TECHNICAL DOCUMENT

LIFE CYCLE ASSESSMENT (LCA) OF KILN-DRIED SAWN TIMBER IN PENINSULAR MALAYSIA

VERSION 1.0

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LIST OF ABBREVIATIONS

AP	Acidification potential
EFB	Empty fruit bunch
EP	Eutrophication potential
EPD	Environmental Product Declaration
GHG	Greenhouse gas
GWP	Global warming potential
HHW	Heavy hardwood
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LHW	Light hardwood
MDF	Medium density fibreboard
MHW	Medium hardwood
ODP	Ozone depletion potential
PEDnr	Primary energy demand from non-renewable resources
PEDr	Primary energy demand from renewable resources
POCP	Photochemical ozone creation potential
PRF	Permanent Reserved Forest
RIL	Reduced impact logging
SFM	Sustainable Forest Management
SME	Small Medium Enterprise
VOC	Volatile organic compound

PROJECT BACKGROUND

Project Title:
Life Cycle Assessment (LCA) of Primary Wood Products in Peninsular Malaysia

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Implementing Agency:
Forest Research Institute Malaysia

Collaborating Agency:
Malaysian Timber Industry Board

Life Cycle Assessment of Kiln-Dried Sawn Timber in Peninsular Malaysia was conducted as a component of the project. The resulting technical document was prepared with the active involvement and expert guidance of the following Technical Working Group members:

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EXECUTIVE SUMMARY

The Life Cycle Assessment (LCA) conducted for kiln-dried sawn timber production in Peninsular Malaysia represents the first comprehensive evaluation of its kind, aimed at quantifying the environmental performance of this key sector in the Malaysian timber industry. This study marks a critical milestone in the effort to establish a national life cycle inventory (LCI) database for the timber sector in Peninsular Malaysia, with the objective of supporting the timber sector's demand and competitiveness in the international market, identifying major environmental hotspots and proposing targeted strategies for sustainability improvements. The LCA was carried out in accordance with ISO 14040/44 standards, ensuring methodological consistency, transparency, and scientific rigor in assessing the environmental impacts from log harvesting through to kiln-dried sawn timber production.

The primary objectives of this LCA study are:

- To contribute to the creation of an LCI database for the Malaysian timber industry.
- To assess and quantify the potential environmental impacts associated with kiln-dried sawn timber production in Peninsular Malaysia.
- To identify critical points in the production process where environmental performance can be improved, thereby supporting sustainable development goals.

The LCA results reveal the potential environmental impacts associated with each stage of the sawn timber production process. The main potential impacts focused upon were global warming, acidification, eutrophication, photochemical ozone creation, ozone depletion and primary energy consumption. These impacts are largely concentrated in three key stages of the production process: harvesting, sawing, and kiln drying.

Among these, harvesting activities emerged as the highest contributors across all impact categories. This is due primarily to emissions from diesel-powered machinery used during harvesting operations. Kiln drying was identified as energy-intensive phase, particularly for dense hardwood species, and is a major contributor to non-renewable energy use and global warming potential. Sawing, although less intensive than drying, still plays a significant role in energy consumption and is a key contributor to photochemical ozone creation potential due to the mechanical processing demands. Transportation showed moderate but variable potential environmental impacts, largely influenced by the distance between logging sites and processing facilities. The sensitivity analysis further highlighted the strong influence of electricity and diesel consumption, with small variations in these inputs resulting in notable shifts in global warming potential and air pollution-related indicators.

Renewable energy sources, including biomass from wood residues and palm oil waste, are utilised in some kiln drying operations. However, their environmental benefits are underrepresented in conventional impact assessment methods, suggesting that the full value of renewable energy integration is not adequately captured in current LCA metrics.

The study identifies several opportunities for improvement to enhance environmental sustainability in kiln-dried sawn timber production. These include optimizing logging practices through reduced-impact methods and the use of more efficient machinery, enhancing energy efficiency in kiln drying by adopting modern high-efficiency systems and increasing the use of renewable fuels, and upgrading sawing operations with energy-efficient equipment and improved process control. Further, establishing more localised supply chains and implementing shared logistics solutions could help reduce the transportation footprint.

The findings underscore the importance of continuous monitoring of key input variables such as electricity and diesel consumption and the need for industry-wide data standardisation. Developing a national LCA reporting framework and encouraging public disclosure of environmental performance will further support transparency and continuous improvement in the sector.

This LCA provides a foundational reference for improving the environmental performance of kiln-dried sawn timber production in Peninsular Malaysia. By acting on the identified recommendations, industry stakeholders can reduce their environmental impact, strengthen their sustainability credentials, and support the broader transition to a low-carbon, resource-efficient timber sector. The establishment of a national LCI database will also support future LCA studies and benchmarking, driving long-term improvements in environmental stewardship across Malaysia's timber industry.

1 INTRODUCTION

Life Cycle Assessment (LCA) is a scientific method used to evaluate the environmental performance of products or services throughout their entire life cycle. Generally, the life cycle begins with the extraction of raw materials, followed by the production process, product use, and the end-of-life phase. In the timber industry, LCA plays a crucial role in sustainability, particularly with the increasing demand for timber products in sectors such as construction and furniture manufacturing. The findings of this study provide valuable insights into the potential environmental impacts for kiln-dried sawn timber production in Peninsular Malaysia, offering useful perspectives for stakeholders in both local and international timber industries. This assists the timber industry in its contribution to long-term sustainability goals and reduction of environmental impacts.

Verified national life cycle information for the timber industry in Malaysia is currently unavailable. This study aims to address this gap by focusing on the cradle-to-gate production of kiln-dried sawn timber in Peninsular Malaysia**.** Sawn timber, being an intermediate product, is further used in building materials, engineered wood products, secondary wood products and industrial packaging. As a result, the use and end-of-life stages are excluded from this study, though they could be addressed in product-specific studies for a complete LCA. In this study, the LCI database and the accompanying technical report are the key outcomes. This report, adhering to international LCA standards for LCA (ISO 14040 and 14044), has been reviewed by the following expert reviewers:

(a) Professor Dr Matthias Finkbeiner – TU Berlin (Chair), German
(b) Professor Emeritus Dr Richard Murphy – University of Surrey, United Kingdom
(c) Associate Professor Dr Indroneil Ganguly – University of Washington, United States

2 GOAL OF THE STUDY

The goal of this study is to carry out a cradle-to-gate LCA for kiln-dried sawn timber production in Peninsular Malaysia. The study will:

- Develop an LCI database of the inputs and outputs;
- Assess the potential environmental impacts of the production process; and
- Identify the environmental hotspots during the production of kiln-dried sawn timber.

2.1 Intended Application

The data can serve in the future as a foundational resource for LCA studies on timber and timber-based products. The data also provide as the basis for Environmental Product Declarations (EPDs), in accordance with the guidelines and requirements specified in the selected Product Category Rules (PCR). Furthermore, the standardised and transparent environmental data helps identify key hotspots in the supply chain, supports informed decision-making, and thereby promotes continuous improvement in sustainable practices across the timber industry.

2.2 Intended Audience

The intended audience for this study are diverse range members of the wood industries, agencies, customers and users. These audiences are such as furniture manufacturers, construction companies, architects, designers, environmental regulators, commercial builders, retail consumers, LCA practitioners, academic and research institutions and others that might use the data.

2.3 Comparative Assertions

This study is not intended to be used in comparative assertions intended to be disclosed to the public. The dataset will be integrated into an open-source database, making it accessible to those who wish to conduct such comparisons. The LCI data can be used as part of an LCA for comparative studies disclosed to the public if this is stated in the goals and scope of the LCA study, is done based on a proper functional unit and is subject to a study specific critical review by an external panel of experts.

