission values were based on the GWP values from the IPCC Fourth assessment report (IPCC, 2007). The GWP potential of nitrous oxide from the IPCC second assessment report of 310 is relatively higher as compared to 298 in the IPCC fourth assessment report and this directly influence the reporting GHGs emission value as nitrous oxide is the major GHGs emission in the cultivation of rubber trees due to the nitrogen based fertilizers application.

The GHGs emission for the cultivation of one rubber tree from cradle to grave from Phungrussami and Usubharatana (2015) study is 17.0% higher as compare to the GHGs emission from this study. The GHGs emission from the nursery operation is included in the total GHGs emission from this study while in the Phungrussami and Usubharatana (2015), there is no information whether the GHGs emission from the nursery operation is included or excluded from the their study. This difference however did not make any significant impact as the GHGs emission from the nursery operation in this study only represent 0.29% from the total GHGs emission in the cultivation of one rubber tree from cradle to grave. One obvious difference is that the GHGs emission from the fossil fuels used in the land clearing and soil preparation is included in the Phungrussami and Usubharatana (2015) study but excluded from this study. Phungrussami and Usubharatana (2015) did not provide the percentage of the GHGs emission from the fossil fuels used in the land clearing and soil preparation towards the total GHGs emission.

The differences between the GHGs emission value from this study as compared to the Phungrussami and Usubharatana (2015) study is considered as normal variation that are attributed to the various parameters such as type of soil, number of rubber trees per hectare, amount of fertilizers used, types of fertilizers used and other parameters that contribute to the impossibility of comparing these studies based on an apple to apple comparison due to the limited background data available from Phungrussami and Usubharatana (2015) published study.

4.5 LCA Study for the Production of Two Whorl Young Budding in the Polybag

The objective of this study is to quantify the life cycle inventory, life cycle impact assessment and GHGs emission based on the production of one two whorl young budding in the polybag (TWYBP) from rubber nurseries in Malaysia as part of the main goal in quantifying the life cycle inventory, life cycle impact assessment and GHGs emission for the cultivation of one rubber tree from cradle to grave approach. The functional unit for this study is defined as the production of one TWYBP ready to be planted at smallholders holding as shown in Figure 4.12.

Figure 4.12: One unit of TWYBP ready to be planted

There are 110 active rubber nurseries in Malaysia registered with MRB producing various types of rubber planting material (Osman & Nasir, 2012). A total of 32 rubber nurseries that produce TWYBP took part in this study and the details production of each of the respondents is shown in Table 4.31.

Table 4.31: Production capacity of the individual respondent

Respondents Identification Code (Licensed No)	Total production of TWYBP for 2013 by respondent* (Polybag Unit)
K04-17340-001-1	321,054
K04-18568-001-2	56,400
K06-14536-001-1	825
K11-18567-001-1	116,683
K11-18095-001-1	6,600
K11-18886-001-1	10,950
A02-14376-001-1	43,375
R01-17759-001-1	179,905
D09-18533-001-1	2,295
T02-11971-008-1	73,947
T01-11971-009-1	179,394
M02-14852-001-1	12,301
K04-16580-001-1	120,425
K04-12104-001-1	1,242,836
K04-11628-002-1	779,052
K04-16940-001-1	36,385
K04-15610-001-1	20,147
K04-16863-001-1	263,301
K09-11900-002-1	21,614
K01-15622-002-1	23,256
K01-14559-001-1	178,463
K01-16523-001-1	38,860
K04-17322-011-1	40,129
A01-11971-003-1	79,208
N03-13334-001-1	108,729
M03-17688-001-1	3,340
M02-10643-003-1	7,220
D09-15141-001-1	7,249
D09-12187-003-1	412,617
T05-11971-007-1	239,637
F1	Data not available
F2	Data not available
Total	4,626,197

*Source: (Malaysian Rubber Board, 2014b)

The production capacity of the TWYBP from individual respondents is varied with the lowest production is 825 unit per year which is normally catering for small demands within the vicinity of the said rubber nursery while the highest production is 1,242,836 unit per year which is catering for big contract purchasing from the plantation owners and rubber related agencies in Malaysia (Table 4.31).

The production figure for two other respondents i.e. F1 and F2 remains confidential as it is owned by the large plantation group in Malaysia and produces the TWYBP purely for their own consumption. The total production of 4,626,197 units of TWYBP from 30 respondents in this study represent 32.6% from the total production of two whorl young budding in Malaysia for 2013 (Malaysian Rubber Board, 2014b).

4.5.1 Efficiency Indicator in the Production of TWYBP

The efficiency indicator in the production of TWYBP by the respondents in this study is shown in Table 4.32.

Table 4.32: Efficiency indicator in the production of TWYBP by respondents

Seed germination success rate (%)	Lowest	50
	Highest	90
	Average	70.5
Bud-grafted success rate (%)	Lowest	60
	Highest	90
	Average	77.5

The efficiency indicator in the production of TWYBP will influence the resource usage in the production of TWYBP.

Seed germination success rate

The rubber seeds are needed to raise rootstock for bud-grafting of clones to produce a quality TWYBP. The rubber seed germination success rate from the survey is from 50% to 90% with an average of 70.5% (Table 4.32).

In Malaysia, the flowering seasons of rubber trees are in March and August and the peak seed falls follows approximately six month later according to Malaysian Rubber Board in Daud et al. (2012). The rubber seeds need to be germinated as quickly as possible in order to get the best rate of seed germination success rate (Sulaiman & Yaakob, 2011). According to Husin in Sulaiman and Yaakob (2011), prolong delayed to germinate the rubber seeds will likely result in a relatively lower germination rate. Rubber seeds possess short viability, which declines dramatically after three days exposure to sunlight (Daud et al., 2012).

Most of the rubber nurseries in this study purchase their rubber seeds from their suppliers and they have minimum control on the freshness of the purchased rubber seeds and this attribute to the large variation on the germination success rate in this study. The role of seed germination rate in influencing the resource consumption for the defined functional unit in this study is very minimal and insignificant as the rubber seeds germination success rate will only influence the amount of rubber seedlings needed to produce one rootstock.

Bud-grafted success rate

The bud-grafted success rate from the survey is from 60% to 90% with an average of 77.5 % (Table 4.32). The average bud-grafted success rate used as the basis of calculation in determining the number of rubber seedling needed in the MRB training manual is 85% (Sulaiman & Yaakob, 2011).

The grafting process of the young rootstock is done when the young rootstock reach the diameter of 6mm and this normally occur within 10-12 weeks after the seeds germination process (Sulaiman & Yaakob, 2011). The young rootstock that failed the bud grafted process will normally be grafted for the second time and if the young rootstock failed the second trial of the bud grafted process, this young rootstock will be either discarded immediately or simply abandoned at the site depending on the management of the individual rubber nursery.

Based on the discussion with the management of the rubber nurseries participating in this study, the individual skills of the rubber grafters play a very important role in determining the success rate of the bud grafted process and the large variation of the bud grafted success rate among the rubber nurseries in this study is mainly due to the differences in grafting skills of the grafters involved.

Other than the individual skills of the rubber grafters, the number of young rootstocks assigned for each of the grafters, the financial incentives by the management of the individual rubber nurseries also influence the bud-grafted success rate.

The bud-grafted success rate has a direct influence in the resource consumption for the defined functional unit in this study. The relatively lower bud-grafted success rate will increase the average number of young rootstocks needed to produce one TWYBP. The discarded young rootstock that failed the bud-grafted process is the source of the resources loss in the form of polybag, fertilizers and other resources associate with it.

4.5.2 Life Cycle Inventory

The life cycle inventory (LCI) input output table for the production of one TWYBP in this study is shown in Table 4.33.

Table 4.33: LCI table for the production of one TWYBP

Input	Unit	Average value	Output
Number of rubber seedlings	Piece	1.92	One unit of TWYBP
Young rootstock	Polybag unit	1.29	
Polybag	kg	0.0130	
Fertilizer N	kg	0.0042	
Fertilizer P205	kg	0.0042	
Fertilizer K20	kg	0.0039	
Fertilizer MgO	kg	0.0010	
Rock phosphate	kg	0.0790	
Fungicide (80% w/w mancozeb)	kg	0.0009	
Fungicide (50% w/w chlorothalonil)	kg	0.0002	
Insecticides (various active ingredients)	kg	0.0003	
River water	m^3	0.2227	
Diesel	L	0.0399	
Emission			
Nitrous oxide	kg	8.701E-5	

Fertilizer usage in the production of TWYBP

NPK compound fertilizers are the main fertilizers used in the production of TWYBP and these fertilizers are used by all the rubber nurseries in this study. According to Malaysian Rubber Board (2009), compound fertilizers are made up of two or more straight fertilizers that are compounded through chemical process.

NPK green compound fertilizer was used by 27 rubber nurseries while the remaining 5 rubber nurseries used NPK yellow compound fertilizer. Rock phosphate fertilizer is a straight fertilizer which contain 36% P205 (Malaysian Rubber Board, 2009). In the nursery operation, rock phosphate fertilizer is mixed with the top soil in bulk before the top soil containing the rock phosphate fertilizer is filled into the polybag and ready to receive the germinated rubber seeds. The summary on the nutrients consumption for the production of one TWYBP is shown in Table 4.34.

Table 4.34: Nutrients consumption for the production of one TWYBP

Nutrient	Source of nutrient	Quantity used (kg/One TWYBP)	Percentage from the nutrient used in the cultivation of one rubber tree from cradle to grave (%)
N	NPK compounds fertilizers	4.17E-03	0.1
P205	NPK compounds fertilizers and rock phosphate fertilizer	3.26E-02	0.8
K20	NPK compounds fertilizers	3.84E-03	0.1
MgO	NPK yellow compound fertilizer	1.00E-03	0.1

The nutrients consumption for the production of one TWYBP is very small and insignificant as compared to the nutrients usage during the cultivation of one rubber tree from cradle to grave (Table 4.34).

In 2013, a total of 14,170,743 units of TWYBP is produced in Malaysia (Malaysian Rubber Board, 2014b). The estimated fertilizers consumption in the form of nutrients from the production of TWYBP in Malaysia is summarized in Table 4.35.

Table 4.35: Estimated nutrients consumption for the production of TWYBP in Malaysia

Nutrient	Quantity used in the production of TWYBP for Malaysia (Tonne)	Percentage from 2013 Malaysia consumption* (%)
N	59.1	0.01
P205	462.0	0.11
K20	54.4	0.01
Total Nutrient	575.5	0.13

* Source:(FAO, 2017)

From Table 4.35, it is obvious that the nutrients consumption from the rubber nurseries industry in Malaysia is very low and insignificant as compared to the total Malaysian nutrients consumption.

4.5.3 LCIA in the Production of TWYBP

Characterization

The characterization result for the production of one unit of TWYBP is represented by Figure 4.13 while the characterization values are shown in Table 4.36.

Diesel production is the highest and second highest contributor to 9 out of 11 characterization impact categories (Figure 4.13). Diesel production is the main contributor to the ozone layer, land use and fossil fuels impact categories with contribution of 85.7%, 61.1% and 54.9% from the total impact of the respective impact categories (Figure 4.13).

Diesel production is also the second highest contributor towards the respiratory organics, respiratory inorganics, radiation, ecotoxicity, acidification/eutrophication and minerals impact categories at 39.3%, 22.2%, 26.5%, 23.2%, 21.8% and 21.5% respectively (Figure 4.13).

HDPE resin E production is the major contributor to carcinogens and respiratory organics impact categories with contribution of 72.8% and 49.0% respectively (Figure 4.13). Production of HDPE resin E also contribute significantly to climate change and fossil fuels impact categories at 18.3% and 30.9% respectively from the total value of climate change and fossil fuels impact categories (Figure 4.13).

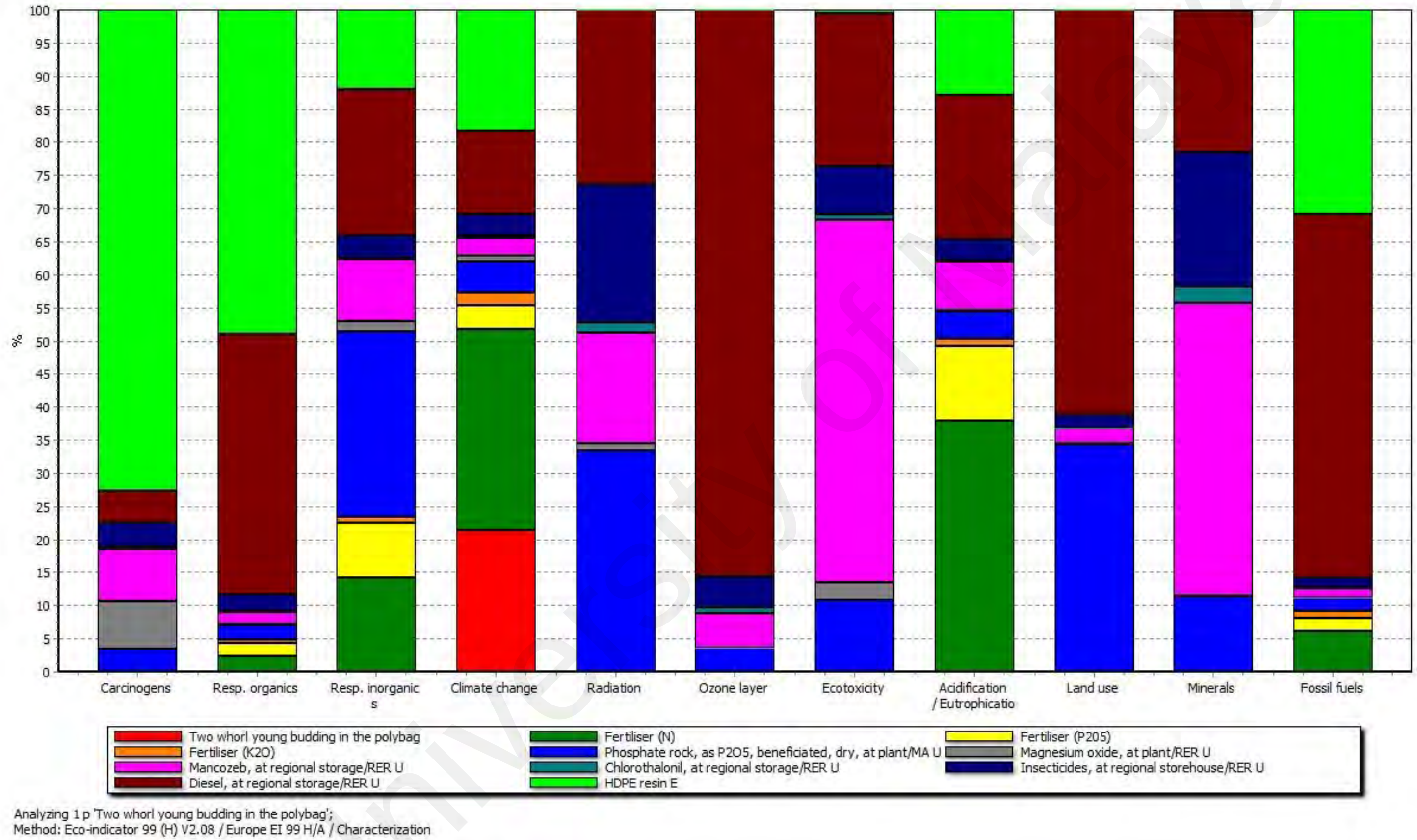

Figure 4.13: Characterization for the production of one TWYBP based on impact categories

Table 4.36: Characterization values for the production of one TWYBP

Impact category	Unit	Total	Fertilizer N application	Fertiliser (N)	Fertiliser (P205)	Fertiliser (K2O)	Phosphate rock	Magnesiun oxide	Mancozeb	Chlorothalonil	Insecticides	Diesel	HDPE resin E
Carcinogens	DALY	3.5E-08	0.0E+00	1.1E-12	4.1E-13	2.3E-13	1.2E-09	2.6E-09	2.8E-09	1.2E-10	1.3E-09	1.7E-09	2.6E-08
Resp. organics	DALY	1.5E-10	0.0E+00	3.5E-12	3.1E-12	7.5E-13	3.5E-12	1.6E-13	2.8E-12	4.6E-13	3.9E-12	6.0E-11	7.5E-11
Resp. inorganics	DALY	8.1E-08	0.0E+00	1.2E-08	6.6E-09	8.3E-10	2.3E-08	1.4E-09	7.6E-09	1.7E-10	2.7E-09	1.8E-08	9.7E-09
Climate change	DALY	2.8E-08	6.0E-09	8.5E-09	1.0E-09	5.4E-10	1.3E-09	2.2E-10	7.7E-10	7.7E-11	9.2E-10	3.5E-09	5.1E-09
Radiation	DALY	1.9E-10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.2E-11	1.8E-12	3.1E-11	3.0E-12	3.8E-11	4.9E-11	0.0E+00
Ozone layer	DALY	1.9E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.8E-13	9.2E-15	1.0E-12	1.7E-13	8.7E-13	1.6E-11	0.0E+00
Ecotoxicity	PAF*m2yr	1.8E-02	0.0E+00	1.1E-08	8.0E-09	2.6E-09	1.9E-03	4.8E-04	9.6E-03	1.7E-04	1.3E-03	4.1E-03	8.7E-05
Acidification/ Eutro	PDF*m2yr	2.3E-03	0.0E+00	8.7E-04	2.6E-04	2.7E-05	9.1E-05	6.0E-06	1.7E-04	5.0E-06	7.2E-05	5.0E-04	2.9E-04
Land use	PDF*m2yr	2.0E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-04	1.3E-06	4.7E-05	3.0E-06	4.0E-05	1.2E-03	0.0E+00
Minerals	MJ surplus	7.2E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00	8.1E-05	1.9E-06	3.2E-04	1.8E-05	1.5E-04	1.5E-04	1.0E-06
Fossil fuels	MJ surplus	4.4E-01	0.0E+00	2.7E-02	8.6E-03	4.7E-03	9.1E-03	1.4E-04	5.9E-03	7.1E-04	6.7E-03	2.4E-01	1.4E-01

Production of rock phosphate fertilizer is the highest contributor to the radiation and respiratory inorganic impact categories at 33.4% and 27.9% respectively (Figure 4.13). Rock phosphate fertilizer production is also the second biggest contributor to land use impact category at 34.3% (Figure 4.13). Fertilizer N production is the highest contributor to the climate change and acidification/eutrophication impact categories with contribution of 30.3% and 37.9% from the total value of the respective impact categories (Figure 4.13).

For climate change impact category, fertilizer N production and application represent 51.7% from the total value of this impact category (Figure 4.13). Mancozeb production is the main contributor to ecotoxicity and minerals impact categories at 54.6% and 44.1% respectively (Figure 4.13).

Damage Assessment

For human health damage category, HDPE resin E production is the biggest contributor at 28.1%, followed by phosphate rock production at 17.4% and diesel production at 16.1% (Figure 4.14). For ecosystem quality damage category, the three main process contributors are diesel production, mancozeb production and phosphate rock production (Figure 4.14). Diesel production represents 35.4% while mancozeb production and phosphate rock production represent 19.3% and 16.1% respectively towards the total value of ecosystem quality damage category (Figure 4.14).

For resource damage category, diesel production and HDPE resin E production are the two main processes that contribute 85.7% from the total value of this damage category (Figure 4.14).

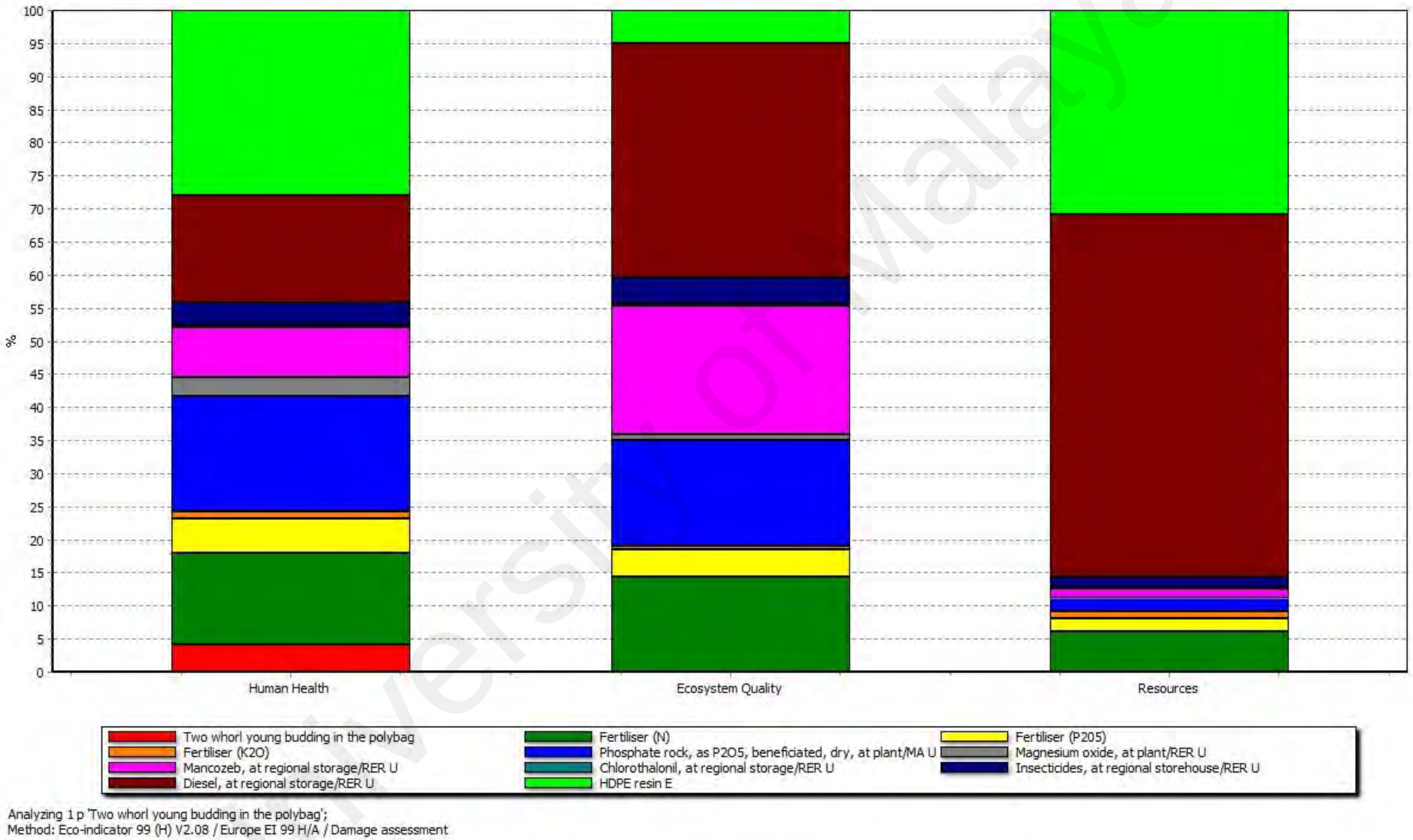

Figure 4.14: Damage assessment for the production of one TWYBP based on damage categories

Diesel production and HDPE resin E production contribute 54.8% and 30.9% respectively toward the total value of resource damage category (Figure 4.14).

These three damage categories are non-comparable between them as they only show relative distribution within their respective damage categories but this damage assessment results did gave a strong indication that diesel production and HDPE resin E production are the most polluting processes in the production of one TWYBP.

Normalization

Fossil fuels impact category is the single most dominant contributor in the normalization impact assessment for the production of one TWYBP (Figure 4.15). The two major process contributors toward the total value of fossil fuels impact category are diesel production and HDPE resin E production at 54.9% and 30.9% respectively (Figure 4.15). Respiratory inorganics, carcinogens and climate change impact categories plays minor role in the production of one TWYBP while the rest of impact categories are considered as insignificant contributor (Figure 4.15).

The estimated impact from the production of 14170743 units of TWYBP in Malaysia towards the damage categories is summarized in Table 4.37. The estimated impact from the production of TWYBP in Malaysia is considered as insignificant as compared to the Malaysian total impact of these three damage categories (Table 4.37).

The impact from the production of TWYBP in Malaysia towards the one year average impact from the rubber trees cultivation in Malaysia is from 0.78% to 2.35% for these 3 damage categories (Table 4.37). Resource damage category show a relatively higher impact at 2.35% as compared to two other damage categories due to the diesel usage in the running of water sprinkler system.

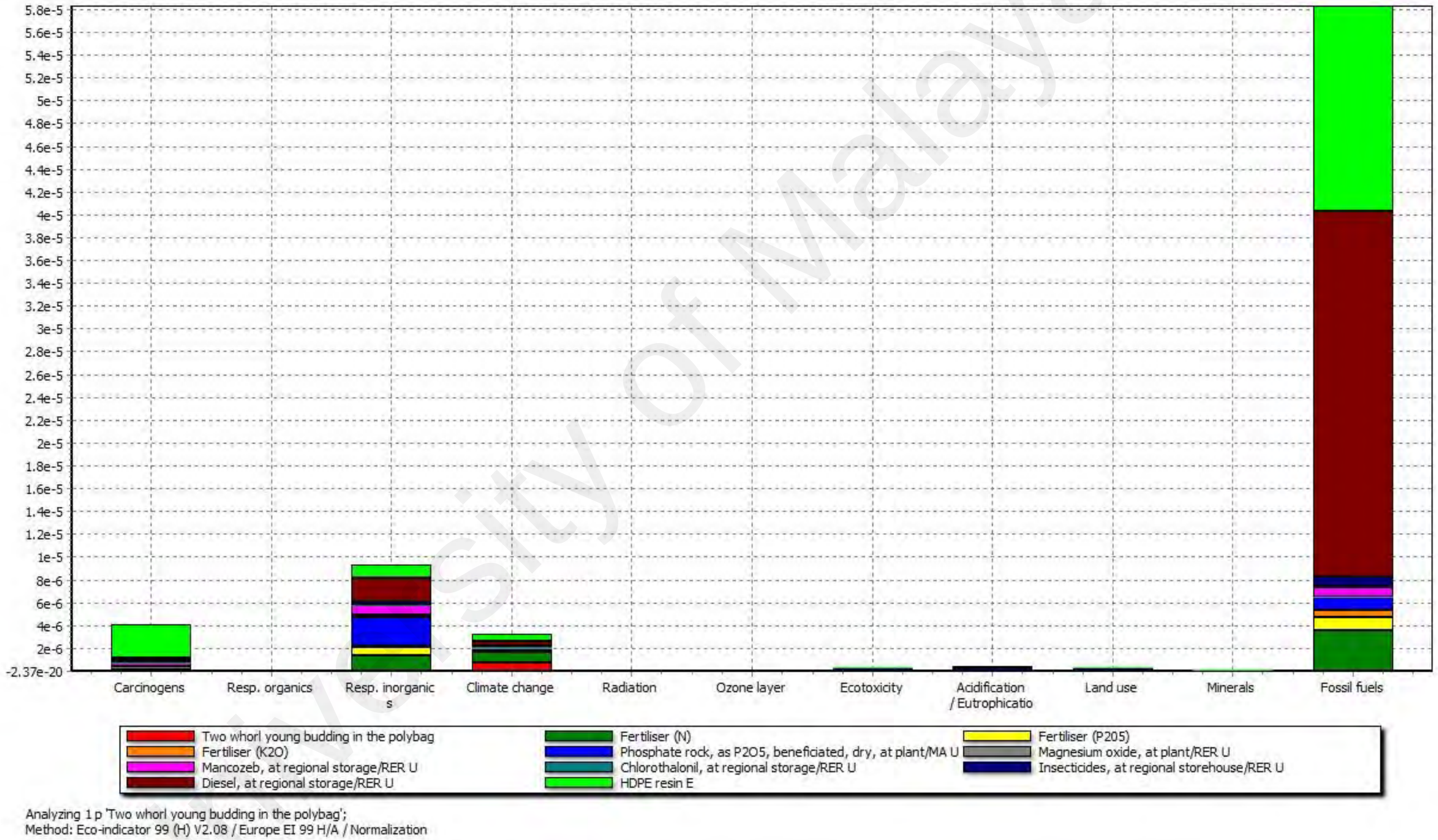

Figure 4.15: Normalization for the production of one TWYBP based on impact categories

Table 4.37: Estimated impact from the production of TWYBP in Malaysia based on damage categories

Damage category	Normalization value (PE)	Malaysian population 2016# (Million)	Impact to Malaysia (%)	Normalization value from the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (PE)	Impact to the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (%)
Human health	2.35E+02	31.7	0.00074	2.62E+04	0.90
Ecosystem quality	1.50E+01	31.7	0.00005	1.93E+03	0.78
Resources	8.28E+02	31.7	0.00261	3.52E+04	2.35

Source: (Department of Statistic Malaysia, 2016)

Weighting

The weighting result for the production of one TWYBP is shown in Figure 4.16 and Table 4.38. Fossil fuels impact category is the single most dominant contributor in the weighting impact assessment for the production of one TWYBP (Figure 4.16). Fossil fuels impact category represents 62.3% from the total value of 11 weighting impact categories (Figure 4.16 and Table 4.38).

The other 3 significant impact categories contributors are respiratory inorganics, carcinogens and climate change represent 19.8%, 8.6% and 6.9% respectively from the total value of 11 weighting impact categories (Table 4.38 and Figure 4.16). Another 7 impact categories i.e. acidification/eutrophication, land use, ecotoxicity, minerals, radiation, respiratory organics and ozone layer contribute less than 1% respectively from the total value of the 11 weighting impact categories and considered as insignificant impact categories contributors (Table 4.38 and Figure 4.16).

For fossil fuels impact category, the two major processes that contribute to the total value of this impact category are diesel production at 54.9% and HDPE resin E production at 30.9% (Figure 4.16).

In the production of TWYBP, diesel was used to run the refurbished commercial vehicle diesel engine. This refurbished commercial vehicle diesel engine is used to pump water from the river into the water sprinkler system to water the young rootstock in the polybag and young budding in the polybag at various stage of growing.

HDPE resin E in this study represents the raw material used in the production of the polybag. The polybag is an essential item in the production of TWYBP as the germinated seeds are planted in the polybag containing top soil before it can be grown into young rootstock and subsequently grafted to produce TWYBP.

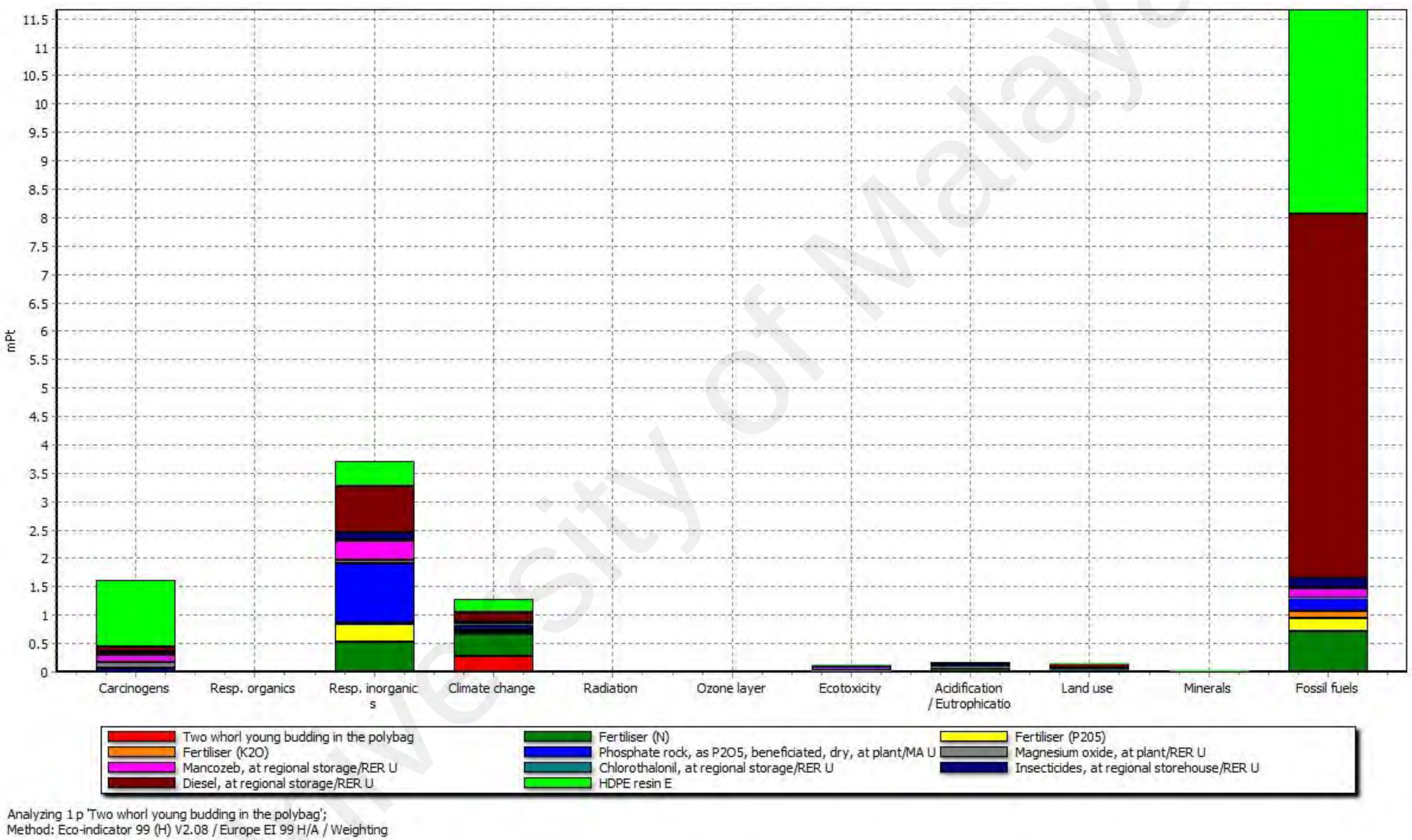

Figure 4.16: Weighting for the production of one TWYBP based on impact categories

Table 4.38: Weighting values for the production of one TWYBP

Damage category	Impact category	Unit	Impact category value	Damage category value	Impact to the cultivation of one rubber tree from cradle to grave (%)
Human Health	Carcinogens	Pt	1.62E-03		0.48
Human Health	Resp. organics	Pt	7.02E-06		0.93
Human Health	Resp. inorganics	Pt	3.71E-03		0.54
Human Health	Climate change	Pt	1.28E-03		0.28
Human Health	Radiation	Pt	8.47E-06		0.19
Human Health	Ozone layer	Pt	8.67E-07		0.50
Total Human Health		Pt		6.62E-03	0.45
Ecosystem Quality	Ecotoxicity	Pt	1.22E-04		0.21
Ecosystem Quality	Acidification/ Eutrophication	Pt	1.59E-04		0.84
Ecosystem Quality	Land use	Pt	1.42E-04		0.46
Total Ecosystem Quality		Pt		4.24E-04	0.39
Resources	Minerals	Pt	1.90E-05		0.04
Resources	Fossil fuels	Pt	1.17E-02		1.22
Total Resources		Pt		1.17E-02	1.17
Total		Pt	1.87E-02	1.87E-02	0.72

The contribution of HDPE resin E production towards the total value of fossil fuels impact category in the production of TWYBP is through the usage of raw material in the form of crude oil and natural gas in the manufacturing of HDPE resin (Franklin Associates, 2011).

The impact from the production of one TWYBP towards the impact from the cultivation of one rubber tree from cradle to grave is very low and can be considered as insignificant as summarized in Table 4.38. The total impact from the production of one TWYBP represents only 0.72% from the total impact in the cultivation of one rubber tree from cradle to grave (Table 4.38). Fossil fuels impact category from the production of one TWYBP recorded the highest contribution at 1.22% from the total fossil fuels impact category value in the cultivation of one rubber tree from cradle to grave (Table 4.38).

The estimated impact from the production of 14170743 units of TWYBP in Malaysia based on the three main weighting impact categories that represent 90.7% from the total value of 11 weighting impact categories in the production of two whorl young budding in Malaysia is summarized in Table 4.39.

Table 4.39: Estimated impact from the production of TWYBP in Malaysia based on three main impact categories

Impact category	Weighting value (Pt)		Impact to the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (%)
	Production of TWYBP in Malaysia	Cultivation of rubber trees from cradle to grave in Malaysia based on one year average	
Fossil fuels	165,237.13	6,741,112.54	2.45
Respiratory inorganics	52,529.12	4,851,215.6	1.08
Carcinogens	22,907.40	2,392,611.6	0.96

The damage in the form of extra energy that future generation must use to extract fossil fuels from the production of TWYBP in Malaysia contribute only 2.45% from the total fossil fuels impact category from the cultivation of rubber trees in Malaysia based on a year average (Table 4.39).

The respiratory effects on mankind due to the emission of inorganics substances to the air from the production of TWYBP in Malaysia represent only 1.08% from the total respiratory inorganics impact category inflicted from the cultivation of rubber trees in Malaysia based on a year average (Table 4.39).

The carcinogenic effects on mankind due to the emission of carcinogenic substances to air, water and soil from the production of TWYBP in Malaysia represent only 0.96% from the total carcinogens impact from the cultivation of rubber trees in Malaysia based on a year average (Table 4.39).

From these three main impact categories, it is obvious that the impact from the production of TWYBP which is part of the rubber cultivation activities in Malaysia is very small and insignificant if compared to the effect from the cultivation of rubber trees in Malaysia based on a year average (Table 4.39).

The total weighted value from the 11 weighting impact categories in the production of one TWYBP is 1.87E-02Pt which is equal to 1.87E-05 PE as explained by (PRe Consultants, 2000)(Table 4.25). The impact from the production of 14170743 units of TWYBP in Malaysia is responsible for only 0.0008% of the Malaysian environmental impact based on Malaysian population of 31.7 million and can be considered as totally insignificant.

Single Score

In the production of one TWYBP, the impact towards resource depletion is the highest at 62.4% from the total value of the three damage categories (Table 4.40 and Figure 4.17). Ecosystem quality recorded the lowest impact at 2.3% while health effects to the human contribute 35.4% from the total value of the three damage categories (Table 4.40 and Figure 4.17).

