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ENVIRONMENTAL PERFORMANCE OF MERANTI SAWMILLING IN PENINSULAR MALAYSIA

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By

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Chairman : Prof. Jegatheswaran Ratnasingam, PhD
Faculty : Forestry

The sawmilling sector generates a large amount of wood waste and consequently, discharges several gases as a result of the resources consumption in the sawmilling activity. Therefore, the general objective of this study was to evaluate the environmental profile of the sawmilling activity in Malaysia, with particular reference to the sawing of Light Red and Dark Red Meranti (*Shorea* spp.) wood species. Meanwhile, the specific objectives were to measure the resources consumption, quantify the environmental burdens and evaluate the potential environmental impacts of the sawmilling activity. The resources consumption, environmental burdens and potential environmental impacts were compared against the test factors which were the wood species and the two different sawmills. The environmental performance of the sawmilling activity was evaluated using life cycle assessment (LCA) analytical tool. The methodological framework of LCA consists of four phases: goal and scope definition, life cycle inventory, life cycle impact assessment and life cycle interpretation. Two sawmills, known in this study as sawmill A and sawmill B were chosen for this study. Sawmill A, is the largest mill in Peninsular Malaysia, was set out as the base scenario of environmental performance assessment study. The inclusion of a corresponding medium-sized sawmill B, was to observe the differences in the environmental performance compared to sawmill A. The scope of the study was a gate-to-gate measurement, which began once the saw logs entered the mill gate for the cutting process, until the production of rough green sawn timber. The data on material and energy consumption was collected on a monthly basis throughout the year 2013, in both sawmills. The environmental burdens were then quantified on the basis of the activity data and emission factors. The results of the study were divided into four parts. The first part of the study enumerated the recovery, in which it was found that the recovery of rough green sawn timber was higher for Light Red Meranti, while Dark Red Meranti generated higher amounts of wood losses in the form of splinters, sawdust and shavings for both sawmills. The chosen allocation was sawn timber as the main and the only product. The factorial ANOVA test showed significant difference in sawn timber recovery between the wood species, but not for sawmills and the interaction of sawmills and wood species. Saw logs characteristics (diameter and length), removal of defects and generation of wood residues were among the factors that affected the sawn timber recovery. Meanwhile, the similarity in machining parameters resulted in the

non-significant differences between the sawmills, and also between the interaction of sawmills and wood species. The examination on the energy consumption identified, that electrical energy and diesel fuel energy were consumed higher for the Dark Red Meranti wood species. As a result, the emissions of CO_2, CH_4, N_2O, SO_2, NOx and CO were also higher for this wood species. The non-significant finding from the MANOVA and Mann-Whitney U tests is attributable to the comparable machining parameters and energy consumption. The study was continued to translate the environmental loads into potential environmental impacts. The results obtained were the global warming potential (CO_2, CH_4 and N_2O), acidification potential (NO_2 and SO_2), human toxicity potential (NO_2 and SO_2), photo-oxidant formation potential (NO_2 and SO_2, CH_4 and CO) and eutrophication potential (NO and NO_2). The MANOVA analysis on the potential environmental impacts showed no significant differences between the sawmills, wood species and the interaction of sawmills and wood species, respectively. The results obtained were mostly likely associated with the environmental burdens assessment. Overall, the components depicted a positive and strong relationship with the potential environmental impacts. A comparative study of the potential environmental impacts showed global warming potential had the highest influence on the environment. A comparison of global warming potential has far reading implications on the sawmilling industry in the country. This study recommends further environmental performance studies on other tropical hardwood wood species and forest plantation wood species used in the sawmilling sector. Besides, further research on sawmilling with kiln drying facilities is also suggested.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PRESTASI ALAM SEKITAR BERDASARKAN KEPADA PEMOTONGAN KAYU MERANTI DI KILANG PAPAN DI SEMENANJUNG MALAYSIA