2.4 Standards

The report is drawn up to be consistent with the following international standards:

a) ISO 14040 (2006) Environmental management — Life cycle assessment — Principles and framework
b) ISO 14044 (2006) Environmental management — Life cycle assessment — Requirements and guidelines

3 SAWMILL INDUSTRY IN PENINSULAR MALAYSIA

The sawmill sector has traditionally been the backbone of the Malaysian wood-based industry. The history of the sawmill sector can be traced back to the colonial period. The sector commenced in the 1900s, mainly for domestic consumption. It was only after independence in 1957 that the sawmill sector was developed into manufacturing. The country has also established itself in other timber processing activities, ranging from log processing to the manufacturing of semi-finished and finished timber products. Yet, sawmilling is well-anchored as a key sub-sector of this wider industry, being the main producer and exporter of sawn timber. In general, sawmills in Malaysia can be classified as low production (< 15,000 m^3 log input per year), medium production (15,000-25,000 m^3 log input per year), and high production (> 25,000 m^3 log input per year) (Hamami et al. 1997). Over the past twenty-five years, key developments such as stricter forestry regulations and certification requirements, a shift toward plantations timber, and a growing emphasis on value-added processing have likely influenced sawmill production in Malaysia. While overall production volume may not have significantly increased, these factors suggest a structural evolution within the industry.

3.1 Geographical Distribution

Sawmills in Peninsular Malaysia are owned by Malaysian private companies, with 80% to 90% of sawmills being small and medium-sizes enterprises (SMEs). SMEs are defined as companies with a sales turnover not exceeding RM 20 million (USD 4.46 million) or fewer than 200 full-time employees. As of 2023, there are about 684 sawmills distributed throughout Peninsular Malaysia, with Pahang, Kelantan and Johor being among the largest producers of sawn timber.

3.2 Sources of Logs

The sources of logs for sawn timber production are hardwood logs harvested from natural forests and rubberwood from rubber tree plantations, obtained from Peninsular Malaysia.

3.2.1 Logs from Natural Forest

The primary source of logs for sawn timber production are hardwood logs from natural forests. Figure 3.1 presents the classification of natural forests in Peninsular Malaysia. Harvesting activity is permitted in production forests within the Permanent Reserve Forest (PRF), as well as in State land and alienated forests that have been licensed by the Forestry Department.

Selective Management System (SMS) is implemented in production forests within the PRF in accordance with Sustainable Forest Management (SFM) principles to ensure sustainable timber production while maintaining the long-term health and biodiversity of the forest. The permitted log production in the PRF is estimated based on the annual allowable coupe, which is allocated and capped at the net production of 61 m^3/ha under a 30-year cutting cycle. The annual coupe is established for each state based on forest inventory data. Reduced impact logging (RIL) is practised in production forests to minimise environmental damage to during log harvesting.

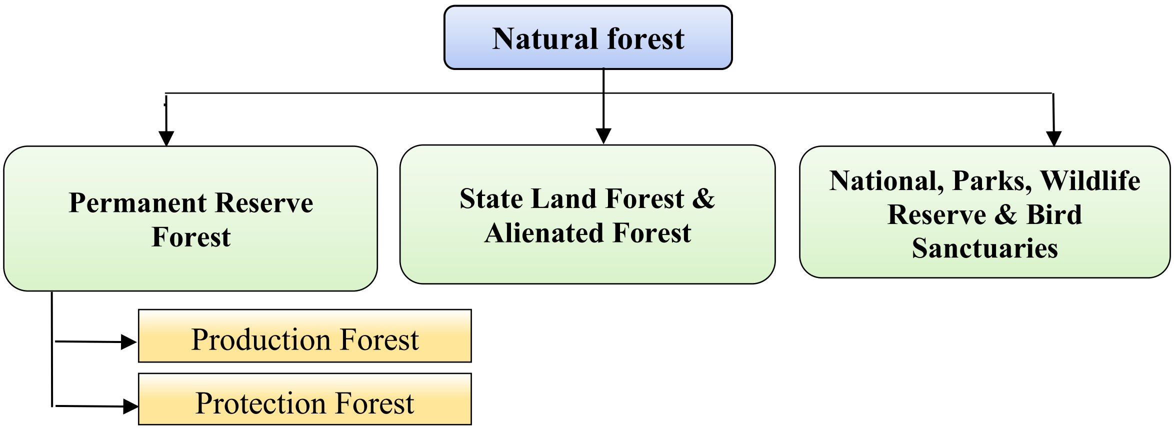

Figure 3.1: Classification of natural forests in Peninsular Malaysia

Logs from the natural forests can be harvested from inland forests and peat swamp forests. The inland forest is classified into three categories depending on elevation - lowland forest (< 300 m), hill forest (300–750 m) and upper hill forest (750–1,000 m). Hill forest is mainly categorised under PRF while lowland forest and peat swamp forest are included under PRF and state/alienated land.

3.2.2 Rubberwood Logs

Rubber trees are primarily cultivated for latex, source of natural rubber. The trees are felled for timber after 25 to 30 years when latex production declines and becomes economically unviable. The use of rubberwood is considered environmentally sustainable as they are repurposed into useful products and reduce pressure on hardwood logs. Rubberwood is mainly used for the manufacture of furniture, flooring, lamination boards, joinery and mouldings, particleboard and medium density fibreboard (MDF). Other co-products are generated during harvesting activities, such as chip logs and stump logs. These co-products are utilized for chipboard and particle board production and energy generation. Rubberwood is regarded as a by-product of the rubber industry and its main purpose is to produce latex, the raw material for natural rubber.

The utilisation of rubberwood in timber production has been reported to enhance resource efficiency by making use of plantation-grown trees at the end of their latex-producing cycle. This approach contributes to reducing reliance on timber sourced from natural forests. The use of rubberwood also helps to minimise waste within the timber production chain, thereby supporting more efficient material use (Ratnasingam et al. 2012). Additionally, rubberwood products can act as carbon storage throughout their life cycle, potentially offering environmental benefits after the trees are harvested (Corpuz et al. 2014).

3.3 Production of Sawn Timber

The production of sawn timber uses a wide variety of tropical timber species and rubberwood. These timber species are distributed across the states of Peninsular Malaysia. Malaysian hardwoods are classified as heavy hardwood (HHW), medium hardwood (MHW) and light hardwood (LHW), based on air-dry density and natural durability (Table 3.1). There are only a few softwoods in Malaysia with commercial importance. The distinction between hardwoods and softwoods is based on anatomical structure. Some timber species are abundant and widely accepted in the domestic and international markets. These timber species are known as 'common commercial timbers'. There are also lesser-known wood species, which are less abundant and smaller in diameter, often marketed collectively as 'mixed-species'.

Table 3.1: Classification of Malaysian hardwoods

Classification	Air-dried density (kg/m^3)
Heavy hardwood (HHW)	800 – 1,120
Medium hardwood (MHW)	720 – 880
Light hardwood (LHW)	400 -720

3.4 Dimensions of Sawn Timber

The measurement method for sawn timber in Malaysia is measured by thickness (inches) x width (inches) x length (feet). The commonly available standard thicknesses are ½", ¾", 1", 1 ¼", 1 ½", 1 ¾", 2", 2 ½", 3", 3 ½", 4", 5" and 6". Sawn timber is supplied in random, fixed or multiple fixed lengths rising in full feet, usually not exceeding 6 inches from the nominal length. Sawn timber may be supplied in full, bare or scant specifications, depending on dimensional allowances and intended use. Bare sawn refers to sawn timber that measures at the time of inspection or the same as the dimensions specified. Full sawn specification applies to timber which has been sawn oversize (measure more than the dimensions specified) to allow for shrinkage. Scant (dressed) sawn timbers measure less than the dimensions specified, referred as undersize. Common commercial sawn timber sizes produced are given in Table 3.2.