Table 4.40: Production of one TWYBP based on damage category

Damage category	Unit	Total	Percentage (%)
Human Health	Pt	6.62E-03	35.37
Ecosystem Quality	Pt	4.24E-04	2.26
Resources	Pt	1.17E-02	62.37
Total	Pt	1.87E-02	100.00

Diesel production and HDPE resin E production are the two major processes that influence the single score impact assessment results in the production of one TWYBP (Figure 4.17). Diesel production represents 40.7% while HDPE resin E production represents 29.3% from the total value of the three damage categories in the production of one TWYBP (Figure 4.17). The remaining 9 processes contribute only 30.0% in total from the total value of the three damage categories in the production of one TWYBP (Figure 4.17).

For diesel production, fossil fuels impact category is the single biggest concern as it represents 84.0% from the total impact in the production of diesel (Figure 4.18). Respiratory inorganics represent 10.8% from the total impact in the diesel production while the remaining 9 impact categories are consider as insignificant contributors to the impact in the production of diesel (Figure 4.18).

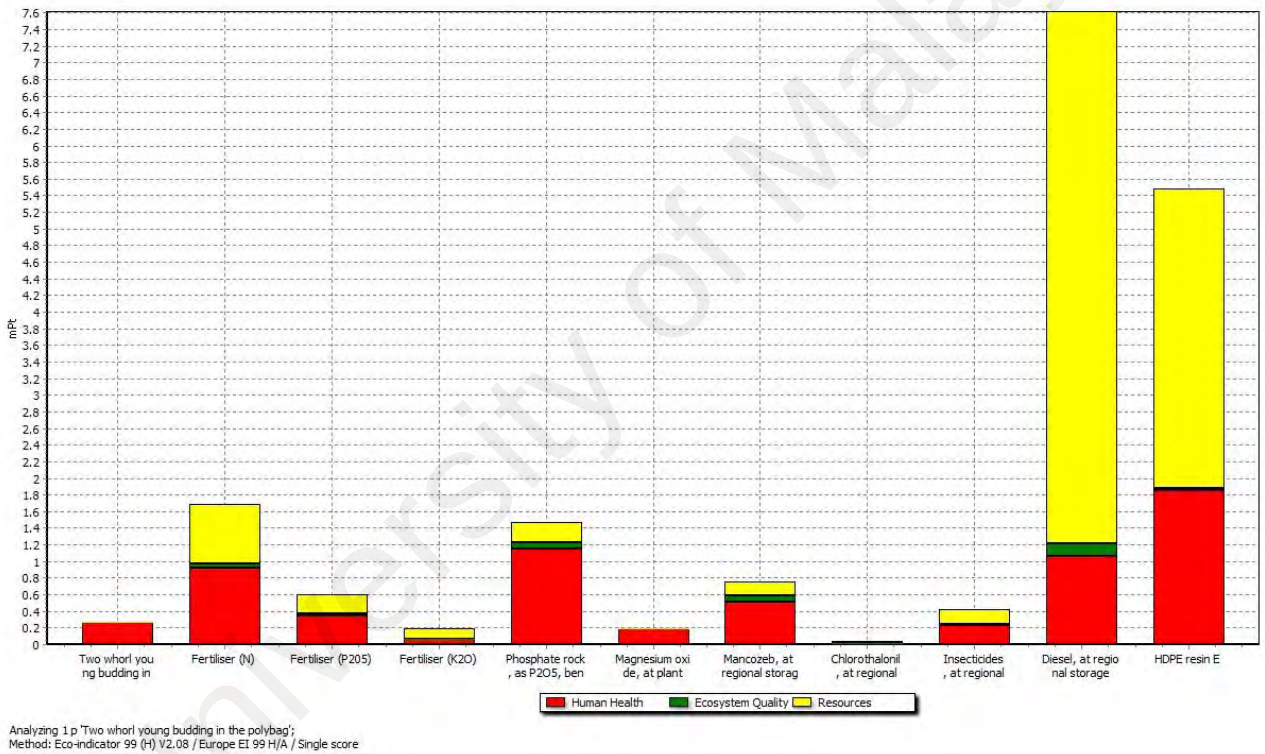

Figure 4.17: Single score for the production of one TWYBP based on damage categories

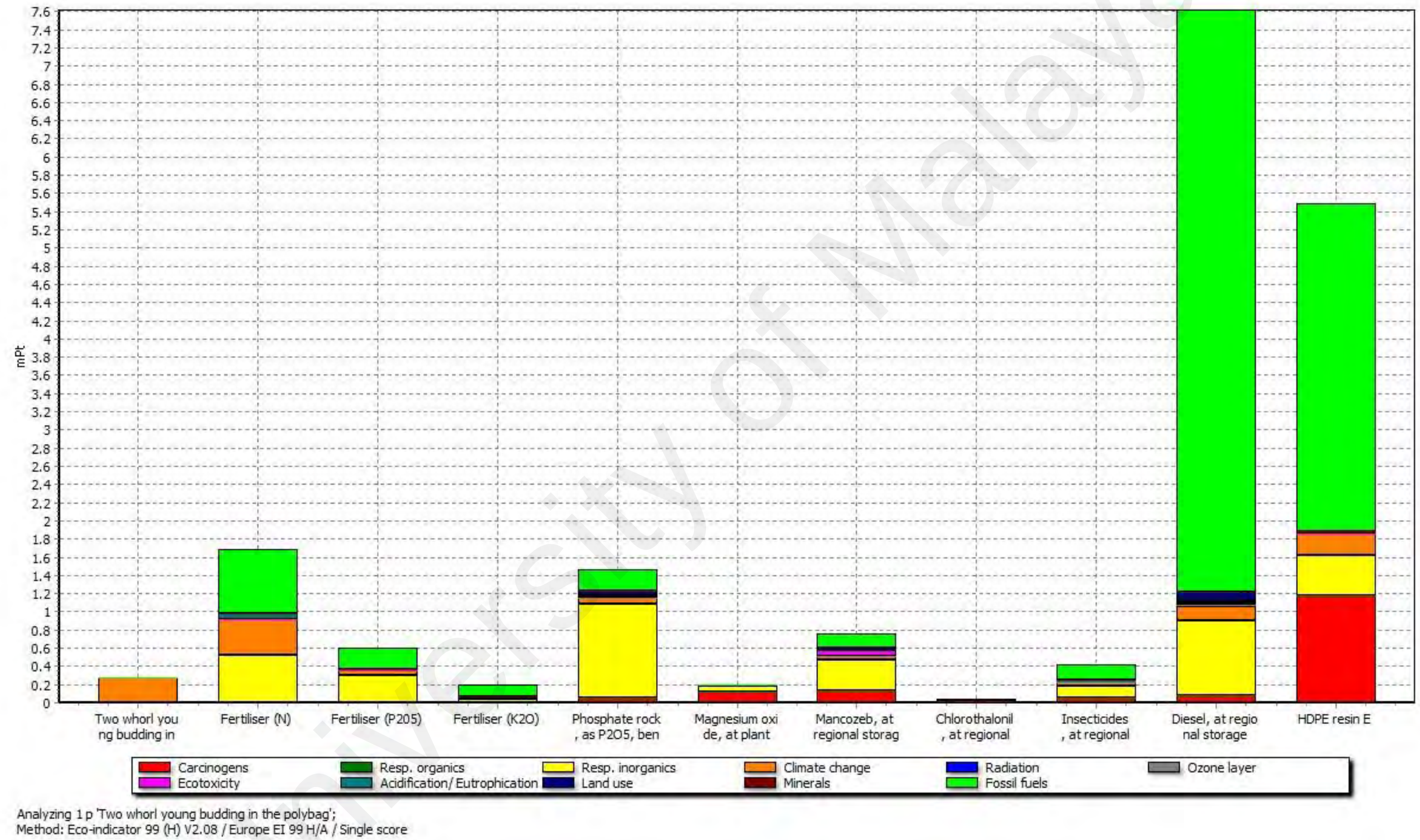

Figure 4.18: Single score results for the production of one TWYBP based on impact categories

For HDPE resin E production, the two main impact categories are fossil fuels and carcinogens representing 65.7% and 21.4% respectively towards the total impact in the production of HDPE resin E (Figure 4.18). The contribution from respiratory inorganics and climate change impact categories towards the total impact in the production of HDPE resin E is very small at 8.1% and 4.3% respectively while the remaining 7 impact categories are consider as insignificant contributors (Figure 4.18).

The reduction in the consumption of diesel and polybag will definitely help in lowering the environmental impact from the production of TWYBP by the rubber nurseries operators in Malaysia. Among possible strategy that can be explore to reduce the consumption of diesel and polybag in the production of TWYBP is through employing very experience and skilled grafters.

According to Kadir and Atan (1991), the bud-grafted success rate can achieve up to 92.3% if the grafters are very experienced and skilled in the bud-grafted process. The increase in the bud-grafted success rate will reduce the amount of diesel needed to water the young rootstock in the polybag that failed the bud-grafted process. The increase in the bud-grafted success rate will also reduce the amount of polybag needed to produce TWYBP through reducing the wastage of polybag in the form of polybag used in the discarded young rootstock that failed the bud-grafted process.

Based on the survey data, 40.6% of the rubber nurseries operators in this study recorded the bud-grafted success rate of below 80% and the difficulty in getting very experienced and skilled grafters is cited as one of the main contributors to the relatively higher rate of failed bud-grafted success rate. One possible way to overcome the problem of getting skilled grafters is for the rubber nurseries operators to request rubber related agencies in Malaysia such as MRB and RISDA to organize a training session specifically for their grafters as these agencies had the expertise in this area.

Another possible way to reduce the diesel consumption in the production of TWYBP is through the reduction in the period to grow this planting material. The TWYBP which can be produced in 6 month time will definitely use fewer diesels in their watering process as compared to 12 month needed to produce TWYBP.

Based on the survey data, the range to produce TWYBP from the individual rubber nursery operator varies from 6 to 12 month. From the total number of rubber nurseries operator in this study, 31.3% recorded the period to produce TWYBP of more than 9 month. Identifying certain agronomic practices that can lead to shorter period in producing the TWYBP will definitely help in reducing the impact to the environment from the production of TWYBP.

4.5.4 LCIA on GHGs Emission from the Production TWYBP

The total GHGs emission value for the production of one TWYBP from this study is 1.299E-01 kgC02eq (Figure 4.19 and Table 4.41).

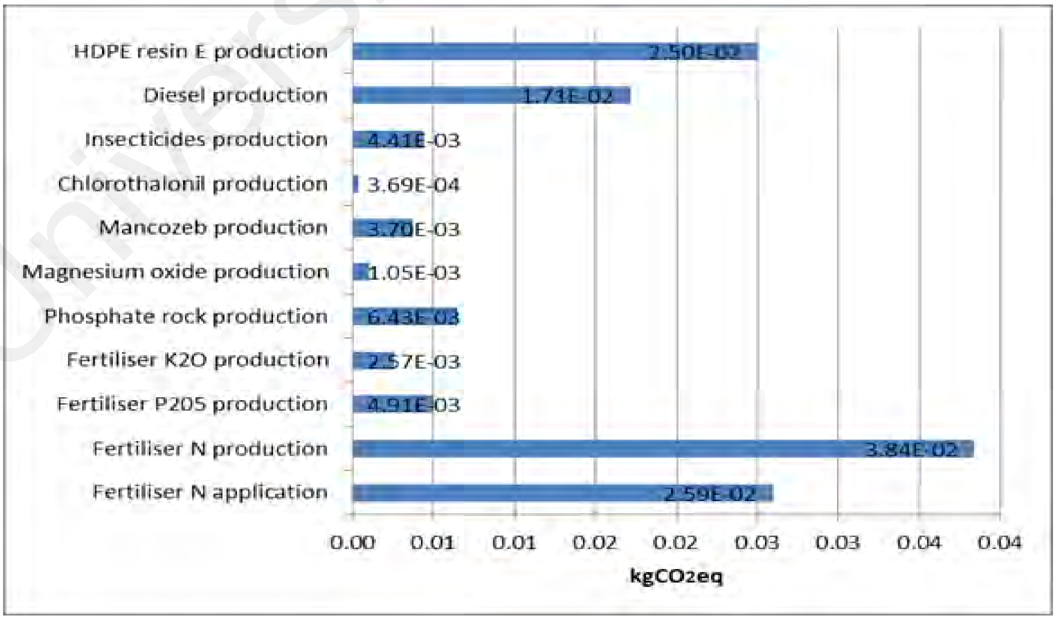

Figure 4.19: GHGs emission values for the production of one TWYBP

Fertilizer N production is the highest process contributor representing 29.5% from the total GHGs emission value for the production of one TWYBP (Figure 4.19). The other main process contributors to the GHGs emission value in the production of one TWYBP are fertilizer N application, HDPE resin E production and diesel production at 20.0%, 19.2% and 13.2% respectively (Figure 4.19). Phosphate rock production recorded 5.0% while the remaining 6 processes are considered as insignificant process contributors towards the total value of GHGs emission in the production of one TWYBP (Figure 4.19).

The GHGs emission from the production of one TWYBP has the potential to be reduced if the usage of fertilizer N, usage of polybag in the form of HDPE resin E and the usage of diesel in the water sprinkler system are reduced significantly (Figure 4.19).

Fertilizer N usage reduction can occur through the reduction in the period needed to produce TWYBP. The reduction in the usage of fertilizer N will also directly reduce the amount of nitrous oxide emission due to the application of fertilizer N. Identifying certain agronomic practices that can lead to shorter period in producing the TWYBP will definitely help in reducing the GHGs emission from the production of TWYBP. The reduction in the period to produce TWYBP also plays an important role in reducing the diesel usage in the water sprinkler system to produce TWYBP.

The usage of polybag in the form of HDPE resin E and the usage of diesel in the water sprinkler system can be reduced through employing very experience and skilled grafters to increase the bud-grafted success rate. The details mechanism on the potential reduction of polybag usage and diesel usage with the increase bud-grafted success rate is already explained in the section 4.6.3.

The GHGs emission value from the production of one TWYBP at 1.299E-01 kgC0$_2$eq represents only 0.29% and is considered as insignificant as compared to the total value of 44.68kgCO$_2$eq for the production of one rubber tree from cradle to grave.

The GHGs emission value for the production of 14170743 units of TWYBP in Malaysia is 1.84GgCO$_2$eq and this represent only 0.58% from the total GHGs emission value from one year average of the GHGs emission for the cultivation of rubber trees in Malaysia from cradle to grave. The list of GHGs emission and its corresponding values in contributing to the total GHGs emission value for the production of one TWYBP is shown in Table 4.41.

Table 4.41: GHGs emission profile for the production of one TWYBP

GHGs	Weight in kgCO$_2$eq
Nitrous oxide	5.04E-02
Carbon dioxide	7.07E-02
Methane	8.78E-03
Sulfur hexafluoride	3.00E-05
Methane, tetrafluoro-, CFC-14	1.09E-05
Methane, bromotrifluoro-, Halon 1301	9.44E-06
Ethane, hexafluoro-, HFC-116	2.23E-06
Methane, tetrachloro-, CFC-10	1.72E-06
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	1.15E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1.04E-06
Methane, chlorodifluoro-, HCFC-22	8.97E-07
Methane, bromochlorodifluoro-, Halon 1211	2.36E-07
Methane, dichlorodifluoro-, CFC-12	1.57E-08
Methane, trifluoro-, HFC-23	8.80E-09
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1.66E-09
Ethane, 1,1-difluoro-, HFC-152a	9.49E-10
Chloroform	2.60E-10
Methane, monochloro-, R-40	2.31E-11
Methane, trichlorofluoro-, CFC-11	1.44E-11
Methane, dichloro-, HCC-30	1.15E-11
Ethane, 1,1,1-trichloro-, HCFC-140	9.64E-12
Methane, dichlorofluoro-, HCFC-21	2.82E-13
Methane, bromo-, Halon 1001	2.11E-17
Total GHGs Emission	1.299E-01

Carbon dioxide and nitrous oxide are the two major GHGs that contribute 93.2% from the total GHGs emission value for the production of one TWYBP (Table 4.41).

Carbon dioxide emission

Carbon dioxide (CO_2) emission contributes 54.4% from the total GHGs emission value for the production of one TWYBP (Table 4.41). The values of the carbon dioxide emission based on process for the production of one TWYBP are shown in Table 4.42.

Table 4.42: Carbon dioxide emission values based on process for the production of one TWYBP

Process	CO_2 (kg)
Fertilizer N production	1.28E-02
Fertilizer P205 production	4.65E-03
Fertilizer K2O production	2.38E-03
Phosphate rock production	6.15E-03
Magnesium oxide production	1.04E-03
Mancozeb production	3.47E-03
Chlorothalonil production	3.39E-04
Insecticides production	4.03E-03
Diesel production	1.55E-02
HDPE resin E production	2.04E-02
Total CO_2 Emission	7.07E-02

HDPE resin E production, diesel production and fertilizer N production are the three major source of carbon dioxide emission representing 68.8% from the total value of carbon dioxide emission in the production of one TWYBP (Table 4.42).

Carbon dioxide emission from HDPE resin E production is the highest contributor representing 28.8% from the total value of carbon dioxide emission in the production of one TWYBP (Table 4.42). The second and third highest contributor to the total value of carbon dioxide emission in the production of one TWYBP is diesel production and fertilizer N production at 21.9% and 18.1% respectively (Table 4.42). The remaining 6 process are consider as minor contributors with contributions from 0.5% to 8.7%

towards the total value of carbon dioxide emission in the production of one TWYBP (Table 4.42).

The carbon dioxide emission from the production of 14,170,743 units of TWYBP in Malaysia is 1.00GgCO_2 and this represent only 0.75% from the carbon dioxide emission from one year average of the carbon dioxide emission from the cultivation of rubber trees in Malaysia from cradle to grave.

Nitrous oxide emission

Nitrous oxide emission represents 38.8% from the total GHGs emission value in the production of one TWYBP (Table 4.41). The values of nitrous oxide emission for the production of one TWYBP based on process are shown in Table 4.43.

Table 4.43: Nitrous oxide (N_20) emission values based on process for the production of one TWYBP

Parameter	N_20 (kg)
Fertilizer N production	8.07E-05
Fertilizer P205 production	1.58E-07
Fertilizer K2O production	1.89E-07
Phosphate rock production	1.88E-07
Magnesium oxide, production	5.51E-09
Mancozeb production	8.6E-08
Chlorothalonil production	6.65E-09
Insecticides production	3.41E-07
Diesel production	2.95E-07
HDPE resin E production	1.03E-14
N fertilizer application	8.7E-05
Total N_20 Emission	1.69E-04

Nitrous oxide emission from the application of fertilizer N and production of fertilizer N are responsible for 99.3% from the total nitrous oxide emission in the production of one TWYBP (Table 4.43). Nitrous oxide in the form of direct and indirect emissions from the application of fertilizer N contributes 51.5% from the total value of nitrous oxide emission in the production of one TWYBP (Table 4.43). The mechanism on the direct and indirect emission of nitrous oxide from the application of nitrogen fertilizer is already been explained in the section 4.1.3. Production of fertilizer N contributes 47.8% from the total value of nitrous oxide emission for the production of one TWYBP (Table 4.43).

4.6 Sensitivity Analysis for the Production of TWYBP

According to (ISO 14044, 2006), additional data quality analysis may be needed in order to understand better the significance, uncertainty and sensitivity of the LCIA results. Sensitivity analysis is a procedure to determine how changes in data and methodological choices affect the results of the LCIA (ISO 14044, 2006).

4.6.1 Sensitivity Analysis Based on Bud-grafted Success Rate

The bud-grafted success rate varies from 60% to 90% with an average of 77.5% among the respondents from this study. Based on available literature search, the highest bud-grafted success of 92.3% was reported by (Kadir & Atan, 1991).

A sensitivity analysis was done to compare the environmental impact from LCIA and GHGs emission perspective between the average bud-grafted success rate from this study of 77.5% and the bud-grafted success rate value of 92.3% as reported by (Kadir & Atan, 1991).

Characterization

The characterization result from this sensitivity analysis is shown in Figure 4.20. Based on the characterization impact assessment, all 11 impact categories values from this study are higher than the value from 92.3% bud-grafted success rate (Figure 4.20). This finding is expected as the relatively lower bud-grafted success rate from this study will consume more resources in the production of one TWYBP and this will lead to relatively higher environmental impact. Land use impact category recorded the highest difference at 20.1% while climate change impact category recorded the lowest different at 13.0%.

Weighting

The weighted result for this sensitivity analysis is shown in Figure 4.21 and Table 4.44. Fossil fuels impact category is the single main contributor to the total value of weighting impact assessment in the production of one TWYBP for both bud-grafted success rates (Figure 4.21 and Table 4.44). Fossil fuels impact category represents 62.3% and 61.8% respectively from the total value of the weighting impact assessment in the production of one TWYBP from 77.5% bud-grafted success rate and 92.3% bud-grafted success rate (Figure 4.21).

Respiratory inorganics, carcinogens and climate change are the three minor contributors to the production of one TWYBP for both bud-grafted success rates while the remaining 7 impact categories are considered as insignificant contributors (Figure 4.21). The values of respiratory inorganics, carcinogens and climate change impact categories from the 77.5% bud-grafted success rate are 16.9%, 16.7% and 13.0% higher as compare to the values from 92.3% bud-grafted success rate in the production of one TWYBP (Figure 4.21 and Table 4.44).

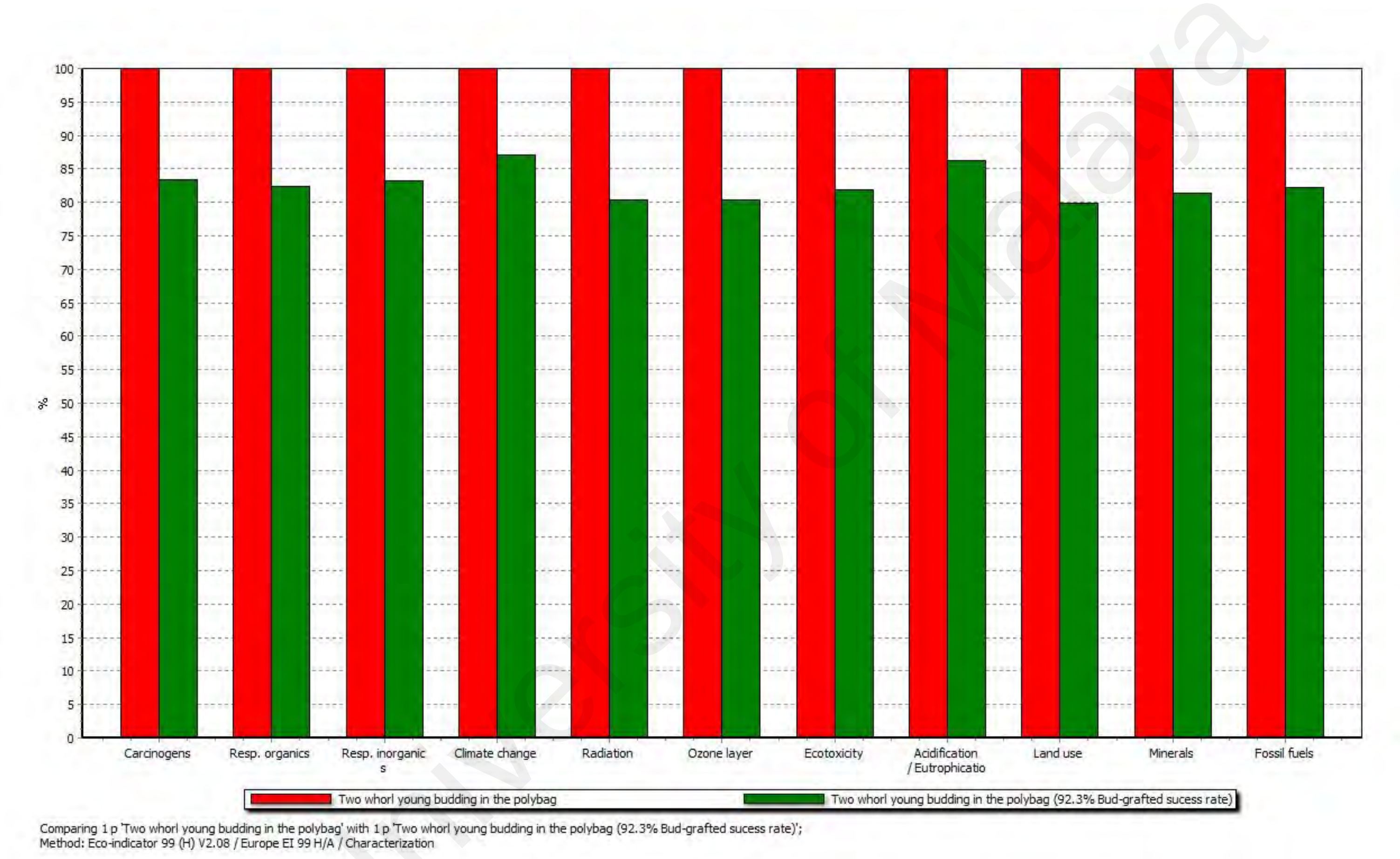

Figure 4.20: LCIA characterization results for the production of one TWYBP based on different bud-grafted success rate

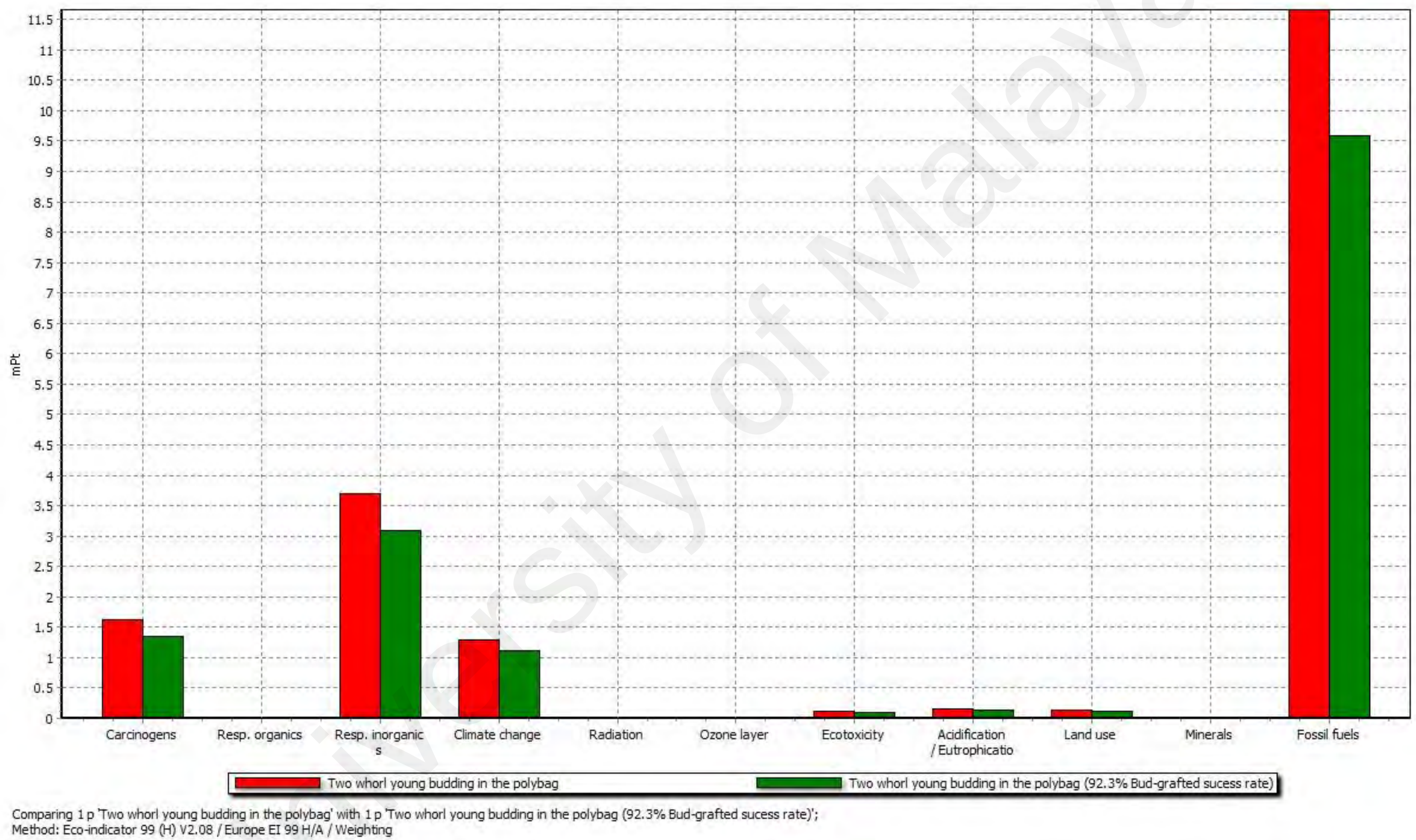

Figure 4.21: LCIA weighting results for the production of one TWYBP based on different bud-grafted success rate

The total weighting impact assessment value for the production of one two whorl young budding from the 77.5% bud-grafted success rate at 1.87E-02 Pt is 17.2% higher than the total weighting impact assessment value from the bud-grafted success rate of 92.3% (Table 4.44). This is due to all 11 weighting impact categories values from the 77.5% bud-grafted success rate are higher in the range of 13.0% to 20.1% than the values from the 92.3% bud-grafted success rate in the production of one TWYBP (Table 4.44).

From this sensitivity analysis, increase in the bud-grafted success rate will definitely reduce the potential environmental impact in the production of one TWYBP as explained in details in section 4.6.3. The potential environmental impact reduction from the increase in the bud-grafted success rate is due to the reduction of wastage in the form of diesel, polybag and chemicals that were used by the discarded young rootstock that failed the bud-grafted.

Table 4.44: Weighting values based on different bud-grafted success rate

Impact category	Unit	Production of one TWYBP	
		This study bud-grafted success rate (77.5%)	(Kadir & Atan, 1991) (92.3%)
Carcinogens	Pt	1.62E-03	1.35E-03
Resp. organics	Pt	7.02E-06	5.78E-06
Resp. inorganics	Pt	3.71E-03	3.08E-03
Climate change	Pt	1.28E-03	1.12E-03
Radiation	Pt	8.47E-06	6.81E-06
Ozone layer	Pt	8.67E-07	6.97E-07
Ecotoxicity	Pt	1.22E-04	1.00E-04
Acidification/ Eutrophication	Pt	1.59E-04	1.37E-04
Land use	Pt	1.42E-04	1.13E-04
Minerals	Pt	1.90E-05	1.55E-05
Fossil fuels	Pt	1.17E-02	9.58E-03
Total	Pt	1.87E-02	1.55E-02

Greenhouse gases emission

The list of the GHGs emission and its corresponding values for different bud-grafted success rate in the production of one TWYBP is shown in Table 4.45.

Table 4.45: GHGs emission profile from different bud-grafted success rate

GHGs	Production of one TWYBP (kgC02eq)	
	This study bud-grafted success rate (77.5%)	(Kadir & Atan, 1991) bud-grafted success rate (92.3%)
Carbon dioxide	7.07E-02	5.96E-02
Chloroform	2.60E-10	2.11E-10
Nitrous oxide	5.04E-02	4.57E-02
Ethane, 1,1-difluoro-, HFC-152a	9.49E-10	7.65E-10
Ethane, 1,1,1-trichloro-, HCFC-140	9.64E-12	7.91E-12
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	1.15E-06	9.33E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1.66E-09	1.36E-09
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1.04E-06	8.40E-07
Ethane, hexafluoro-, HFC-116	2.23E-06	1.82E-06
Methane	8.78E-03	7.39E-03
Methane, bromo-, Halon 1001	2.11E-17	1.75E-17
Methane, bromochlorodifluoro-, Halon 1211	2.36E-07	1.90E-07
Methane, bromotrifluoro-, Halon 1301	9.44E-06	7.58E-06
Methane, chlorodifluoro-, HCFC-22	8.97E-07	7.23E-07
Methane, dichloro-, HCC-30	1.15E-11	9.42E-12
Methane, dichlorodifluoro-, CFC-12	1.57E-08	1.27E-08
Methane, dichlorofluoro-, HCFC-21	2.82E-13	2.31E-13
Methane, monochloro-, R-40	2.31E-11	1.90E-11
Methane, tetrachloro-, CFC-10	1.72E-06	1.41E-06
Methane, tetrafluoro-, CFC-14	1.09E-05	8.88E-06
Methane, trichlorofluoro-, CFC-11	1.44E-11	1.18E-11
Methane, trifluoro-, HFC-23	8.80E-09	7.20E-09
Sulfur hexafluoride	3.00E-05	2.42E-05
Total GHGs Emission	1.30E-01	1.13E-01

Carbon dioxide and nitrous oxide are the two main GHGs contributors to the total GHGs emission value for the production of one TWYBP for both bud-grafted success rate (Table 4.45). Carbon dioxide and nitrous oxide contribute 93.2% and 93.4% respectively towards the total GHGs emission value from the 77.5% bud-grafted success rate and 92.3% bud-grafted success rate.

From this sensitivity analysis, it can be concluded that the relatively lower GHGs emission value from the 92.3% bud-grafted success rate as compared to this study success rate of 77.5% is due to the reduction of wastage in the form of diesel, polybag and chemicals that were used by the discarded young rootstock that failed the bud-grafted.

4.7 LCA Study for the Production of Mature Rubber Tree from Immature Rubber Stage

The objective of this study is to quantify the life cycle inventory, life cycle impact assessment and GHGs emission based on the production of one mature rubber tree from the immature rubber stage in Malaysia as part of the main goal in quantifying the life cycle inventory, life cycle impact assessment and GHGs emission for the cultivation of one rubber tree from cradle to grave approach. The functional unit for this study is defined as the production of one mature rubber tree ready for tapping from the immature rubber stage.

The immature rubber stage is referred to the unproductive stage in the rubber holdings where the immature rubber trees are at various growing stages started from day one of planting TWYBP or any other types of planting materials until a day before the immature rubber tree is ready for tapping. In this study, the unproductive immature rubber stage represents 18.9% of the economic lifespan of the rubber tree while Ghaffar et al. (2007) reported that the unproductive immature rubber stage period is about 17% of the economic lifespan of the rubber tree

The most important factor in determining whether the immature rubber trees can be considered as mature and ready for tapping is not the age of the immature rubber trees but the trunk girth size (Malaysian Rubber Board, 2009). The immature rubber trees are considered as mature and ready for tapping when their trunks attained 45cm girth measured at a height of 150cm from the ground level (Malaysian Rubber Board, 2009).

A total of 10 FELDA schemes, 7 FELCRA projects and 2 rubber estates with 6 stages of planting in Malaysia agreed to participate in this study. The respondents from this study represent 29.4% and 20.6% respectively from the total number of immature FELDA schemes and immature FELCRA projects. In terms of the immature rubber planted area, the respondents from FELDA scheme represent 26.0% from the total FELDA immature planted rubber area in Malaysia while the respondents from FELCRA projects represent 23.6% from the total FELCRA immature rubber planted area in Malaysia.

The details information on the respondents for this study is shown in Table 4.46. The age of the immature rubber trees from these respondents are varied and represent the whole range of immature rubber stage beginning from a few month of planting up to a few more months before the rubber trees are ready for tapping (Table 4.46).

Table 4.46: Information on the respondents for the immature rubber stage

Agency	Scheme/Project Code	Rubber Planted area (Hectare)	Immature rubber tree age (Year)
FELDA	Fi 1	219.35	1
	Fi 2	492.53	< 1
	Fi 3	785.98	1
	Fi 4	339.00	1
	Fi 5	925.84	3
	Fi 6	814.51	2
	Fi 7	794.14	2
	Fi 8	2,004.87	5
	Fi 9	776.75	< 1
	Fi 10	790.82	3
FELCRA	Fri 1	428.36	5
	Fri 2	291.90	4
	Fri 3	290.68	4
	Fri 4	110.00	5
	Fri 5	167.81	3
	Fri 6	236.00	3
	Fri 7	105	5
Private rubber estates	Rei 1-Batch 1	98.51	1
	Rei 1-Batch 2	97.06	2
	Rei 1-Batch 3	152.21	2
	Rei 1-Batch 4	168.26	4
	Rei 1-Batch 5	173.92	4
	Rei 2	177.44	1

4.7.1 Life Cycle Inventory

The average life cycle inventory (LCI) input-output table to maintain the healthy growth of one immature rubber tree from the first day of planting at the rubber smallholders land until that particular immature rubber tree is mature and ready for tapping is shown in Table 4.47 and Table 4.48.

Table 4.47: LCI table for the production of one mature rubber tree in 6 years

Input	Unit	Average value	Output		
Ammonium sulphate fertilizer	kg	2.578678	Output	Unit	Average value
Rock phosphate fertilizer	kg	2.191714	Mature rubber tree	Pcs	1
Potassium chloride fertilizer	kg	0.705831	Emission		
Magnesium sulphate fertilizer	kg	0.497239	Nitrous oxide	kg	0.0113
Herbicide with 41% glyphosate	L	0.237946			
Herbicide with 13% paraquat dichloride	L	0.095975			

Table 4.48: LCI table to maintain the healthy growth of one immature rubber tree for a year

Input	Unit	Average value	Output
Ammonium sulphate fertilizer	kg	0.4298	
Rock phosphate fertilizer	kg	0.3653	
Potassium chloride fertilizer	kg	0.1176	
Magnesium sulphate fertilizer	kg	0.0829	
Herbicide with 41% glyphosate	L	0.0397	
Herbicide with 13% paraquat dichloride	L	0.0160	
Emission			
Nitrous oxide	kg	0.00188	

Fertilizer usage in the production of mature rubber tree from immature rubber stage

The summary on the fertilizer usage during the immature rubber stage based on one rubber tree is summarized in Table 4.49.