Oleh

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Sektor kilang papan menghasilkan sejumlah besar sisa kayu dan seterusnya, membebaskan beberapa jenis gas disebabkan oleh penggunaan sumber yang tidak efisien ketika aktiviti di kilang papan dilakukan. Oleh itu, objektif utama bagi kajian ini adalah untuk menilai profil alam sekitar semasa aktiviti pemotongan dijalankan di kilang papan di Malaysia, dengan memberi perhatian khusus kepada Meranti Merah Muda (*Shorea* spp.) dan Meranti Merah Tua (*Shorea* spp.). Sementara itu, spesifik objektif adalah untuk menganggarkan penggunaan sumber, mengira kuantiti beban alam sekitar dan menilai potensi impak kepada alam sekitar. Penggunaan sumber, beban alam sekitar dan potensi impak kepada alam sekitar dibandingkan terhadap faktor analisis iaitu spesies kayu dan kilang papan. Kaedah *life cycle assessment* (LCA) digunakan untuk menilai prestasi alam sekitar aktiviti kilang papan. Kaedah Kaedah LCA terdiri daripada empat fasa iaitu *goal and scope definition*, *life cycle inventory* (LCI), *life cycle impact assessment* (LCIA) and *life cycle interpretation*. Dua buah kilang, diklasifikasikan sebagai kilang papan A dan kilang papan B dipilih bagi kajian ini. Kilang papan A, adalah sektor kilang papan yang terbesar di Semenanjung Malaysia, ditetapkan sebagai senario asas bagi kajian penilaian prestasi alam sekitar. Kilang papan B yang bersaiz sederhana dan mempunyai persamaan dengan kilang papan A disertakan dalam kajian ini bagi tujuan untuk memerhatikan perbezaan dalam prestasi alam sekitar dengan kilang papan A. Skop kajian adalah di dalam kawasan kilang sahaja, bermula apabila kayu balak dibawa masuk untuk proses pemotongan sehingga terhasilnya kayu papan. Data bagi penggunaan sumber dan tenaga diambil pada setiap bulan sepanjang tahun 2013, di kedua-dua buah kilang papan. Beban alam sekitar dikira berdasarkan kepada aktiviti data dan faktor-faktor pembebasan. Keputusan kajian telah dibahagikan kepada empat bahagian. Bahagian pertama kajian menghitung peratusan isipadu kayu papan, di mana keputusan mendapati peratusan isipadu kayu gergaji adalah lebih tinggi bagi Meranti Merah Muda, manakala Meranti Merah Tua menghasilkan jumlah kuantiti sisa kayu yang tinggi berbentuk serpihan, habuk papan dan tatal bagi kedua-dua kilang papan. Penghasilan pelbagai jenis output di kilang kayu papan menimbulkan keperluan untuk memilih pendekatan peruntukan kayu gergaji adalah dan hanya produk utama. Ujian faktorial ANOVA menunjukkan bahawa terdapat perbezaan yang signifikan dalam peratusan isipadu kayu papan di antara spesies kayu, tetapi kilang papan dan interaksi kilang papan dan spesis kayu

tiada signifikan. Faktor-faktor yang mempengaruhi dalam peratusan isipadu kayu gergaji adalah ciri-ciri kayu balak (diameter dan panjang), penyingkiran kecacatan di kayu balak dan penghasilan sisa kayu yang berbeza. Persamaan dalam parameter pemesinan menyebabkan perbezaan yang tidak ketara di antara kilang papan, dan juga antara interaksi kilang papan dan spesis kayu. Penilaian penggunaan tenaga mengenalpasti tenaga elektrik dan bahan api diesel adalah lebih tinggin bagi spesies kayu Meranti Merah Muda. Akibatnya, pembebasan gas CO_2, CH_4, N_2O, SO_2, NOx and CO adalah lebih tinggi bagi spesies kayu ini juga. Penentuan yang tidak signifikan hasil daripada ujian statistik MANOVA dan Mann-Whitney U boleh dikaitkan dengan persamaan dalam parameter pemesinan dan penggunaan tenaga. Kajian ini seterusnya menterjemahkan beban alam sekitar kepada potensi impak kepada alam sekitar. Keputusan yang diperolehi adalah potensi kepada pemanasan global (CO_2, CH_4 and N_2O), pengasidan (NO_2 and SO_2), ketoksikan manusia (NO_2 and SO_2), pembentukan foto-oksida (NO_2 and SO_2, CH_4 and CO) and eutrofikasi (NO and NO_2). Analisis MANOVA ke atas potensi impak kepada alam sekitar menunjukkan tiada perbezaan yang signifikan di antara kilang papan, spesies kayu dan interaksi kilang papan dan spesies kayu, masing-masing. Keputusan yang diperolehi boleh dikaitan dengan beban penilaian persekitaran. Secara keseluruhan, komponen gas menunjukkan hubungan yang positif dan kuat dengan potensi impak kepada alam sekitar. Perbandingan potensi impak kepada alam sekitar menunjukkan potensi pemanasan global mempunyai pengaruh yang paling tinggi kepada alam sekitar. Perbandingan dengan dengan spesies kayu lain pula menunjukkan bacaan yang sangat tinggi. Kajian ini mencadangkan untuk mengenalpasti prestasi alam sekitar bagi spesies kayu keras tropika yang lain dan spesies ladang hutan yang digunakan dalam aktiviti kilang papan. Selain itu, kajian lanjut ke atas kilang papan yang mempunyai kemudahan tanur pengeringan adalah disyorkan.