Table 3.2: Common commercial timber sizes (MS 544 - Part 2:2001)

Shape	Nominal size - Thickness (mm) x Width (mm)	Minimum timber sizes Thickness (mm) x Width (mm)		
		Full sawn	Bare sawn	Dressed timber (kiln dried)
Square	25 x 25 (1" x 1")	28 x 28	25 x 25	20 x 20
	50 x 50 (2" x 2")	55 x 56	50 x 50	45 x 45
	75 x 75 (3" x 3")	80 x 81	75 x 75	70 x 70
	100 x 100 (4" x 4")	106 x 106	100 x 100	90 x 90
	125 x 125 (5" x 5")	131 x 131	125 x 125	115 x 115
	150 x 150 (6" x 6")	159 x 159	150 x 150	140 x 140
Rectangle	25 x 50 (1" x 2")	28 x 56	25 x 50	20 x 45
	25 x 75 (1" x 3")	28 x 81	25 x 75	20 x 70
	25 x 100 (1" x 4")	28 x 106	25 x 100	20 x 90
	25 x 125 (1" x 5")	28 x 131	25 x 125	20 x 115
	25 x 150 (1" x 6")	28 x 159	25 x 150	20 x 140
	25 x 175 (1" x 7")	28 x 184	25 x 175	20 x 165
	25 x 200 (1" x 8")	28 x 212	25 x 200	20 x 190
	38 x 50 (1½" x 2")	41 x 56	38 x 50	33 x 45
	38 x 75 (1½" x 3")	41 x 81	38 x 75	33 x 70
	38 x 100 (1½" x 4")	41 x 106	38 x 100	33 x 90
	38 x 125 (1½" x 5")	41 x 131	38 x 125	33 x 115
	38 x 150 (1½" x 6")	41 x 159	38 x 150	33 x 140
	38 x 175 (1½" x 7")	41 x 184	38 x 175	33 x 165
	38 x 200 (1½" x 8")	41 x 212	38 x 200	33 x 190
	50 x 75 (2" x 3")	55 x 81	50 x 75	45 x 70
	50 x 100 (2" x 4")	55 x 106	50 x 100	45 x 90
	50 x 125 (2" x 5")	55 x 131	50 x 125	45 x 115
	50 x 150 (2" x 6")	55 x 159	50 x 150	45 x 140
	50 x 175 (2" x 7")	55 x 184	50 x 175	45 x 165
	50 x 200 (2" x 8")	55 x 212	50 x 200	45 x 190
	63 x 100 (2½" x 4")	68 x 106	63 x 100	58 x 90
	63 x 125 (2½" x 5")	68 x 131	63 x 125	58 x 115
	63 x 150 (2½" x 6")	68 x 159	63 x 163	58 x 140
	63 x 175 (2½" x 7")	68 x 184	63 x 175	58 x 165

	63 x 200 (2½" x 8")	68 x 212	63 x 200	58 x 190
	75 x 100 (3" x 4") 75 x 125 (3" x 5") 75 x 150 (3" x 6")	80 x 106 80 x 131 80 x 159	75 x 100 75 x 125 75 x 175	70 x 90 70 x 115 70 x 140

3.5 Sawn Timber Markets

Sawn timber production in Peninsular Malaysia plays a significant role in the nation's timber industry, being the key product for the construction, furniture manufacturing and packaging sectors. Sawn timber from Peninsular Malaysia is highly regarded in international markets for its quality, variety, and versatility, which makes it suitable for a wide range of applications. The global demand for Malaysian sawn timber is substantial, with significant exports to regions such as ASEAN, South and East Asia, West Asia, European Union, Europe (others), Africa, America, Oceania/Pacific and other countries.

3.6 Grading of Sawn Timber

Green rough-sawn timber is sorted and visually graded by licensed timber graders according to its size and quality. The grading system applied for the local market is usually based on the customers' requirements. The export sawn timber is commonly graded according to the *Malaysian Grading Rules for Sawn Hardwood Timbers* (Malaysian Timber Industry Board 2009). The grading is based on the quality of cut (the cutting system) or based on the amount of cutting defects that are allowed in each grade (the defect system), based on its intended use. Under the cutting system, the higher grade is accorded to the sawn timber that yields a higher percentage of defect-free cutting. This system is used for grading timber that is usually re-sawn into smaller dimensions before use. Under the defect system, natural defects that cannot be eliminated through technology may be included, provided they do not interfere with the final utilisation and structural integrity of the timbers.

Rubberwood is visually graded in accordance with the *Malaysian Grading Rules for Rubberwood Sawn Timber* (Malaysian Timber Industry Board 2013). The rules are based on the defect system where appearance is given priority over its strength. Under these rules, any size of rubberwood can be specified but the timber should be treated with appropriate preservative and kiln dried to less than 12% moisture content. The grading is carried out by trained and licensed rubberwood graders.

4 SCOPE OF THE STUDY

The following sections details the scope of the cradle-to-gate LCA study for production of kiln-dried sawn timber in Peninsular Malaysia.

4.1 Selection of Timber Groups

A wide variety of hardwood species are used in the sawn timber production. For this study, twelve hardwood species and three timber groups with commercial relevance were selected to generate the LCI data. The selection of these timber species/groups was based on the production and export volumes from 2019 to 2021. In addition to the twelve identified species, other harvested hardwoods were included in the timber grouping comprising mixed heavy hardwood, mixed medium hardwood, and mixed light hardwood. The hardwood species/timber groups are highlighted in Table 4.1.

Table 4.1: List of fifteen hardwood species/timber groups

Num	Local name	Scientific name
1.	Light Red Meranti	*Rubroshorea* spp.
2.	Dark Red Meranti	*Rubroshorea* spp.
3.	Rubberwood	*Hevea brasiliensis*
4.	Keruing	*Dipterocarpus* spp.
5.	Merbau	*Intsia palembanica*
6.	Balau	*Shorea* spp.
7.	Kelat	*Syzygium* spp.
8.	Kapur	*Dryobalanops aromatica*
9.	Gerutu	*Parashorea* spp.
10.	Meranti mix	*Anthoshorea* spp.
11.	Kedondong	Spp. of Burseraceae
12.	Kempas	*Koompassia malaccensis*
13.	Mixed heavy hardwood	-
14.	Mixed medium hardwood	-
15.	Mixed light hardwood	-

4.2 Functional Unit

The main product of this study is kiln-dried sawn timber. Sawmills in Peninsular Malaysia commonly use volume as the output unit for sawn timber. Therefore, the functional unit and the reference flow of the study are 1 m^3 of kiln-dried sawn timber of specific timber species/groups.

4.3 System Boundary

The system boundary for this study begins with log harvesting, transportation of materials to sawmill, sawmilling activity and ends with the production of kiln-dried sawn timber at the plant gate (Figure 4.1). The downstream logistics are excluded from the study as they are considered to be within use phase which is beyond this cradle-to-gate scope. This is due to the fact that the trade of kiln-dried sawn timber is managed by traders or agents, through whom customers purchase the timber based on specified requirements for species and dimensions.