Table 4.49: Quantity of fertilizer used during the immature rubber stage

Fertilizer	Quantity used (kg/Tree/6year)	Quantity used (kg/tree/Year)
Ammonium sulphate	2.5787	0.4298
Rock phosphate	2.1917	0.3653
Potassium chloride	0.7058	0.1176
Magnesium sulphate	0.4972	0.0829
Total	5.9735	0.9956

Ammonium sulphate and rock phosphate recorded the highest usage at 43.2% and 36.7% respectively from the total amount of fertilizers used during the immature rubber stage (Table 4.49). Potassium chloride and magnesium sulphate recorded the contribution of 11.8% and 8.3% respectively from the total amount of fertilizers used during the immature rubber stage (Table 4.49).

All the fertilizers listed in the Table 4.49 are straight fertilizers and these fertilizers are applied to the immature rubber trees in the form of mixture fertilizers. In general, straight fertilizers contain only one type of nutrient (Malaysian Rubber Board, 2009). Ammonium sulphate contains 21%N while rock phosphate, potassium chloride and magnesium sulphate contains 36%P205, 61%K20 and 26%MgO respectively (Malaysian Rubber Board, 2009).

All the respondents in this study used RRIM mixture fertilizers to fertilize their immature rubber trees and this finding is not a surprising as RRIM mixture fertilizers are formulated specifically for use on rubber and is widely used in Malaysia especially in the immature rubber planted area.

Mixture fertilizers are made up of more than one straight fertilizer mixed together by physical means (Malaysian Rubber Board, 2009). There are three types of RRIM mixture fertilizers used by the respondents in this study. The majority of the respondents used RRIM mix Mag.X, 2 respondents used a combination of RRIM mix Mag.X and RRIM mix Mag.Y, 4 respondents used RRIM mix Mag.Y and 1 respondent use RRIM mix Y. RRIM mix Mag.X and RRIM Mix.Mag Y are the two types of RRIM mixtures fertilizers recommended by Malaysian Rubber Board (MRB) to be used during the immature rubber stage (Malaysian Rubber Board). The formulation for the RRIM mix fertilizers used by the respondents in this study is shown in Table 4.50.

Table 4.50: RRIM formulated mixture fertilizers used by the respondents in this study

Type	Formulation (% straight fertilizer composition)			
	Ammonium sulphate	Rock phosphate	Potassium chloride	Magnesium sulphate
RRIM mix Mag.X	40	40	12	8
RRIM Mix.Mag Y	51	29	12	8
Mix.Y	56	30	14	-

Source: (Malaysian Rubber Board, 2009)

The consumption of fertilizers during the immature rubber stage based on one rubber tree as compared to the fertilizers consumption from the cultivation of one rubber tree from cradle to grave is shown in Table 4.51.

Table 4.51: Fertilizers consumption from the immature rubber stage as compared to the consumption from the whole life cycle from cradle to grave for one rubber tree

Fertilizer	Quantity used for one tree		Percentage of fertilizer usage in the immature stage as compared to the whole life cycle from cradle to grave (%)
	Immature rubber stage (kg/Tree/6years)	Cultivation of rubber from cradle to grave (kg/tree/31Years)	
Ammonium sulphate	2.5787	18.61	13.9
Rock phosphate	2.1917	11.58	18.9
Potassium chloride	0.7058	11.92	5.9
Magnesium sulphate	0.4972	2.83	17.6
Total	5.9735	44.94	13.3

The total fertilizers consumption from one immature rubber tree during the immature rubber stage of 6 years represents 13.3% from the total fertilizers used in the cultivation of one rubber tree from cradle to grave in 31 years (Table 4.51). Rock phosphate recorded the highest representation of 18.9%, followed by magnesium sulphate and ammonium sulphate at 17.6% and 13.9% respectively (Table 4.51). Potassium chloride recorded the lowest value representing only 5.9% from the total fertilizers used in the cultivation of one rubber tree from cradle to grave in 31 years (Table 4.51).

Based on literature search, there is no publicly available data on the percentage of the rubber in the immature stage in Malaysia. All publicly available data from the rubber related agencies in Malaysia mostly refer to the total planted rubber area in Malaysia without specifying the percentage of rubber in the immature stage and mature stage. The only source of information on the percentage of the rubber in the immature stage is from the classified survey data conducted by MRB in 2011-2012 as reported in (Malaysian Rubber Board, 2012).

In 2014, there are a total of 1.066 million hectares of rubber planted area in Malaysia comprising the immature stage and mature stage (Malaysian Rubber Board, 2016b). From the survey carried out by MRB involving 0.338 million hectares of rubber planted area owned by the individual rubber smallholders, 35.6% from the total planted rubber area from this survey is in the immature rubber stage (Malaysian Rubber Board, 2012). From this survey, 35.15% of the planted rubber areas in the immature rubber stage receive fertilizers at the recommended dosage, 33.28% of the planted rubber areas in the immature rubber stage receive fertilizers lower than the recommended dosage while the remaining 31.57% of the planted rubber areas in the immature rubber stage did not receive any fertilizer for the past one year (Malaysian Rubber Board, 2012).

Due to the limited information available, the figures from the MRB survey were used as the basis of calculation in this study to in order to estimate the fertilizer consumption during the immature rubber stage. It is estimated that 51.8% of the total rubber planted area in the immature rubber stage in Malaysia receives fertilizers at the recommended dosage. The basis for this estimation is as below:

- The percentage of the rubber planted area in the immature rubber stage that received fertilizers at the recommended dosage for the past one year in (Malaysian Rubber Board, 2012) represent the percentage of the rubber planted area in the immature rubber stage in Malaysia that received fertilizers at the recommended dosage
- From the total percentage of the rubber planted area in the immature rubber stage that receive fertilizers lower than the recommended dosage for the past

one year in (Malaysian Rubber Board, 2012), half of it is considered as receiving fertilizers at the recommended dosage

Based on 51.8% of the planted rubber area in the immature rubber stage in Malaysia is fertilized at the recommended dosage and with the average stand of 410 rubber trees per hectare from this study, the estimated amount of fertilizer consumption from 0.379 million hectares of the immature rubber area in Malaysia is summarized in Table 4.52.

Table 4.52: Estimated fertilizer consumption from the immature rubber area in Malaysia

Fertilizer	Quantity used (Tonne)	
	6 years	One year
Ammonium sulphate	207,836.4	34,639.4
Rock phosphate	176,645.2	29,440.9
Potassium chloride	56,885.6	9,480.9
Magnesium sulphate	40,073.0	6,678.8
Total	481,440.3	80,240.0

The average for one year consumption of ammonium sulphate and potassium chloride from the immature rubber stage in Malaysia as shown in Table 4.52 represent 4.4% and 0.6% respectively from the Malaysian ammonium sulphate and potassium chloride consumption in 2014(FAO, 2017).

Herbicide usage in the production of mature rubber tree from immature rubber stage

The usage of herbicides in controlling the weeds during the immature rubber stage is very important in order to ensure the growing process of the immature rubber trees is not interrupted as the weed compete with the immature rubber trees for nutrients and sunlight (Alif, 1992; Liu, 1980). These weeds if not eliminated will compete with the rubber trees for nutrients resulting in the higher consumption of fertilizers to maintain the healthy growth of the immature rubber trees. Weed control program during the immature rubber stage is very important as the immature rubber tree canopy is not fully developed at this stage resulting in abundant sunlight to fall on the ground that encourage the vigorous growth of weeds (Alif, 1993).

The summary on the herbicide usage based on one immature rubber tree during the immature rubber stage is summarized in Table 4.53.

Table 4.53: Quantity of herbicides usage during the immature rubber stage

Herbicide	Amount of herbicide usage	
	(L/tree/6 Years)	(L/tree/year)
Herbicide with 41% glyphosate	0.2379	0.0397
Herbicide with 13% paraquat dichloride	0.0960	0.0160

There are two methods of weed control during the immature rubber stage used by the respondents in this study. A total of 52.2 % of the respondents used only herbicides to control the weed while the balance of 47.8% of the respondents uses a combination of herbicides and manual slashing in their weed control program.

Glyphosate based herbicide is the most widely used herbicide by the respondents in this study and the numbers of respondents that use this type of herbicide represent 78.3% from the total respondents in this study. Despite its controversial health effect, paraquat dichloride based herbicide is still being used by a few of the respondents in this study either in combination with glyphosate based herbicide or in combination with manual slashing.

The usage of herbicides during the immature rubber stage based on one rubber tree as compared to the herbicides usage from the cultivation of one rubber tree from cradle to grave is shown in Table 4.54.

Table 4.54: Herbicide usage from immature rubber stage as compared to usage from the whole life cycle from cradle to grave for one rubber tree

Herbicide	Quantity used for one tree		Percentage of herbicide usage in the immature stage as compared to the whole life cycle from cradle to grave (%)
	Immature rubber stage (L/Tree/6years)	Cultivation of rubber from cradle to grave (L/tree/31.75Years)	
Herbicide with 41% glyphosate	0.2379	0.605	39.3
Herbicide with 13% paraquat dichloride	0.0960	0.572	16.8

Glyphosate based herbicide usage from one immature rubber tree during the immature rubber stage of 6 years represents 39.3% from the total glyphosate based herbicide usage in the cultivation of one rubber tree from cradle to grave in 31.75 years (Table 4.54).

The contribution of 39.3% glyphosate based herbicide usage during the immature rubber stage towards the total glyphosate based herbicide usage from cradle to grave stage is relatively higher as compared to the immature rubber stage period of 18.9% from the whole lifespan of the rubber tree from cradle to grave. This finding indicates that the respondents in this study follow the recommendation of MRB weed control recommendation. MRB recommended that the frequency of weed control in the form of herbicides spraying to be applied more frequent during the initial stage of rubber growth and the frequency can be slowly reduce as the rubber trees grow as the shading effect from the grown up rubber trees will reduce the sunlight falling on the ground thus making difficulties for the weeds to grow (Malaysian Rubber Board, 2009).

Based on the survey by MRB involving 0.120 million hectares of immature rubber planted area in Malaysia owned by the individual rubber smallholders, 73.1% of this immature rubber planted area is carrying out weed control using herbicides for the past one year (Malaysian Rubber Board, 2012). Due to the limited information available, the figures from the MRB survey is used as the basis of calculation in this study to estimate the herbicides consumption during the immature rubber stage.

Assuming that the weed control in 73.1% of the immature rubber area in Malaysia is carried out by using herbicides at the recommended frequency as the basis of calculation and with the average stand of 410 rubber trees per hectare, the estimated usage of herbicides active ingredients from 0.379 million hectares of immature rubber area in Malaysia is summarized in Table 4.55.

Table 4.55: Estimated herbicides active ingredients usage from the immature rubber area in Malaysia

Herbicide	Herbicide active ingredient	Amount of herbicide active ingredients used	
		(Tonne/6 years)	(Tonne/ year)
Herbicide with 41% glyphosate	glyphosate	11,094.0	1,849.0
Herbicide with 13% paraquat dichloride	paraquat dichloride	1,419.5	236.6

4.7.2 LCIA in the Production of Mature Rubber Tree from Immature Rubber Stage

Characterization

The characterization result to maintain the healthy growth of one immature rubber tree for a year is summarized in Figure 4.22 and the characterization values are shown in Table 4.56. Ammonium sulphate production is the main contributor to 6 characterization impact categories (Figure 4.22). Ammonium sulphate production is the main contributor to carcinogens, respiratory organics, ecotoxicity, acidification/eutrophication, minerals and fossil fuels at 42.4%, 44.9%, 48.9%, 38.6%, 54.6% and 52.8% from the total value of the respective impact categories (Figure 4.22). Ammonium sulphate production also contribute significantly to respiratory inorganics, climate change and land use impact categories at 26.8%, 21.2% and 24.4% respectively (Figure 4.22).

Glyphosate production is the single major contributor to radiation and ozone layer impact categories with contribution of 60.3% and 69.7% respectively from the total value of the respective impact categories (Figure 4.22). Glyphosate production is also the main contributor to respiratory inorganics, land use, carcinogens, respiratory organics, ecotoxicity, acidification/eutrophication, minerals and fossil fuels impact categories at 27.5%, 32.8%, 39.1%,40.7%, 33.4%,38.5%,28.2% and 32.1% respectively (Figure 4.22). For climate change impact category, nitrous oxide emission from the application of ammonium sulphate is the main contributor at 54.2%, follow by ammonium sulphate production and glyphosate production at 21.2% and 16.8% from the total value of this impact category (Figure 4.22).

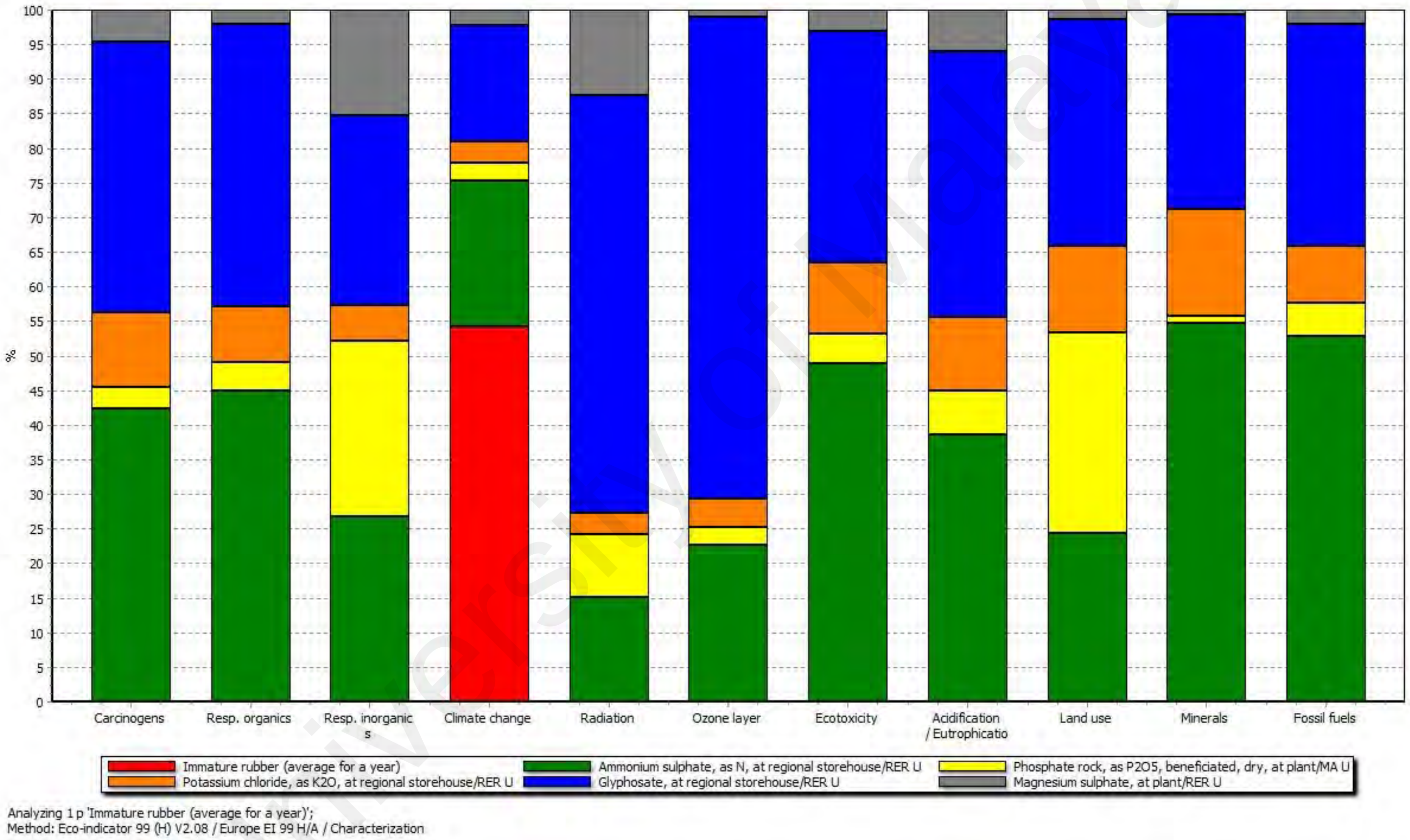

Figure 4.22: Characterization to maintain the healthy growth of one immature rubber tree for a year based on impact categories

Table 4.56: Characterization values to maintain the healthy growth of one immature rubber tree for a year

Impact category	Unit	Total	Ammonium sulphate application	Ammonium sulphate	Phosphate rock	Potassium chloride	Glyphosate	Magnesium sulphate
Carcinogens	DALY	1.81E-07	0.00E+00	7.68E-08	5.62E-09	1.96E-08	7.08E-08	8.30E-09
Resp. organics	DALY	3.92E-10	0.00E+00	1.76E-10	1.60E-11	3.19E-11	1.59E-10	8.29E-12
Resp. inorganics	DALY	4.14E-07	0.00E+00	1.11E-07	1.05E-07	2.14E-08	1.14E-07	6.30E-08
Climate change	DALY	2.39E-07	1.30E-07	5.07E-08	6.22E-09	7.43E-09	4.02E-08	5.14E-09
Radiation	DALY	3.16E-09	0.00E+00	4.75E-10	2.87E-10	1.00E-10	1.90E-09	3.90E-10
Ozone layer	DALY	1.19E-10	0.00E+00	2.70E-11	3.12E-12	4.82E-12	8.31E-11	1.22E-12
Ecotoxicity	PAF*m2yr	2.04E-01	0.00E+00	9.97E-02	8.75E-03	2.11E-02	6.81E-02	6.22E-03
Acidification/ Eutrophication	PDF*m2yr	6.65E-03	0.00E+00	2.57E-03	4.22E-04	7.07E-04	2.56E-03	3.96E-04
Land use	PDF*m2yr	1.11E-02	0.00E+00	2.71E-03	3.22E-03	1.39E-03	3.65E-03	1.53E-04
Minerals	MJ surplus	3.46E-02	0.00E+00	1.89E-02	3.73E-04	5.34E-03	9.75E-03	2.19E-04
Fossil fuels	MJ surplus	8.70E-01	0.00E+00	4.59E-01	4.20E-02	7.13E-02	2.79E-01	1.80E-02

Damage assessment

The damage assessment result to maintain the healthy growth of one immature rubber tree for a year is shown in Figure 4.23. For human health damage category, ammonium sulphate production and glyphosate production are the two main process contributors. Ammonium sulphate production and glyphosate production represented 28.5% and 27.1% respectively from the total human health damage category value (Figure 4.23).

Nitrous oxide emission from the application of ammonium sulphate is the third highest contributor at 15.5% while rock phosphate production, magnesium sulphate production and potassium chloride production contribute 13.9%, 9.2% and 5.8% toward the total human health damage category value in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.23).

For ecosystem quality damage category, ammonium sulphate production is the highest contributor at 40.0% followed by the production of glyphosate at 34.1% (Figure 4.23). The remaining three process contributor i.e. rock phosphate production, potassium chloride production and magnesium sulphate production contribute 11.8%, 11.0% and 3.1% toward the total ecosystem quality damage category value in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.23).

For resources damage category, ammonium sulphate production and glyphosate production are the two most dominant processes represent 84.8% from the total resource damage category value in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.23). Ammonium sulphate production is the highest contributor at 52.9%, follow by glyphosate production at 31.9% from the total resource damage category value (Figure 4.23).

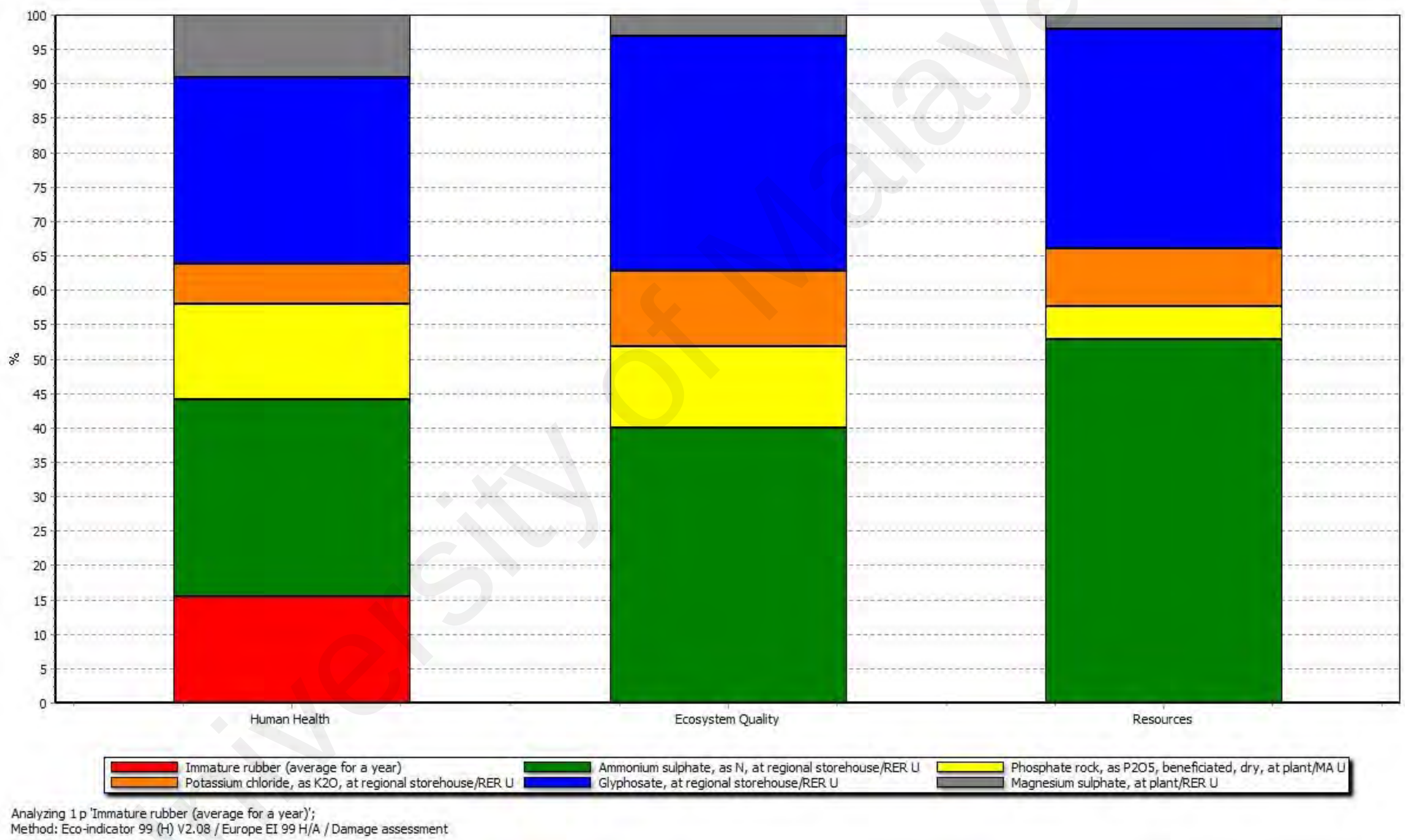

Figure 4.23: Damage assessment to maintain the healthy growth of one immature rubber tree for a year based on damage categories

The damage assessment results based on three damage categories from this study are non-comparable between them as they only show relative distribution within the respective damage categories. The damage assessment results from this study however did indicate that ammonium sulphate production and glyphosate production are the two most polluting process contributors in maintaining the healthy growth of one immature rubber tree for a year.

Normalization

The normalization results to maintain the healthy growth of one immature rubber tree for a year is summarized in Figure 4.24. Fossil fuels is the single most dominant impact category in the normalization impact assessment to maintain the healthy growth of one immature rubber tree for a year (Figure 4.24). For fossil fuels impact category, ammonium sulphate production and glyphosate production are the two main process contributors at 52.8% and 32.1% respectively towards the total value of this impact category (Figure 4.24).

Respiratory inorganics, climate change and carcinogens impact categories play minor role in maintaining the healthy growth of one immature rubber tree for a year while the rest of the impact categories are considered as insignificant (Figure 4.24).

Using the estimation that 51.8% from the 0.379 million hectares of immature rubber planted area in Malaysia is fertilized at the recommended dosage and with the average stand of 410 rubber trees per hectare, the estimated impact towards the damage categories in maintaining the healthy growth of immature rubber trees in Malaysia for a year is summarized in Table 4.57.

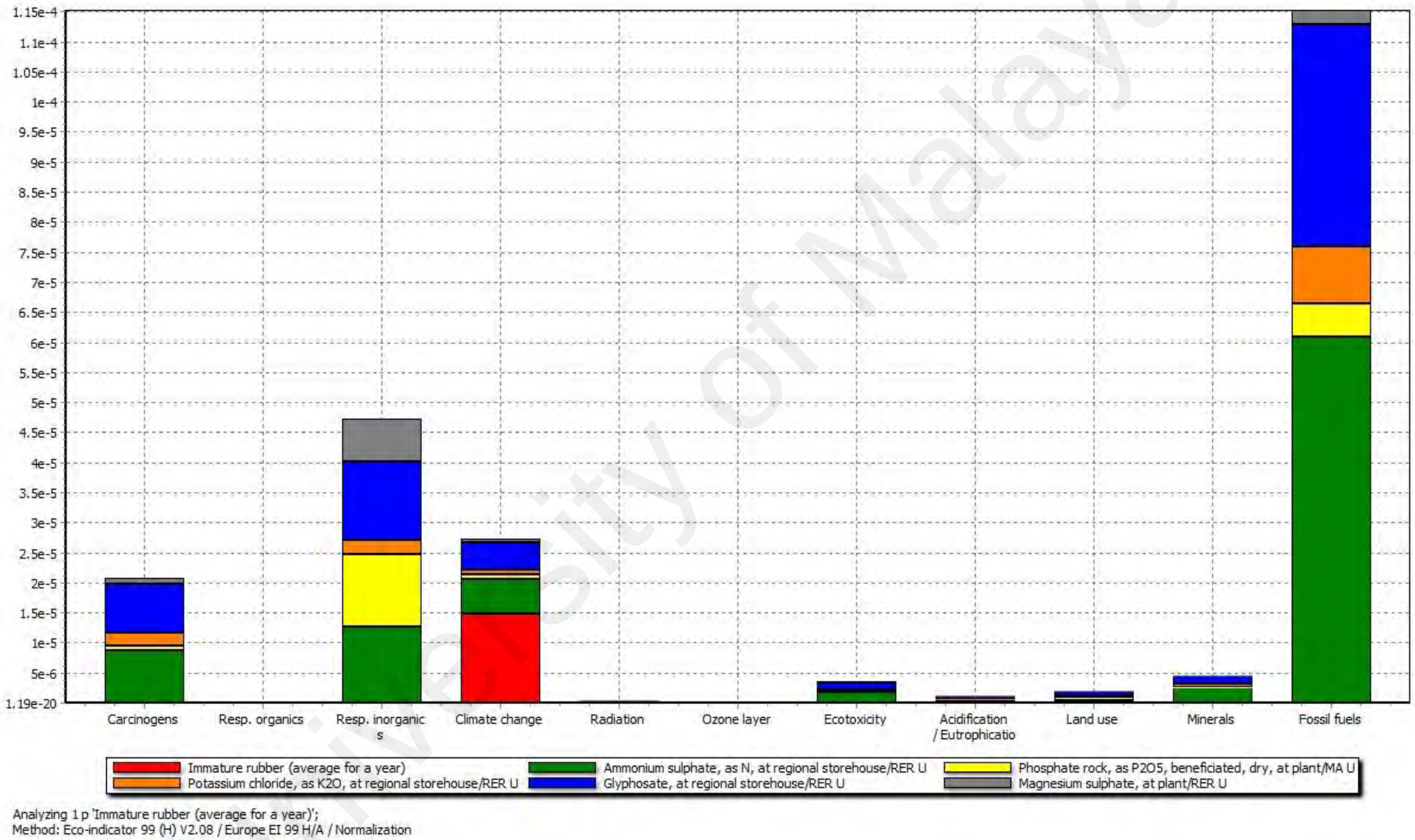

Figure 4.24: Normalization to maintain the healthy growth of one immature rubber tree for a year based on impact categories

Table 4.57: Estimated impact to maintain the healthy growth of immature rubber trees in Malaysia for a year based on damage categories

Damage category	Normalization value (PE)	Malaysian population 2016[#] (Million)	Impact to Malaysia (%)	Normalization value for the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (PE)	Impact to the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (%)
Human health	7.71E+03	31.7	0.0243	2.62E+04	29.4
Ecosystem quality	5.38E+02	31.7	0.0017	1.93E+03	27.9
Resources	9.66E+03	31.7	0.0305	3.52E+04	27.4

[#] Source: (Department of Statistic Malaysia, 2016)

Based on Table 4.57, the estimated impact to maintain the healthy growth of immature rubber trees in Malaysia for a year is in the range of 0.0017% to 0.0305% from the total Malaysian impact for these three normalization damage categories and is considered as insignificant. The impact in maintaining the healthy growth of immature rubber trees in Malaysia for a year is in the range of 27.4% to 29.4% as compared to the respective damage categories from the one year average impact from the rubber trees cultivation in Malaysia from cradle to grave (Table 4.57).

Weighting

The weighting result to maintain the healthy growth of one immature rubber tree for a year is shown in Figure 4.25 while the weighting results to maintain the healthy growth of one immature rubber tree for the total duration of immature rubber stage in 6 years is shown in Table 4.58. Fossil fuels and respiratory inorganics are the two most dominant contributors in the weighting impact assessment to maintain the health growth of one immature rubber tree for a year representing a total of 64.7% from the total value of 11 weighting impact categories (Figure 4.25).

Fossil fuels and respiratory inorganics impact categories represent 35.6% and 29.1% respectively from the total value of 11 weighting impact categories (Figure 4.25 and Table 4.58). The other 2 significant impact categories contributors are climate change and carcinogens at 16.8% and 12.7% from total value of 11 weighting impact categories (Figure 4.25 and Table 4.58). The remaining 7 impact categories i.e. ecotoxicity, minerals, land use, acidification/eutrophication, radiation, respiratory organics and ozone layer contribute a total of 5.8% from total value of 11 weighting impact categories and are considered as insignificant impact categories contributors in maintaining the health growth of one immature rubber tree for a year (Figure 4.25 and Table 4.58).

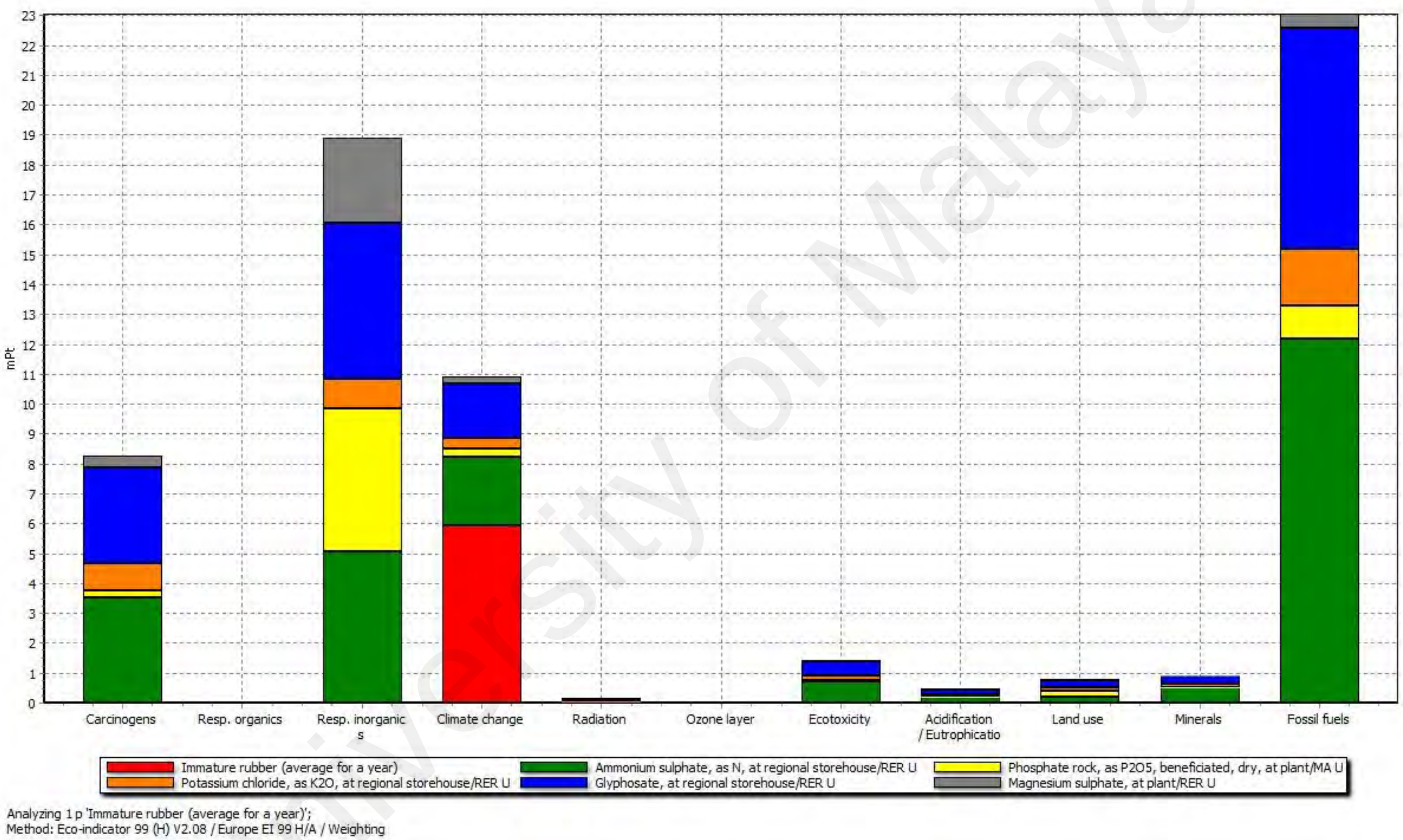

Figure 4.25: Weighting to maintain the healthy growth of one immature rubber tree for a year based on impact categories

Table 4.58: Weighting values to maintain the healthy growth of one immature rubber tree for 6 years in immature rubber stage

Damage category	Impact category	Unit	Impact category value	Damage category value	Impact to the cultivation of one rubber tree from cradle to grave (%)
Human Health	Carcinogens	Pt	4.96E-02		14.6
Human Health	Resp. organics	Pt	1.07E-04		14.3
Human Health	Resp. inorganics	Pt	1.13E-01		16.5
Human Health	Climate change	Pt	6.55E-02		14.5
Human Health	Radiation	Pt	8.64E-04		19.9
Human Health	Ozone layer	Pt	3.27E-05		18.8
Total Human Health		Pt		2.30E-01	15.5
Ecosystem Quality	Ecotoxicity	Pt	8.55E-03		14.3
Ecosystem Quality	Acidification/ Eutrophication	Pt	2.79E-03		14.8
Ecosystem Quality	Land use	Pt	4.67E-03		15.1
Total Ecosystem Quality		Pt		1.60E-02	14.7
Resources	Minerals	Pt	5.50E-03		12.9
Resources	Fossil fuels	Pt	1.38E-01		14.5
Total Resources		Pt		1.44E-01	14.4
Total		Pt		3.89E-01	15.0

For fossil fuels impact category, ammonium sulphate production and glyphosate production are the two most dominant processes contributors representing 52.8% and 32.1% respectively from the total value of this impact category (Figure 4.25). The usage of fossil fuels in the form of natural gas, crude oil and hard coal as the feed materials for industrial furnaces during the production of ammonium sulphate is responsible for the cumulative impact of fossil fuels impact category in maintaining the healthy growth of one immature rubber tree for a year (Ecoinvent, 2010).

For the production of glyphosate, the use of fossil fuels in the form of natural gas is responsible for the cumulative impact of fossil fuels impact category in maintaining the healthy growth of one immature rubber tree for a year. Natural gas was used as the feedstock for the production of methanol, the early precursor for acetic anhydride, one of the main material used in the production of glyphosate (Ecoinvent, 2010; SPE, 2017). Natural gas was also burned in the industrial furnace to supply the needed heat in the production of glyphosate (Ecoinvent, 2010).

For respiratory inorganics impact category, glyphosate production, ammonium sulphate production and phosphate rock production are the three most dominant processes representing 79.6% from the total value of this impact category (Figure 4.25). Glyphosate production, ammonium sulphate production and rock phosphate production contribute 27.5%, 26.8% and 25.3% respectively towards the total value of respiratory inorganics impact category in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.25). The emission to the air of inorganics substances in the form of PM 2.5 and PM 10 particulates, sulphur dioxide and nitrogen oxides from the production of glyphosate and ammonium sulphate is responsible for the cumulative impact of respiratory inorganics impact category in maintaining the healthy growth of one immature rubber tree for a year (Ecoinvent, 2010). The emission of PM 2.5 and PM

10 particulates from the rock phosphate production is responsible in contributing to the total value of respiratory inorganics impact category in maintaining the healthy growth of one immature rubber tree for a year (Ecoinvent, 2010).

The total impact in maintaining the healthy growth of one immature rubber tree in 6 years period of immature rubber stage represent 15.0% from the total impact from the cultivation of one rubber tree from cradle to grave in 31.75 years (Table 4.58). The effect to the human health damage category in maintaining the healthy growth of one immature rubber tree in 6 years period of immature rubber stage is the highest at 15.5% from the total human health effect from the cultivation of one rubber tree from cradle to grave in 31.75 years (Table 4.58).

The damage to the ecosystem quality and resource depletion from the process to maintain the healthy growth of one immature rubber tree in 6 years period of immature rubber stage represent 14.7% and 14.4% respectively from the total ecosystem quality damage and resource depletion from the cultivation of one rubber tree from cradle to grave in 31.75 years (Table 4.58).

Using the estimation that 51.8% from the 0.379 million hectares of immature rubber planted area in Malaysia is fertilized at the recommended dosage as the basis of calculation and the average stand of 410 rubber trees per hectare, the estimated impact from the process of maintaining the healthy growth of immature rubber trees for a year in Malaysia towards the four main weighting impact categories is summarized in Table 4.59.