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

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%	percentage
1,4-DCB-eq	1,4-dichlorobenzene equivalent
ANOVA	analysis of variance
g	gram
kg	kilogram
kWh	kilowatt hour
L	Litre
m^3	cubic metre
MJ	megajoule
BJC	builders, joinery and carpentery
C_2H_4-eq	ethylene equivalent
CH_4	methane
CML	Centre of Environmental Science-Leiden University
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
CORRIM	Consortium for Research on Renewable Material
EI	Ecoindicator
HHV	High heating value
IMP	Industrial Master Plan
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standard of Organization
LCA	life cycle assessment
LCI	life cycle inventory

LCIA	life cycle impact assessment
MANOVA	multivariate analysis of variance
NMVOC	non-methane volatile organic compound
N_2O	nitrous oxide
NO	nitric oxide
NO_2	nitrogen dioxide
NOx	mono-nitrogen oxides
PO_4^{3}-eq	phosphate ion equivalent
SETAC	Society of Environmental Toxicology and Chemistry
SFM	Sustainable Forest Management
SO_2	sulphur dioxide
SO_2-eq	sulphur dioxide equivalent
TJ	terajoule

CHAPTER 1

INTRODUCTION

1.1 Research Background

There is a long history in the consumption of wood, in which wood has been a valuable material for communities and also important for the economy. Rivela et al. (2007) stated that wood has been mainly harvested in large scale for industrial roundwood production when the industrial revolution started worldwide. Gopalakrishnan et al. (2005) underlined that sawn timber is the most important form in which wood is being used. Sawn timber is described as the wood product from the saw and planning mill, not further manufactured by sawing, re-sawing and passing lengthwise through a standard planning machine, crosscutting to length (Brown and Bethel, 1958).

Demand for sawn timber for further processed value-added wood products is inevitable. The population growth in the world is among the main drivers for the increasing demand of wood-based products (Gemechu et al., 2013). Besides that, wood has become the preferred choice of raw material when compared to other materials such as steel, plastic and concrete, as wood is well known as a renewable resource with low resource input as well as an environmental favourable material (Martínez-Alonso and Berdasco, 2015; Bergman et al., 2014; González-García et al., 2012).

In the same vein, sawn timber is significantly important in Malaysia. As a result, the sawmilling sector evolved from primarily for domestic consumption into an important export sector in Malaysia. The export of sawn timber became one the main sources of revenue for the country (Khairul Izzudin et al., 2014; National Timber Policy, 2009; Menon, 2000; Othman et al., 1991). The sawn timber market share rose from 19% in 1970 (Othman et al., 1991) to 78% in 2013 (Ministry of Plantations Industries and Commodities, 2014). The availability of resources have supported the timber industry's growth and helped it endure the global market competition (Loke, 1996).

A competent production is highly required in the sawmilling sector in order to ensure the sawn timber demand is satisfactorily for the local and international markets. However, the conversion of log into sawn timber currently attracted the attention of consumers and several environmental organizations. Several studies have revealed that the sawmilling activity triggered to environmental issues in terms of environmental burdens and environmental impacts (Bergman and Bowe, 2012; PE International AG, 2012; Tellnes et al., 2012; Eshun et al., 2010; Kinjo et al., 2005).

The flow of log which not only produced sawn timber as the final products, in fact leads to losses in the form of bark, chips, sawdust and off-cuts as well in every unit process. Other solid wastes, such as ash were also released during the production process. Besides that, several substances namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), mono-nitrogen oxides (NOx) of nitric oxide (NO) and nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), non-methane volatile organic compound (NMVOC) and particulates were discharged from all stages of the processing, as a result of the processing energy. Besides solid waste generation and air emission, waterborne emissions were also noticed in the sawmilling sector.