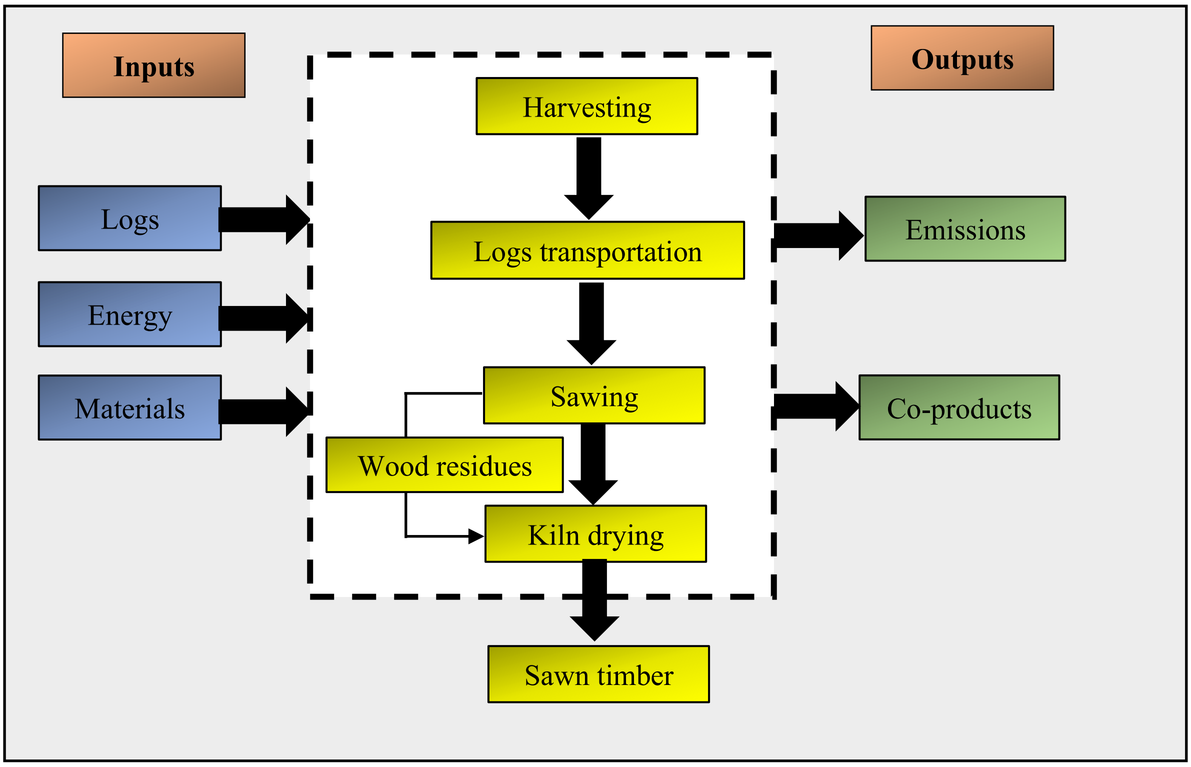

Figure 4.1 The cradle-to-gate system boundary for kiln-dried sawn timber production

Table 4.2 outlines the inclusion and exclusion criteria within the system boundary, providing a clear framework for defining the criteria that are taken into the scope and those that fall outside of it. These boundaries are essential in order to set the limits of the study.

Table 4.2: The inclusion and exclusion criteria within the system boundary

Included	Excluded
Production of upstream processes for resources, materials, and energy	Fixed capital equipment and facilities
Transportation of materials	Human labour
	Cradle-to-grave study of rubber production
	Maintenance of related equipment

4.4 Cut-off Rules

In this study, no cut-off criteria were applied.

4.5 Data Quality Assessment

The data quality assessment for this study considered key dimensions including technological, temporal, and geographical coverage, as well as completeness, consistency, and reproducibility. The modelling of kiln-dried sawn timber production was based on technologies commonly used in sawmills across Peninsular Malaysia to ensure technological relevance. The reference period of 2021–2024 was selected to reflect current industry practices, with primary data collected during this timeframe and secondary data chosen to align temporally. Geographically, data were sourced from sawmills across Peninsular Malaysia to ensure national representativeness. In cases where local secondary data were unavailable, internationally representative datasets were used. The study includes all major material and energy flows within the defined system boundary, with any exclusions are clearly documented and justified. Methodological consistency was maintained through standardized data collection templates and the use of a single, reputable secondary data source (Ecoinvent v3.11), enhancing data compatibility. Reproducibility is supported through transparent documentation of all data sources, assumptions, and modelling procedures.

4.6 Allocation rules

The environmental burdens were distributed between the main product and co-products, where applicable, during the harvesting and sawmilling activities. A mass allocation approach was applied in this study and the allocation used are detailed in the relevant sections of the report, outlining how the impacts were assigned.

4.7 Selection of Environmental Impact Categories

In the next phase of LCA, the inventory data are categorized into several environmental impacts indicators. Each indicator is designed to measure the potential environmental impact. However, it is important to note that these indicators do not make any decisions regarding the severity or the absolute significance of these impacts. Instead, they serve to quantify the potential for harm, owing to scientific models and data. This approach allows the identification and prioritisation of areas where actions can be taken to reduce negative environmental effects. LCIA results are relative expressions and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

CML v4.8 2016 method was applied to assess these potential environmental impacts associated with the kiln-dried sawn timber production process. The approach is built on a well-established database developed by the Institute of Environmental Sciences at Leiden University**.** The CML-v4.8 2016 method is widely regarded as one of the most well-established and scientifically validated methods for impact assessment in LCA studies. It provides "characterization factors" that convert the inventory data into measurable potential environmental impacts, as listed in Table 4.3.

Table 4.3: **Descriptions of selected environmental impact categories**

Environmental impact category	Descriptions	Equivalency factor
Global warming potential (GWP)	GWP measures how much heat a greenhouse gas traps in the atmosphere compared to carbon dioxide over a specific time period (usually 100 years).	kg CO_2-eq
Acidification potential (AP)	AP measures the potential of emissions to form acidifying compounds, primarily through the release of sulfur dioxide and nitrogen oxides.	kg SO_2-eq
Eutrophication potential (EP)	EP describes the potential for nutrients (mainly nitrogen and phosphorus) released into water or soil to cause excessive algae growth**,** leading to oxygen depletion and disruption of aquatic ecosystems.	kg PO_4-eq
Ozone depletion potential (ODP)	ODP measure the potential of substances to deplete the stratospheric ozone layer, which protects earth from harmful ultraviolet radiation.	kg CFC11-eq

Photochemical ozone creation potential (POCP)	POCP quantify how much substances contributes to ground-level ozone formation, also known as smog, with the presence of sunlight.	kg C_2H_4-eq
Energy resources from renewable (PEDr)	Primary energy from renewable raw materials refers to the amount of energy derived from renewable sources such as hydropower, wind power, solar energy, and biomass that is consumed throughout the life cycle of the product.	MJ, NCV
Energy resources from non-renewable (PEDnr)	Primary energy from non-renewable resources provides a measure of the total non-renewable energy consumed over the entire life cycle of the product. This includes energy derived from fossil fuels (such as coal, crude oil, and natural gas) as well as nuclear energy.	MJ, NCV

4.8 Interpretation Approach

The results of LCI and LCIA were interpreted according to the goal and scope. The interpretation addresses the identification of significant issues, evaluation of completeness and consistency, sensitivity analysis, and conclusions, limitations and recommendations.

4.9 Software and Database

The model for this study was developed using openLCA v2.4, with the Ecoinvent v3.11 database serving as the primary source of background data for the LCI analysis.