Table 4.59: Estimated impact to maintain the healthy growth of immature rubber trees in Malaysia for a year based on four main weighting impact categories

Impact category	Weighting value (Pt)		Impact to the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (%)
	Maintaining the healthy growth of immature rubber trees in Malaysia based on one year average	Cultivation of rubber trees from cradle to grave in Malaysia based on one year average	
Fossil fuels	1,857,911.47	6,741,112.54	27.56
Respiratory inorganics	1,524,380.90	4,851,215.6	31.42
Climate change	880,434.45	3,184,824.2	27.64
Carcinogens	666,207.63	2,392,611.6	27.84

These four main weighting impact categories represent 94.2% from the total value of 11 weighting impact categories in maintaining the healthy growth of immature rubber trees for a year in Malaysia (Table 4.59).

The respiratory effects on mankind due to the emissions of inorganics substances to the air from the process of maintaining the healthy growth of the immature rubber trees in Malaysia for a year recorded the contribution of 31.42% from the total respiratory inorganics impact category value from the cultivation of rubber trees in Malaysia based on a year average (Table 4.59). The carcinogenic effects on mankind due to the emission of carcinogenic substances from the process of maintaining the healthy growth of the immature rubber trees in Malaysia for a year recorded 27.84% from the total carcinogens impact category value from the cultivation of rubber trees in Malaysia based on a year average (Table 4.59).

The damage causes by the climate change and the damage in the form of extra energy needed for future extraction of fossil fuels from the process of maintaining the healthy growth of the immature rubber trees in Malaysia for a year represent 27.64% and 27.56% respectively from the total value for these two impact categories in the cultivation of rubber trees in Malaysia based on a year average (Table 4.59).

The total weighted value from the 11 weighting impact categories to maintain the healthy growth of one immature rubber tree for a year is 6.49E-02 Pt which is equal to 6.49E-05 PE as explained by PRe Consultants (2000)(Figure 4.25).Relating the value of 6.49E-05 PE for one immature rubber tree to 0.379 million hectares of immature rubber area in Malaysia at the average stand of 410 rubber trees per hectare with 51.8% of this area is fertilized at the recommended dosage and the population of 31.7 million in Malaysia, the impact from the process of maintaining the healthy growth of immature rubber trees for a year is only responsible for 0.0165% of the Malaysian environmental impact. Thus the environmental impact from the process of maintaining the healthy growth of immature rubber trees for a year in Malaysia is considered as insignificant as compared to the total Malaysian environmental impact.

Single Score

In the process of maintaining the healthy growth of one immature rubber tree for a year, health effects to the human and resource depletion are the two greatest concerns that need to be taking into consideration by the management of the rubber smallholdings (Table 4.60 and Figure 4.26).

Table 4.60: The process of maintaining the healthy growth of one immature rubber tree for a year based on damage categories.

Damage category	Unit	Total	Percentage (%)
Human Health	Pt	3.83E-02	59.0
Ecosystem Quality	Pt	2.67E-03	4.1
Resources	Pt	2.40E-02	36.9
Total	Pt	6.49E-02	100.0

Human health and resources damage categories represent 59.0% and 36.9% respectively from the total value of the three damage categories in order to maintain the healthy growth of one immature rubber tree for a year (Table 4.60).Ecosystem quality damage category is less affected in the process of maintaining the healthy growth of one immature rubber tree for a year with contribution of 4.1% from the total value of the three damage categories (Table 4.60 and Figure 4.26).

Ammonium sulphate production and glyphosate production is the first and second highest contributor to the total value of the three damage categories in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.26).

Ammonium sulphate production represent 38.0% while glyphosate production represent 29.2% from the total value of the 3 damage categories in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.26). Ammonium sulphate production and nitrous oxide emissions associated with its application represent 47.1% from the total value of the 3 damage categories (Figure 4.26).

For ammonium sulphate production, fossil fuels impact category is the biggest concern as it represents 49.4% from the total impact in the production of ammonium sulphate (Figure 4.27). This is follow by respiratory inorganics, carcinogens and climate change impact categories with contribution of 20.6%, 14.2% and 9.4% respectively towards the total impact from the production of ammonium sulphate (Figure 4.27). The remaining 7 impact categories are considered as insignificant contributors towards the environmental impact in the production of ammonium sulphate (Figure 4.27).

For glyphosate production, fossil fuels and respiratory inorganics are the two biggest concerns representing 39.1% and 27.5% from the total impact in the production of glyphosate (Figure 4.27). The contribution from carcinogens and climate change is relatively small at 17.1% and 9.7% from the total impact in the production of glyphosate (Figure 4.27). The remaining 7 impact categories are considered as insignificant contributors towards the total impact in the production of glyphosate (Figure 4.27).

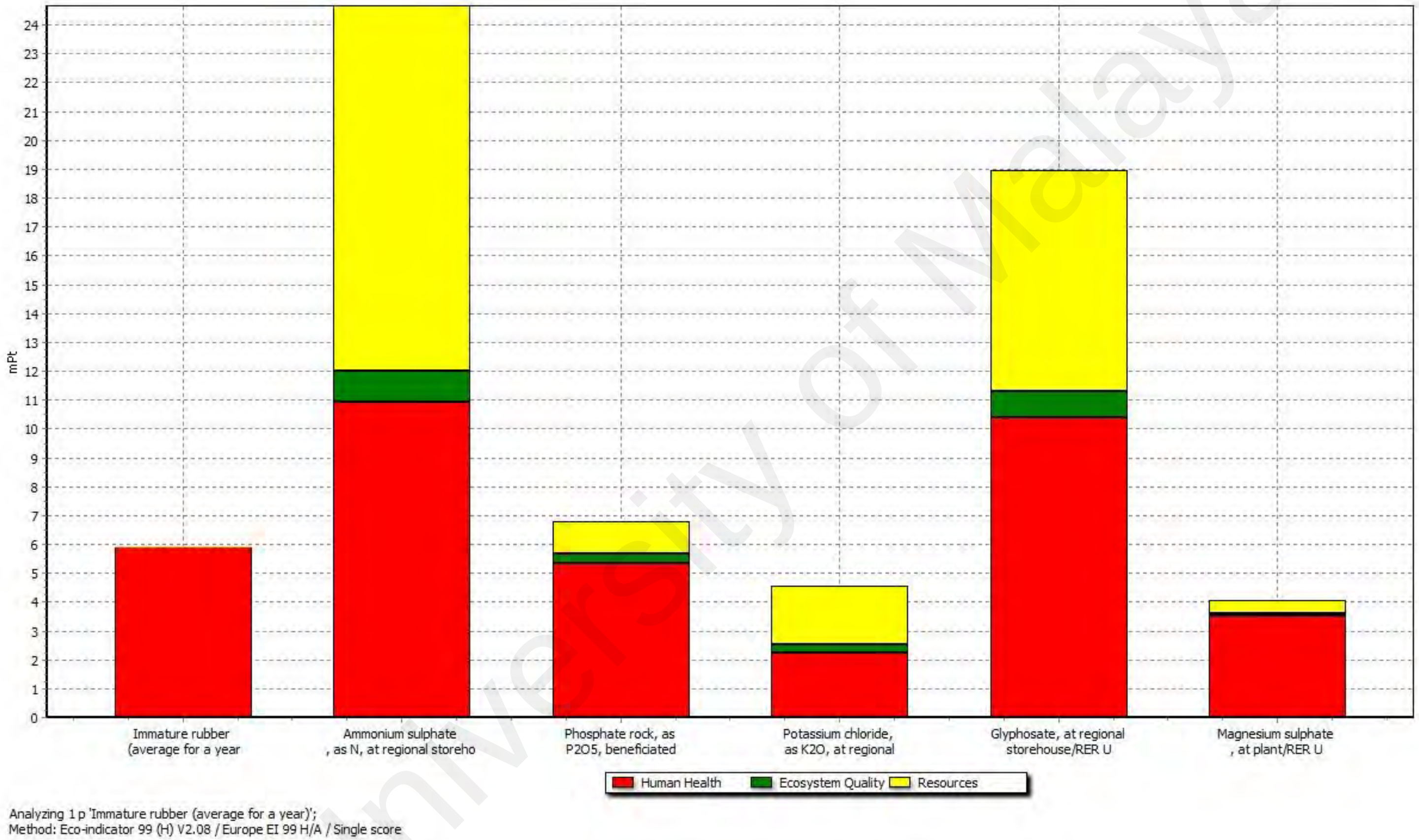

Figure 4.26: Single score to maintain the healthy growth of one immature rubber tree for a year based on damage categories

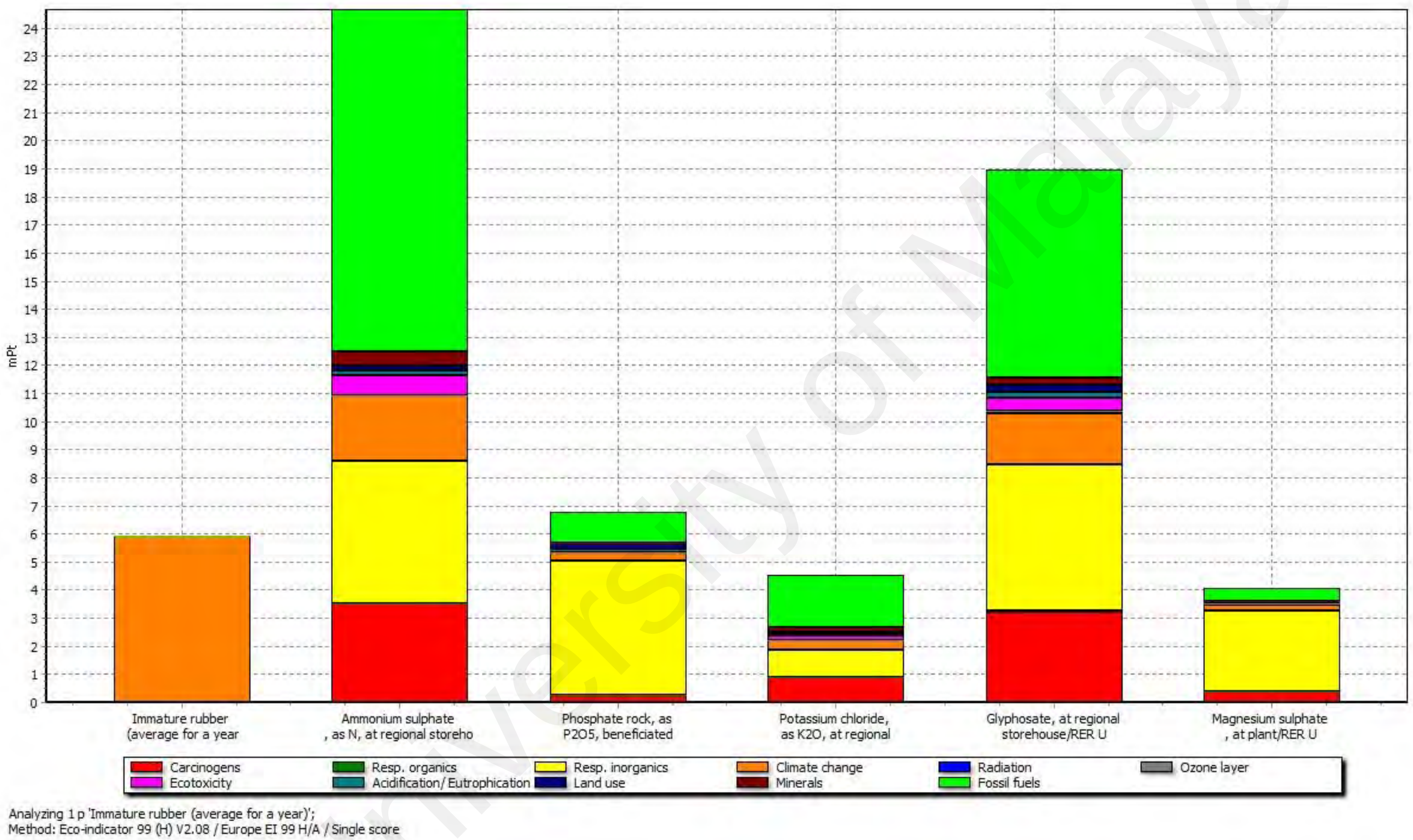

Figure 4.27: Single score results to maintain the healthy growth of one immature rubber tree for a year based on impact categories

The environmental impact from the process of maintaining the healthy growth of the immature rubber trees had the potential to be reduced through the reduction in the immaturity rubber stage period. The reduction in the immaturity rubber stage period will lead to a lower usage of ammonium sulphate, glyphosate and other resources and this will directly reduce the environmental impact in maintaining the healthy growth of the immature rubber trees during the immature rubber stage.

The majority of the immature rubber trees from this study is projected to be ready for tapping in six years period and this is within the range of the average immature rubber period in Malaysia from five to seven years as reported by Ghaffar et al. (2007).(Jawjit et al., 2010; Petsri et al., 2013) reported that in general, the immaturity rubber stage period in Thailand is 7 years.

Based on literature, the immaturity rubber stage period can be shorten up to 4 and half years after planting if the two whorled young budding from prodigious clone were used as the planting material (Ahmad et al., 2006). This is supported by Mokhatar, Daud, and Ishak (2012) which reported the using of prodigious clone such as RRIM 2000 series can lead to the relatively shorter rubber immature stage period. In this study, the information on the types of planting materials used and the types of clones used by the respondents was not collected due to the difficulties in getting the information.

Among possible practice that can shorten the immaturity rubber stage period is through increasing the efficiency of the nutrients uptake by applying the mixed fertilizers at the place where active feeder roots are concentrated as suggested by (Karim, 2008b; Sulaiman, Ashraf, et al., 2010). Sulaiman, Ashraf, et al. (2010) suggested the practice of pruning the immature rubber trees to increase the girth size of the immature rubber trees which can lead to the relatively shorter rubber immature stage period.

Apart from the strategies to reduce the immaturity period of the rubber trees stage, the environmental impact from the process of maintaining the healthy growth of the immature rubber trees can also be reduce through the reduction in the herbicide usage by incorporating the manual weeding method in the form of hand-held motorized slasher, manual slashing and using a hoe in the weed control program.

The rubber smallholders management must also caution the rubber smallholders on the type of herbicides that can be used to maintain their immature rubber trees. This is important as some of the herbicides available in the market has a very detrimental effect to the health of the people who used it and some of these herbicides were already been ban in other part of the world.

4.7.3 LCIA on GHGs Emission in the Production of Mature Rubber Tree from Immature rubber stage

The total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year for this study is 1.08 $kgCO_2eq$ (Figure 4.28 and Table 4.62). Nitrous oxide emission from the usage of ammonium sulphate at 5.60E-01 $kgCO_2eq$ is the single highest contributor representing 51.6% from the total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year (Figure 4.28).

The second highest contributor to the total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year is ammonium production at 22.4% while glyphosate production recorded the third highest contribution at 17.7% (Figure 4.28). The remaining 3 processes are considered as insignificant contributors towards the total value of GHGs emission to maintain the healthy growth of one immature rubber tree for a year (Figure 4.28).

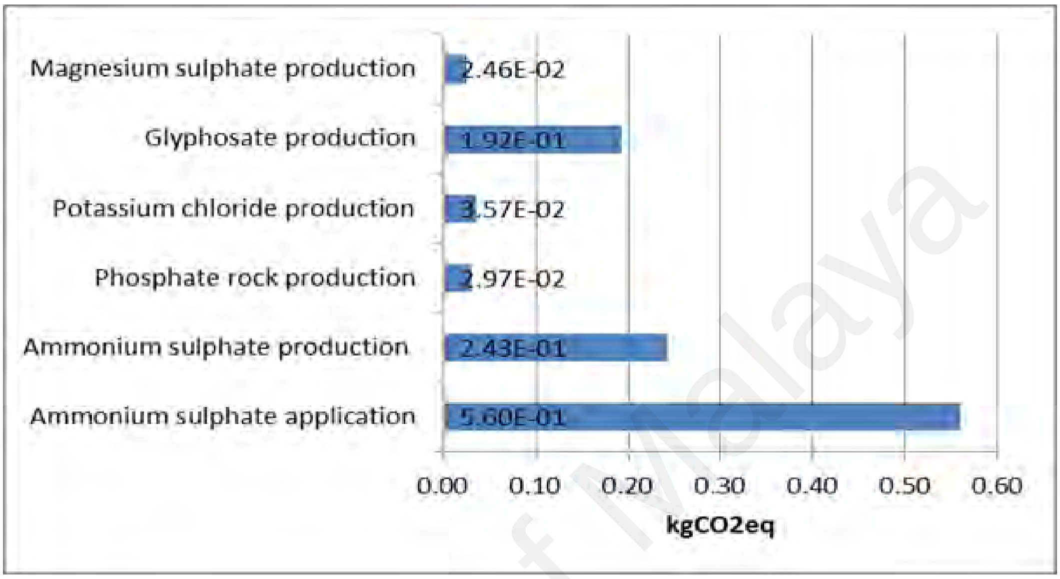

Figure 4.28: GHGs emissions in maintaining the healthy growth of one immature rubber tree for a year

From Figure 4.28, it is obvious that the reduction in the usage of ammonium sulphate and glyphosate will definitely reduce the total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year. This can be achieve through the reduction in the immaturity rubber stage period and through incorporating the manual weeding method in the weed management as described in section 4.8.2.

The GHGs emission value in maintaining the healthy growth of one immature rubber tree for 6 years duration during the immature rubber stage is 6.51kgCO_2eq and this represent 14.6% from the total value of GHGs emission for the cultivation of one rubber tree from cradle to gate of 44.68kgCO2eq.

The GHGs emission in maintaining the healthy growth of immature rubber trees in Malaysia for a year based on 0.379 million hectares of immature rubber area in Malaysia at the average stand of 410 rubber trees per hectare and with 51.8% of this area is fertilized at the recommended dosage is summarized in Table 4.61.

Table 4.61: GHGs emission to maintain the healthy growth of immature rubber trees in Malaysia

	Immature rubber stage (6 Years)	Average one year for immature rubber stage
GHGs emission ($GgCO_2eq$)	524.69	87.45
Percentage from Malaysia 2011 GHGs emission (%)*	0.18	0.03
Percentage from agriculture sector in Malaysia 2011 GHGs emission (%)*	3.33	0.55

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on the Table 4.61, the GHGs emission value from the perspective to maintain the healthy growth of immature rubber trees in Malaysia for 6 years immature rubber stage and one year average for immature rubber stage are considered as insignificant as compared to the Malaysian 2011 GHGs emission of 290,230 $GgCO_2eq$ (Ministry of Natural Resources and Environment Malaysia, 2015).

The GHGs emission value of 524.69 $GgCO_2eq$ for 6 years duration of immature rubber stage in maintaining the healthy growth of immature rubber trees in Malaysia is very low and represent only 3.3% from the 2011 Malaysian agricultural sector GHGs emission of 15775.3 GgCO2eq (Table 4.61). The GHGs emission value of 87.45 $GgCO_2eq$ based on the average one year for immature rubber stage is considered as insignificant as compared to the GHGs emissions value from Malaysian agricultural sector in 2011(Table 4.61).

The list of GHGs emission and its corresponding values in contributing to the total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year is shown in Table 4.62.

Table 4.62: GHGs emission profile to maintain the healthy growth of one immature rubber tree for a year

GHGs	Weight in $kgCO_2eq$
Nitrous oxide	5.63E-01
Carbon dioxide	4.91E-01
Methane	2.87E-02
Methane, tetrafluoro-, CFC-14	6.34E-04
Sulfur hexafluoride	5.38E-04
Ethane, hexafluoro-, HFC-116	1.34E-04
Methane, tetrachloro-, CFC-10	7.70E-05
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	4.05E-05
Methane, chlorodifluoro-, HCFC-22	3.82E-05
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1.92E-05
Methane, bromochlorodifluoro-, Halon 1211	1.06E-05
Methane, bromotrifluoro-, Halon 1301	9.76E-06
Methane, dichlorodifluoro-, CFC-12	8.30E-07
Methane, trifluoro-, HFC-23	6.64E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1.31E-07
Ethane, 1,1-difluoro-, HFC-152a	1.74E-08
Chloroform	1.48E-08
Methane, trichlorofluoro-, CFC-11	1.09E-09
Methane, dichloro-, HCC-30	2.21E-10
Methane, monochloro-, R-40	2.00E-10
Ethane, 1,1,1-trichloro-, HCFC-140	7.90E-11
Methane, dichlorofluoro-, HCFC-21	2.13E-11
Methane, bromo-, Halon 1001	2.86E-17
Total GHGs Emission	1.08

Nitrous oxide and carbon dioxide are the two major GHGs that contribute 97.2% from the total GHGs emission in maintaining the healthy growth of one immature rubber tree for a year (Table 4.62).

Carbon dioxide emission

Carbon dioxide emission represents 45.3% from the total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year (Table 4.62). The details on the carbon dioxide (CO_2) emission in maintaining the healthy growth of one immature rubber tree for a year is shown in Table 4.63.

Table 4.63: Carbon dioxide emission values based on process to maintain the healthy growth of one immature rubber tree for a year

Process	CO_2 (kg)
Ammonium sulphate production	2.30E-01
Glyphosate production	1.78E-01
Potassium chloride production	3.17E-02
Phosphate rock production	2.84E-02
Magnesium sulphate production	2.33E-02
Total Emission	4.91E-01

Ammonium sulphate production and glyphosate production are the two major carbon dioxide emission contributors representing 83.0% from the total value of carbon dioxide emissions in maintaining the healthy growth of one immature rubber tree for a year (Table 4.63). The remaining 3 processes are considered as minor contributors to the total carbon dioxide emission in maintaining the healthy growth of one immature rubber tree for a year (Table 4.63).

The carbon dioxide emission in maintaining the healthy growth of one immature rubber tree for a year is 4.91E-01 $kgCO_2$ (Table 4.63). Relating this to 0.379 million hectares of immature rubber area in Malaysia at the average stand of 410 rubber trees per hectare with 51.8% of this area is fertilized at the recommended dosage, the estimated carbon dioxide emission to maintain the healthy growth of the immature rubber trees in Malaysia is summarized in Table 4.64.

Table 4.64: Carbon dioxide emission to maintain the healthy growth of immature rubber trees in Malaysia

	Immature rubber stage (6 Years)	Average one year for immature rubber stage
Carbon dioxide emission ($GgCO_2$)	237.44	39.57
Percentage from Malaysia 2011 CO2 emission (%)*	0.11	0.02

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on the Table 4.64, carbon dioxide emission value from the perspective to maintain the healthy growth of immature rubber trees in Malaysia for 6 years immature rubber stage and one year average for immature rubber stage are considered as insignificant as compared to the Malaysian 2011 carbon dioxide emission of 208,258 $GgCO_2$ (Ministry of Natural Resources and Environment Malaysia, 2015).

Nitrous oxide emission

Nitrous oxide emission represents 51.9% from the total GHGs emission value in maintaining the healthy growth of one immature rubber tree for a year (Table 4.62). The values of the nitrous oxide emission in maintaining the healthy growth of one immature rubber tree for a year is shown in Table 4.65.

Table 4.65: Nitrous oxide (N_20) emission values based on process to maintain the healthy growth of one immature rubber tree for a year

Process	N_20 (kg)
Ammonium sulphate production	2.79E-06
Glyphosate production	4.17E-06
Potassium chloride production	2.61E-06
Phosphate rock production	8.70E-07
Magnesium sulphate production	7.84E-07
Ammonium sulphate application	1.88E-03
Total Emission	1.89E-03

Nitrous oxide in the form of direct and indirect emissions from the application of ammonium sulphate to the soil is the single most dominant source of nitrous oxide representing 99.4% from the total nitrous oxide emission value in maintaining the healthy growth of one immature rubber tree for a year (Table 4.65).

The nitrous oxide emission in maintaining the healthy growth of one immature rubber tree for a year is 5.63E-01 $kgCO_2eq$ based on its global warming potential of 298 (IPCC, 2007). Relating this to 0.379 million hectares of immature rubber area in Malaysia with 51.8% of this area is fertilized at the recommended dosage, the estimated nitrous oxide emission to maintain the healthy growth of the immature rubber trees in Malaysia is summarized in Table 4.66.

Table 4.66: Nitrous oxide emission to maintain the healthy growth of immature rubber trees in Malaysia

	Immature rubber stage (6 Years)	Average one year for immature rubber stage
Nitrous oxide emission ($GgCO_2eq$)	272.36	45.39
Percentage from Malaysia 2011 Nitrous oxide emission (%)*	2.01	0.33

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on the Table 4.66, nitrous oxide emission from the perspective to maintain the healthy growth of immature rubber trees in Malaysia for 6 years immature rubber stage and one year average for immature rubber stage are considered as very low and insignificant respectively as compared to the Malaysian 2011 nitrous oxide emission value of 13574 GgCO_2eq (Ministry of Natural Resources and Environment Malaysia, 2015).

4.8 LCA Study for the Mature Rubber Stage

The objective of this study is to quantify the life cycle inventory, life cycle impact assessment and GHGs emission in maintaining the healthy growth of one mature rubber tree from the mature rubber stage in Malaysia as part of the main goal in quantifying the life cycle inventory, life cycle impact assessment and GHGs emission for the cultivation of one rubber tree from cradle to grave approach. The functional unit for this study is defined as the process to maintain the healthy growth of one mature rubber tree in the mature rubber stage.

The process of maintaining the healthy growth of one mature rubber tree through the usage of fertilizers and herbicides will produce the outputs in the form of tree biomass and natural rubber based on allocation as described in section 4.1. For the scope of this study, these two types of outputs i.e. tree biomass and natural rubber from the process of maintaining the healthy growth of one mature rubber tree will only be referred simply as the healthy growth of one mature rubber tree. The mature rubber stage is referred to the productive stage in the rubber holdings started from the first day of tapping until the last day of tapping before the rubber trees are fell down at the end of their economic lifespan. In this study, the productive period of 25 years from the mature rubber stage represents 78.7% from the total economic lifespan of the rubber tree. The economic lifespan of the rubber trees comprises the nursery, immature and mature stage in this study is 31.75 years. The rubber trees can live for more than 100 years in its natural habitat but its economic life period in the plantation is generally around 32 years with 25 years of the productive stage (Indian Rubber Board, 2017).

For this study, the survey only represents the rubber smallholders under the supervision of rubber related agencies in Malaysia. Individual rubber smallholders are excluded from this survey as there are great difficulties in getting verified information from this group of rubber smallholders on their agronomic practices as these smallholders normally did not have any proper written record on their agronomic practices and few of them are even illiterate. From the three main government agencies in Malaysia which are responsible in supervising and managing the small plot of rubber planted area owned by the rubber smallholders, only FELDA and FELCRA agreed to take part in this study while RISDA did not allow this study to be conducted in the rubber planting areas owned by the rubber smallholders under their supervision. Based on the discussion with FELDA and FELCRA management and supported by (FELCRA, 2015; Ghani, 2015) data, there are 21 FELDA schemes and 274 FELCRA projects that are currently in the mature rubber stage in Peninsular Malaysia.

A total of 9 FELDA schemes, 33 FELCRA projects and 2 rubber estates in Malaysia agreed to participate in this study. The respondents for this study represent 42.9 % from the total number of mature FELDA schemes in Malaysia and 12.0% from the total number of FELCRA mature project in Malaysia respectively. In terms of mature rubber planted area, the respondents from FELDA schemes represent 30.5% from the total FELDA mature rubber planted area in Malaysia while the respondents from FELCRA projects represent 17.1% from the total FELCRA mature rubber planted area in Malaysia. The details information on the respondents for this study is shown in Table 4.67.

Table 4.67: Information on the respondents for the mature rubber stage

Agency	Scheme/Project Code	Rubber planted area (Hectare)	Rubber tree age (Year)	Tapping period (Year)
FELDA	Fm 1	266.48	18	12
	Fm 2	603.31	22	16
	Fm 3	50	9	3
	Fm 4	300.69	17	12
	Fm 5	382.75	22	16
	Fm 6	74.42	18	12
	Fm 7	1,384.96	12	4
	Fm 8	565.59	13	7
	Fm 9	1,605.37	12	4
FELCRA	Frm 1	44.565	26	16
	Frm 2	15.6	23	15
	Frm 3	124.7	23	16
	Frm 4	27.04	23	15
	Frm 5	47.52	22	15
	Frm 6	60.1	23	15
	Frm 7	94.9	23	15
	Frm 8	32.29	22	15
	Frm 9	23.06	22	14
	Frm 10	108.44	22	15
	Frm 11	15.49	22	15
	Frm 12	40.98	23	17
	Frm 13	419	33	24
	Frm 14	20	17	10
	Frm 15	201.13	21	14
	Frm 16	206.2	21	14
	Frm 17	77.09	22	15
	Frm 18	39.817	23	16
	Frm 19	67.802	27	19
	Frm 20	29.571	24	18
	Frm 21	31.934	22	17
	Frm 22	135.238	32	24
	Frm 23	237.147	31	23
	Frm 24	171.707	25	18
	Frm 25	177.798	26	20
	Frm 26	204.605	11	5
	Frm 27	180	10	4
	Frm 28	71.414	23	16
	Frm 29	190.27	25	18
	Frm 30	374.01	23	17
	Frm 31	324.549	33	27
	Frm 32	113.097	28	22
	Frm 33	689.758	33	25
Private rubber estates	Rem 1	30.26	11	4
	Rem 2	89.7	7	1

The age of the mature rubber trees from these respondents varies from the newly open panel for tapping at the age of 7 years old up to 33 years old of rubber trees which had been identified to be fell down for replanting (Table 4.67). The tapping period for the mature rubber trees among the respondents also varies from 1 year of tapping up to 27 years of tapping with the majority being in the 15-16 years of tapping period (Table 4.67).

4.8.1 Life Cycle Inventory

The average life cycle inventory (LCI) input-output table to maintain the healthy growth of one mature rubber tree from the first day of tapping at the rubber smallholders land until that particular mature rubber tree is tapped for the last time before it is fell down is shown in Table 4.68 and Table 4.69.

Table 4.68: LCI table to maintain the healthy growth of one mature rubber tree in 25 years period of mature rubber stage

Input	Unit	Average value	Output		
Ammonium sulphate fertilizer	kg	16.036	Output	Unit	Average value
Rock phosphate fertilizer	kg	9.389	Healthy mature rubber tree	Pcs	1
Potassium chloride fertilizer	kg	11.21	Emission		
Magnesium sulphate fertilizer	kg	2.328	Nitrous oxide	kg	0.0701
Herbicide with 41% glyphosate	L	0.367			
Herbicide with 13% paraquat dichloride	L	0.476			
Herbicide with 32.1% triclopyr butotyl	L	0.285			
Herbicide with 20% metsulfuron methyl	L	0.026			

Table 4.69: LCI table to maintain the healthy growth of one mature rubber tree for a year

Input	Unit	Average value	Output
Ammonium sulphate fertilizer	kg	6.41E-01	
Rock phosphate fertilizer	kg	3.76E-01	
Potassium chloride fertilizer	kg	4.48E-01	
Magnesium sulphate fertilizer	kg	9.31E-02	
Herbicide with 41% glyphosate	L	1.47E-02	
Herbicide with 13% paraquat dichloride	L	1.91E-02	
Herbicide with 32.1% triclopyr butotyl	L	1.14E-02	
Herbicide with 20% metsulfuron methyl	L	1.05E-03	
Emission			
Nitrous oxide	kg	2.80E-03	

Fertilizer usage in the production of mature rubber tree from immature rubber stage

The summary on the fertilizer usage during the mature rubber stage based on one rubber tree is summarized in Table 4.70.

Table 4.70: Quantity of fertilizer used during the mature rubber stage

Fertilizer	Quantity used (kg/Tree/25year)	Quantity used (kg/tree/Year)
Ammonium sulphate	16.04	0.64
Rock phosphate	9.4	0.38
Potassium chloride	11.21	0.45
Magnesium sulphate	2.33	0.09
Total	38.98	1.56

The general trend of fertilizer usage from the mature rubber stage is following the same pattern of the fertilizer usage from the cultivation of rubber from cradle to grave scenario. This is expected as the mature rubber stage of 25 years represents 78.7% from the total period of rubber cultivation from cradle to grave in 31.75 years.

Ammonium sulphate recorded the highest usage at 41.1% from the total amount of fertilizer used followed by potassium chloride (28.8%) and rock phosphate (24.1%) (Table 4.70). Magnesium sulphate fertilizer recorded the lowest usage at 6.0% from the total amount of fertilizer used (Table 4.70). The respondents in this study in general used either two types of straight fertilizers in the form of ammonium sulphate and potassium chloride or mixed fertilizers to fertilize their mature rubber trees.

Ammonium sulphate and potassium chloride are the source of nitrogen and potassium for mixed fertilizers used by the respondents in this study. Nitrogen is essential for the formation of plant tissues, plant proteins and chlorophyll in the rubber trees (Malaysian Rubber Board, 2009). Potassium is involved in most of the rubber tree physiological processes like photosynthesis, protein and carbohydrates synthesis and adequate potassium helps in bark renewal and increase in the amount of natural rubber latex produced (Daud, 2013).

The usage of the fertilizers during the mature rubber stage based on one rubber tree as compared to the fertilizers usage from the cultivation of one rubber tree from cradle to grave is shown in Table 4.71. The total fertilizers usage from one mature rubber tree during the mature rubber stage of 25 years represents 86.7% from the total fertilizers used in the cultivation of one rubber tree from cradle to grave in 31 years (Table 4.71). This indicates the great influence of the mature rubber stage fertilizers consumption towards the overall usage of fertilizers in the cultivation of rubber trees from cradle to grave.

Table 4.71: Fertilizers consumption from the mature rubber stage as compared to the consumption from the whole life cycle from cradle to grave for one rubber tree

Fertilizer	Quantity used for one tree		Percentage of fertilizer usage in the mature stage as compared to the whole life cycle from cradle to grave (%)
	Mature rubber stage (kg/Tree/25years)	Cultivation of rubber from cradle to grave (kg/tree/31Years)	
Ammonium sulphate	16.04	18.61	86.2
Rock phosphate	9.4	11.58	81.2
Potassium chloride	11.21	11.92	94.0
Magnesium sulphate	2.33	2.83	82.3
Total	38.98	44.94	86.7

Based on the literature search, there is no publicly available data on the percentage of the rubber in the mature stage in Malaysia. All publicly available data from the rubber related agencies in Malaysia mostly refer to the total planted rubber area in Malaysia without specifying the percentage of rubber in the immature stage and mature stage. The only source of information on the percentage of the rubber in the mature stage is from the classified survey data conducted by MRB in 2011-2012 as reported in (Malaysian Rubber Board, 2012). In 2014, there are a total of 1.066 million hectares of rubber planted area in Malaysia comprising the immature stage and mature stage (Malaysian Rubber Board, 2016b).

From the survey carried out by MRB involving 0.338 million hectares of rubber planted area owned by the individual rubber smallholders, 64.4% from the total planted rubber area from this survey is in the mature rubber stage (Malaysian Rubber Board, 2012). From this survey, 43.27% of the planted rubber areas in the mature rubber stage receive fertilizers at the recommended dosage, 15.84% of the planted rubber areas in the mature rubber stage receive fertilizers lower than the recommended dosage while the remaining 40.89% of the planted rubber areas in the mature rubber stage did not receive any fertilizer for the past one year (Malaysian Rubber Board, 2012).

Due to the limited information available, the figures from the MRB survey are used as the basis of calculation in this study to estimate the fertilizer consumption during the mature rubber stage. It is estimated that 51.2% of the total rubber planted area in the mature rubber stage in Malaysia receives fertilizers at the recommended dosage. The basis for this estimation is as below:

- The percentage of the rubber planted area in the mature rubber stage that received fertilizers at the recommended dosage for the past one year in (Malaysian Rubber Board, 2012) represent the percentage of the rubber planted area in the mature rubber stage in Malaysia that received fertilizers at the recommended dosage

- From the total percentage of the rubber planted area in the mature rubber stage that receive fertilizers lower than the recommended dosage for the past one year in (Malaysian Rubber Board, 2012), half of it is considered as receiving fertilizers at the recommended dosage

Based on 51.2% of the planted rubber area in the mature rubber stage in Malaysia is fertilized at the recommended dosage and with the average stand of 410 rubber trees per hectare from this study, the estimated amount of fertilizer consumption from 0.687 million hectares of mature rubber area in Malaysia is summarized in Table 4.72.

Table 4.72: Estimated fertilizer consumption from the mature rubber stage in Malaysia

Fertilizer	Quantity use for 25 years (Tonne)	Quantity use for one year (Tonne)
Ammonium sulphate	2,311,539.2	92,461.6
Potassium chloride	1,354,642.6	54,185.7
Rock phosphate	1,615,483.4	64,619.3
Magnesium sulphate	335,778.4	13,431.1
Total	5,617,443.6	224,697.7

The average for one year consumption of ammonium sulphate and potassium chloride from the mature rubber stage in Malaysia as shown in Table 4.72 represent 11.7% and 4.1% respectively from the Malaysian ammonium sulphate and potassium chloride consumption in 2014(FAO, 2017). The average for one year total consumption of ammonium sulphate and potassium chloride from the mature rubber stage in Malaysia is estimated at 6.6% from the total Malaysia consumption for 2014 (FAO, 2017).

Herbicide usage in the production of mature rubber tree from immature rubber stage

The summary on the herbicide usage based on one mature rubber tree during the mature rubber stage is summarized in Table 4.73. Glyphosate based herbicide is the most widely used herbicide by the respondents in this study and the numbers of respondents that use this type of herbicide represent 75.0% from the total respondents.

Table 4.73: Quantity of herbicides usage during the mature rubber stage

Herbicide	Amount of herbicide usage (L/tree/25 Years)	Amount of herbicide usage (L/tree/year)
Herbicide with 41% glyphosate	0.367	1.47E-02
Herbicide with 13% paraquat dichloride	0.476	1.91E-02
Herbicide with 32.1% triclopyr butotyl	0.285	1.14E-02
Herbicide with 20% metsulfuron methyl	0.026	1.05E-03

From the 33 respondents that use glyphosate based herbicide to eliminate the weeds from their mature rubber area, 12 respondents use it as a standalone herbicide, 8 respondents used it in combination with metsulfuron methyl based herbicide, 6 respondents used it in combination with triclopyr butotyl based herbicide, 4 respondents use it in combination with paraquat dichloride based herbicide and metsulfuron methyl based herbicide while the remaining 3 respondents use it in combination with paraquat dichloride based herbicide.