The generation of wood waste, water pollutants, air emissions and solid waste generation is becoming the major concern associated with the sawmilling activity. These environmental emissions subsequently affected the ecosystem quality, health and future availability of natural resources (González-García et al., 2009) owing to the impact on the environment. The recognized environmental impacts evaluated from the environmental emissions from sawmilling activities consist of global warming potential, photochemical ozone formation potential, ozone depletion potential, acidification potential, human toxicity potential, eutrophication potential, energy depletion and material depletion (PE International AG 2012; Tellness et al. 2012; Eshun et al. 2011; Puettmann et al. 2010; Kinjo et al. 2005). Tellnes et al. (2012) highlighted that global warming potential appear to form the highest profile in the environment. The main factor is caused by the discharge of CO_2 gas to the environment in large quantities. This observation is supported by other researchers who carried out studies in different fields (Muñoz *et al.* 2013; Gemechu *et al.* 2013; Wu *et al.* 2012; Röös *et al.* 2010).

Eshun et al. (2010) highlighted that these environmental issues are distinct between countries and production plants caused by the differences in technology, methods and the environmental standards used in the production processes. Yet, this issue has become the topic of criticism at both the national and international levels.

From the viewpoint of these facts, the environmental issues in the sawmilling sector should not be neglected although sawmilling sector's performance in this country changed dramatically since the implementation of the First Industrial Master Plan (IMP 1) in 1986. The new policy forced the wood-based industry to restructure from a commodity industry to a value-added products manufacturing industry. As a consequence, there was a steady decline in the number of sawmills over the years (Figure 1.1), while the downstream industries, namely furniture components and furniture industry, mouldings and builders, joinery and carpentery (BJC) industry increased significantly. The message was clear: the country could no longer afford to export timber in the unprocessed form, and must instead generate maximum value from the limited resources available (Ong, 1986).

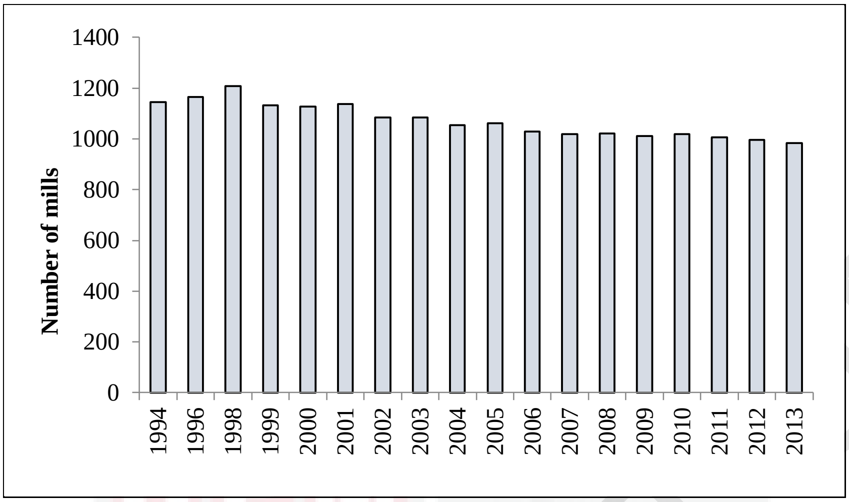

Figure 1.1: Number of Sawmills in Malaysia

Source: 1994-1999: Malaysian Timber Council (MTC)
2000-2004: Ministry of Plantations Industries and Commodities 2007 (2008)
2005-2010: Ministry of Plantations Industries and Commodities 2011 (2012)
2011-2013: Ministry of Plantations Industries and Commodities 2013 (2014)

The reduction in the number of mills is quite noticeable since the late of 90s. The achievements of the IMP 1 (1986-1995) caused the government to look more seriously the policy to restructure value-added products in the IMP 2 (1996-2005) and IMP 3 (2006-2020). Tight regulations, namely no issuance of licenses for new sawmilling activities, the doubling of export duties for sawn timber and the imposition of export levies and quotas on sawn timber exports were imposed with the purpose of encouraging manufacturers to shift or to give attention to secondary wood processing activity. Aside from that, the government's interests in conserving the environment resulted in restriction in logging activities, reduction of logging areas based on the annual growth rates and cutback in logging licenses. These factors led to the closure of many sawmills (Woon and Norini, 2002; Menon, 2000).