4.10 Critical Review

The critical review of the study was performed according to ISO 14044 (2006) and ISO 14071 (2024). The study was reviewed by following international experts:

(a) Professor Dr Matthias Finkbeiner – Chair, TU Berlin, German
(b) Professor Emeritus Dr Richard Murphy – University of Surrey, United Kingdom
(c) Associate Professor Dr Indroneil Ganguly – University of Washington, United States

The reviewers were not engaged or contracted as official representative of his organization but acted as independent expert reviewer. The review was performed concurrently to the study, i.e. after goal and scope and the final report. The verification of input data and LCI data sets are outside the scope of the review.

5 DATA COLLECTION

Data on resources consumption associated with the cradle-to-gate production of kiln-dried sawn timber were collected using written survey forms. Two survey forms were prepared for the study: log harvesting activities (Appendix A) and sawmilling activities (Appendix B). The data was collected throughout Peninsular Malaysia from 2022 until 2024. The State Forestry Department identified the harvesting sites and sawmill locations for data collection, following approval from the Forestry Department Peninsular Malaysia (FDPM). Site visits and interviews were conducted with logging contractors and sawmillers, in the presence of officers from the District Forestry Office. Follow-up communications with logging contractors and sawmillers were conducted via email and phone calls to ensure data consistency and completeness. All data collected from the participants were kept under strict confidentiality.

A total of eighteen harvesting sites located in the states of Perak, Negeri Sembilan, Pahang and Kedah were surveyed for harvesting activities. The selection of study locations was determined by the Forestry Department based on the previous year's timber production statistics, major log-producing states and the availability of active logging contractors during the survey period. Meanwhile, the selection of rubberwood logging sites was based on discussions with rubberwood sawmill operators, as identified by MWIA personnel. The total log production reported from the surveyed sites accounted for 20% of the total log production in Peninsular Malaysia for the year 2024. Although the number of survey sites may have been small, this is considered a representative sampling and still provides a comprehensive overview of the country's harvesting practices. This is due to the relative consistency in species distribution, machinery and equipment used, and logging methods applied across the country.

Data collection for sawmilling activities began with the transportation of logs to sawmills and continued until the production of kiln-dried sawn timber. A total of 200 sawmills across Peninsular Malaysia participated in the survey, providing data for the year 2021. Based on the survey, the total production reported represents 80% of the total sawmilling output in Peninsular Malaysia for 2021. These sawmills were selected to ensure a representative sample, covering a range of small-scale to large-scale operations.

5.1 Conversion Units

In Peninsular Malaysia, volume of log is measured in Imperial unit of hoppus ton. Meanwhile, sawn timber is measured in ton volume. Since the functional unit for this study is expressed in m^3, the conversion of both units, Hoppus tons and ton volume into cubic meter (m^3) is shown below:

1 Hoppus ton of logs = 63.66 ft^3 = 1.8026474 m^3

1 ton of sawn timber = 50 ft^3 = 1.416 m^3

5.2 Calculation Rules

The survey results for each unit process were standardised on a production basis for every timber species/groups. Values reported by every surveyed sawmill were used to calculate a production-weighted average for the respective timber species/groups (Eq. 1). This approach generates a composite value that represents the surveyed mills, ensuring the final result reflects an industry-average specific to each timber species/groups while maintaining the confidentiality of individual sawmills (Milota 2015).

$$W_n = \frac{y_n}{y_{total}} \qquad (1)$$

Where:

W_n = weighting factor for mill n

y_{total} = total annual production of y mills (y_1+y_2+...+y_n)

y_n = annual production of mill n

The collected data was checked to identify any missing data. The missing data were verified with manufacturers/contractors to identify if the data were represented as unknown or zero values. In this study, missing data are defined as unreported by the manufacturers/ contractors.

5.3 Secondary Data

This study primarily relied on data collected from the logging contractors and sawmill. Secondary data were also used in the study to complete the cradle-to-gate process and link it with upstream activities, as detailed in Table 5.1. These secondary datasets were essential for filling gaps in primary data and ensuring a more comprehensive life cycle assessment of kiln-dried sawn timber production. A thorough data quality assessment was conducted to ensure the reliability and representativeness of the data. The results of this assessment are summarized in Table 5.1, providing an overview of data strengths and areas requiring improvement.

Table 5.1: Secondary data use and assessment of data quality

Inputs	LCI data source	Time related coverage	Geographical coverage	Technological coverage	Data quality assessment
Diesel use for log transportation	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1; Geography: 2; Technology: 1
Electricity	Database: Ecoinvent 3.11 Electricity, medium voltage, production mix – MY	2024	Malaysia	Production mix	Time: 1; Geography: 1; Technology: 1
Diesel	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1; Geography: 2; Technology: 1
Petrol	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1; Geography: 2; Technology: 1
Lubricating oil	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1; Geography: 2; Technology: 1
Boric acid	Database: Ecoinvent 3.11	2024	Global	Same technology	Time: 1; Geography: 2; Technology: 1
Borax	Database: Ecoinvent 3.11	2024	Global	Same technology	Time: 1; Geography: 2; Technology: 1

6 LIFE CYCLE INVENTORY (LCI)

The LCI presents the inputs and outputs associated with each unit process in the production of kiln-dried sawn timber. This analysis is conducted based on a functional unit of 1 m^3 of kiln-dried sawn timber for different wood species or timber groups.

6.1 Harvesting

Harvesting activity for hardwood logs begins with the construction and maintenance of forest road, typically carried out using bulldozers (crawler tractors) and agricultural tractors. The construction and maintenance of logging roads are prerequisites for machinery, workers, and transport vehicles to reach harvest sites. Therefore, they are considered a direct input to the harvesting system. Trees are felled, delimbed, and bucked using chainsaw. Logs are then skidded from the felling site to an intermediate log yard in the forest. An excavator is used to load the logs onto a winched lorry, which is then used for short-distance hauling between the intermediate and main log yard. A wheeled loader (log grabber) is used to unload and stack the logs at the main log yard. The harvesting operation is supported by a harvesting camp and four-wheel drive pick-up truck to transport workers and supplies. Logs are sorted by species and quality, then scaled (measured for volume) before being transported to sawmills. The typical log length ranges from 16 to 21 feet to accommodate the length of a trailer lorry. No co-products were generated during the harvesting of hardwood logs.

Rubber trees are felled using an excavator, which uproots the entire tree. The felled trees are then delimbed and bucked using chainsaws. Rubber trees are typically cut into 1.8 m long logs to fit the width of the lorry body. An excavator is used to load the logs onto 5-6 tonne lorry. In some cases, the logs are loaded onto a winched lorry and hauled to the main log yard before being transported to rubberwood sawmills. Along with the rubberwood logs, stump and chip logs are also generated as co-products during the harvesting process. These co-products are sold to other mills for further processing into products such as wood chips and pellets. As these outputs are considered as co-products, allocation between the rubberwood logs and associated co-products is included in this study to accurately reflect the distribution of environmental burdens. The inputs and outputs per m^3 of harvested logs are presented in Table 6.1.