Based on the survey by MRB involving 0.218 million hectares of mature rubber planted area in Malaysia owned by the individual rubber smallholders, 64.2% of this mature rubber planted area is carrying out weed control using herbicides for the past one year (Malaysian Rubber Board, 2012). Due to the limited information available, the figures from the MRB survey is used as the basis of calculation in this study to estimate the herbicides consumption during the mature rubber stage.

Assuming that the weed control in 64.2% of the mature rubber area in Malaysia is carried out using herbicides at the recommended frequency as the basis of calculation and with the average stand of 410 rubber trees per hectare, the estimated usage of herbicides active ingredients from 0.687 million hectares of mature rubber area in Malaysia is summarized in Table 4.74.

Table 4.74: Estimated herbicides active ingredients usage from the mature rubber area in Malaysia

Herbicide	Herbicide active ingredient	Amount of herbicide active ingredients used	
		(Tonne/25 years)	(Tonne/ year)
Herbicide with 41% glyphosate	glyphosate	27,190.2	1,087.6
Herbicide with 13% paraquat dichloride	paraquat dichloride	11,181.8	447.3
Herbicide with 32.1% triclopyr butotyl	triclopyr butotyl	16,531.5	661.3
Herbicide with 20% metsulfuron methyl	metsulfuron methyl	939.6	37.6

4.8.2 LCIA Study for the Mature Rubber Stage

Characterization

The characterization result to maintain the healthy growth of one mature rubber tree for a year is shown in Figure 4.29 and the characterization values are shown in Table 4.75. Ammonium sulphate production is the major contributor to 8 impact categories (Figure 4.29). Ammonium sulphate production is the major contributor to carcinogens, respiratory organics, respiratory inorganics, ozone layer, ecotoxicity, acidification/eutrophication, minerals, and fossil fuels impact categories at 45.5%, 47.1%, 33.2%, 32.7%, 51.0%, 41.9%, 50.3% and 56.5% from the total value of the respective impact categories (Figure 4.29). Ammonium sulphate production also contribute significantly to climate change, radiation and land use impact categories at 22.5%, 23.3% and 27.2% respectively (Figure 4.29)

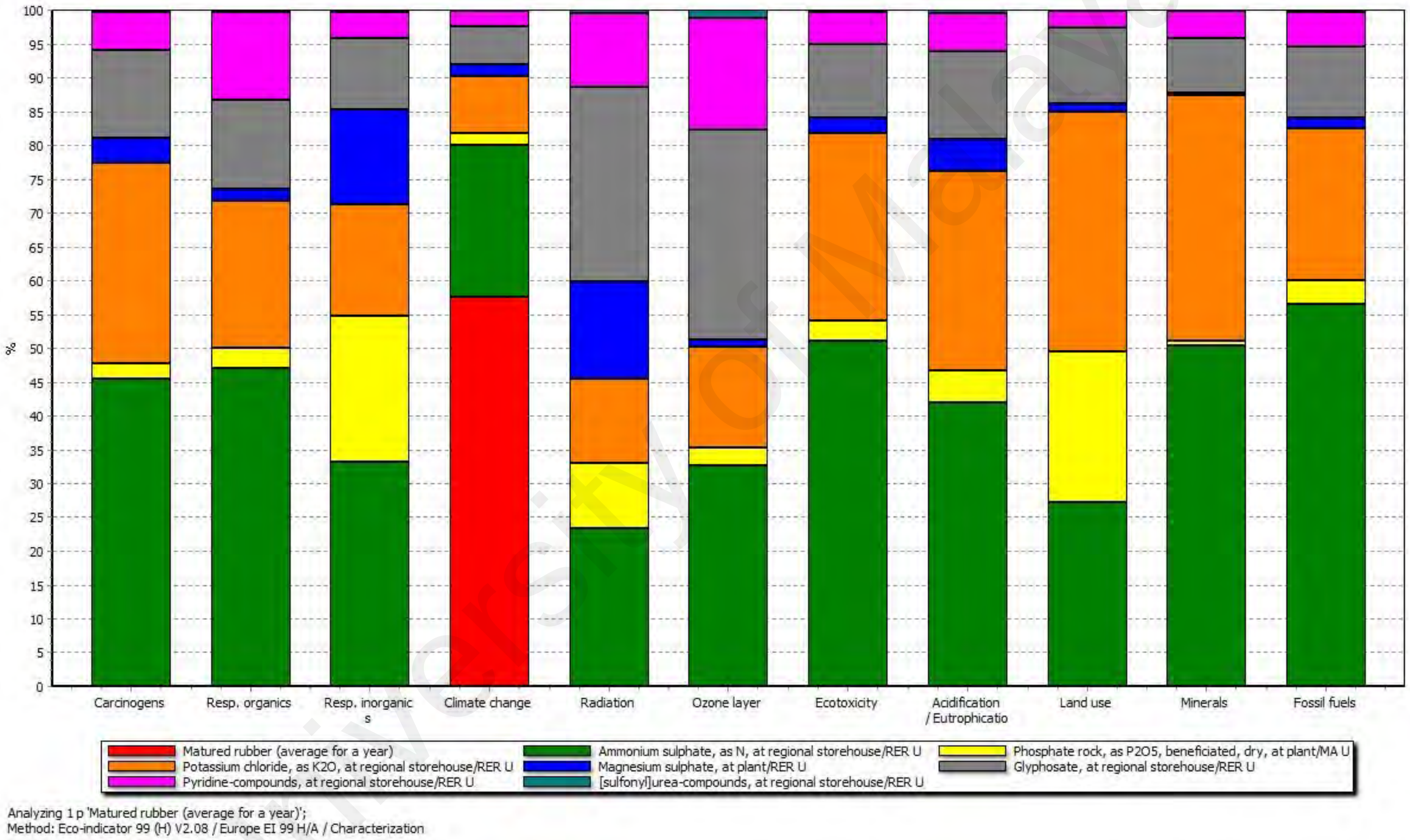

Figure 4.29: Characterization to maintain the healthy growth of one mature rubber tree for a year based on impact categories

Table 4.75: Characterization values to maintain the healthy growth of one mature rubber tree for a year

Impact category	Unit	Total	Ammonium sulphate application	Ammonium sulphate	Phosphate rock	Potassium chloride	Magnesium sulphate	Glyphosate	Pyridine-compounds	[sulfonyl]urea-compounds
Carcinogens	DALY	2.52E-07	0.00E+00	1.15E-07	5.78E-09	7.45E-08	9.33E-09	3.26E-08	1.44E-08	7.81E-10
Resp. organics	DALY	5.58E-10	0.00E+00	2.63E-10	1.64E-11	1.22E-10	9.31E-12	7.35E-11	7.20E-11	2.42E-12
Resp. inorganics	DALY	4.99E-07	0.00E+00	1.66E-07	1.08E-07	8.17E-08	7.07E-08	5.26E-08	1.91E-08	1.57E-09
Climate change	DALY	3.37E-07	1.94E-07	7.56E-08	6.40E-09	2.83E-08	5.77E-09	1.85E-08	8.06E-09	4.74E-10
Radiation	DALY	3.05E-09	0.00E+00	7.10E-10	2.95E-10	3.83E-10	4.38E-10	8.77E-10	3.31E-10	1.69E-11
Ozone layer	DALY	1.23E-10	0.00E+00	4.03E-11	3.21E-12	1.84E-11	1.38E-12	3.83E-11	2.02E-11	1.56E-12
Ecotoxicity	PAF*m2yr	2.92E-01	0.00E+00	1.49E-01	9.00E-03	8.04E-02	6.99E-03	3.14E-02	1.42E-02	7.88E-04
Acidification/ Eutrophication	PDF*m2yr	9.15E-03	0.00E+00	3.83E-03	4.34E-04	2.69E-03	4.45E-04	1.18E-03	5.25E-04	4.16E-05
Land use	PDF*m2yr	1.49E-02	0.00E+00	4.05E-03	3.31E-03	5.29E-03	1.72E-04	1.68E-03	3.64E-04	2.08E-05
Minerals	MJ surplus	5.61E-02	0.00E+00	2.82E-02	3.84E-04	2.04E-02	2.46E-04	4.49E-03	2.25E-03	1.29E-04
Fossil fuels	MJ surplus	1.21E+00	0.00E+00	6.86E-01	4.32E-02	2.72E-01	2.02E-02	1.29E-01	6.16E-02	3.53E-03

Potassium chloride production contribute significantly towards land use, carcinogens, respiratory organics, ecotoxicity, acidification/eutrophication, minerals and fossil fuels impact categories at 35.5%, 29.6%, 21.8%, 27.6%, 29.4% , 36.3% and 22.4% respectively (Figure 4.29).Glyphosate production contributes significantly towards radiation and ozone layer at 28.7% and 31.0 % respectively (Figure 4.29).For climate change impact category, nitrous oxide emission from the application of ammonium sulphate is the single main contributor at 57.5% from the total value of this impact category (Figure 4.29).

Damage Assessment

The damage assessment result to maintain the healthy growth of one mature rubber tree for a year is shown in Figure 4.30. For human health damage category, ammonium sulphate production is the highest process contributor at 32.7% from the total human health damage category value (Figure 4.30). Application of ammonium sulphate and potassium chloride production are the two other main process contributors at 17.7% and 17.0% respectively from the total human health damage category value (Figure 4.30).

The combination of ammonium sulphate production and application represent 50.4% from the total value of human health damage category (Figure 4.30). Phosphate rock production, glyphosate production, magnesium sulphate production and pyridine-compounds production contribution of 11.0%, 9.6%, 7.9% and 3.8% are considered as minor contributors towards the total value of human health damage category in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.30). Sulfonylurea-compounds production is considered as insignificant contributor at 0.26% from the total value of human health damage category (Figure 4.30)

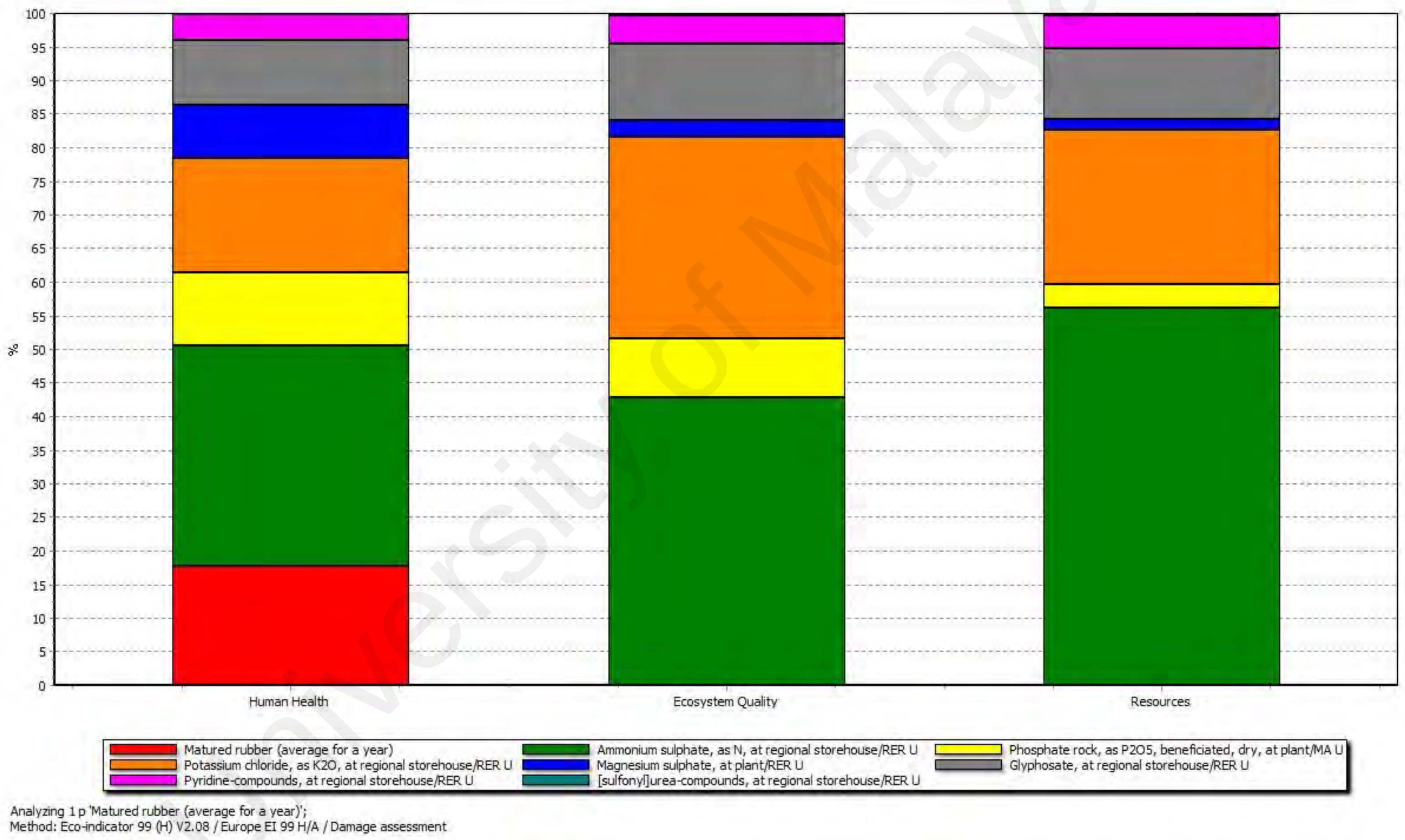

Figure 4.30: Damage assessment to maintain the healthy growth of one mature rubber tree for a year based on damage categories

For ecosystem quality damage category, ammonium sulphate production and potassium chloride production are the two main process contributors in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.30). Ammonium sulphate production and potassium chloride production recorded 42.8% and 30.1% respectively from the total value of ecosystem quality damage category (Figure 4.30). Glyphosate production, phosphate rock production, pyridine-compounds production and magnesium sulphate production contribution of 11.3%, 8.7%, 4.3% and 2.5% are considered as minor contributors towards the total value of ecosystem quality damage category in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.30). Sulfonylurea-compounds production is considered as insignificant contributor at 0.27% from the total value of ecosystem quality damage category (Figure 4.30)

For resources damage category, ammonium sulphate production is the single highest contributor at 56.2% from the total value of resources damage category (Figure 4.30). Potassium chloride is the second highest contributor to resources damage category at 23.0% from the total value of this damage category (Figure 4.30). Glyphosate production, pyridine-compounds production, phosphate rock production and magnesium sulphate production contribution of 10.5%, 5.0%, 3.4% and 1.6% are considered as minor contributors towards the total value of resources damage category in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.30). Sulfonylurea-compounds production is considered as insignificant contributor at 0.29% from the total resource damage category value (Figure 4.30)

The damage assessment results based on three damage categories from this study are non-comparable between them as they only show relative distribution within the respective damage categories. The damage assessment results from this study however did indicate that ammonium sulphate production and potassium chloride production are the two most polluting processes in maintaining the healthy growth of one mature rubber tree for a year.

Normalization

The normalization results to maintain the healthy growth of one mature rubber tree for a year is summarized in Figure 4.31. Fossil fuels is the single major impact category in the normalization impact assessment to maintain the healthy growth of one mature rubber tree for a year (Figure 4.31). For fossil fuels impact category, ammonium sulphate production is the single main process contributor at 56.5% from the total value of this impact category (Figure 4.31). Potassium chloride production and glyphosate production is the second and third highest contributor to the fossil fuels impact category representing 22.4% and 10.6% respectively from the total value of this impact category (Figure 4.31).

Respiratory inorganics, climate change and carcinogens impact categories contributions towards the normalization impact assessment to maintain the healthy growth of one mature rubber tree for a year is considered as minor while the remaining 7 impact categories are considered as insignificant contributor (Figure 4.31).

Based on 51.2% of the 0.687 million hectares of mature rubber area in in Malaysia is fertilized at the recommended dosage and with the average stand of 410 rubber trees per hectare from this study, the estimated impact towards the damage categories in maintaining the healthy growth of mature rubber trees in Malaysia for a year is summarized in Table 4.76.

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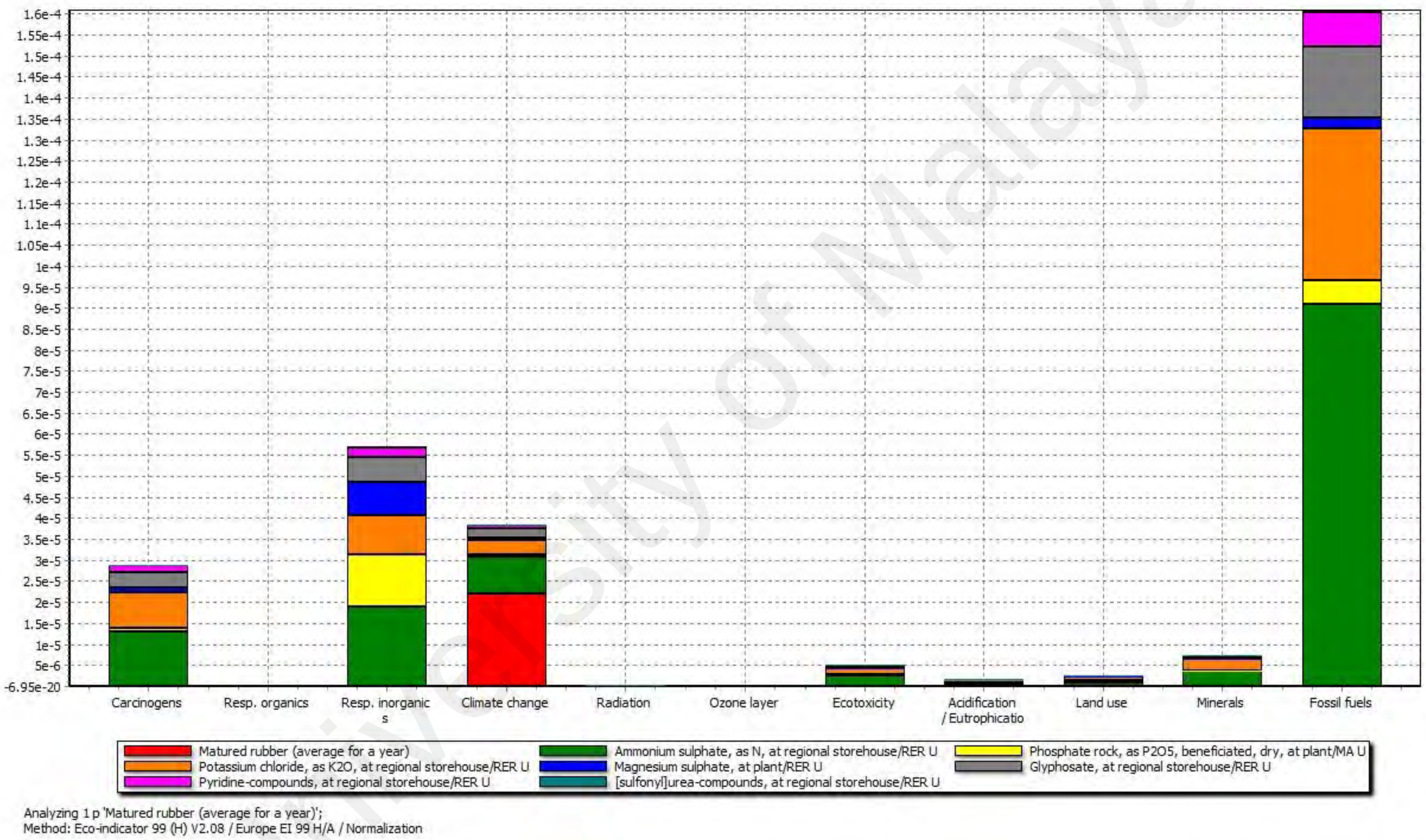

Figure 4.31: Normalization to maintain the healthy growth of one mature rubber tree for a year based on impact categories

Table 4.76: Estimated impact to maintain the healthy growth of mature rubber trees for a year in Malaysia based on damage categories

Damage category	Normalization value (PE)	Malaysian population 2016# (Million)	Impact to Malaysia (%)	Normalization value from the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (PE)	Impact to the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (%)
Human health	1.80E+04	31.7	0.0566	2.62E+04	68.7
Ecosystem quality	1.34E+03	31.7	0.0042	1.93E+03	69.4
Resources	2.43E+04	31.7	0.0765	3.52E+04	69.0

Source: (Department of Statistic Malaysia, 2016)

Based on Table 4.76, the estimated impact to maintain the healthy growth of mature rubber trees in Malaysia for a year is in the range of 0.004% to 0.077% from the total Malaysian impact for these three normalization damage categories and is considered as insignificant. The impact in maintaining the healthy growth of mature rubber trees in Malaysia for a year is in the range of 68.7% to 69.4% as compared to the respective damage categories from the one year average impact from the rubber trees cultivation in Malaysia from cradle to grave (Table 4.76).

Weighting

The weighting result to maintain the healthy growth of one mature rubber tree for a year is shown in Figure 4.32 while the weighting results to maintain the healthy growth of one mature rubber tree for the total duration of mature rubber stage in 25 years is shown in Table 4.77. Fossil fuels and respiratory inorganics are the two most dominant contributors in the weighting impact assessment to maintain the health growth of one mature rubber tree for a year representing 63.0% from the total value of 11 weighting impact categories (Figure 4.32). Fossil fuels and respiratory inorganics impact categories represent 36.9% and 26.1% respectively from the total value of 11 weighting impact categories (Figure 4.32).

Another 2 significant impact categories contributors in maintaining the healthy growth of one mature rubber tree for a year are climate change and carcinogens at 17.6% and 13.2% from total value of 11 weighting impact categories (Figure 4.32). The remaining 7 impact categories i.e. ecotoxicity, minerals, land use, acidification/eutrophication, radiation, respiratory organics and ozone layer contribute a total of 6.2% from total value of 11 weighting impact categories and are considered as insignificant impact categories contributors in maintaining the health growth of one mature rubber tree for a year (Figure 4.32).

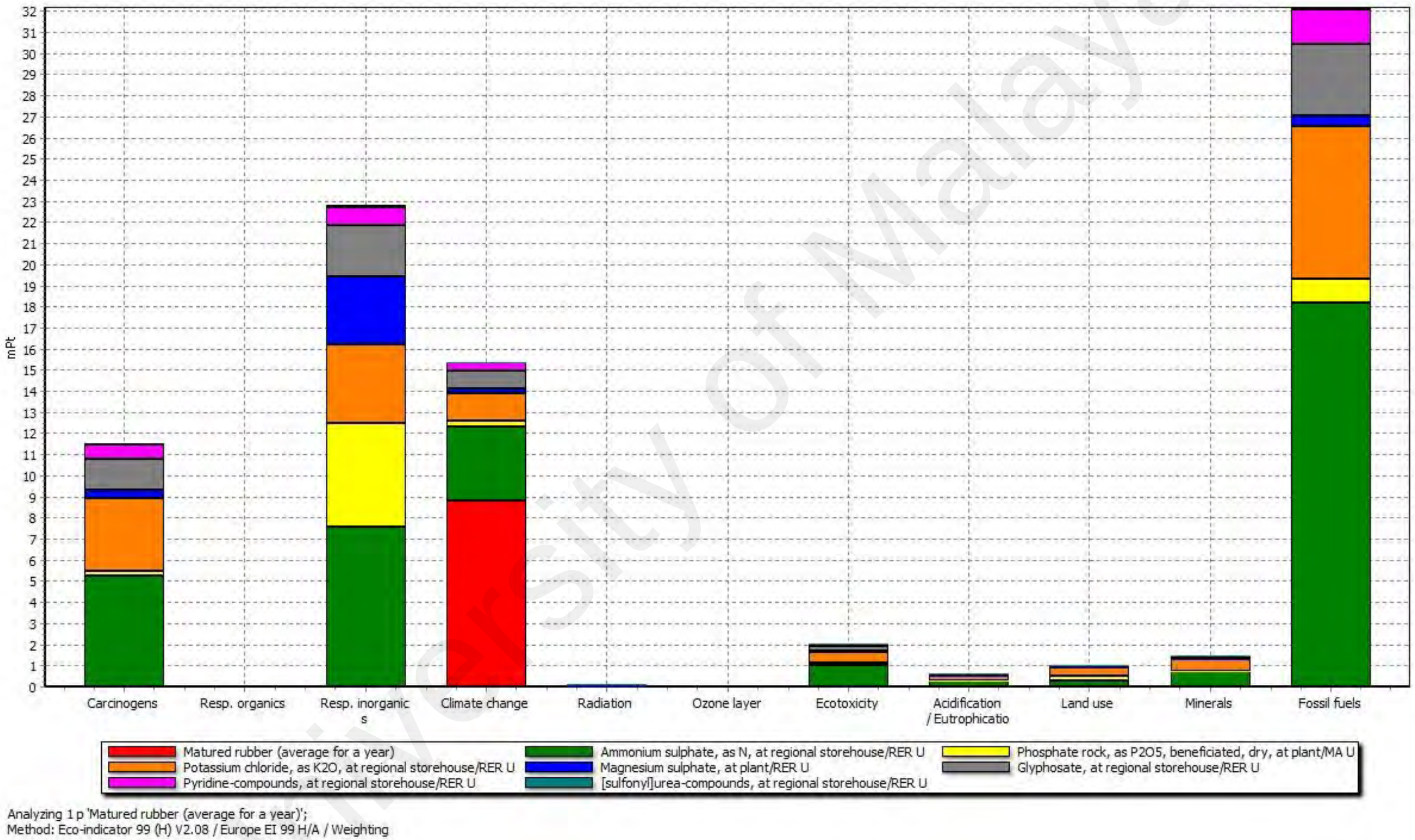

Figure 4.32: Weighting to maintain the healthy growth of one mature rubber tree for a year based on impact categories

For fossil fuels impact category, ammonium sulphate production is the single main process contributor representing 56.5% from the total value of this impact category (Figure 4.32). The usage of fossil fuels in the form of natural gas, crude oil and hard coal as the feed materials for industrial furnaces during the production of ammonium sulphate is responsible for the cumulative impact of fossil fuels impact category in maintaining the healthy growth of one mature rubber tree for a year (Ecoinvent, 2010).

Potassium chloride production is the second highest contributor to fossil fuels impact category at 22.4% from the total value of this impact category (Figure 4.32). The natural gas burned in the cogeneration as part of the process in the production of potassium chloride is the main source of fossil fuels that contribute to the cumulative impact of fossil fuels impact category in maintaining the healthy growth of one mature rubber tree for a year (Ecoinvent, 2010)

For respiratory inorganics impact category, ammonium sulphate production, phosphate rock production and potassium chloride production are the three most dominant processes representing 71.2% from the total value of this impact category (Figure 4.32). Ammonium sulphate production, phosphate rock production and potassium chloride production contribute 33.2%, 21.6% and 16.4% respectively towards the total value of respiratory inorganics impact category in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.32). The emission to the air of inorganics substances in the form of PM 2.5 and PM 10 particulates, sulphur dioxide and nitrogen oxides from the production of ammonium sulphate, phosphate rock and potassium chloride is responsible for the cumulative impact of respiratory inorganics impact category in maintaining the healthy growth of one mature rubber tree for a year (Ecoinvent, 2010).

Table 4.77: Weighting values to maintain the healthy growth of one mature rubber tree for 25 years in mature rubber stage

Damage category	Impact category	Unit	Impact category value	Damage category value	Impact to the cultivation of one rubber tree from cradle to grave (%)
Human Health	Carcinogens	Pt	2.88E-01		84.8
Human Health	Resp. organics	Pt	6.37E-04		84.8
Human Health	Resp. inorganics	Pt	5.70E-01		82.9
Human Health	Climate change	Pt	3.84E-01		85.2
Human Health	Radiation	Pt	3.48E-03		80.0
Human Health	Ozone layer	Pt	1.41E-04		80.9
Total Human Health		Pt		1.25E+00	84.2
Ecosystem Quality	Ecotoxicity	Pt	5.10E-02		85.5
Ecosystem Quality	Acidification/ Eutrophication	Pt	1.60E-02		84.7
Ecosystem Quality	Land use	Pt	2.60E-02		84.5
Total Ecosystem Quality		Pt		9.30E-02	85.3
Resources	Minerals	Pt	3.72E-02		87.0
Resources	Fossil fuels	Pt	8.05E-01		84.3
Total Resources		Pt		8.42E-01	84.4
Total		Pt		2.18E+00	84.2

The total impact in maintaining the healthy growth of one mature rubber tree in 25 years period of mature rubber stage represent 84.2% from the total impact from the cultivation of one rubber tree from cradle to grave in 31.75 years (Table 4.77). The effect to the damage categories in maintaining the healthy growth of one mature rubber tree in 25 years period is 84.2% for human health, 85.3% for ecosystem quality and 84.4% for resources as compared to the effect of these three damage categories from the cultivation of one rubber tree from cradle to grave in 31.75 years (Table 4.77). This indicates that the mature rubber stage is a very dominant contributor for the cultivation of one rubber tree from cradle to grave perspective.

Based on 51.2% of the 0.687 million hectares of mature rubber area in in Malaysia is fertilized at the recommended dosage and with the average stand of 410 rubber trees per hectare from this study, the estimated impact from the process of maintaining the healthy growth of mature rubber trees for a year in Malaysia towards the four main weighting impact categories is summarized in Table 4.78. These four main weighting impact categories represent 93.8% from the total value of 11 weighting impact categories in maintaining the healthy growth of mature rubber trees for a year in Malaysia.

The damage causes by these four main impact categories from the process of maintaining the healthy growth of the mature rubber trees in Malaysia for a year represent 67.70% to 69.53% from the value in the cultivation of rubber trees in Malaysia based on a year average for the respective impact category (Table 4.78). The damage causes by climate change from the process of maintaining the healthy growth of the mature rubber trees in Malaysia for a year recorded the highest contribution at 69.53% from the total climate change impact category value in the cultivation of rubber trees in Malaysia based on a year average (Table 4.78).

Table 4.78: Estimated impact to maintain the healthy growth of mature rubber trees in Malaysia for a year based on four main weighting impact categories

Impact category	Weighting value (Pt)		Impact to the cultivation of rubber trees from cradle to grave in Malaysia based on one year average (%)
	Maintaining the healthy growth of mature rubber trees in Malaysia based on one year average	Cultivation of rubber trees from cradle to grave in Malaysia based on one year average	
Fossil fuels	4,638,175.68	6,741,112.54	68.80
Respiratory inorganics	3,284,455.26	4,851,215.6	67.70
Climate change	2,214,510.88	3,184,824.2	69.53
Carcinogens	1,657,847.48	2,392,611.6	69.29

The carcinogenic effects on mankind due to the emission of carcinogenic substances from the process of maintaining the healthy growth of the mature rubber trees in Malaysia for a year recorded 69.29% from the total carcinogens impact category value in the cultivation of rubber trees in Malaysia based on a year average (Table 4.78).

The damage in the form of extra energy needed for future extraction of fossil fuels and the respiratory effects on mankind due to the emissions of inorganics substances to the air from the process of maintaining the healthy growth of the immature rubber trees in Malaysia for a year represent 68.80% and 67.70% respectively from the total value for these two impact categories in the cultivation of rubber trees in Malaysia based on a year average (Table 4.78).

The total weighted value from the 11 weighting impact categories to maintain the healthy growth of one mature rubber tree for a year is 8.72E-02 Pt which is equal to 8.72E-05 PE as explained by PRe Consultants (2000)(Figure 4.32).

Relating the value of 8.72E-05 PE for one mature rubber tree to 0.687 million hectares of mature rubber area in Malaysia at the average stand of 410 rubber trees per hectare with 51.2% of this area is fertilized at the recommended dosage and the population of 31.7 million in Malaysia, the impact from the process of maintaining the healthy growth of mature rubber trees for a year is only responsible for 0.0396% of the Malaysian environmental impact. Thus the environmental impact contribution from the process of maintaining the healthy growth of mature rubber trees for a year in Malaysia is considered as insignificant as compared to the total Malaysian environmental impact.

Single Score

In the process of maintaining the healthy growth of one mature rubber tree for a year, health effects to the human and resource depletion are the two greatest concerns that need to be addressing properly (Table 4.79 and Figure 4.33).

Table 4.79: The process of maintaining the healthy growth of one mature rubber tree for a year based on damage categories

Damage category	Unit	Total	Percentage (%)
Human Health	Pt	4.98E-02	57.1
Ecosystem Quality	Pt	3.72E-03	4.3
Resources	Pt	3.37E-02	38.6
Total	Pt	8.72E-02	100.0

Human health and resources damage categories represent 57.1% and 38.6% respectively from the total value of the three damage categories in order to maintain the healthy growth of one mature rubber tree for a year (Table 4.79). Ecosystem quality damage category is less affected in the process of maintaining the healthy growth of one mature rubber tree for a year with contribution of only 4.3% from the total value of the three damage categories (Table 4.79).

Ammonium sulphate production is the most dominant process contributor that influences the single score impact assessment results in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.33). Ammonium sulphate production represents 42.2% from the total value of the three damage categories in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.33). For ammonium sulphate production, 51.4% of the impact from this process is towards resource damage category and 44.3% towards human health damage category (Figure 4.33).

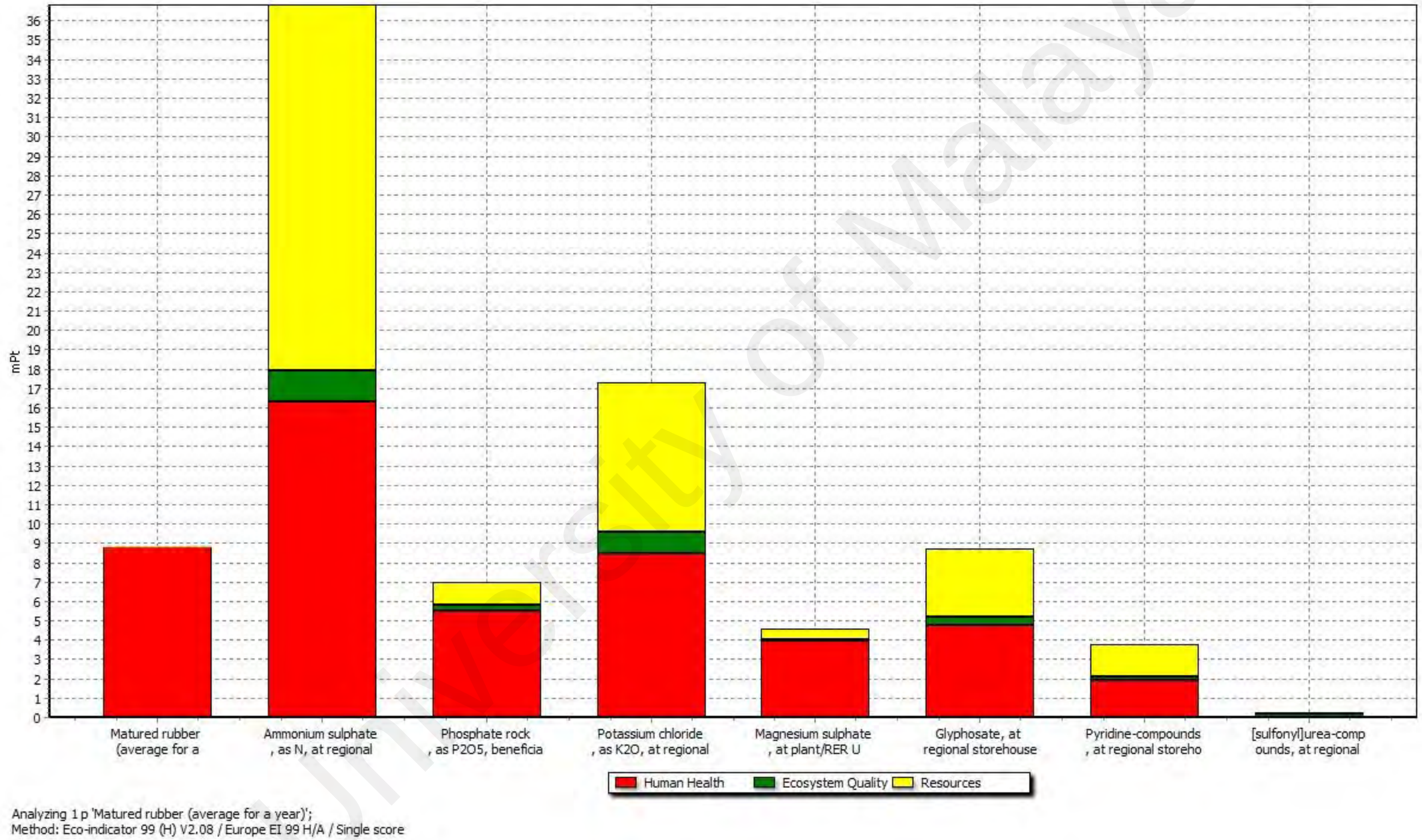

Figure 4.33: Single score to maintain the healthy growth of one mature rubber tree for a year based on damage categories

The impact from the production of ammonium sulphate towards ecosystem quality damage category is only 4.3% (Figure 4.33)

Ammonium sulphate plays an important role in the growth of the mature rubber trees thus the environmental impacts from usage of this fertilizer either as a straight fertilizer or as a part of the fertilizers mixture is unavoidable. The amount of fertilizers application to the mature rubber trees in the mature rubber stage in this study was determined through a yearly soil and leaves analysis conducted by the respondents in this study. The soil and leaves analysis is important in order to make sure that the mature rubber trees received the correct amount of nutrients that they need to grow properly (Karim, 2008a). The optimum usage of ammonium sulphate during the mature rubber stage based on the soil and leaves analysis recommendation is one of the possible ways to minimize the potential environmental impact associated with the usage of this fertilizer.

4.8.3 LCIA on GHGs Emission for the Mature Rubber Boundary

The total GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year based on this study is 1.52 kgCO_2eq (Figure 4.34 and Table 4.81). Nitrous oxide emission from the usage of ammonium sulphate at 8.36E-01 kgCO_2eq is the single highest contributor representing 54.9% from the total GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.34).