Despite this circumstance, sawmilling is still well anchored as an on-going sub-sector in the Malaysian wood-based industry (National Timber Policy, 2009). Sawmilling activity is still considered notable in this country as sawn timber production at present is primarily being used by the secondary wood processing industry (Menon, 2000). Furthermore, NATIP (2009) emphasized that the installed capacity of the mills was more adequate to encounter the requirement for downstream processing activities, although the number of sawmilling has reduced (Table 1.1).

In view that the sawmilling sector still has interest to the timber industry in Malaysia, the aspects on the environmental issues due to resources consumption needs to be given more attention. In addition to this, the growing numbers of environmental organizations has obliged the industries to manufacture greener products, while environmental conscious among the consumers demand for products with less impacts to the environment (Lipušček et al., 2010; Straka and Layton, 2010).

Table 1.1: The Capacity Utilization of Sawmilling Sector in Peninsular Malaysia

Year	Capacity utilization (m^3)	Capacity utilization (%)
2003	12 271	23.9
2004	10 899	29.4
2005	10 953	29.5
2006	11 016	27.4
2007	11 096	24.0
2008	11 137	21.4
2009	11 182	18.6
2010	11 276	23.6
2011	11 411	23.4
2012	11 567	27.9

Source: Malaysian Timber Industry Board (MTIB)

An integrated approach of life cycle assessment (LCA) has become a central focus to assess the environmental performance of products or processes. The LCA technique has been widely applied in the sawmilling industry as well as wood-based industry. LCA technique was chosen in this study as LCA assesses the environmental performance by calculating the material and energy consumption, quantifying the wastes as well as the emissions and evaluating the impacts of those releases to the environment.

1.2 Research Problem

Pressures from the public and government to reduce the environmental burdens which subsequently impact the environment have become very demanding in recent years. The birth of environmental protection organizations, environmental standards legislative regulations and limitations is inescapable, as the inability of the ecosystem to absorb the countless quantities of pollutants which resulted to environmental threats. Furthermore, consumers are also becoming aware of environmental friendly products or greener processes.

This issue entailed the wood-based industry too. There has been growing concern that the processes to transform wood into wood products contributed to environmental problems. The consumption of resources particularly material and energy during the sawn timber production process was proven to contribute to environmental issues. The woodworking machines and equipments used in wood-based industry to some extent influence the consumption of resources (Silva et al., 2013; González-García et al., 2012; Eshun et al., 2011; Kinjo et al., 2005; Lopes et al., 2003).

In Peninsular Malaysia, the automated machineries and equipments which are widely used in the wood-based industry were found to be on par with other developed countries. These machines and equipments are imported from countries such as Japan, Italy, German and Taiwan (Yap, 2004). This situation is in contradiction for sawmilling sector. The machinery used is substantially older and obsolete due to undercapitalization (Ho and Gan, 2003; Ong, 1986). The attempt to modernize and automate the machines and equipments was unsuccessful owing to differences in log species and log diameters along with variable target sizes. Yap (2004) explained that the variation between tropical hardwood and softwood was the cause for modernized and automated machines and equipments unsuitable for Malaysian logs.

As a result, the conversion of logs into sawn timber generated wood wastes in a high level, in view that the recovery was quite low (ITTO-CITES, 2010). In view to the fact that the cutting process is inefficient, sawmilling sector is energy intensive (Kinjo et al., 2005). Options for other materials with the intention to substitute wood are not the right choice, as these materials can cause environmental impacts greater than wood itself (González-García et al., 2012).

In accordance to this difference, a preliminary study of environmental performance in the sawmilling sector using the life cycle approach is thereby needed. LCA concept has not been widely applied among the research communities in Malaysia. The method is still unknown, and data relevant for the Malaysian timber sector is limited in availability. Hence, there is a knowledge gap present in the Malaysian sawmilling sector addressing the environmental issues.

Such evaluation of material and energy consumption will facilitate the assessment of the environmental emissions, and subsequently the impacts to the environment, as consumers, policy makers and stakeholders are now demanding for green products (Eshun et al., 2010; Puettmann et al., 2010a; Lipušček et al., 2010). The information of environmental assessment for hardwood in Malaysia which has been significantly lacking is essentially important for better utilization of resources in the sawmilling industry.

1.3 Objectives

The general objective of this study was therefore, to assess the environmental profile from the gate-to-gate activities carried out in the sawmilling sector in Peninsular Malaysia. LCA methodological framework was applied in this study to investigate the environmental profile of the sawmilling sector. Thus, the specific objectives of this study were as follows:

1. To measure the resources consumption namely material and energy that was used in the sawmilling activity. The material flow was evaluated on the basis of saw log and sawn timber volume in order to determine the recovery. The energy consumed in the sawmilling activity was determined on the account of electrical energy used to run the sub-system processes and diesel fuel used for off-road transportation activities.