Table 6.1: Inputs and outputs for production of 1 m³ of harvested logs

Timber species/group	Output	Input		Allocation (%)
	Log volume (m^3)	Fuel consumption (L/m^3)		
		Diesel	Petrol	
Light Red Meranti	1	13.12	0.67	100
Dark Red Meranti	1	15.04	0.96	100
Rubberwood Stump logs (co-products) Chip logs (co-products)	1 0.89 0.55	8.95	0.52	40.98 36.48 22.54
Keruing	1	16.24	1.03	100
Merbau	1	18.34	0.89	100
Balau	1	25.92	0.51	100
Kelat	1	21.37	0.79	100
Kapur	1	10.15	0.16	100
Gerutu	1	22.01	0.51	100
Meranti mix	1	16.32	1.01	100
Kedondong	1	21.58	0.56	100
Kempas	1	15.88	1.05	100
Mixed heavy hardwood	1	20.28	0.61	100
Mixed medium hardwood	1	20.56	0.62	100
Mixed light hardwood	1	16.68	0.55	100

6.2 Logs Transportation

The transportation activity in this study includes the delivery of logs from harvesting sites to sawmills using 16-32 ton Euro 3 double-axle lorries. All the participating sawmills reported using lorries to transport logs. Logs are sourced from various parts of Peninsular Malaysia, leading to potential variability in transportation distances, with some materials traveling shorter distances while others cover longer routes depending on the location of the harvesting sites and sawmills. It is assumed that all lorries return to their point of origin without carrying a load. The input, output, and transportation distance associated with log transportation are shown in Table 6.2.

Table 6.2: Input and output for transportation averages of 1 m^3 of harvested logs

Timber species/group	Input / Output	Weighted average distance (km)
	Log volume (m^3)	
Light Red Meranti	1	99.86
Dark Red Meranti	1	64.97
Rubberwood	1	52.82
Keruing	1	88.05
Merbau	1	92.37
Balau	1	52.89
Kelat	1	47.88
Kapur	1	114.66
Gerutu	1	34.11
Meranti mix	1	75.26
Kedondong	1	41.98
Kempas	1	57.16
Mixed heavy hardwood	1	63.02
Mixed medium hardwood	1	63.94
Mixed light hardwood	1	53.89

6.3 Sawing

Transported logs to sawmills are kept in the open log yard. A log grapple is used to load, unload and stack the logs according to their species or timber groups. The logs are then moved into the sawmill for the sawing process. The sawing process begins with the breakdown of logs into flitches using breakdown band saws. These flitches are then squared up with medium-sized, band re-saws to obtain standardised dimensions for further processing. Green sawn timber is then trimmed with circular saws to remove any major defects. The recovery rate of sawn timber from hardwood logs was reported to be between 56% and 65%.

For rubberwood, freshly felled logs are processed within a few days after felling to prevent sapstain fungi and insect attacks that can degrade the wood's quality. The logs are commonly sawn using medium-sized vertical bandsaws for both breaking down and re-sawing operations. Multiple circular rip saws are also used to saw logs into sawn timber. Circular cross-cut saws are used to remove any defects. The recovery of rubberwood sawn timber observed in this study ranged between 13% and 17%. After sawing, rubberwood sawn timbers are treated with boron-based preservative consisting of a mixture of boric acid and borax. This treatment is applied to protect the wood from pests and fungal decay, particularly in climates where such biological degradation can be a concern.

During the conversion of logs into sawn timber, a substantial volume of wood residues is generated**.** These residues, primarily off-cuts, sawdust, and wood chips are produced in their green condition. In some participating sawmills, these residues are not always categorised separately; instead, they are often reported collectively as mixed residues. The wood residues generated during processing are either sold or utilised on-site as fuel, primarily in boilers used for wood drying process. The Wood residues that are sold are classified as co-products due to their economic value. Allocation methods are applied between the sawn timber and co-products, ensuring that the environmental impacts are appropriately distributed, as shown in Table 6.3.

Table 6.3: Mass allocation among the products and co-products (%)

Timber species/group	Sawn timber	Sawdust	Off-cuts	Mix residues
Light Red Meranti	68.82	9.24	12.49	9.45
Dark Red Meranti	63.38	6.20	19.82	10.60
Rubberwood	20.19	3.10	2.90	73.81
Keruing	60.85	11.60	15.69	11.86
Merbau	65.16	10.33	13.96	10.56
Balau	61.86	11.30	15.28	11.55
Kelat	64.28	7.89	14.22	13.61
Kapur	68.26	9.40	12.72	9.61
Gerutu	66.69	8.43	10.00	14.88
Meranti mix	65.15	5.72	15.83	13.30
Kedondong	66.84	5.33	7.97	19.87
Kempas	66.05	9.16	8.23	16.56
Mixed heavy hardwood	62.33	6.67	13.47	17.53
Mixed medium hardwood	67.72	4.12	12.69	15.46
Mixed light hardwood	71.60	5.02	11.02	12.36

Electricity is used during sawmilling to power the various motors that run the machinery and equipment. Machinery and equipment used for sawmilling activities are band saws, circular saws, dust extractors, tool sharpeners, and conveyors. Diesel fuel is used for off-road transportation, such as operating forklifts and log grapples, which are essential for moving logs and sawn timber within the sawmill premises. Petrol is used in small quantities to power chain saws. Lubricants are used for cleaning and maintenance of equipment. The inputs and outputs for the production of 1 m^3 of green sawn timber in this unit process are shown in Table 6.4.

Table 6.4: Inputs and outputs for the production averages of 1 m^3 of green sawn timber

Inputs and outputs	Unit	Light Red Meranti	Dark Red Meranti	Rubberwood	Keruing	Merbau	Balau	Kelat	Kapur	Gerutu	Meranti mix	Kedondong	Kempas	Mixed heavy hardwood	Mixed medium hardwood	Mixed light hardwood
Resources																
Logs	m^3	1.56	1.58	6.70	1.79	1.66	1.76	1.64	1.57	1.64	1.68	1.59	1.63	1.71	1.62	1.53
Electricity	kWh	20.25	18.16	32.02	15.52	21.18	30.29	37.53	28.26	35.94	23.15	47.58	54.96	45.88	33.87	29.23
Diesel	L	5.09	4.39	5.55	3.89	7.97	8.84	6.96	7.25	8.40	3.78	5.96	4.38	4.46	6.41	6.32
Petrol	L	0.43	0.40	0.94	0.15	0.25	0.34	0.76	0.35	0.15	0.22	0.42	0.56	0.27	0.86	0.28
Lubricants	L	0.13	0.12	0.25	5.0E-4	5.0E-3	0.09	0.18	0.39	0.14	0.34	0.94	0.29	0.11	6.0E-03	3.6E-02
Product																
Sawn timber	m^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Co-products																
Sawdust, green, sold	kg	67.93	64.48	87.99	149.88	117.91	171.93	99.15	90.65	78.74	57.53	55.70	112.36	94.02	48.11	41.71
Off-cuts, green, used	kg	91.87	247.61	82.26	202.68	159.44	232.51	178.68	122.59	93.42	159.13	83.31	100.92	189.73	148.00	91.57
Mix residues, green	kg	69.44	132.39	2094.18	153.20	120.52	175.75	171.09	92.66	139.01	133.76	207.82	203.09	246.87	180.33	102.75
Fuel, green	kg	54.16	2.95	1000.14	119.50	94.01	137.09	66.13	72.28	88.52	93.93	63.88	97.84	93.18	112.15	80.92

6.4 Kiln Drying

A few sawmills have their own kiln drying facilities, while others rely on external kiln drying facilities for drying sawn timber. Thus, the drying process began with the transportation of green sawn timber to kiln drying facilities up to the production of kiln-dried sawn timber. Transportation of green sawn timber to kiln-drying mills is typically carried out using lorries**,** which transport green sawn timber from various locations across Peninsular Malaysia**.** As green sawn timber is sourced from various parts of Peninsular Malaysia, transportation distances vary depending on the location of the sawmills and the kiln-drying facilities.