The second highest contributor to the total GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year is ammonium sulphate production at 23.8% while potassium chloride production and glyphosate production recorded the contribution of 8.9% and 5.8% respectively (Figure 4.34).The remaining 4 processes are considered as insignificant contributors towards the total GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year (Figure 4.34).

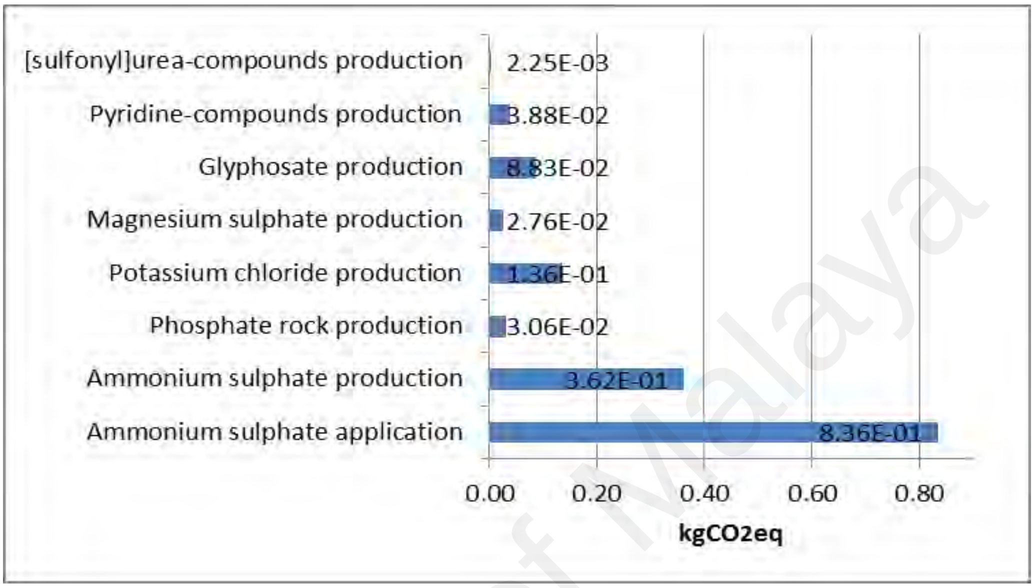

Figure 4.34: GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year

The findings from this study highlighted the dominant contribution of ammonium sulphate application and its production towards the total GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year. The GHGs emission value in maintaining the healthy growth of one mature rubber tree for 25 years period of mature rubber stage is 38.05 kgCO_2eq and this represent 85.2% from the total value of GHGs emission for the cultivation of one rubber tree from cradle to gate i.e. 44.68kgCO2eq.

The GHGs emissions in maintaining the healthy growth of mature rubber trees in Malaysia for a year based on 0.687 million hectares of mature rubber area in Malaysia at the average stand of 410 rubber trees per hectare with 51.2% of this area is fertilized at the recommended dosage is summarized in Table 4.80.

Table 4.80: GHGs emission to maintain the healthy growth of mature rubber trees in Malaysia

	Mature rubber stage (25 Years)	Average one year for mature rubber stage
GHGs emission ($GgCO_2eq$)	5,483.4	219.3
Percentage from Malaysia 2011 GHGs emission (%)*	1.89	0.08
Percentage from agriculture sector in Malaysia 2011 GHGs emission (%)*	34.76	1.39

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on Table 4.80, the GHGs emission value from the 25 years period of mature rubber stage at 5483.4 $GgCO_2eq$ is very low as compared to the Malaysian 2011 GHGs emission of 290,230$GgCO_2eq$ (Ministry of Natural Resources and Environment Malaysia, 2015). The GHGs emission value from the average one year of maintaining the healthy growth of mature rubber trees in Malaysia at 219.3 $GgCO_2eq$ is considered as insignificant as compared to the Malaysian 2011 GHGs emission (Table 4.80).

The GHGs emission value of 5483.4 $GgCO_2eq$ from the 25 years mature stage period in maintaining the healthy growth of mature rubber trees in Malaysia represent 34.8% from the 2011 Malaysian agricultural sector GHGs emission of 15,775.3 $GgCO_2eq$ (Table 4.80). The GHGs emission from the average one year of maintaining the healthy growth of mature rubber trees in Malaysia at 219.3 $GgCO_2eq$ only represent 1.4% from the 2011 Malaysian agricultural sector GHGs emission (Table 4.80).

The list of GHGs emission and its corresponding values in contributing to the total GHGs emission value in maintaining the healthy growth of one mature rubber tree for a year is shown in Table 4.81.

Table 4.81: GHGs emission profile to maintain the healthy growth of one mature rubber tree for a year

GHGs	Weight in $kgCO_2eq$
Nitrous oxide	8.41E-01
Carbon dioxide	6.39E-01
Methane	3.98E-02
Methane, tetrafluoro-, CFC-14	1.03E-03
Sulfur hexafluoride	5.08E-04
Ethane, hexafluoro-, HFC-116	2.18E-04
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	6.71E-05
Methane, tetrachloro-, CFC-10	5.73E-05
Methane, chlorodifluoro-, HCFC-22	5.49E-05
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	1.87E-05
Methane, bromochlorodifluoro-, Halon 1211	1.54E-05
Methane, bromotrifluoro-, Halon 1301	1.37E-05
Methane, dichlorodifluoro-, CFC-12	1.06E-05
Methane, trifluoro-, HFC-23	1.10E-06
Methane, dichloro-, HCC-30	2.22E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	2.17E-07
Chloroform	2.23E-08
Ethane, 1,1-difluoro-, HFC-152a	1.67E-08
Methane, trichlorofluoro-, CFC-11	1.80E-09
Methane, monochloro-, R-40	2.30E-10
Ethane, 1,1,1-trichloro-, HCFC-140	8.83E-11
Methane, dichlorofluoro-, HCFC-21	3.52E-11
Methane, bromo-, Halon 1001	4.68E-17
Total GHGs Emission	**1.52**

Nitrous oxide and carbon dioxide are the two major GHGs that contribute 97.3% from the total GHGs emissions in maintaining the healthy growth of one mature rubber tree for a year (Table 4.81).

Carbon dioxide emission

Carbon dioxide emission represents 42.0% from the total GHGs emission in maintaining the healthy growth of one mature rubber tree for a year (Table 4.81). The details on the carbon dioxide emission in maintaining the healthy growth of one mature rubber tree for a year is shown in Table 4.82.

Table 4.82: Carbon dioxide (CO_2) emission values based on process involved in maintaining the healthy growth of one mature rubber tree for a year

Process	CO_2 (kg)
Ammonium sulphate production	3.43E-01
Potassium chloride production	1.21E-01
Glyphosate production	8.20E-02
Pyridine-compounds production	3.58E-02
Phosphate rock production	2.92E-02
Magnesium sulphate production	2.61E-02
[sulfonyl]urea-compounds production	1.96E-03
Total CO_2 Emission	6.39E-01

Ammonium sulphate production is the single major carbon dioxide emission contributor representing 53.7% from the total value of carbon dioxide emission in maintaining the healthy growth of one mature rubber tree for a year (Table 4.82). Potassium chloride production, glyphosate production, pyridine-compounds production, phosphate rock production and magnesium sulphate production represent 18.9%, 12.8%, 5.6%, 4.6% and 4.1% respectively towards the total value of carbon dioxide emission in maintaining the healthy growth of one mature rubber tree for a year (Table 4.82). Carbon dioxide emission from the production of sulfonyl-urea compounds is considered as insignificant contributor as it only represent 0.3% from the total value of carbon dioxide emission in maintaining the healthy growth of one mature rubber tree for a year (Table 4.82).

The carbon dioxide emission in maintaining the healthy growth of one mature rubber tree for a year is 6.39E-01 kgCO_2 (Table 4.82). Relating this to 0.687 million hectares of mature rubber area in Malaysia at the average stand of 410 rubber trees per hectare and with 51.2% of this area is fertilized at the recommended dosage, the estimated carbon dioxide emission to maintain the healthy growth of the mature rubber trees in Malaysia is summarized in Table 4.83.

Table 4.83: Carbon dioxide emission to maintain the healthy growth of mature rubber trees in Malaysia

	Mature rubber stage (25 Years)	Average one year for mature rubber stage
Carbon dioxide emission (GgCO_2)	2302.2	92.1
Percentage from Malaysia 2011 CO2 emission (%)*	1.11	0.04

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on the Table 4.83, carbon dioxide emission from the 25 years period of mature rubber stage in maintaining the healthy growth of mature rubber trees in Malaysia at 2302.2 GgCO_2 is very low as compared to the Malaysian 2011 carbon dioxide emission value of 208,258 GgCO_2 (Ministry of Natural Resources and Environment Malaysia, 2015). Carbon dioxide emission for the average of one year in maintaining the healthy growth of mature rubber trees in Malaysia at 92.1 GgCO_2 is considered as insignificant as compared to the Malaysian 2011 carbon dioxide emission value (Table 4.83)

Nitrous oxide emission

Nitrous oxide emission represents 55.3% from the total GHGs emission in maintaining the healthy growth of one mature rubber tree for a year (Table 4.81). The details on the nitrous oxide emission in maintaining the healthy growth of one mature rubber tree for a year is shown in Table 4.84.

Table 4.84: Nitrous oxide (N_20) emission values based on process to maintain the healthy growth of one mature rubber tree for a year

Process	N20 (kg)
Ammonium sulphate production	4.16E-06
Potassium chloride production	9.96E-06
Glyphosate production	1.92E-06
Pyridine-compounds production	7.35E-07
Phosphate rock production	8.94E-07
Magnesium sulphate production	8.81E-07
[sulfonyl]urea-compounds production	3.52E-07
Ammonium sulphate application	2.80E-03
Total N_20 Emission	2.82E-03

Nitrous oxide emission from the application of ammonium sulphate to the soil is the single most dominant source of nitrous oxide emission representing 99.3% from the total nitrous oxide emission in maintaining the healthy growth of one mature rubber tree for a year (Table 4.84).

The nitrous oxide emission in maintaining the healthy growth of one mature rubber tree for a year is 8.40E-01 kgCO2eq based on its global warming potential of 298 (IPCC, 2007). Relating this to 0.687 million hectares of mature rubber area in Malaysia at the average stand of 410 rubber trees per hectare with 51.2% of this area is fertilized at the recommended dosage, the estimated nitrous oxide emission to maintain the healthy growth of the mature rubber trees in Malaysia is summarized in Table 4.85.

Table 4.85: Nitrous oxide emission to maintain the healthy growth of mature rubber trees in Malaysia

	Mature rubber stage (25 Years)	Average one year for mature rubber stage
Nitrous oxide emission ($GgCO_2eq$)	3,027.6	121.1
Percentage from Malaysia 2011 nitrous oxide emission (%)*	22.3	0.89

* Source: (Ministry of Natural Resources and Environment Malaysia, 2015)

Based on Table 4.85, nitrous oxide emission for the 25 years period of mature rubber stage in maintaining the healthy growth of mature rubber trees in Malaysia at 3,027.6 GgCO2eq is very significant as compared to the Malaysian 2011 nitrous oxide emission value of 13,574 $GgCO_2eq$ (Ministry of Natural Resources and Environment Malaysia, 2015). Nitrous oxide emission from the average one year of mature rubber stage in maintaining the healthy growth of mature rubber trees in Malaysia at 121.1 $GgCO_2eq$ is considered as very low as compared to the Malaysian 2011 nitrous oxide emission (Table 4.85).

4.9 LCA for Natural Rubber Cuplump Production from Cradle to Gate

The objective of this study is to quantify the life cycle inventory, life cycle impact assessment and GHGs emission for the production of natural rubber from cradle to gate as part of the main goal in quantifying the life cycle inventory, life cycle impact assessment and GHGs emission for the production of one kg SMR block rubber from cradle to gate approach. The functional unit for this study is defined as the production of one kg natural rubber cuplump with 56% dry rubber content (DRC). This functional unit is chosen as it represent 93.6% from the total natural rubber production for 2015 by Malaysian rubber upstream (Malaysian Rubber Board, 2016b).

Natural rubber latex extracted from the rubber tree is a colloidal dispersion of rubber particles in an aqueous serum with DRC varying roughly 20%-40% and contains about 2%-4% non-rubber substances (Alex et al., 2003). According to Yip (1990), the DRC of the natural rubber latex can vary between 25% and 45%. Natural rubber latex will slowly coagulate in the tapping cup as result of microbial degradation to form natural rubber cuplump if no latex preservation chemical is applied in the tapping cup. The natural rubber cuplump can be defined as natural rubber latex that had fully coagulated in the tapping cup.

Natural rubber cuplump DRC value from the respondents in this study varies from 46%-63% with an average of 56%. These DRC figures are within the normal DRC range of 45%-75% as reported by Nor, Muhamad, Mohamed, and Maidunny (2007).

The Malaysian rubber smallholders prefer to produce natural rubber cuplump as it is a much easier job as compared to produce natural rubber latex. The DRC is the basis of payment in the natural rubber transaction. Rubber smallholders will be paid based on the natural rubber cuplump DRC and not the total weight of the natural rubber cuplump.

The sources of raw data used in this study are from the same source of data as used in the study on the life cycle assessment for the cultivation of rubber tree from cradle to grave in the section 4.1. The inputs and emission from the production of 1 kg of natural rubber cuplump (56% DRC) represents 0.11% from the inputs and emission from the cultivation of one rubber tree from cradle to grave. The details explanation on the allocation used for the production of natural rubber in the dry form i.e. 100% DRC from the cultivation of one rubber tree from cradle to grave can be found in section 4.1.

As production of cuplump (56%DRC) is a fraction of the output i.e. 0.11% from the total outputs (combination of tree biomass and natural rubber in the form of 100%DRC) from the cultivation of one rubber tree from cradle to grave, the life cycle inventory, life cycle impact assessment and GHGs emission associated with it is expected to follow the same trend as the cultivation of one rubber tree from cradle to grave but at a relatively lower value. The possible strategies to reduce the environmental impacts from the production of cuplump (56%DRC) are also expected to be the same strategies used to reduce the environmental impacts from the cultivation of rubber trees from cradle to grave.

4.9.1 Life Cycle Inventory

The average life cycle inventory (LCI) input output table for the production of natural rubber 100% DRC from the whole life cycle of one rubber tree in 31.75 years is shown in Table 4.86. This LCI table represent the 21% mass allocation from the cultivation of one rubber tree from cradle to grave as shown in Table 4.2 in section 4.1.1.

Table 4.86: LCI table for the production of natural rubber 100% DRC from the whole life cycle of one rubber tree in 31.75 years

Input	Unit	Average value	Output	Unit	Average value
Polybag	kg	2.73E-03	Natural rubber (100%DRC)	kg	107.37
Fertilizer N	kg	8.78E-04	Emission		
Fertilizer P205	kg	8.73E-04	Nitrous oxide	kg	0.0171
Fertilizer K20	kg	8.10E-04			
Magnesium Oxide	kg	2.09E-04			
Rock Phosphate	kg	2.45			
Ammonium Sulphate	kg	3.91			
Potassium Chloride	kg	2.50			
Magnesium sulphate	kg	5.93E-01			
Fungicide (80% w/w mancozeb)	kg	1.85E-04			
Fungicide (50% w/w chlorothalonil)	kg	4.28E-05			
Insecticide (various active ingredients)	kg	5.58E-05			
Herbicide with 41% glyphosate	L	1.27E-01			
Herbicide with 13% paraquat dichloride	L	1.20E-01			
Herbicide with 32.1% triclopyr butotyl	L	5.98E-02			
Herbicide with 20% metsulfuron methyl	L	5.51E-03			
River water	m3	4.68E-02			
Diesel	L	8.39E-03			

Note: 107.37 kg natural rubber (100% DRC) is equal to 191.73 kg natural rubber cuplump (56%DRC)

Table 4.87 shows the average life cycle inventory (LCI) input output table for the production of one kg natural rubber cuplump (56%DRC).

Table 4.87: LCI table for the production of one kg natural rubber cuplump(56%DRC)

Input	Unit	Average value	Output	Unit	Average value
Polybag	kg	1.42E-05	Cuplump(56%DRC)	kg	1.00
Fertilizer N	kg	4.58E-06	Emission		
Fertilizer P205	kg	4.56E-06	Nitrous oxide	kg	8.92E-05
Fertilizer K20	kg	4.22E-06			
Magnesium Oxide	kg	1.09E-06			
Rock Phosphate	kg	1.28E-02			
Ammonium Sulphate	kg	2.04E-02			
Potassium Chloride	kg	1.31E-02			
Magnesium sulphate	kg	3.09E-03			
Fungicide (80% w/w mancozeb)	kg	9.62E-07			
Fungicide (50% w/w chlorothalonil)	kg	2.23E-07			
Insecticide (various active ingredients)	kg	2.91E-07			
Herbicide with 41% glyphosate	L	6.63E-04			
Herbicide with 13% paraquat dichloride	L	6.27E-04			
Herbicide with 32.1% triclopyr butotyl	L	3.12E-04			
Herbicide with 20% metsulfuron methyl	L	2.87E-05			
River water	m3	2.44E-04			
Diesel	L	4.37E-05			

Note: 1 kg natural rubber cuplump (56%DRC) is equal to 0.56 kg dry rubber (100% DRC)

4.9.2 LCIA for Natural Rubber Production from Cradle to Gate

Characterization

The characterization results for the production of 1kg natural rubber cuplump (56%DRC) is shown in Figure 4.35.

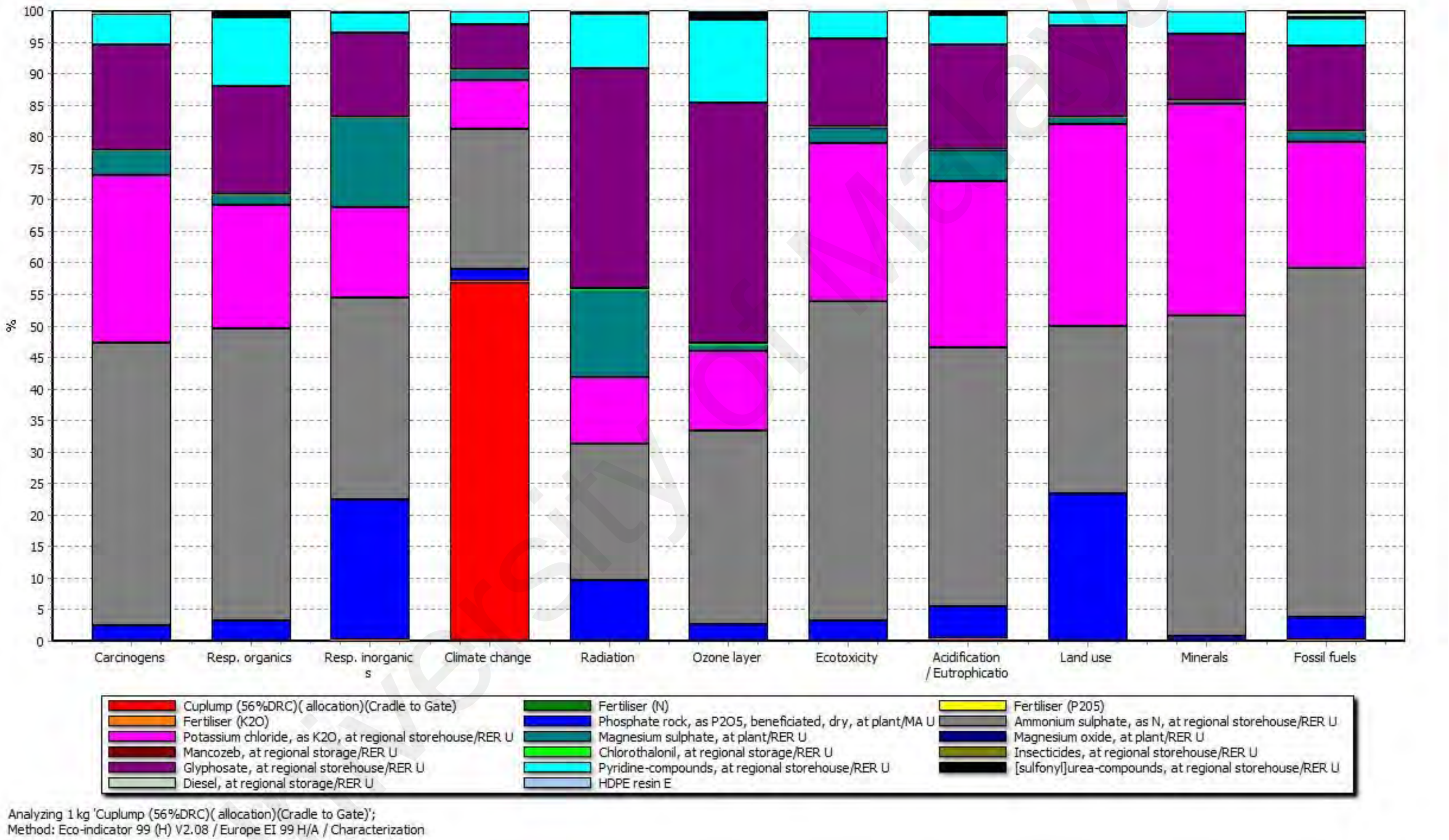

Figure 4.35: Characterization results for the production of 1 kg natural rubber Cuplump (56%DRC)

As expected, the characterization results from the production of natural rubber cuplump (56%DRC) follow exactly the same trend as the characterization results from the cultivation of one rubber tree from cradle to grave. Ammonium sulphate production is the main contributor to 7 impact categories i.e. carcinogens, respiratory organics, respiratory inorganics, ecotoxicity, acidification/eutrophication, minerals and fossil fuels with contribution of 44.8%, 46.3%, 32.0%, 50.6%, 41.1%, 50.8% and 55.3% respectively towards their respective impact categories (Figure 4.35). Ammonium sulphate production also contributed significantly towards climate change, radiation, ozone layer and land use impact categories at 22.2%, 21.6%, 30.6% and 26.7% respectively (Figure 4.35).

Glyphosate production is the main contributor to radiation and ozone layer impact categories at 35.0% and 38.1% respectively while potassium chloride production is the main contributor to land use impact category at 31.9% (Figure 4.35).

Direct and indirect nitrous oxide emission from the application of ammonium sulphate recorded the highest contribution at 56.9% from the total value of climate change impact category (Figure 4.35).

Normalization

The normalization results for the production of 1kg natural rubber cuplump (56%DRC) is shown in Figure 4.36. As in the case of characterization, the normalization results from the production of natural rubber cuplump (56%DRC) also follow exactly the same trend as the normalization results from the cultivation of one rubber tree from cradle grave.

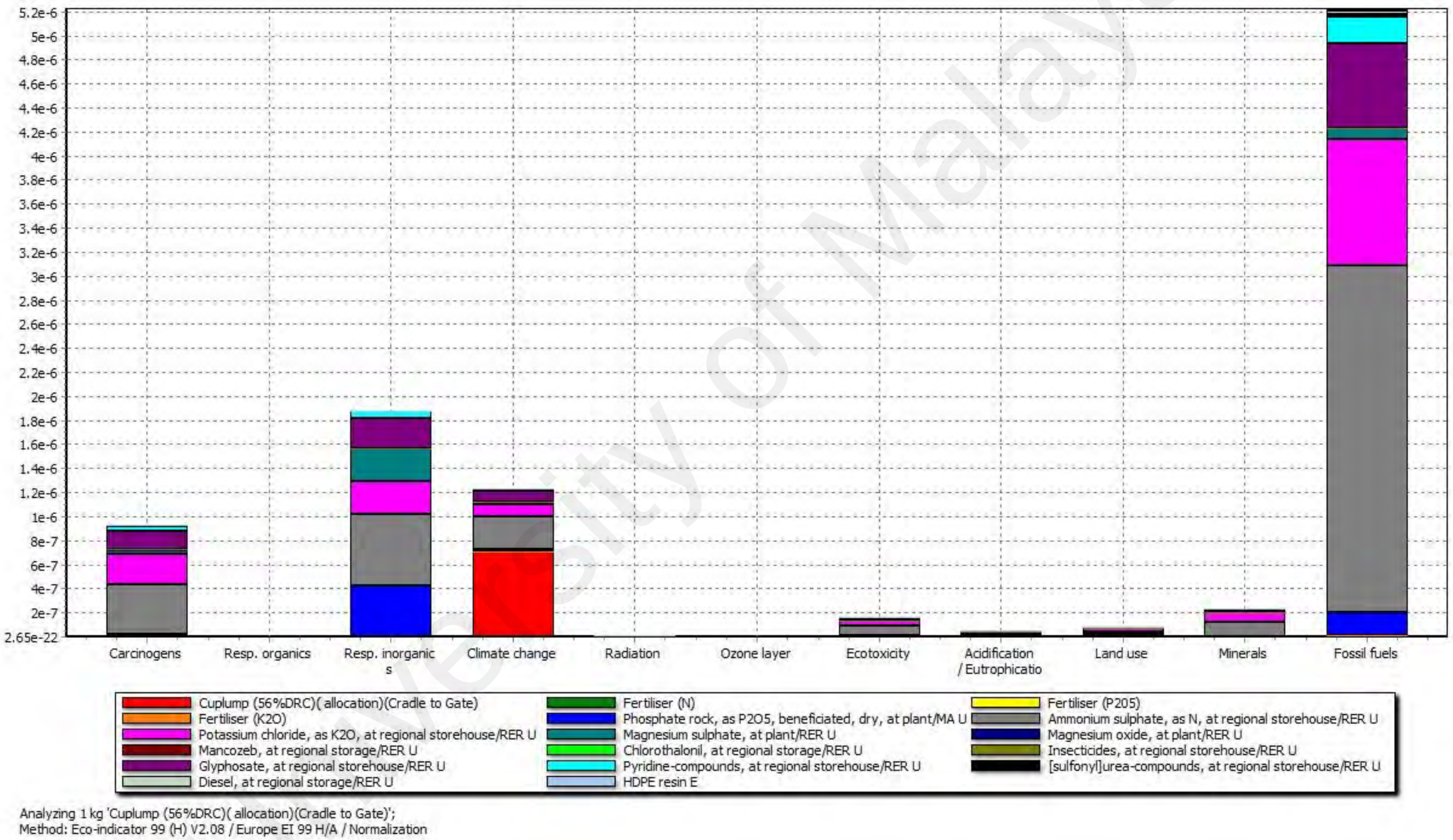

Figure 4.36: Normalization results for the production of 1 kg natural rubber Cuplump (56%DRC)

For normalization results based on impact categories, it is a very clear indication that fossil fuels impact category is the most dominant (Figure 4.36). Ammonium sulphate production is the single main contributor at 55.3% followed by potassium chloride production at 20.0% towards the total value of fossil fuels impact category (Figure 4.36). Respiratory inorganics, climate change and carcinogens plays minor role while the rest of the impact categories are considered as insignificant.

The total dry rubber production in Malaysia for 2014 is 668,610 tonnes which is equal to 1193946 tonnes of natural rubber cuplump (56% DRC)(Malaysian Rubber Board, 2016b). The estimated impact towards the damage categories in the production of 1193946 tonnes of natural rubber cuplump (56% DRC) in Malaysia is summarized in Table 4.88.

Table 4.88: Estimated impact from the production of natural rubber cuplump (56%DRC) in Malaysia based on damage categories

Damage category	Normalization value (PE)	Malaysian population 2016# (Million)	Impact to Malaysia (%)
Human health	4.85E+03	31.7	0.0153
Ecosystem quality	3.58E+02	31.7	0.0011
Resources	6.52E+03	31.7	0.0206

Source: (Department of Statistic Malaysia, 2016)

Based on Table 4.88, the estimated impact from the production of 1193946 tonnes of natural rubber cuplump (56% DRC) in Malaysia is in the range of 0.001% to 0.021% and is considered as insignificant.

Weighting

The weighting results for the production of 1kg natural rubber cuplump (56%DRC) is shown in Figure 4.37 and Table 4.89. Fossil fuels impact category is the most dominant representing 36.9% from the total value of 11 weighting impact categories in the production of 1kg natural rubber cuplump (56%DRC) (Figure 4.37 and Table 4.89).

The other 3 dominant impact categories which are lower than fossil fuels are respiratory inorganics, climate change and carcinogens representing 26.5%, 17.4% and 13.1% respectively from the total weighting value for the production of 1kg natural rubber cuplump (56%DRC) (Figure 4.37 and Table 4.89). The remaining 7 impact categories only represent a total of 6.1% from the total value of 11 impact categories in the production of 1kg natural rubber cuplump (56%DRC) and are considered as insignificant impact categories contributors (Figure 4.37 and Table 4.89).

For fossil fuels impact category, ammonium sulphate production is the single biggest contributor at 55.2% from the total value of 1.05E-03 Pt (Figure 4.37). For respiratory inorganics impact category, ammonium sulphate production is the highest contributor at 32.0% and follow by phosphate rock production at 22.2% from the total value of 7.52E-04Pt (Figure 4.37). For climate change impact category, the application of ammonium sulphate is the single highest contributor at 56.9% from the total value of 4.94E-04 Pt (Figure 4.37).

The total weighted value from the 11 weighting impact categories to produce 1 kg natural rubber cuplump (56%DRC) is 2.84E-03 Pt which is equal to 2.84E-06 PE as explained by (PRe Consultants, 2000)(Table 4.89).

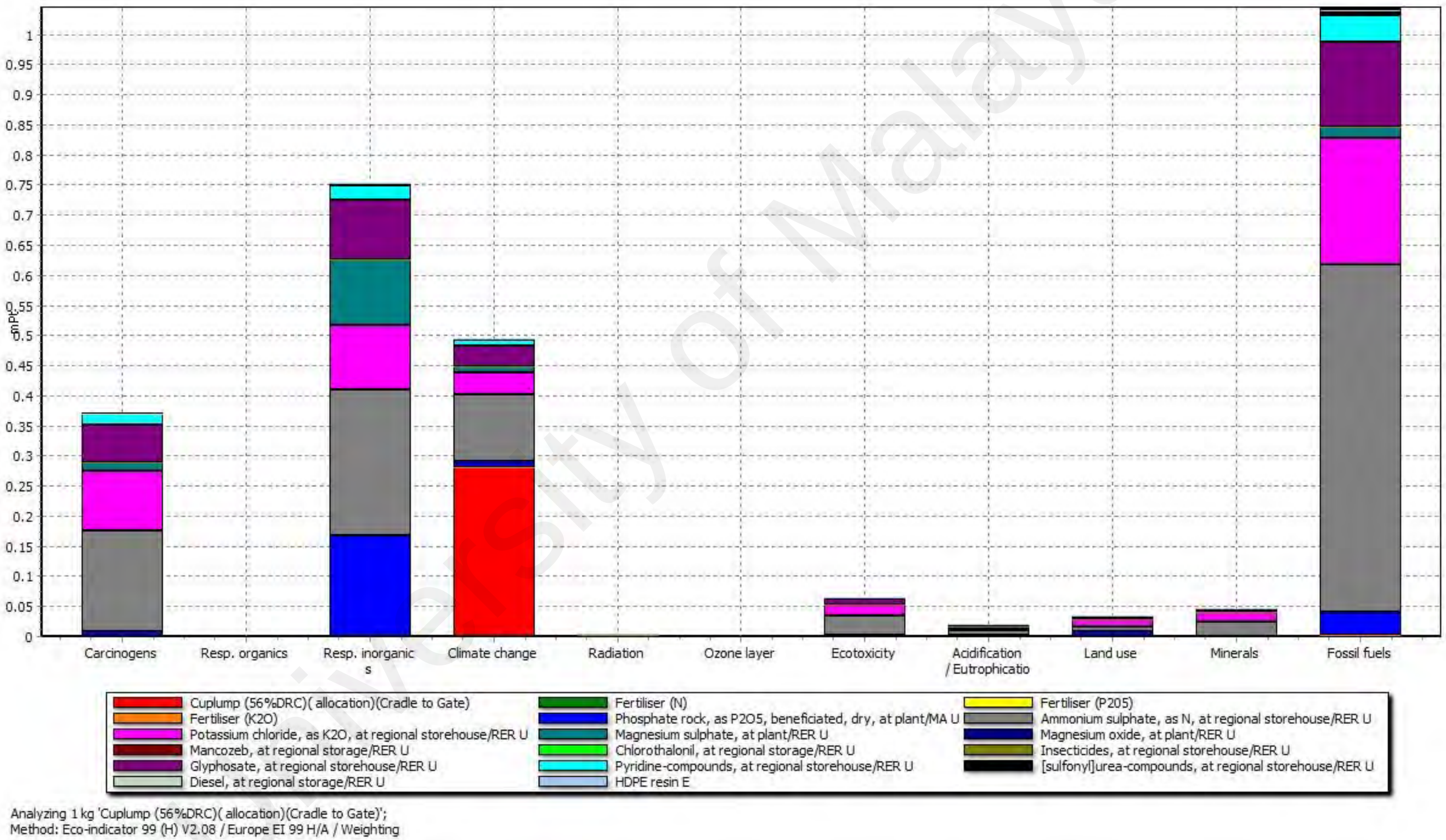

Figure 4.37: Weighting for the production of one kg Cuplump(56%DRC)

Table 4.89: Weighted value in the production of one kg Cuplump (56%DRC)

Impact Category	Unit	Value	Contribution towards total weighting value (%)
Carcinogens	Pt	3.71E-04	13.09
Resp. organics	Pt	8.23E-07	0.03
Resp. inorganics	Pt	7.52E-04	26.54
Climate change	Pt	4.94E-04	17.42
Radiation	Pt	4.77E-06	0.17
Ozone layer	Pt	1.91E-07	0.01
Ecotoxicity	Pt	6.53E-05	2.30
Acidification/ Eutrophication	Pt	2.08E-05	0.73
Land use	Pt	3.38E-05	1.19
Minerals	Pt	4.67E-05	1.65
Fossil fuels	Pt	1.05E-03	36.87
Total	Pt	2.84E-03	100.00

Relating the value of 2.84E-06 PE for the production of 1kg natural rubber cuplump (56%DRC), the impact from the production of 1193946 tonnes of natural rubber cuplump (56% DRC) in Malaysia is responsible for 0.011% of the Malaysian environmental impact.

4.9.3 LCIA on GHGs Emission for Natural Rubber Cuplump Production from Cradle to Gate

The total GHGs emission value for the production of 1kg natural rubber cuplump (56%DRC) is 4.89E-02 kgCO2eq and its represent 0.11% from the total GHGs emission value for the cultivation of one rubber tree from cradle to grave (Figure 4.38).

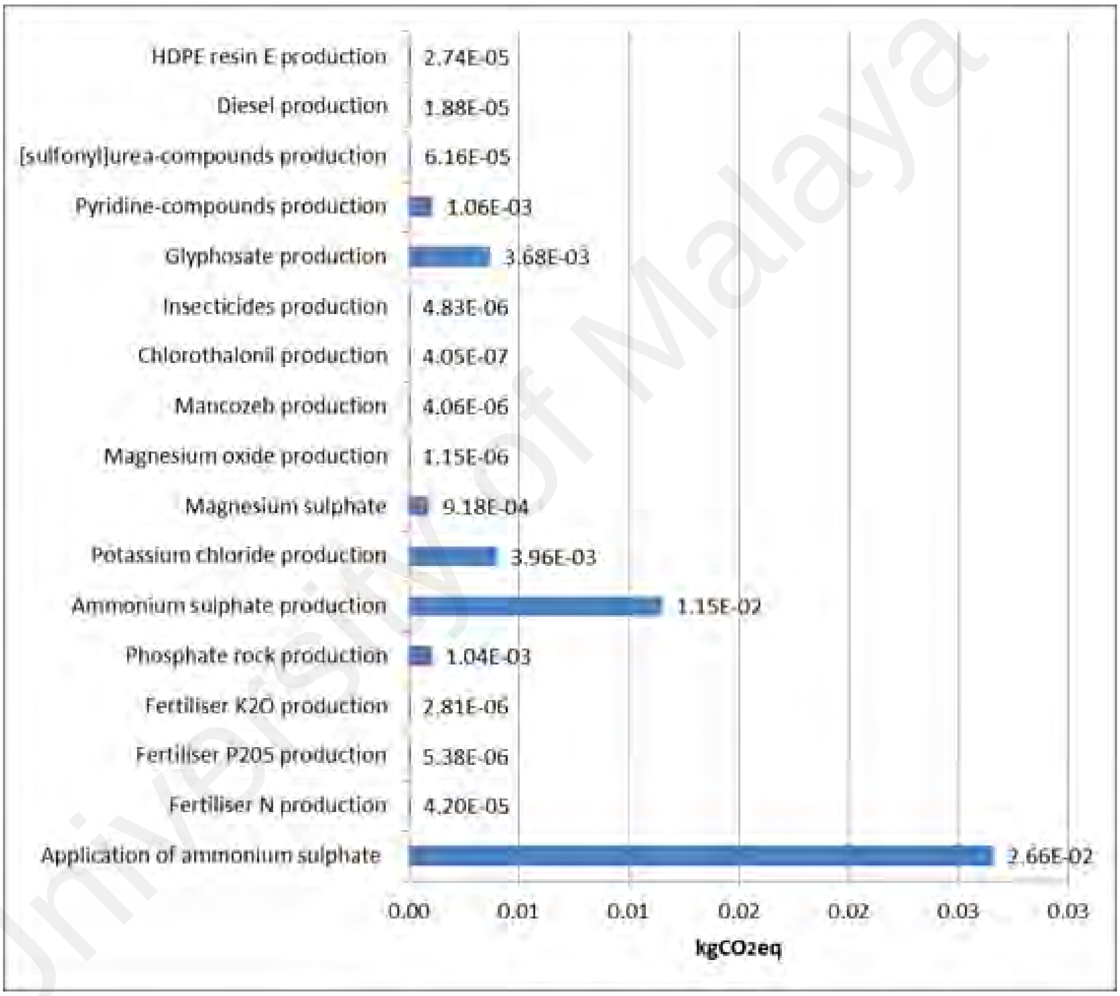

Figure 4.38: GHGs emission values for the production of 1kg natural rubber cuplump (56%DRC)

From Figure 4.38, it is very obvious that the trend from the GHGs emission for the production of 1kg natural rubber cuplump (56%DRC) is basically identical to the GHGs emission for the cultivation of one rubber tree from cradle to grave.