2. To evaluate the environmental emissions as a result of material and energy consumption in the sawmilling activity. The environmental emissions that were taken into consideration in this study were the ones that led to the environmental burdens.

3. To assess the potential environmental impacts of the sawmilling activity based on the findings of the inventory study. These potential environmental impacts which

comprise of global warming, acidification, human toxicity, photo-oxidant formation and eutrophication potentials were compared to determine the most important effects to the environment, as a result of the sawmilling activity.

4. To account for the variability in the recovery, energy consumption, environmental burdens and potential environmental impacts from the perspective of the different types of wood species and also between sawmills.

1.4 Significance of the Study

The data from this study provided useful information to meet the demand of green consumers, promote sawn timber as green product and provide a benchmark for improvement in terms of its sustainability and environmental performance. The basic knowledge obtained from this study can be applied for green concept management of sawmilling standards, guidelines and policies. Besides enhancing the production of the sawmilling industry, it is also important for the continuous operations of this industry, as well as the other wood-based industries in Peninsular Malaysia.

The assessment of environmental performance forms the foundation of a LCA study for the sawmilling industry in this country. Hence, the data obtained can also be applied as reference when LCA study is performed on other wood-based sector. The data can also be used for comparison purpose with other materials that follow the LCA concept for better performance assessment of sawn timber production. In addition, the data can also be used for an improvement in terms of resources used and its' effects on the environment.

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APPENDICES

Appendix A

Electricity Consumption Data Collection in Sawmill A

Primary Breakdown

	Light Red Meranti			Dark Red Meranti		
ID	Amperage	Voltage	Number of hours	Amperage	Voltage	Number of hours
1	514	240	10.33	464	240	13.00
2	518	240	11.17	462	240	3.67
3	511	240	3.17	465	240	9.67
4	510	240	2.50	462	240	3.17
5	516	240	7.83	460	240	3.67
6	515	240	6.83	467	240	13.67
7	512	240	2.67	461	240	9.33
8	520	240	5.50	458	240	6.67

Secondary Breakdown

	Light Red Meranti			Dark Red Meranti		
ID	Amperage	Voltage	Number of hours	Amperage	Voltage	Number of hours
1	303	240	5.17	284	240	6.50
2	312	240	5.58	286	240	1.83
3	309	240	1.58	288	240	4.83
4	306	240	1.25	281	240	1.58
5	311	240	3.92	283	240	1.83
6	301	240	3.42	280	240	6.83
7	307	240	1.33	281	240	4.67
8	312	240	2.75	282	240	3.33

Quality Control

	Light Red Meranti			Dark Red Meranti		
ID	Amperage	Voltage	Number of hours	Amperage	Voltage	Number of hours
1	129	240	5.17	98	240	6.50
2	125	240	5.58	94	240	1.83
3	126	240	1.58	95	240	4.83
4	122	240	1.25	93	240	1.58
5	127	240	3.92	95	240	1.83
6	126	240	3.42	96	240	6.83
7	120	240	1.33	94	240	4.67
8	122	240	2.75	91	240	3.33

Conveyor

	Light Red Meranti	Dark Red Meranti
ID	Number of hours	
1	5.17	6.50
2	5.58	1.83
3	1.58	4.83
4	1.25	1.58
5	3.92	1.83
6	3.42	6.83
7	1.33	4.67
8	2.75	3.33

Electricity Consumption Data Collection in Sawmill B

Primary Breakdown

	Light Red Meranti			Dark Red Meranti		
ID	Amperage	Voltage	Number of hours	Amperage	Voltage	Number of hours
1	495	240	10.83	298	240	10.33
2	501	240	10.33	295	240	3.33
3	497	240	2.50	297	240	9.50
4	494	240	3.17	294	240	3.33
5	494	240	9.00	297	240	4.17
6	499	240	8.17	299	240	14.00
7	497	240	3.83	296	240	10.83
8	503	240	7.17	294	240	8.33

Secondary Breakdown

	Light Red Meranti			Dark Red Meranti		
ID	Amperage	Voltage	Number of hours	Amperage	Voltage	Number of hours
1	303	240	5.42	269	240	5.17
2	312	240	5.17	264	240	1.67
3	309	240	1.25	265	240	4.75
4	306	240	1.58	267	240	1.67
5	311	240	4.50	262	240	2.08
6	301	240	4.08	264	240	7.00
7	307	240	1.92	268	240	5.42
8	312	240	3.58	267	240	4.17