Green sawn timbers are stickered and then loaded into the drying chamber for the kiln drying process. Sawn timber is commonly dried to 10-12% moisture content, which is the standard for ensuring dimensional stability and suitability for various applications. The primary equipment used in this stage include forklifts, which are employed to load and unload the sawn timber into and out of the drying chamber. Electricity is used to power the kiln's control system, fan motors and lighting within the kiln drying facility.

During recent field data collection at several kiln drying facilities, it was observed that the boiler used wood residues, oil palm's empty fruit bunches (EFB) and mesocarp fibre as sources of on-site energy production for the timber drying process. The participating sawmills did not purchase wood for the boilers but instead relied 100% on the wood waste generated from their own sawmilling activities. The wood combusted in the boiler generates thermal energy, which is then used to generate steam Kilns utilise the steam to establish the controlled heat and humidity conditions required for effective timber drying. Ash is generated as a by-product of combustion. However, its exact quantity could not be quantified during the data collection. It was, however, reported that the ash is repurposed as fertiliser for agricultural use. The inputs and outputs for production of 1 m^3 of kiln-dried sawn timber, are summarised in Table 6.5.

Table 6.5: Inputs and outputs for the production of 1 m^3 of kiln-dried sawn timber

Input and output	Unit	Light Red Meranti	Dark Red Meranti	Rubberwood	Keruing	Merbau	Balau	Kelat	Kapur	Gerutu	Meranti mix	Kedondong	Kempas	Mixed heavy hardwood	Mixed medium hardwood	Mixed light hardwood
Inputs																
Sawn timber, green	m^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Electricity	kWh	24.77	36.43	11.65	38.86	47.60	65.57	35.46	42.26	27.20	26.71	27.69	52.94	46.14	43.23	25.26
Transportation of green sawn timber	km	57.63	62.6	27.5	51.16	29.67	59.33	22.9	36.09	62.36	52.65	38.49	34.2	63.02	44.90	35.2
Off-road transportation	L	0.57	0.49	0.86	0.27	0.05	0.04	0.70	0.07	0.04	0.02	0.04	0.17	0.56	0.58	0.39
Sawdust, green	kg	6.69	4.55	20.70	4.27	3.48	2.53	4.67	3.92	6.09	6.20	5.99	3.13	3.59	3.83	6.56
Off-cuts, green	kg	14.23	9.68	3.72	9.07	7.41	5.38	9.94	8.34	12.96	13.19	12.74	6.67	7.64	8.16	13.96
Empty fruit bunch	kg	34.47	23.44	-	21.97	17.94	13.02	24.08	20.20	31.39	31.96	30.84	16.13	18.50	19.75	33.80
Mesocarp fibre	kg	36.73	24.97	-	23.41	19.11	13.87	25.66	21.53	33.47	34.06	32.86	17.18	19.72	33.80	36.02
Boric acid	kg	-	-	5.91	-	-	-	-	-	-	-	-	-	-	-	-
Borax	kg	-	-	3.63	-	-	-	-	-	-	-	-	-	-	-	-
Output																
Kiln-dried sawn timber	m^3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

6.5 Packaging

The materials commonly used for packaging sawn timber for shipping are serrated clips and plastic straps. The quantities of these materials used for 1 m³ of various timber species or groups are detailed in Table 6.6. It is important to note that these packaging inputs are not associated with the by-products generated during the sawing process. The entire allocation of these packaging materials are assigned 100% to the kiln-dried sawn timber final product.

Table 6.6: Packaging inputs for 1 m^3 of kiln-dried sawn timber

Timber species/group	Plastic strap (kg)	Serrated clip (kg)
Light Red Meranti	24.14	40.98
Dark Red Meranti	74.972	16.82
Rubberwood	58.60	0.90
Keruing	21.04	28.45
Merbau	52.34	17.55
Balau	60.90	7.77
Kelat	20.58	26.09
Kapur	14.09	2.55
Gerutu	27.49	5.73
Meranti mix	56.60	7.30
Kedondong	14.89	4.31
Kempas	32.27	2.96
Mixed heavy hardwood	98.59	13.33
Mixed medium hardwood	25.05	26.52
Mixed light hardwood	50.96	46.57

7 LIFE CYCLE IMPACT ASSESSMENT

The assessment uses a cradle-to-gate approach to evaluate the potential environmental impacts of harvesting, transportation, sawing, and kiln drying stages. The study identifies that harvesting is the dominant contributor across all assessed categories, due to fuel consumption from diesel-powered machinery (Table 7.1 – Table 7.6). Kiln drying also represents a significant source of potential environmental impacts, largely driven by electricity demand. However, in some cases, sawing also makes a substantial contribution to the environment burden. Transportation shows the lowest contribution, though it remains relevant where significant distances exist between harvesting sites and processing facilities.

Global warming potential primarily results from the combustion of diesel fuel in machinery releases significant amounts of carbon dioxide. Methane and other greenhouse gases, although emitted in smaller amounts, have higher warming potentials and thus also contribute to the overall impact. Acidification potential arises mainly from emissions of nitrogen oxides and sulfur dioxide, which are released during fossil fuel combustion in harvesting and kiln drying processes. Eutrophication-related emissions resulted from indirect effects of harvesting activities, such as nutrient runoff and soil disturbance. Ozone depletion potential is largely attributed to emissions linked to the use of certain refrigerants or chemicals used in machinery. In terms of energy demand from non-renewable resources, the energy input is largely derived from crude oil, followed by hard coal, natural gas, and other sources.

Table 7.1: Global warming potential of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species/group	Harvesting	Transportation	Sawing	Kiln drying	Total
	kg CO_2-eq / m^3				
Light Red Meranti	71.52	13.47	30.22	31.27	146.48
Dark Red Meranti	77.13	11.74	24.45	41.19	154.51
Rubberwood	25.29	5.47	11.72	34.79	77.27
Keruing	90.75	20.73	20.02	45.64	177.14
Merbau	100.62	19.08	37.88	46.69	204.28
Balau	140.73	12.60	43.69	69.34	266.35

Kelat	113.23	10.42	44.36	38.56	206.57
Kapur	54.21	13.85	42.02	42.22	152.31
Gerutu	120.27	7.17	48.55	35.48	211.47
Meranti Mix	91.19	15.83	25.82	33.12	165.96
Kedondong	114.48	7.53	48.68	30.42	201.11
Kempas	87.84	10.43	46.77	20.36	165.39
Mixed heavy hardwood	111.26	14.34	39.84	55.74	221.18
Mixed medium hardwood	121.38	13.62	28.61	48.73	212.34
Mixed light hardwood	91.91	8.70	40.85	29.17	170.63

Table 7.2: Acidification potential of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species/group	Harvesting	Transportation	Sawing	Kiln drying	Total
	kg SO_2-eq/m^3				
Light Red Meranti	0.40	0.06	0.15	0.13	0.74
Dark Red Meranti	0.43	0.05	0.12	0.17	0.77
Rubberwood	0.14	0.02	0.06	0.22	0.44
Keruing	0.50	0.09	0.10	0.19	0.88
Merbau	0.56	0.08	0.19	0.19	1.03
Balau	0.79	0.05	0.22	0.29	1.35
Kelat	0.63	0.04	0.21	0.16	1.05
Kapur	0.30	0.06	0.21	0.17	0.74
Gerutu	0.67	0.03	0.24	0.15	1.09
Meranti Mix	0.50	0.07	0.12	0.14	0.83
Kedondong	0.64	0.03	0.23	0.13	1.03
Kempas	0.49	0.04	0.21	0.09	0.83
Mixed heavy hardwood	0.62	0.06	0.18	0.24	1.10
Mixed medium hardwood	0.68	0.06	0.15	0.21	1.09
Mixed light hardwood	0.51	0.04	0.20	0.12	0.87