The application and production of ammonium sulphate are the two major processes responsible for 77.9% from the total GHGs emission value for the production of 1kg natural rubber cuplump (56%DRC) (Figure 4.38). Potassium chloride production and glyphosate production recorded the contribution of 8.1% and 7.5% respectively while the remaining 13 processes are considered as insignificant contributors towards the total GHGs emission value for the production of 1kg natural rubber cuplump (56%DRC) (Figure 4.38).

The GHGs emission from the production of 1,193,946 tonnes of natural rubber cuplump (56% DRC) in Malaysia is 58.4 3GgCO_2eq and this only represent 0.02% from the Malaysian 2011 GHGs emission of 290,230GgCO2eq (Ministry of Natural Resources and Environment Malaysia, 2015). Based on this value, the contribution of the GHGs emission from the production of 1,193,946 tonnes of natural rubber cuplump (56% DRC) in Malaysia is considered as insignificant as compared to the Malaysian 2011 GHGs emission.

4.10 LCA Study on the Production of SMR Block Rubber from Cradle to Gate

The objective of this study is to quantify the life cycle inventory, life cycle impact assessment and GHGs emission for the production of one kg SMR block rubber from cradle to gate. The functional unit for this study is defined as the production of one kg SMR block rubber.

Five of the SMR block rubber factories representing 12.5% from the total SMR block rubber factories in Malaysia agreed to participate in this study. These 5 factories requested that they remain strictly anonymous as some of the data are quite sensitive in nature. The details production capacity for each of the respondents in this study is shown in Table 4.90

Table 4.90: Production capacity of the SMR block rubber factories respondents

Factory identification code	Production of SMR Block rubber for 2012 (Tonnes)	Design capacity (Tonne/Hour)
F1	11,527	10
F2	10,604	7
F3	10,487	4
F4	15,558	4
F5	18,260	8

The production of SMR block rubber from the individual SMR block rubber factories in this study varies from 10,487.3 tonne to 18,260 tonne annually (Table 4.90). The total production from these 5 SMR block rubber factories represents 11.8% from the total natural rubber cuplump based SMR block rubber production in Malaysia for 2012 (Malaysian Rubber Board, 2014a).

The projected availability of raw material supply in the form of natural rubber cuplump is one of the main factors in the design processing capacity of the SMR block rubber factories. SMR block rubber factories are normally constructed within the centre of rubber planted area so as to get easy access to the raw materials for their production.

The design capacity of the individual SMR block rubber factories in this study varied from 4 tonne per hour to 7 tonne per hour (Table 4.90).From the Table 4.90, it is obvious that the production of SMR block rubber from the respondents in this study is not following the design capacity of their factories due to the shortage of local natural rubber cuplump.

The inadequate supply of raw materials in the form of local natural rubber cuplump is a well-known problem facing by the SMR block rubber industry. According to Kin (2010), the local production of natural rubber cuplump from 2005-2009 can only cater up to 73.3% from the total processing capacity of all the SMR block rubber factories in Malaysia.

The shortage of the local raw materials has resulted in the rising processing cost to produce SMR block rubber owing to the under-utilization of capacity and because the SMR block rubber processors have to import the raw materials from abroad (Malaysian Rubber Board, 2014c).

One respondent from this study manage to produce 100% SMR block rubber using only local raw material and this is not surprising as this particular block rubber factory is located within the centre of the major rubber planted area in Malaysia.

The other four respondents use 3.6% to 14.7% of imported raw materials in the production of their SMR block rubber in 2012 and these figures are lower than the average of 20.9% imported raw materials used in the SMR block rubber production in Malaysia from 2005-2009 as reported by (Kin, 2010).

4.10.1 Life Cycle Inventory

The average LCI table for the production of SMR block rubber from cradle to gate based on 1 kg of SMR block rubber in this study is shown in Table 4.91.

Table 4.91: LCI table for the production of one kg SMR block rubber

Input	Unit	Average value
Cuplump (56% DRC)	kg	1.79
River water	L	24.4
Electricity	kWh	0.215
Diesel	L	0.036
LDPE film	kg	4.65E-04
Transportation of raw material	Tan.km	0.568
Output	Unit	Average value
SMR Block rubber 	kg	1
Emission to water		
Chemical oxygen demand	kg	1.97E-03
Biological Oxygen demand (BOD3)	kg	2.55E-04
Suspended solid	kg	7.55E-04
Total nitrogen	kg	7.22E-04
Ammoniacal-nitrogen	kg	5.81E-04
Emission to air		
Methane	kg	4.18E-03

Electricity usage

The SMR block rubber processing line is basically a series of machineries which is run by individual electric motor attached to each of the machine to form a continuous processing line. The average electricity consumption from the respondents in this study is 0.215 kWh per one kg of SMR block rubber produced. The estimated breakdown on the average electricity usage based on different section of the SMR block rubber processing line from the respondents in this study is shown in Table 4.92.

Table 4.92: Average electricity consumption based on sections in the SMR block rubber processing line

Section	Electricity usage from the processing line (%)	Machineries list
Pre-cleaning and size reduction	18.5	• Slabcutter • Single scroll prebreaker • Twin scroll prebreaker • Bucket conveyors
Creping	35.8	• Crepers • Belt convenyors
Shredding	17.4	• Shredder • Crumb transfer pump
Drying	26.1	• Trolley dryer chain system • Dryer exhaust fan • Dryer cooling fan
Baling and packing	2.2	1. Hydraulic press

Creping and drying sections are the two main contributors to the total electricity usage in the production of SMR block rubber (Table 4.92). Creping section recorded the highest electricity usage at 35.8% while drying section recorded 26.1% from the total SMR block rubber processing line electricity consumption (Table 4.92). The creping section is basically a series of crepers connected with belt conveyors with the function to shear and break the natural rubber cuplump received from the pre-cleaning and size reduction section through bucket conveyor and transform it into a thin blanket or crepe to expose new surface areas (Figure 4.39). The numbers of crepers used by the respondents in this study varies from 7 to 8 units with the electrical motor capacity of 75 horsepower (hp) to 125 hp.

Figure 4.39: A typical creping section in the production of SMR block rubber

The drying of wet rubber crumbs is carried out in hot air through bed circulation tunnel dryer. The dryers exhaust fans were responsible for the distribution of hot air in the tunnel dryer to dry the rubber homogenously. The dryer operation is semi continuous whereby wet rubber crumbs in the drying trolley are fed into the dryer at regular interval at one end of the tunnel and trolley containing dry rubber crumbs to emerge at the opposite end using trolley dryer chain system operated by the electrical motor.

The electrical motors capacity for this trolley dryer chain system from the respondents in this study varies from 75 hp to 125 hp. The dried rubber will be cooled to below 60° C using the dryer cooling fans to avoid the moisture trap in the rubber. This dried rubber will then be weighed into 33.33 kg or 35 kg and pressed into a block rubber and ready to be marketed as SMR block rubber provided that it pass the analysis for SMR specification.

The electricity consumption from the SMR block rubber industry in Malaysia is very low as compared to the total Malaysian electricity consumption. The estimated electricity consumption from the production of 562,967 tonnes of SMR block rubber in 2012 at 121.04 GWh only represent 0.1% from the total Malaysian electricity consumption of 116428 GWh in 2012 as reported by (Energy commission, 2016).

4.10.2 LCIA on the Production of SMR Block Rubber from Cradle to Gate

Characterization

The characterization results for the production of one kg SMR block rubber from cradle to gate is summarized in Figure 4.40 and Table 4.93. Production of natural rubber cuplump (56%DRC) from cradle to gate is the single highest contributor to 4 characterization impact categories in the production of one kg SMR block rubber from cradle to gate (Figure 4.40). Production of natural rubber cuplump (56%DRC) from cradle to gate is responsible for 83.4% of the carcinogens impact category, 76.5% of radiation impact category, 76.2% of ecotoxicity impact category and 91.6% of minerals impact category in the production of one kg SMR block rubber from cradle to gate (Figure 4.40).

Production of natural rubber cuplump (56%DRC) from cradle to gate is also a major contributor for respiratory inorganics, climate change and land use impact categories at 23.0%, 23.4% and 35.7 % respectively towards the total value of each of these impact categories in the production of one kg SMR block rubber from cradle to gate (Figure 4.40). Electricity generation is the highest contributor to four characterization impact categories in the production of one kg SMR block rubber from cradle to gate i.e. 25.5% for respiratory organics, 30.5% for climate change, 44.0% for ozone layer and 39.6% for fossil fuels (Figure 4.40).

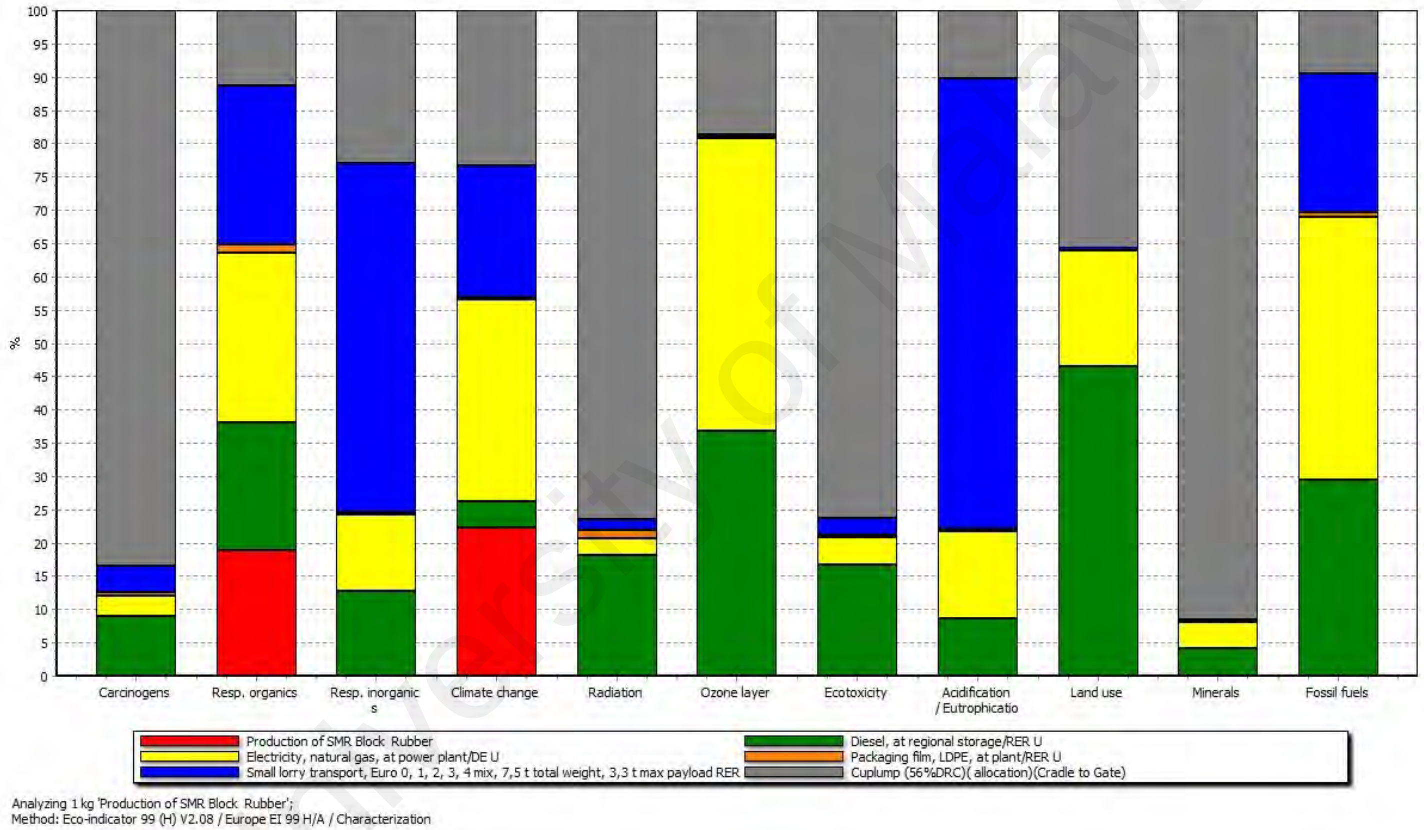

Figure 4.40: Characterization for the production of one kg SMR block rubber from cradle to gate based on impact categories

Table 4.93: Characterization values for the production of one kg SMR block rubber from cradle to gate

Impact category	Unit	Total	Effluent treatment	Diesel	Electricity	LDPE packaging film	Transport	Cuplump (56%DRC)
Carcinogens	DALY	1.7E-08	0.0E+00	1.6E-09	5.6E-10	8.3E-11	7.0E-10	1.5E-08
Resp. organics	DALY	2.8E-10	5.4E-11	5.5E-11	7.3E-11	3.2E-12	6.8E-11	3.2E-11
Resp. inorganics	DALY	1.3E-07	0.0E+00	1.6E-08	1.5E-08	5.3E-10	6.7E-08	3.0E-08
Climate change	DALY	8.3E-08	1.8E-08	3.2E-09	2.5E-08	2.6E-10	1.6E-08	1.9E-08
Radiation	DALY	2.4E-10	0.0E+00	4.5E-11	6.1E-12	2.9E-12	3.8E-12	1.9E-10
Ozone layer	DALY	4.0E-11	0.0E+00	1.5E-11	1.8E-11	1.5E-14	1.6E-13	7.5E-12
Ecotoxicity	PAF*m2yr	2.2E-02	0.0E+00	3.7E-03	8.8E-04	8.8E-05	5.8E-04	1.7E-02
Acidification/ Eutroph	PDF*m2yr	5.2E-03	0.0E+00	4.5E-04	6.9E-04	1.6E-05	3.5E-03	5.3E-04
Land use	PDF*m2yr	2.4E-03	0.0E+00	1.1E-03	4.2E-04	1.2E-05	0.0E+00	8.6E-04
Minerals	MJ surplus	3.4E-03	0.0E+00	1.4E-04	1.4E-04	6.4E-06	5.6E-06	3.2E-03
Fossil fuels	MJ surplus	7.4E-01	0.0E+00	2.2E-01	2.9E-01	4.6E-03	1.6E-01	7.1E-02

Transportation of raw materials from the source to SMR block rubber factory is the single highest contributor to 2 characterization impact categories in the production of one kg SMR block rubber from cradle to gate (Figure 4.40). Transportation of raw materials is responsible for 52.3% of the respiratory inorganics impact category and 67.8% of the acidification/eutrophication impact categories in the production of one kg SMR block rubber from cradle to gate (Figure 4.40). Transportation of raw materials is also the major contributor to respiratory organics and fossil fuels impact categories at 23.9% and 20.9% respectively (Figure 4.40).

Diesel production is the highest contributor to land use impact category at 46.4% from the total value of this impact category in the production of one kg SMR block rubber from cradle to gate (Figure 4.40). Diesel production is also the major contributor to 3 other impact categories i.e. respiratory organics, ozone layer and fossil fuels at 19.3%, 36.8% and 29.4% respectively (Figure 4.40).

Damage assessment

The damage assessment result for the production of one kg SMR block rubber from cradle to gate is shown in Figure 4.41. Transportation of raw materials from the source to the block rubber factory and the production of natural rubber cuplump (56%DRC) from cradle to gate are the two main contributors towards the total human health damage category value in the production of one kg SMR block rubber from cradle to gate (Figure 4.41). Transportation of raw materials contributes 36.7% while natural rubber cuplump (56%DRC) production contribute 27.8% towards the total human health damage category value (Figure 4.41). Electricity generation is the third highest contributor at 17.7% from the total human health damage category value in the production of one kg SMR block rubber from cradle to gate (Figure 4.41).

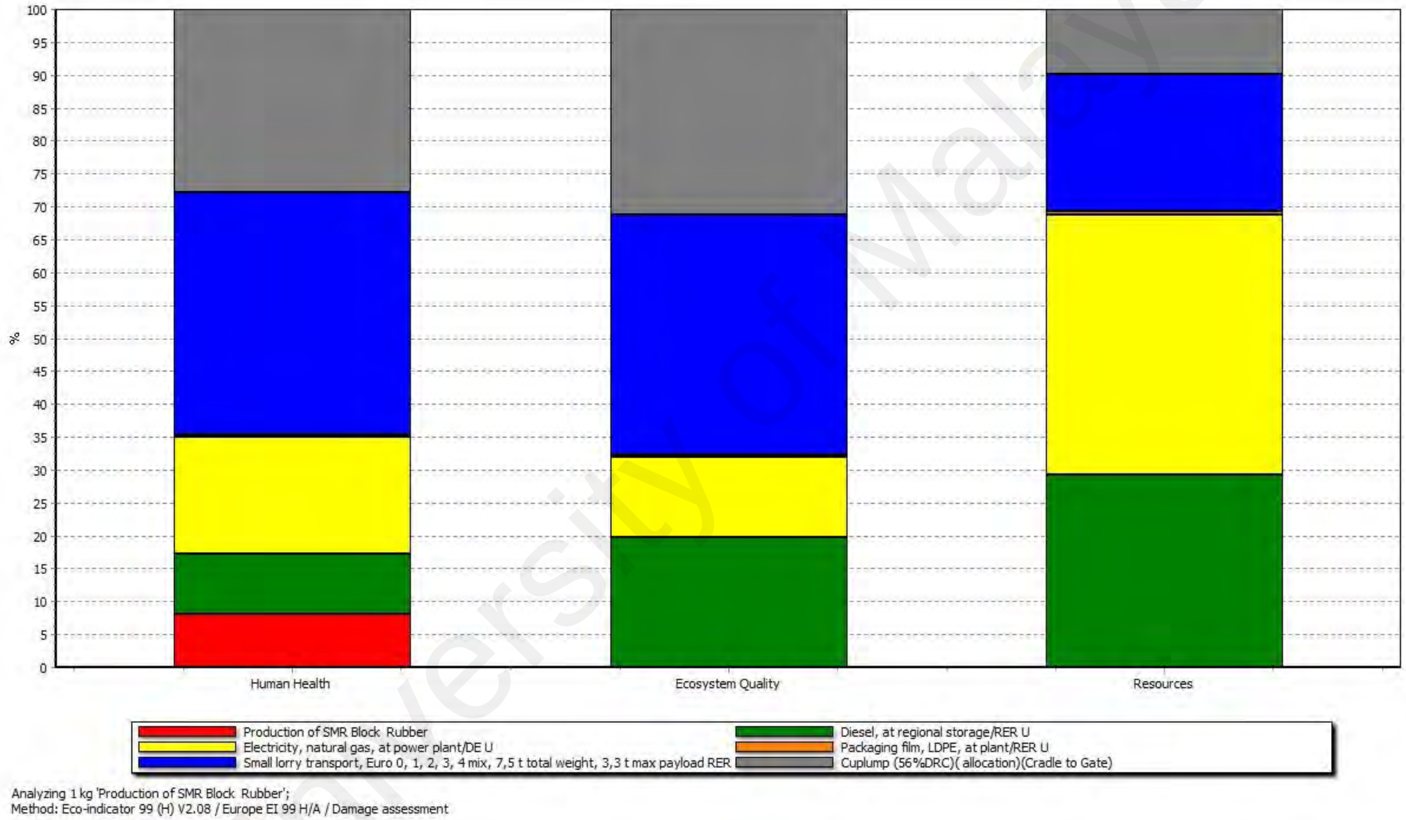

Figure 4.41: Damage assessment for the production of one kg SMR block rubber from cradle to gate based on damage categories

For ecosystem quality damage category in the production of one kg SMR block rubber from cradle to gate, transportation of raw materials from the source to the SMR block rubber factory and the production of natural rubber cuplump (56%DRC) from cradle to gate are the two main contributors (Figure 4.41). Transportation of raw materials contribute 36.6% while natural rubber cuplump (56%DRC) production contribute 31.2% towards the total ecosystem quality damage category value (Figure 4.41). Diesel production is the third highest contributor at 19.7% from the total value of ecosystem quality damage category in the production of one kg SMR block rubber from cradle to gate (Figure 4.41).

Electricity generation and diesel production are the two main contributors towards the total recources damage category value in the production of one kg SMR block rubber from cradle to gate (Figure 4.41). Electricity generation contribute 39.4% while diesel production contribute 29.3% towards the total value of resources damage category (Figure 4.41). Transportation of raw materials from the source to the block rubber factory is the third highest contributor at 20.8% from the total resources damage category value in the production of one kg SMR block rubber from cradle to gate (Figure 4.41).

Even though these three damage categories are non-comparable between them, but it did gave a strong indication that transportation of raw materials from the source to the SMR block rubber factory, production of natural rubber cuplump (56%DRC) from cradle to gate, electricity generation and diesel production are the four main polluting processes in the production of one kg SMR block rubber from cradle to gate.

Normalization

The normalization results to produce one kg SMR block rubber from cradle to gate is summarized in Figure 4.42. Fossil fuels is the single most dominant impact category in the normalization impact assessment for the production of one kg SMR block rubber from cradle to gate (Figure 4.42).

The three major processes contributors towards the total value of fossil fuels impact category in the production of one kg SMR block rubber from cradle to gate are electricity generation, diesel production and transportation of raw materials from the source to the block rubber factory (Figure 4.42).

Electricity generation, diesel production and transportation of raw materials from the source to the block rubber factory contribute 39.6%, 29.4% and 20.9% respectively from the total fossil fuels impact category value in the production of one kg SMR block rubber from cradle to gate (Figure 4.42).

Respiratory inorganics and climate change impact categories plays minor role in the production of one kg SMR block rubber from cradle to gate while the rest of the impact categories are considered as insignificant (Figure 4.42).

The production of natural rubber cuplump based SMR block rubber in Malaysia for 2012 is 562,967 tonnes (Malaysian Rubber Board, 2014a). The estimated impact from the production of 562,967 tonnes SMR block rubber is summarized in Table 4.94.

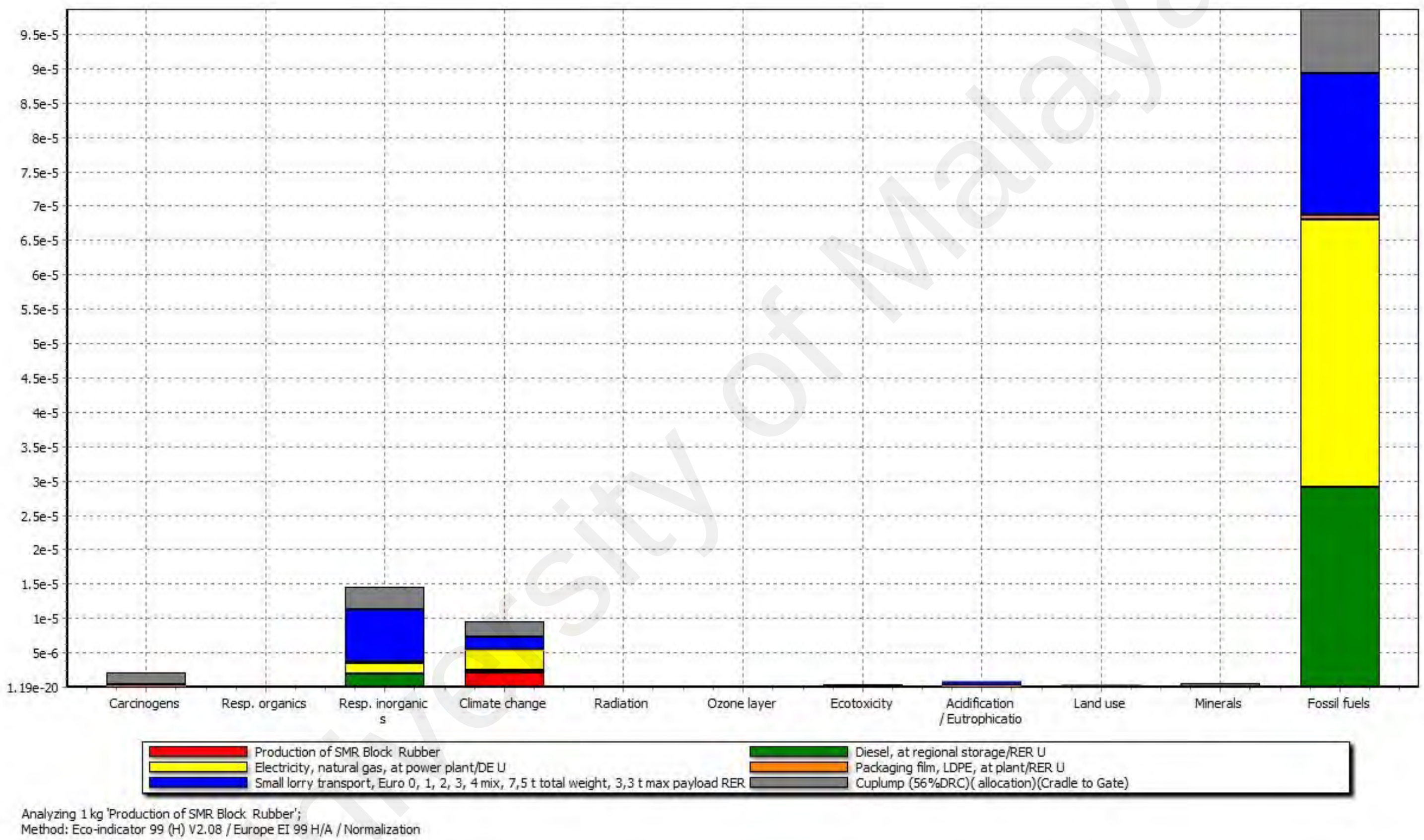

Figure 4.42: Normalization for the production of one kg SMR block rubber from cradle to gate based on impact categories

Table 4.94: Estimated impact for the production of SMR block rubber in Malaysia

Damage category	Normalization value (PE)	Malaysian population 2016[#] (Million)	Impact to Malaysia (%)
Human health	1.47E+04	31.7	0.046
Ecosystem quality	9.68E+02	31.7	0.003
Resources	5.58E+04	31.7	0.176

[#] Source: (Department of Statistic Malaysia, 2016)

The impact from the production of natural rubber cuplump based SMR block rubber in Malaysia is from 0.003% to 0.176% for these 3 damage categories (Table 4.94). Resources damage category shows a relatively higher impact at 0.18% as compared to two others damage categories (Table 4.94). The impact from these 3 damage categories is considered as insignificant as compared to the Malaysian total impact for these 3 damage categories.

Weighting

The weighting result for the production of one kg SMR block rubber from cradle to gate is shown in Figure 4.43 and Table 4.95. Fossil fuels impact category is the single most dominant contributor in the weighting impact assessment for the production of one kg SMR block rubber from cradle to gate (Figure 4.43). Fossil fuels impact category represents 63.7% from the total value of 11 weighting impact categories (Figure 4.43 and Table 4.95). The other 2 significant impact categories contributors for the production of one kg SMR block rubber from cradle to gate is respiratory inorganics and climate change at 18.9% and 12.2% respectively (Figure 4.43 and Table 4.95). The remaining 8 impact categories i.e. carcinogens, acidification/eutrophication, land use, ecotoxicity, minerals, respiratory organics, radiation and ozone layer are considered as insignificant impact categories contributors (Figure 4.43 and Table 4.95).

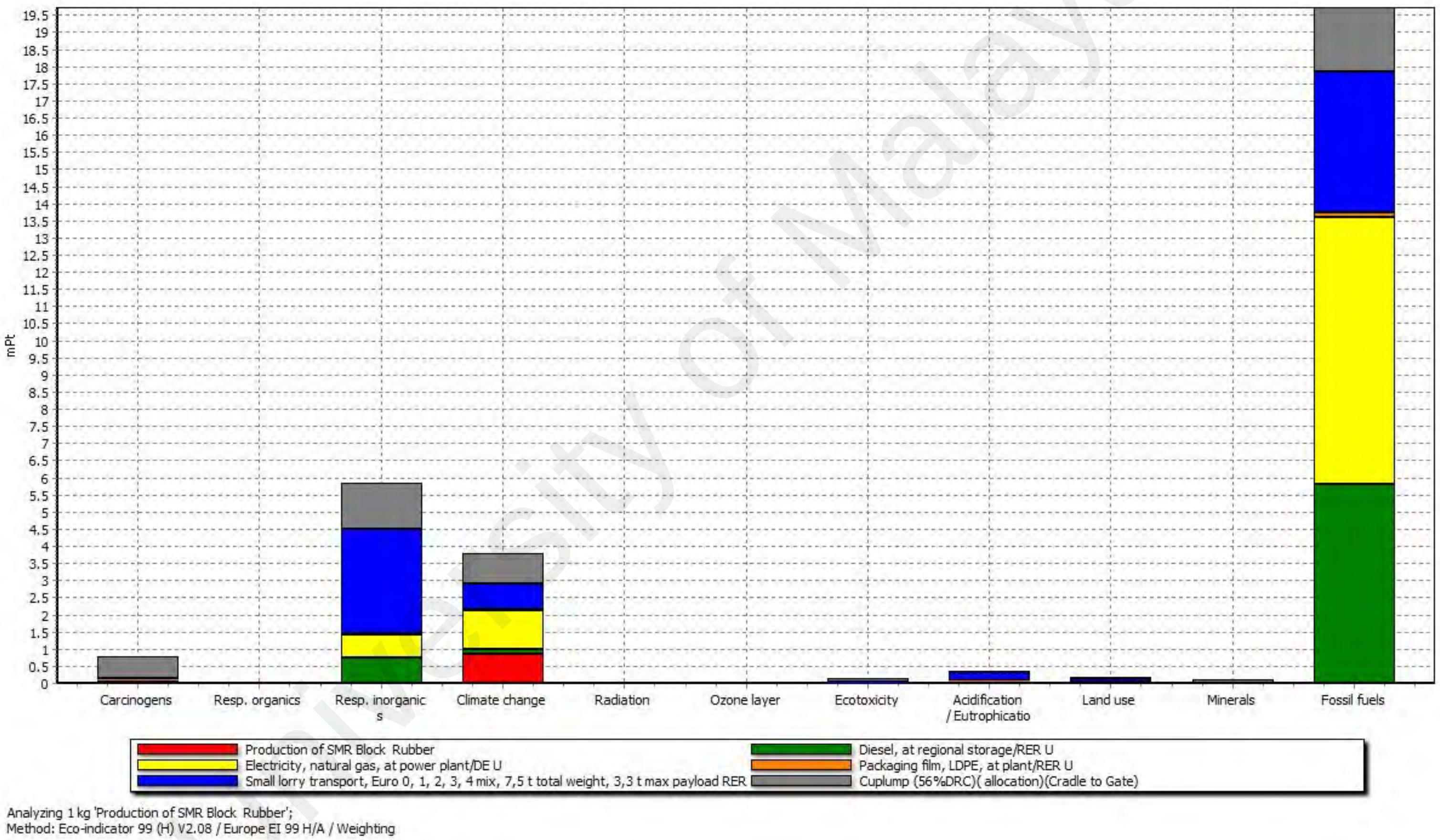

Figure 4.43: Weighting for the production of one kg SMR block rubber from cradle to gate based on impact categories

For fossil fuels impact category in the production of one kg SMR block rubber from cradle to gate, electricity generation, diesel production and transportation of the raw materials from the source to the block rubber factories are the three major contributors (Figure 4.43). Electricity generation, diesel production and transportation of the raw materials from the source to the block rubber factories contribute 39.6%, 29.4% and 20.9% respectively towards the total fossil fuels impact category value (Figure 4.43). The use of natural gas in the power plant to produce electricity, diesel production from the crude oil and the use of diesel in the lorry for the transportation of raw material are responsible for the cumulative impact of fossil fuels in the production of one kg SMR block rubber from cradle to gate (Ecoinvent, 2010).

Table 4.95: Weighting values for the production of one kg SMR block rubber from cradle to gate

Damage category	Impact Category	Unit	Impact category value	Damage category value
Human Health	Carcinogens	Pt	7.96E-04	
Human Health	Resp. organics	Pt	1.30E-05	
Human Health	Resp. inorganics	Pt	5.85E-03	
Human Health	Climate change	Pt	3.77E-03	
Human Health	Radiation	Pt	1.12E-05	
Human Health	Ozone layer	Pt	1.83E-06	
Total Human Health		Pt		1.04E-02
Ecosystem Quality	Ecotoxicity	Pt	1.53E-04	
Ecosystem Quality	Acidification/ Eutrophication	Pt	3.65E-04	
Ecosystem Quality	Land use	Pt	1.69E-04	
Total Ecosystem Quality		Pt		6.88E-04
Resources	Minerals	Pt	9.13E-05	
Resources	Fossil fuels	Pt	1.97E-02	
Total Resources		Pt		1.98E-02

The total weighted value from the 11 weighting impact categories for the production of one kg SMR block rubber from cradle to gate is 3.09E-02 Pt which is equal to 3.09E-05 PE as explained by PRe Consultants (2000)(Table 4.95). Relating the value of 3.09E-05 PE to the production of 562967 tonnes of natural rubber cuplump based SMR block rubber in Malaysia and the Malaysia population of 31.7 million, the impact from the production of natural rubber cuplump based SMR block rubber from cradle to gate in Malaysia is responsible for 0.055% of the Malaysian environmental impact. Thus the environmental impact contribution from the SMR block rubber processing industry in Malaysia is considered as insignificant as compared to the total Malaysian environmental impact.

Single Score

In the production of one kg SMR block rubber from cradle to gate, the impact towards resource depletion is the highest at 64.0% from the total value of the three damage categories (Table 4.96 and Figure 4.44). Ecosystem quality recorded the lowest impact at 2.0% while health effects to the human represent 34.0% from the total value of the three damage categories (Table 4.96 and Figure 4.44).

Table 4.96: Production of one kg SMR block rubber based on damage categories

Damage category	Unit	Total	Percentage (%)
Human Health	Pt	1.04E-02	34.0
Ecosystem Quality	Pt	6.88E-04	2.0
Resources	Pt	1.98E-02	64.0
Total	Pt	3.09E-02	100.0

Electricity generation, transportation of raw material from the source to block rubber factory, diesel production and production of natural rubber cuplump (56% DRC) from cradle to gate are the four main processes that influence the single score impact assessment results in the production of one kg SMR block rubber from cradle to gate (Figure 4.44). Electricity generation, transportation of raw material from the source to block rubber factory, diesel production and production of natural rubber cuplump (56% DRC) from cradle to gate represent 31.0%, 27.0%, 22.0% and 16.0% respectively from the total value of the three damage categories in the production of one kg SMR block rubber from cradle to gate (Figure 4.44).

The impact in the form of extra energy that future generation must use to produce natural gas represents 80.1% from the total impact in the electricity generation that is used for the production of one kg SMR block rubber from cradle to gate (Figure 4.45). For the process of transporting raw materials from the source to the block rubber factory in the production of one kg SMR block rubber from cradle to gate, 87.5% of the total impact is in the form of extra energy that future generation must use to extract the fossil fuels and the respiratory effects to human due to emission of inorganic substances to the air (Figure 4.45).

For the diesel used in the production of one kg SMR block rubber from cradle to gate, the impact in the form of extra energy that future generation must use to extract the crude oil for diesel production as results of lower quality crude oil represent 84.0% from the total impact (Figure 4.45). For the production of natural rubber cuplump (56%DRC) from cradle to gate as the raw materials in the SMR block rubber from cradle to gate production, the main concerns are the effects to the fossil fuels impact category, respiratory inorganics and climate change which had been described thoroughly in the section 4.10.