Quality Control

	Light Red Meranti			Dark Red Meranti		
ID	Amperage	Voltage	Number of hours	Amperage	Voltage	Number of hours
1	135	240	5.42	84	240	5.17
2	131	240	5.17	86	240	1.67
3	134	240	1.25	81	240	4.75
4	129	240	1.58	82	240	1.67
5	133	240	4.50	77	240	2.08
6	129	240	4.08	80	240	7.00
7	128	240	1.92	82	240	5.42
8	130	240	3.58	79	240	4.17

Conveyor

	Light Red Meranti	Dark Red Meranti
ID	Number of hours	
1	5.42	5.17
2	5.17	1.67
3	1.25	4.75
4	1.58	1.67
5	4.50	2.08
6	4.08	7.00
7	1.92	5.42
8	3.58	4.17

Appendix B

Data collection of transportation energy

	Sawmill A (Litre)		Sawmill B (Litre)	
ID	**Light Red Meranti**	**Dark Red Meranti**	**Light Red Meranti**	**Dark Red Meranti**
1	250	230	250	310
2	250	198.62	260	210
3	250	71.97	250	187.50
4	51.38	87.30	62.50	81.08
5	178.03	250	218.92	101.35
6	162.70	233.33	198.62	290.00
7	66.67	147.95	65.34	184.66
8	122.05	230	104.68	190.32

Appendix C

Total environmental emission - Sawmill A - Light Red Meranti

ID	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	CO (kg)	NOx (kg)
1	5456.90325	0.126388491	0.276754351	6.043085204	24.69006353
2	5939.108742	0.135284682	0.278016429	6.308254232	26.15783926
3	2158.428482	0.065535056	0.268121238	4.229225011	14.6499016
4	1296.090226	0.02919632	0.057335502	1.337982052	5.605725194
5	4166.396694	0.095177355	0.197816271	4.457610965	18.43587347
6	3588.11846	0.082931921	0.180207959	3.953057701	16.18020411
7	1416.799605	0.032995969	0.073704222	1.590427426	6.467317007
8	2923.870141	0.066496085	0.135791476	3.093105979	12.84451944

Total environmental emission - Sawmill A - Dark Red Meranti

ID	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	CO (kg)	NOx (kg)
1	6274.603065	0.144559919	0.310391157	6.857819854	28.14863225
2	2184.259571	0.063954469	0.247191088	4.000046853	14.08213603
3	4672.567834	0.106633516	0.220758267	4.98652161	20.64205865
4	1524.112015	0.035520914	0.079549497	1.713935929	6.965257084
5	1781.511289	0.041846464	0.096317971	2.042035041	8.244209341
6	6431.128992	0.144361945	0.279304196	6.578820481	27.65548994
7	4554.136854	0.10801876	0.256889905	5.3437864	21.40338281
8	3196.252141	0.074185252	0.163696479	3.558072087	14.51069566

Total environmental emission - Sawmill B - Light Red Meranti

ID	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	CO (kg)	NOx (kg)
1	5633.987564	0.129655513	0.277217834	6.140465421	25.22908696
2	5532.456944	0.12881095	0.287450977	6.206324294	25.24323608
3	1841.609421	0.059690073	0.267292026	4.055003432	13.68554234
4	1620.840072	0.036331389	0.069860225	1.651885732	6.953618937
5	4771.477127	0.11054629	0.242329867	5.287946342	21.59921489
6	4259.687465	0.099016301	0.219677633	4.759475075	19.38530029
7	1943.720688	0.042580316	0.073686984	1.864000986	8.028216551
8	3630.567853	0.077747296	0.119404566	3.270347197	14.43423086

Total environmental emission - Sawmill B - Dark Red Meranti

ID	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	CO (kg)	NOx (kg)
1	4529.437517	0.115449141	0.337320164	6.26321237	23.80614593
2	1745.742366	0.053807139	0.225045597	3.515519495	12.10094988
3	3853.059048	0.090370658	0.206938609	4.40054565	17.78817798
4	1398.885838	0.034147651	0.08878622	1.755933868	6.878515307
5	1726.663217	0.042279717	0.110925342	2.182850093	8.531348984
6	5709.153629	0.135156535	0.319410083	6.668565702	26.75066809
7	4344.004468	0.099135976	0.205241881	4.635960469	19.1907693
8	3457.269521	0.083358809	0.208863391	4.217214508	16.67458341

Appendix D

Potential environmental impacts – Sawmill A - Light Red Meranti

ID	GWP	AP	EP	HTP	POCP
1	2313.483659	50.52888496	8.147720965	32.68278449	2.382921862
2	2477.66421	55.12103305	8.632086956	34.75277619	2.585562933
3	1190.424266	19.11679019	4.834467528	18.52322907	0.99677743
4	534.9104228	12.047331	1.849889314	7.466427705	0.56310639
5	1742.957233	38.65319469	6.083838245	24.4778688	1.814772293
6	1518.133135	33.2343273	5.339467356	21.42778295	1.566255945
7	603.8693289	13.10890051	2.134214612	8.550799769	0.619320564
8	1217.902405	27.1424287	4.238691415	17.07103685	1.272524476

Potential environmental impacts – Sawmill A - Dark Red Meranti

ID	GWP	AP	EP	HTP	POCP
1	2646.555899	58.14341127	9.289048643	37.30388631	2.737317247
2	1162.777114	19.4778569	4.64710489	17.89350635	1.000454734
3	1952.814691	43.35510666	6.811879355	27.41319657	2.034874289
4	650.0640371	14.10036602	2.298534838	9.207727499	0.666319459
5	765.6357832	16.46343307	2.720589083	10.88035748	0.779990276
6	2645.186475	59.80664922	9.12631168	36.86490027	2.792328537
7	1975.736732	42.02755583	7.063116327	28.19012853	1.997562339
8	1357.835085	29.58736417	4.788529568	19.1993961	1.396285125

Potential environmental impacts – Sawmill B - Light Red Meranti

ID	GWP	AP	EP	HTP	POCP
1	2373.777041	52.21529751	8.325598697	33.44296467	2.45733942
2	2370.067675	51.19086347	8.330267906	33.37742293	2.418261346
3	1082.554222	16.09965316	4.516228972	17.16320137	0.863638022
4	665.7425255	15.07601481	2.294694249	9.272279152	0.703569528
5	2023.479881	44.18024375	7.127740914	28.58950877	2.083725302
6	1812.237847	39.42315685	6.397149096	25.64080088	1.86136627
7	780.8511749	18.1345372	2.649311462	10.76349417	0.840275494
8	1426.86776	33.97240485	4.763296184	19.46150019	1.5632717

Potential environmental impacts – Sawmill B - Dark Red Meranti

ID	GWP	AP	EP	HTP	POCP
1	2107.027856	41.35121164	7.856028157	30.92322621	2.014699224
2	977.0294	15.4168335	3.99331346	15.27044854	0.80899524
3	2129.931156	35.61472552	5.870098733	23.4834645	1.686494644
4	624.0265969	12.8553947	2.269910051	9.007509332	0.616964195
5	772.5617612	15.86026511	2.815345165	11.16518603	0.761983508
6	2472.253624	52.70097713	8.82772047	35.24685316	2.503282859
7	1815.509393	40.30644603	6.332953869	25.48580807	1.891789303
8	1523.90841	31.82931042	5.502612525	21.88886159	1.52118093

BIODATA OF STUDENT

Geetha Ramasamy was born on 20th September 1984 at Kuala Lipis, Pahang. She attended for primary education in SRK Sri Kinta, Ipoh. She attended secondary education at SMK Seri Intan, Ipoh for one year. She continued her secondary education at SMK Dato Shamsudin Nain, Negeri Sembilan until form five. Later, she went to SMK King George V in Negeri Sembilan to do her form six. She pursued her bachelor study in University Malaysia Sabah in 2004. She completed her degree in Bachelor of Forestry Science majoring in Wood Fiber Industry Technology from the School of International Tropical Forestry, University Malaysia Sabah in 2007. She completed her Master at Faculty of Forestry, University Putra Malaysia in 2011. She is pursuing her Doctor of Philosophy at Faculty of Forestry, University Putra Malaysia.

LIST OF PUBLICATIONS

Ratnasingam, J., Ramasamy, G., Toong, W. Abdul Latib, S., Mohd Ashadie, K. and Muttiah, M. (2015). An Assessment of the Carbon Footprint of Tropical Hardwood Sawn Timber Production. *Bioresources* 10(3), 5174-5190.

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