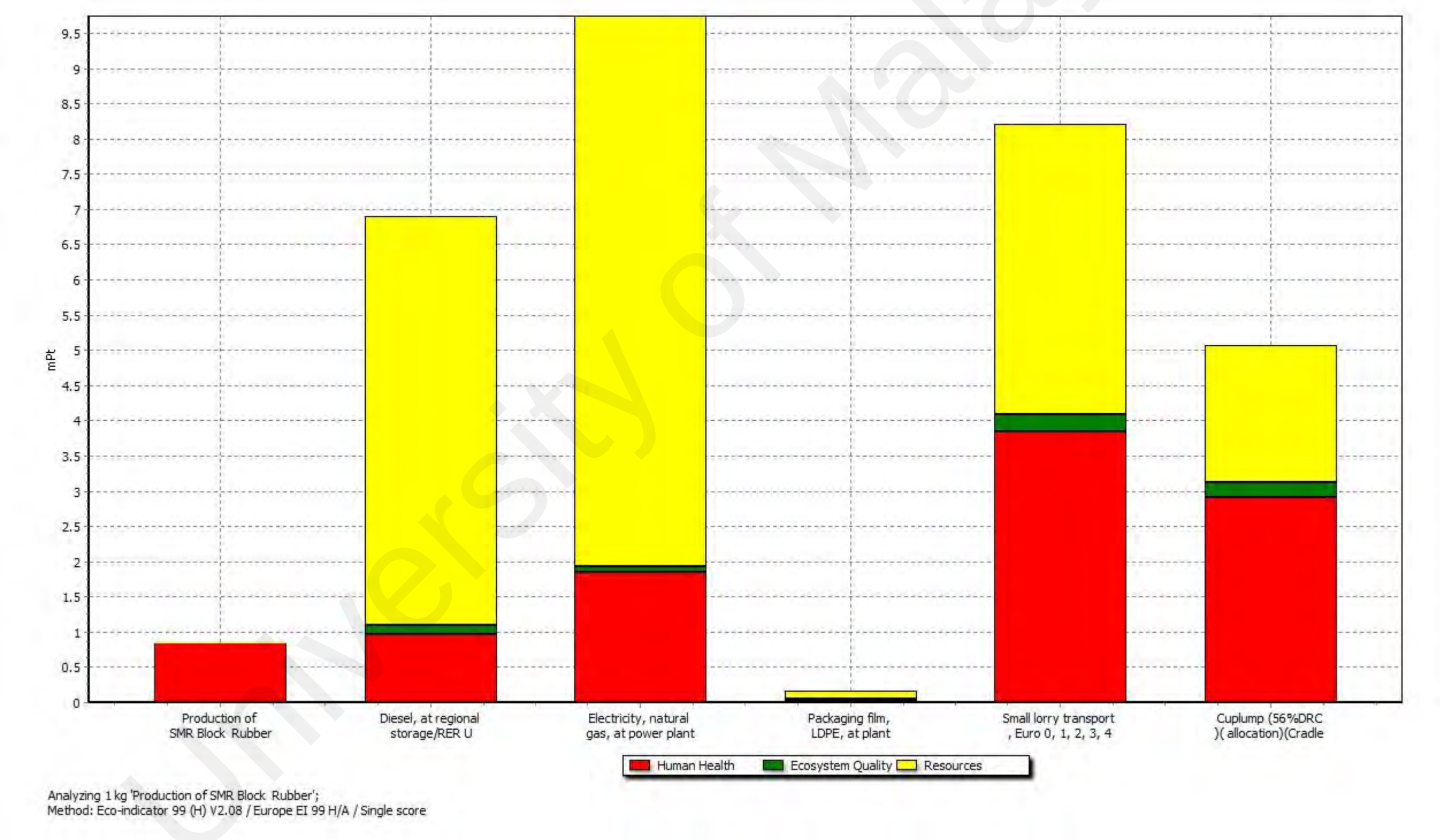

Figure 4.44: Single score for the production of one kg SMR block rubber from cradle to gate based on damage categories

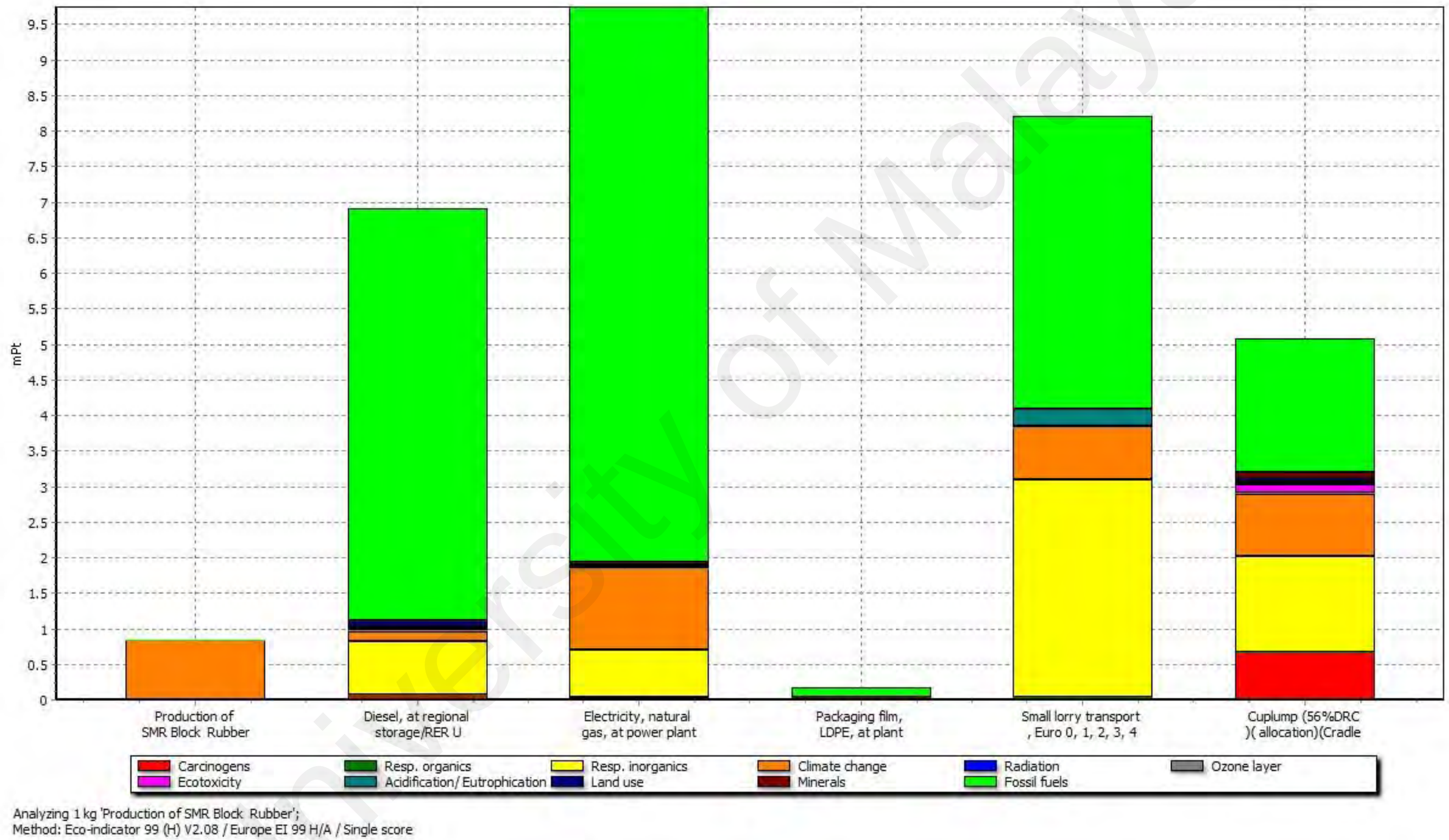

Figure 4.45: Single score results for the production of one kg SMR block rubber from cradle to gate based on impact categories

The environmental impact from the production of one kg SMR block rubber from cradle to gate had the potential to be reduce through the reduction in the electricity consumption, reduction in the fossil fuels based usage in the transporting of raw materials and reduction in the diesel usage.

For the block rubber to be classified as SMR, it must meet stringent quality SMR specification as specified in details in the SMR bulletin No. 11 published by RRIM (Rubber Research Institute of Malaysia, 1991). The samples from each of the SMR block rubber production lot must be analysed by the Malaysian Rubber Board (MRB) accredited laboratory and the samples must pass the SMR quality specification before the block rubber can be sell as SMR block rubber.

Failure to meet the SMR specification will resulted in the block rubber not being recognized as SMR and are therefore forbidden by MRB regulation to use the SMR logo for the purpose of selling as this rubber is consider as inferior quality rubber. The block rubber produced with the non-rubber contaminants of more than 0.16% for dirt content and 1.0% for the ash content as a result of poor cleaning of the raw material during the production of SMR bock rubber are considered as failure to meet the SMR specification and are not allowed to be marketed as SMR block rubber.

Contamination of natural rubber cuplump which is the main source of SMR block rubber production in Malaysia is a very common problem in Malaysia. Stones, sand and clays are some of the contaminants that were deliberately put inside the tapping cup during the tapping by a few of the rubber smallholders with the intention to manipulate the weight of the natural rubber cuplump produced (Mohamed, 2006). The practices by some rubber smallholders in putting tree barks inside the tapping cup during the tapping with the intention to speed up the coagulation of natural rubber latex into natural rubber cuplump also contribute to the contaminations of the raw material. There is also indirect contaminant in the form of raffia strings that were used to tie the gunny bag containing natural rubber cuplump during collection process which was supposed to be discarded but eventually end up in the SMR processing line. According to (Kin, 2010), contamination of raw materials which require manual screening at the SMR block rubber factory is one of the main challenges to the SMR block rubber processing industry.

Failure to address the raw materials contaminants issues properly will result in the failure to meet the SMR block rubber specification and this will be a huge loss for the SMR block rubber factory. In order to mitigate this problem, the SMR block rubber factory normally installs a pre-cleaning stage consisting of few types of machineries with high electrical motor capacity such as slabcutter and prebreaker to break up the natural rubber cuplump into small pieces and to expose its interior for manual screening and removal of the contaminants prior to the processing. The pre-cleaning stage plays an important role in the SMR block rubber production in order to ensure that only raw materials free or have a very minimum amount of contaminants are used to produce the block rubber as to avoid failing to meet the SMR specification.

The pre-cleaning machines electricity consumption from the respondents in this study represents an average of 18.5% from the total electricity consumption for the whole line of SMR block rubber machineries. The electricity consumption in the production of SMR block rubber has the potential to be reduced if the natural rubber cuplump purchased have a very minimum amount of contaminants as this will minimize the usage of the machineries in the pre-cleaning stage. Clean and free of contaminants natural rubber cuplump will reduce the operations time for the pre-cleaning machineries and this will be reflected in the relatively lower electrical consumption in the production of SMR block rubber.

The use of carrots and stick strategy should be used by the MRB in order to promote the supply of good quality natural rubber cuplump from the rubber smallholders until it reach the block rubber factory. The rubber smallholders need to be educated on the importance of field hygiene as some aspects of the natural rubber cuplump contaminants such as leaving the natural rubber cuplump on the ground prior to collecting is easier way of working without fully aware the consequences of the practices to the quality of SMR block rubber produced (Mohamed, 2006).

MRB should also promote the idea of setting up a fund to give small financial incentives to the rubber smallholders that produce clean raw materials. If this mechanism works as it intended objective, the block rubber processor will definitely benefit as it will lower the cost in the production of SMR block rubber as electricity cost contribute an average of 14.5% from the total cost of SMR block rubber production as reported by Halim (2008). The enforcement and more supervision at the rubber smallholders plot should also be conducted by MRB and other rubber related agencies to ensure the practice of intentionally cheating by putting foreign materials in the natural rubber cuplump can be rooted out. MRB has the power to confiscate the heavily contaminated natural rubber cuplump as a form of punishment to the rubber smallholders involved to safe guard the image of Malaysian rubber industry.

Transportation process plays an important role in delivering the natural rubber cuplump from the rubber smallholdings plots to SMR block rubber factories. The natural rubber cuplump is normally transported to the SMR block rubber factories on a daily basis using small and medium size lorry with an average distance of 116.5 km. The shortest distance recorded from the respondents in this study is 2 km while the longest distance is recorded at 250 km.

In theory, the best way to reduce the environmental impact from the transportation of raw materials from the source to the block rubber factory and its subsequent impact to the production of SMR block rubber is through the reduction in the distance from the source to the block rubber factories. Although the reduction in the distance from the source of raw materials to block rubber factories is one of the simplest solutions to reduce the environmental impact from the production of SMR block rubber, the reality facing the SMR block rubber processing industry in Malaysia is more complicated than that. The major challenge facing by the SMR block rubber processing industry in Malaysia is the inadequate supply of the raw materials as reported by Kin (2010). As the competition to get the supply of raw materials among the SMR block rubber processors are very stiff, the distance from the source to the SMR block rubber factories is not a main factor in making decision regarding the purchase of the raw materials by the SMR block rubber factories.

The average diesel consumption from the respondents in this study is 0.036 L per one kg of SMR block rubber produced. The diesel is used mainly to run the burners to produce hot air in the dryer. The respondents in this study reported their diesel consumption for dryer operation is in the range of 89% to 96% from the total diesel consumption. The average diesel consumption for tunnel dryer operation from all the respondents in this study is 91.2% while the rest are used for general operation of vehicles in the factory like forklift and front loader. Regular maintenance and servicing of the dryer especially the dryer burners, proper insulation of the tunnel dryer to avoid excessive heat loss are very important steps in in order to maintain the efficiency of the tunnel dryer and avoid the excessive amount of diesel used to dry the rubber crumbs. In terms of tunnel dryer operation, proper adjustment on the dryer temperature and the dwell time settings is also an important aspect in the minimizing the usage of diesel for the drying of rubber crumbs.

4.10.3 LCIA on GHGs Emission for the Production of SMR Block Rubber from Cradle to Gate

The total GHGs emission value for the production of one kg SMR block rubber from this study is 0.407 $kgCO_2eq$ (Figure 4.46 and Table 4.97).

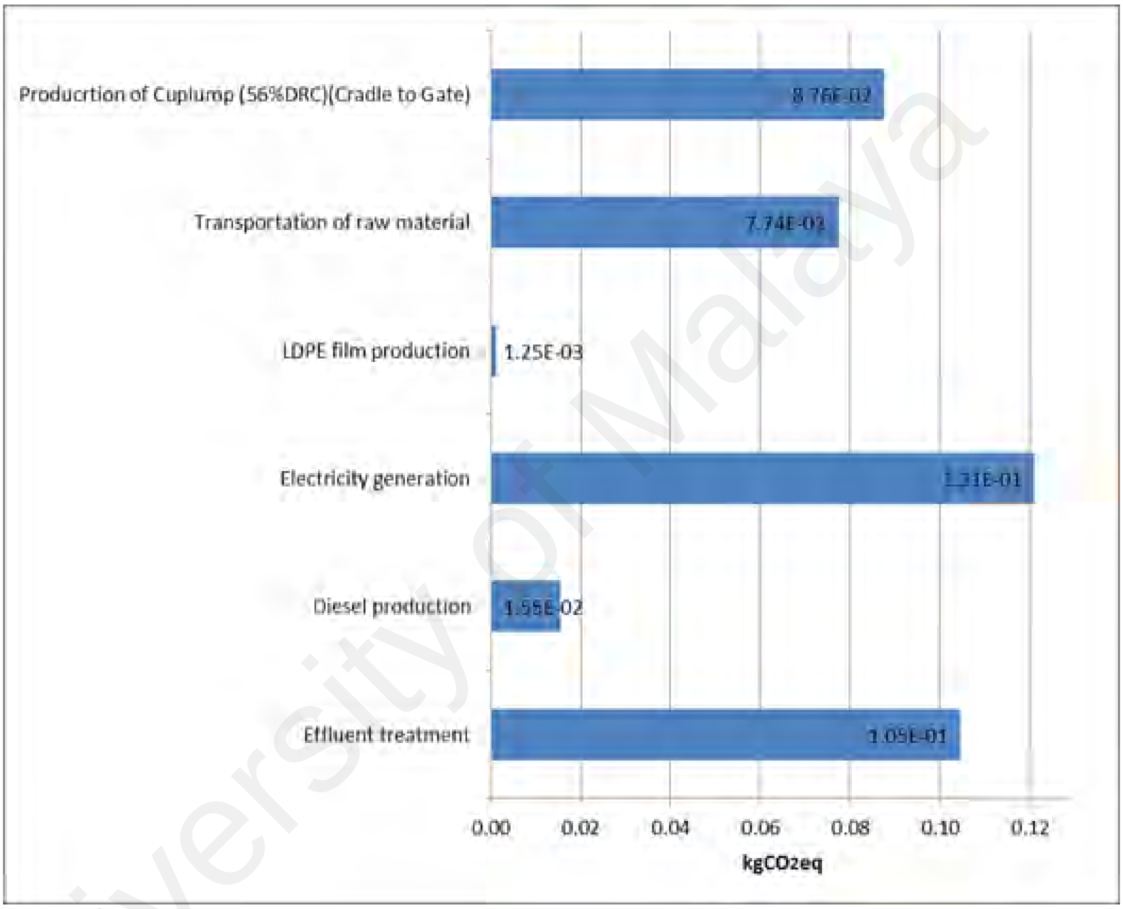

Figure 4.46: GHGs emission values for the production of one kg SMR block rubber from cradle to gate

Electricity generation, methane emission from the effluent treatment system, production of natural rubber cuplump from cradle to gate and transportation of raw material from the source to the SMR block rubber factories are the four main process contributors representing 95.9% from the total GHGs emission value in the production of one kg SMR block rubber from cradle to gate (Figure 4.46).

Electricity generation, methane emission from the effluent treatment system, production of natural rubber cuplump from cradle to gate and transportation of raw material from the source to the block rubber factories contribute 29.7%, 25.7%, 21.5% and 19.0% respectively towards the total value of GHGs emission in the production of one kg SMR block rubber from cradle to gate (Figure 4.46).

From Figure 4.46, it is obvious that the reduction in the electricity consumption during the production of SMR block rubber, elimination in the methane emission from the effluent treatment system, reduction in the total GHGs emission from the production of natural rubber cuplump (56%DRC) from cradle to gate and the reduction of fossil fuels based usage in the transporting of raw material from the source to SMR block rubber factory will definitely reduce the total GHGs emission from the production of one kg SMR block rubber from cradle to gate.

The possibility to reduce the electricity consumption during the production of SMR block rubber and the possibility reduction of fossil fuels based usage in the transporting of raw material from the source to block rubber factory has been described in section 4.11.2 while the possible strategy to reduce the GHGs emission from the production of natural rubber cuplump (56%DRC) from cradle to gate has been described in section 4.1.2 and section 4.10.3

All the respondents in this study used anaerobic facultative ponding system to treat their raw effluent in meeting the effluent discharge standard under the Environmental Quality (Prescribed Premises) (Raw Natural Rubber) Regulations 1978. The biochemical process in the anaerobic pond can be divided into three stages namely hydrolysis of complex organic molecules, acidogenesis and methanogenesis (Isa, 1991). Methanogenesis is the final stage in the anaerobic pond which involves the conversion of acidogenesis products to methane and carbon dioxide by methane producing bacteria or methanogens (Isa, 1991). Facultative ponds are ponds which have aerobic conditions in the upper layers and anaerobic process occurring in the bottom layers. At the upper layer, the aerobic microorganism decompose organic matters into carbon dioxide and water (Isa, 2004).

The GHGs emission from the production of SMR block rubber from cradle to gate had the potential to be reduced through the elimination of methane release from the effluent treatment system. The methane release from the treatment of SMR block rubber factory effluent can be eliminated through changing the current effluent treatment system of facultative/anaerobic ponding system to a fully aerobic system. At present, the methane emission from the effluent treatment plant in the block rubber factories are not subjected to any environmental regulations.

The GHGs emission from the production of 562967 tonnes of natural rubber cuplump based SMR block rubber in Malaysia is 229.41GgCO_2eq and this only represent 0.08% from the Malaysian total GHGs emission of 290,230 GgCO2eq in 2011 (Ministry of Natural Resources and Environment Malaysia, 2015).

The list of GHGs emission and its corresponding values in contributing to the total GHGs emission value for the production of one kg SMR block rubber from cradle to gate is shown in Table 4.97.

Carbon dioxide, methane and nitrous oxide are the three major GHGs that contribute 99.96% from the total GHGs emission value in the production of one kg SMR block rubber from cradle to gate (Table 4.97).

Table 4.97: GHGs emission profile for the production of one kg SMR block rubber from cradle to gate

GHGs	Weight in $kgCO_2eq$
Carbon dioxide	2.40E-01
Methane	1.18E-01
Nitrous oxide	4.90E-02
Methane, tetrafluoro-, CFC-14	6.16E-05
Sulfur hexafluoride	4.18E-05
Methane, chlorodifluoro-, HCFC-22	2.25E-05
Ethane, hexafluoro-, HFC-116	1.30E-05
Methane, bromotrifluoro-, Halon 1301	9.13E-06
Methane, bromochlorodifluoro-, Halon 1211	6.92E-06
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	4.39E-06
Methane, tetrachloro-, CFC-10	3.75E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	2.24E-06
Methane, dichlorodifluoro-, CFC-12	7.84E-07
Methane, trichlorofluoro-, CFC-11	3.39E-07
Methane, chlorotrifluoro-, CFC-13	1.39E-07
Methane, trifluoro-, HFC-23	6.21E-08
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	1.23E-08
Methane, dichloro-, HCC-30	1.09E-08
Ethane, 1,1-difluoro-, HFC-152a	1.37E-09
Chloroform	1.31E-09
Methane, monochloro-, R-40	1.68E-11
Ethane, 1,1,1-trichloro-, HCFC-140	6.50E-12
Methane, dichlorofluoro-, HCFC-21	1.99E-12
Methane, bromo-, Halon 1001	2.84E-18
Total GHGs Emission	0.407

Carbon dioxide emission

Carbon dioxide emission represents 58.98% from the total GHGs emission value for the production of one kg SMR block rubber (Table 4.97). The details on the carbon dioxide emissions for the production of one kg SMR block rubber from cradle to gate is shown in Table 4.98.

Table 4.98: Carbon dioxide ($C0_2$) emission values based on process for the production of one kg SMR block rubber

Process	CO_2 (kg)
Electricity generation	1.13E-01
Transport of raw material	7.50E-02
Cuplump (56%DRC) production	3.72E-02
Diesel production	1.40E-02
LDPE film production	1.05E-03
Total CO_2 emission	2.40E-01

Electricity generation is the highest contributor representing 47.1% from the total carbon dioxide emission in the production of SMR block rubber from cradle to gate (Table 4.98). This is follow by transportation of raw material at 31.2% while production of natural rubber cuplump (56%DRC) from cradle to gate and diesel production represent 15.5% and 5.8% respectively from the total carbon dioxide emission in the production of SMR block rubber from cradle to gate (Table 4.98). The production of LDPE film used to wrap the SMR block rubber is consider as insignificant contributor at 0.4% from the total carbon dioxide emission in the production of SMR block rubber from cradle to gate (Table 4.98).

The carbon dioxide emission from the production of 562,967 tonnes of natural rubber cuplump based SMR block rubber in Malaysia is 135.3 $GgCO_2$ and this represent 0.06% from the total Malaysian 2011 carbon dioxide emission value of 208,258 GgCO2 (Ministry of Natural Resources and Environment Malaysia, 2015).

Methane emission

Methane emission represents 28.96% from the total GHGs emission for the production of one kg SMR block rubber (Table 4.97). The details on the methane emission for the production of one kg SMR block rubber from cradle to gate is shown in Table 4.99.

Table 4.99: Methane (CH_4) emission values based on process for the production of one kg SMR block rubber

Process	CH_4(kg)
Electricity generation	3.07E-04
Transport of raw material	7.35E-05
Cuplump (56%DRC) production	9.22E-05
Diesel production	5.72E-05
LDPE film production	8.16E-06
Effluent treatment	4.18E-03
Total CH_4 emission	4.72E-03

Methane release from the anaerobic pond of the effluent treatment system is the single biggest contributor representing 88.6% from the total methane emission in the production of SMR block rubber from cradle to gate (Table 4.99).

The methane emission from the production of 562,967 tonnes of natural rubber cuplump based SMR block rubber in Malaysia is 66.4 $GgCO_2eq$ and this represent only 0.1% from the total Malaysian 2011 methane emission value of 67,532 $GgCO_2eq$ (Ministry of Natural Resources and Environment Malaysia, 2015).

Nitrous oxide emission

Nitrous oxide emission represents 12.02% from the total GHGs emission for the production of one kg SMR block rubber (Table 4.97). The details on the nitrous oxide emission for the production of one kg SMR block rubber from cradle to gate is shown in Table 4.100.

Table 4.100: Nitrous oxide (N_20) emission values based on process for the production of one kg SMR block rubber

Process	N_20 (kg)
Electricity generation	1.10E-06
Transport of raw material	2.05E-06
Cuplump (56%DRC) production	1.61E-04
LDPE film production	6.67E-09
Total N_20 emission	1.64E-04

For nitrous oxide emission, production of cuplump (56%DRC) from cradle to gate is the single biggest contributor representing 98.1% from total nitrous oxide emission in the production of SMR block rubber from cradle to gate (Table 4.100). This nitrous oxide emission is originated from the application of N fertilizer during the cultivation of the rubber tree.

The nitrous oxide emission from the production of 562,967 tonnes of natural rubber cuplump based SMR block rubber in Malaysia is 27.5 $GgCO_2eq$ and this represent 0.2% from the total Malaysian 2011 nitrous oxide emission value of 13,574 $GgCO_2eq$ (Ministry of Natural Resources and Environment Malaysia, 2015).

4.11 Summary of the Results and Discussion

The results and discussion in this chapter as described in details above is summarized in the Table 4.101 for easy references.

Table 4.101: Summary table for results and discussion

	Cultivation of one rubber tree cradle to grave (31.75 Years)	Production of one TWYBP cradle to gate (0.75 Years)	Maintaining the healthy growth of one immature rubber tree gate to gate (1 year average)	Maintaining the healthy growth of one mature rubber tree gate to gate (1 year average)	Production of 1 kg natural rubber cuplump (56%DRC) cradle to gate	Production of 1 kg SMR block rubber cradle to gate
Main weighting impact assessment categories (%)	1. Fossil fuels (36.9) 2. Respiratory inorganics (26.5) 3. Climate change (17.4)	1. Fossil fuels (62.3) 2. Respiratory inorganics (19.8)	1. Fossil fuels (35.6) 2. Respiratory inorganics (29.1)	1. Fossil fuels (36.9) 2.Respiratory inorganics (26.1)	1. Fossil fuels (36.9) 2.Respiratory inorganics (26.5) 3.Climate change (17.4)	1. Fossil fuels (63.7)
Major process contributor towards total weighting impact assessment (%)	1. Ammonium sulphate production (41.3)	1. Diesel production (40.7) 2.HDPE resin E production (29.3)	1. Ammonium sulphate production (38.0) 2. Glyphosate production (29.2)	1. Ammonium sulphate production (42.2)	Not discussed	1. Electricity generation (31.0) 2. Transportation of raw material (27.0) 3. Diesel production (22.0)

Table 4.101, continued

Single score damage categories impact assessment (%)	1. Human health (57.3) 2. Ecosystem quality (4.2) 3. Resources (38.5)	1. Human health (35.4) 2. Ecosystem quality (2.3) 3. Resources (62.4)	1. Human health (59.0) 2. Ecosystem quality (4.1) 3. Resources (36.9)	1. Human health (57.1) 2. Ecosystem quality (4.3) 3. Resources (38.6)	Not discussed	1. Human health (34.0) 2. Ecosystem quality (2.0) 3. Resources (64.0)
Total GHGs emission (kg CO_2eq)	44.68	1.299E-01	1.08	1.52	4.89E-02	0.407
Major process contributor towards total GHGs emission (%)	1. Application of ammonium sulphate (54.3)	1. Fertilizer N production (29.5) 2. Fertilizer N application (20.0) 3. HDPE resin E production (19.2)	1. Application of ammonium sulphate (51.6)	1. Application of ammonium sulphate (54.9)	1. Application of ammonium sulphate (54.3)	1. Electricity generation (29.7) 2. Effluent treatment system (25.7) 3. Production of cuplump (21.5)

CHAPTER 5: CONCLUSION AND RECOMENDATION

5.1 Introduction

As with other crop based industry in Malaysia, the Malaysian rubber industry is not immune from the effect of climate change. In the Malaysian context, the government had formulated two policies i.e. The National Policy on Climate Change and the National Green Technology Policy to address the climate change holistically and to promote the use of green technologies towards meeting the sustainable development goal.

The government of Malaysia also announces its voluntary reduction of up to 40% in terms of carbon emission intensity of GDP by the year 2020 as part of the strategy to address the issues of climate change in the context of sustainable development (Ministry of Natural Resources and Environment Malaysia, 2015; Theseira, 2013).

This study provided very useful information in the form of identifying and quantifying the environmental hotspots from the Malaysian rubber industry. Through this study, few possible solutions to reduce these environmental hotspots are proposed for the betterment of the Malaysian rubber industry in line with Malaysia's goal of achieving sustainable development.

Possible strategies in helping the Malaysian rubber industry to reduce its carbon emission intensity were also identified from this study in line with the Malaysian government pledge at COP 15 to reduce its carbon emission intensity. The most significant aspect of this study is that, this is the first LCA study of its kind ever carried out in Malaysia for the rubber industry.

This study has successfully fulfilled all the 5 objectives set at the beginning of the study as described below:

1. All the inputs and outputs involved in the cultivation of one rubber tree from cradle to grave in 31.75 years average life span, production of one two whorl young budding in the rubber nursery for an average of 9 month, the production of one mature rubber tree for an average of 6 years in the immature stage and the process to maintain the healthy growth of one mature rubber tree in the mature rubber stage for an average of 25 years have successfully been reviewed and quantified in the form of LCI input-output table.
2. The LCI input-output table for the production of one kg natural rubber cuplump (56%DRC) from cradle to gate has been successfully generated by applying the mass allocation ratio from the combination of literature source from Yew et al., in Rahaman and Amu (2002) and Rahaman and Amu (2002) to the LCI table for the cultivation of one rubber tree from cradle to grave in this study.
3. All the inputs and outputs involved in the production of one kg SMR block rubber has successfully been reviewed and quantified in the form of LCI input-output table.
4. The quantification of the environmental impact in the form of Life Cycle Impact Assessment and identification of recommended strategies for improvement based on the individual LCI tables in this study has successfully been achieved and summarized as below:

   i. <u>Cultivation of rubber trees from cradle to grave in Malaysia</u>

   The impact from the cultivation of rubber trees in Malaysia from cradle to grave based on its average life span of 31.75 years is responsible for 1.83% of the Malaysian environmental impact while the impact from the cultivation of rubber trees in Malaysia from cradle to grave based on one year perspective is 0.058% of the Malaysian environmental impact. Utilization of ammonium sulphate at optimum level especially during the mature rubber stage plays an important role and has the potential to reduce the environmental impact from the cultivation of rubber trees in Malaysia.

ii. Production of two whorl young budding in the polybag in Malaysia

The impact from the production of two whorl young budding in Malaysia for an average period of 9 months based on cradle to gate boundary is responsible for 0.0008% of the Malaysian environmental impact and it represents 1.4% from the Malaysian environmental impact for the cultivation of rubber trees from cradle to grave based on average one year perspective. The environmental impact from the production of two whorl young budding in the polybag by the rubber nurseries operators in Malaysia has the potential to be reduced through the employment of very experience and skilled grafters.

iii. Production of mature rubber trees in Malaysia

The impact from the production of mature rubber trees in Malaysia for the average period of one year for gate to gate boundary is responsible for 0.0165% of the Malaysian environmental impact and it represents 28.4% from the Malaysian environmental impact for the cultivation of rubber trees from cradle to grave based on average one year perspective. The environmental impact from the production of mature rubber trees for gate to gate boundary in Malaysia has the potential to be reduced through the reduction in the immaturity rubber stage period.

iv. Process to maintain the healthy growth of mature rubber trees in Malaysia

The impact from the process to maintain the healthy growth of mature rubber trees in Malaysia for the average period of one year for gate to gate boundary is responsible for 0.0396% of the Malaysian environmental impact and it represents 63.6% from the Malaysian environmental impact for the cultivation of rubber trees from cradle to grave based on average one year perspective. The environmental impact from the process to maintain the healthy growth of mature rubber trees in Malaysia for gate to gate boundary has the potential to be reduced through optimum usage of ammonium sulphate fertilizer during the fertilization programme.

v. Production of natural rubber cuplump (56%DRC) in Malaysia

The impact from the production of natural rubber cuplump (56% DRC) in Malaysia for the average period of one year for cradle to gate is responsible for 0.011% of the Malaysian environmental impact and its represent 19.0% from the Malaysia environmental impact for the cultivation of rubber trees from cradle to grave based on average one year perspective.

vi. Production of SMR block rubber in Malaysia

The impact from the production of SMR block rubber in Malaysia for the average period of one year for cradle to gate boundary is responsible for 0.055% of the Malaysian environmental impact and is equal to 94.8% of the Malaysian environmental impact for the cultivation of rubber trees from cradle to grave based on average one year perspective. The environmental impact from the production of SMR block rubber in Malaysia from cradle to gate boundary have the potential to be reduce through increasing the supply of local natural rubber cuplump and making sure natural rubber cuplump are free or have a very minimum amount of contaminants. Proper maintenance and regular servicing of the dryer can also contribute in lowering the environmental impact for the production of SMR block rubber in Malaysia.

5. The quantification of Greenhouse gas (GHGs) emission and identification of recommended strategies for improvement based on the individual LCI tables in this study has successfully been achieved and summarized as below:

   i. Cultivation of rubber trees from cradle to grave in Malaysia

The GHGs emission for the cultivation of rubber trees in Malaysia from cradle to grave based on its average life span of 31.75 years is 10,018.39 $GgCO_2eq$ and it represents 3.45% of the Malaysia 2011 GHGs emission while the GHGs emission from the cultivation of rubber trees in Malaysia from cradle to grave based on average one year perspective is 315.54 $GgCO_2eq$ and it represents 0.11% of the Malaysia 2011 GHGs emission. The reduction in the utilization of ammonium sulphate fertilizer to its optimum level has the potential to reduce the GHGs emission for the cultivation of rubber trees in Malaysia from cradle to grave perspective

ii. Production of two whorl young budding in the polybag in Malaysia

The GHGs emission from the production of two whorl young budding in Malaysia for an average period of 9 months based on cradle to gate boundary is 1.84 $GgCO_2eq$ and it represents 0.58% from the total GHGs emission for the cultivation of rubber trees from cradle to grave based on average one year perspective. The reduction in the period to produce two whorl young budding in the polybag and the employment of very experience and skilled grafters have the potential to reduce the GHGs emission from the production of two whorl young budding in Malaysia.

iii. Production of mature rubber trees in Malaysia

The GHGs emission from the production of mature rubber trees in Malaysia for the average period of one year for gate to gate boundary is 87.45 $GgCO_2eq$ and it represents 27.7% from the total GHGs emission for the cultivation of rubber trees from cradle to grave based on average one year perspective. The reduction in the immaturity rubber stage period and incorporating of manual weeding method in the weed management have the potential to reduce the GHGs emission for the production of mature rubber trees for gate to gate boundary in Malaysia.

iv. Process to maintain the healthy growth of mature rubber trees in Malaysia

The GHGs emission from the process to maintain the healthy growth of mature rubber trees in Malaysia for the average period of one year for gate to gate boundary is 219.3 GgCO_2eq and it represents 69.5% from the total GHGs emission for the cultivation of rubber trees from cradle to grave based on average one year perspective. The GHGs emission from the process to maintain the healthy growth of mature rubber trees in Malaysia for gate to gate boundary has the potential to be reduced through optimum usage of ammonium sulphate fertilizer during the fertilization programme.

v. Production of natural rubber cuplump (56%DRC) in Malaysia

The GHGs emission from the production of natural rubber cuplump (56% DRC) in Malaysia for the average period of one year for cradle to gate is 58.43 GgCO_2eq and it represents 18.5% from the total GHGs emission for the cultivation of rubber trees from cradle to grave based on average one year perspective.

vi. Production of SMR block rubber in Malaysia

The GHGs emission from the production of SMR block rubber in Malaysia for the average period of one year for cradle to gate is 229.41 GgCO_2eq and is equal to 72.7% of the total GHGs emission for the cultivation of rubber trees from cradle to grave based on average one year perspective. The GHGs emission from the production of SMR block rubber in Malaysia for the average period of one year for cradle to gate boundary have the potential to be reduce through increasing the supply of local natural rubber and making sure the natural rubber are free or have a very minimum amount of contaminants. The GHGs emission from the production SMR block rubber in Malaysia for the average period of one year for cradle to gate boundary also has the potential to be reduce through replacing the current effluent treatment system to a fully aerobic system.

5.2 Recommendations

This study is no doubt contributed significantly in the area of environmental management for the Malaysian rubber industry. Being the first study ever conducted in Malaysia, there is still plenty of room for improvement and the possibility of expanding the scope of this study through future work recommendations as follow:

5.2.1 Recommendations for Improvement:

1) Life cycle impact assessment is a fast evolving field of research with methodologies are continuously being developed and updated and the LCA experts need to keep alert on this development. Eco-indicator 99 has been used as the default life cycle impact assessment analysis for this study in line with the study period which started in 2013. In tandem with the latest development in the field of life cycle impact assessment especially with the release of the latest and state-of-the-art life cycle impact assessment methodology i.e. ReCiPe 2016 on 15th December 2016, it is important that inventories data from this study is re-analyse using ReCiPe 2016. A sensitivity analysis should also be carried out between the results from these two methodologies in order to come out with a consensus conclusion despite the differences in the methodologies use.

2) Due to budget and time constraint, the respondents from this study are only limited to Peninsular Malaysia. Even though the standard operating procedures is expected to be almost similar between the rubber nurseries operators, rubber smallholders management agencies and SMR block rubber processors in Peninsular Malaysia and East Malaysia (Sabah and Sarawak), it will be interesting to get the

feedback directly from the rubber nurseries operators, rubber smallholders management agencies and SMR block rubber processors in East Malaysia to fully confirm it.

3) In this study, the allocation for the output from the cultivation of one rubber tree from cradle to grave modelling was made based on available literature data through research works carried out by the Malaysian Rubber Board (MRB) and its predecessor the Rubber Research Institute of Malaysia (RRIM). This is because the rubber smallholders management agencies are only interested with the yield data and not really interested with the biomass calculation of the fallen rubber trees at the end of their life span. These agencies normally did not have or did not keep proper record for the rubber trees biomass. Their priorities are more towards preparing the cleared plot of land to be ready for another cycle of rubber cultivation. It will be very informative and useful if the allocation for the output in the cultivation of one rubber tree from cradle to grave can be calculated based on a case study using the same samples from the identified rubber trees for biomass and dry rubber allocation. For this case study to materialized, the cooperation and support from the rubber smallholders management agencies is very crucial as it will involve compiling the historical yield data from the first day of tapping until the last day of tapping. According to Sone et al. (2014), the yield data are usually considered as confidential and we ourselves do experience it when conducting this study. Without the full commitments from the rubber smallholders agencies involved, it will be very difficult to carry out the proposed case study as its involves destructive sampling of the old rubber trees at the rubber smallholders plot before it can be analyse in the laboratory.

5.2.2 Recommendations for the Expansion the Scope of the Study (Future Work)

1) As this study only focuses on the production of two whorl young budding in the polybag, it is recommended that LCA study to quantify the environmental impacts and

GHGs emission for the production of rubber planting material from ground nursery should also be carried out in the near future. It will be interesting to compare the results from the production of two whorl young budding in the polybag with the planting materials produced from ground nursery.

2) The processing of latex concentrate from rubber midstream industry was excluded from the current scope of the study due to time constraint and the fact that it only represents around 15% from the Malaysian rubber midstream total factory output. Even though the latex concentrate processing capacity in Malaysia is quite limited due to the problem of getting enough supply of the natural rubber latex, it still plays an important role as the alternate source of raw material for the natural rubber gloves manufacturing industry. With this in mind, it is justifiable to do the LCA study for the production of latex concentrate in Malaysia.

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