Table 7.3: Eutrophication potential of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species/group	Harvesting	Transportation	Sawing	Kiln drying	Total
	kg PO_4-eq / m^3				
Light Red Meranti	1.46E-01	2.04E-02	6.56E-02	6.69E-02	2.99E-01
Dark Red Meranti	1.57E-01	1.78E-02	5.31E-02	8.88E-02	3.17E-01
Rubberwood	5.17E-02	8.30E-03	5.23E-02	1.37E-01	2.49E-01
Keruing	1.85E-01	3.15E-02	4.36E-02	9.80E-02	3.58E-01
Merbau	2.06E-01	2.90E-02	8.15E-02	1.05E-01	4.22E-01
Balau	2.90E-01	1.91E-02	9.47E-02	1.53E-01	5.56E-01
Kelat	2.32E-01	1.58E-02	9.70E-02	8.60E-02	4.31E-01
Kapur	1.12E-01	4.97E-02	9.19E-02	9.46E-02	3.48E-01
Gerutu	2.48E-01	1.09E-02	1.06E-01	7.36E-02	4.39E-01
Meranti Mix	1.86E-01	2.40E-02	5.75E-02	6.96E-02	3.37E-01
Kedondong	2.36E-01	1.14E-02	1.10E-01	6.63E-02	4.23E-01
Kempas	1.79E-01	1.58E-02	1.05E-01	3.38E-02	3.34E-01
Mixed heavy hardwood	2.29E-01	2.18E-02	8.94E-02	1.19E-01	4.59E-01
Mixed medium hardwood	2.50E-01	2.07E-02	5.95E-02	1.07E-01	4.37E-01
Mixed light hardwood	1.89E-01	1.32E-02	8.94E-02	6.35E-02	3.55E-01

Table 7.4: Photochemical ozone creation potential of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species/group	Harvesting	Transportation	Sawing	Kiln drying	Total
	kg ethylene-eq / m^3				
Light Red Meranti	4.31E-02	4.48E-03	1.50E-02	8.08E-03	7.06E-02
Dark Red Meranti	4.90E-02	3.90E-03	1.23E-02	9.74E-03	7.49E-02
Rubberwood	1.57E-02	1.81E-03	6.80E-03	1.28E-02	3.71E-02
Keruing	5.75E-02	6.89E-03	8.46E-03	1.11E-02	8.40E-02
Merbau	5.99E-02	6.34E-03	1.68E-02	1.04E-02	9.34E-02
Balau	7.30E-02	4.19E-03	1.90E-02	1.60E-02	1.12E-01
Kelat	6.40E-02	3.47E-03	2.19E-02	9.42E-03	9.88E-02
Kapur	2.76E-02	5.26E-03	1.85E-02	9.44E-03	6.07E-02
Gerutu	6.36E-02	2.38E-03	1.86E-02	8.87E-03	9.34E-02

Meranti Mix	5.75E-02	5.26E-03	1.06E-02	8.12E-03	8.14E-02
Kedondong	6.14E-02	2.50E-03	1.93E-02	7.13E-03	9.03E-02
Kempas	5.62E-02	3.47E-03	1.87E-02	5.29E-03	8.37E-02
Mixed heavy hardwood	6.06E-02	4.77E-03	1.45E-02	1.39E-02	9.37E-02
Mixed medium hardwood	7.02E-02	4.53E-03	1.53E-02	1.19E-02	1.02E-01
Mixed light hardwood	5.10E-02	2.89E-03	1.71E-02	7.20E-03	7.81E-02

Table 7.5: Ozone depletion potential of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species/group	Harvesting	Transportation	Sawing	Kiln drying	Total
	kg CFC11-eq / m^3				
Light Red Meranti	7.32E-07	1.39E-07	3.53E-07	3.92E-07	1.62E-06
Dark Red Meranti	7.90E-07	1.21E-07	2.87E-07	5.28E-07	1.73E-06
Rubberwood	2.59E-07	5.65E-08	4.56E+00	-4.56E+00	8.46E-07
Keruing	9.30E-07	2.14E-07	2.32E-07	5.81E-07	1.96E-06
Merbau	1.03E-06	1.97E-07	1.65E+00	-1.65E+00	2.27E-06
Balau	1.44E-06	1.30E-07	5.03E-07	9.01E-07	2.97E-06
Kelat	1.16E-06	1.08E-07	5.29E-07	4.98E-07	2.29E-06
Kapur	5.53E-07	4.13E-07	4.94E-07	5.55E-07	2.02E-06
Gerutu	1.23E-06	7.41E-08	5.69E-07	4.43E-07	2.31E-06
Meranti Mix	9.34E-07	1.63E-07	3.15E-07	4.17E-07	1.83E-06
Kedondong	1.17E-06	7.77E-08	6.10E-07	3.92E-07	2.25E-06
Kempas	9.00E-07	1.08E-07	5.91E-07	2.52E-07	1.85E-06
Mixed heavy hardwood	1.14E-06	1.48E-07	4.93E-07	7.06E-07	2.48E-06
Mixed medium hardwood	1.24E-06	1.41E-07	3.13E-07	6.25E-07	2.32E-06
Mixed light hardwood	9.39E-07	8.99E-08	4.80E-07	3.72E-07	1.88E-06

Table 7.6: Primary energy demand from non-renewable resources of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species/group	Harvesting	Transportation	Sawing	Kiln drying	Total
	MJ / m^3				
Light Red Meranti	879.66	186.18	361.58	371.12	1798.54
Dark Red Meranti	949.04	162.19	292.44	485.91	1889.59
Rubberwood	311.18	75.61	139.87	434.09	960.74
Keruing	1116.64	286.43	236.85	539.79	2179.71
Merbau	1237.57	263.74	452.23	535.94	2489.48
Balau	1729.36	174.08	520.88	807.86	3232.19
Kelat	1392.15	144.04	526.71	446.41	2509.31
Kapur	666.11	188.64	507.90	486.77	1849.42
Gerutu	1478.08	99.13	576.70	427.77	2581.68
Meranti Mix	1121.99	218.75	311.11	396.44	2048.28
Kedondong	1409.14	104.00	589.25	356.72	2459.11
Kempas	1080.87	144.10	547.05	246.48	2018.50
Mixed heavy hardwood	1367.63	198.19	464.43	660.46	2690.72
Mixed medium hardwood	1492.02	188.21	346.49	569.88	2596.59
Mixed light hardwood	1129.93	120.30	482.72	342.31	2075.25

While renewable energy consumption is not explicitly included in the CML baseline impact categories, it is presented in this study to provide a more holistic view of the energy profile associated with kiln-dried sawn timber production. In particular, this LCA accounts in the range of 482.78 to 1769.78 of renewable energy per cubic meter of kiln-dried sawn timber, which is derived from wood residues generated on-site, empty fruit bunches (EFB) and mesocarp fibre. This renewable energy is utilised in the drying process, one of the most energy-intensive stages in kiln-dried sawn timber production (Table 7.7).

Table 7.7: Primary energy demand from renewable resources of 1 m^3 kiln-dried sawn timber based on mass allocation

Timber species / group	Total (MJ/m^3)
Light Red Meranti	1769.78
Dark Red Meranti	1209.86
Rubberwood	482.78
Keruing	1135.68
Merbau	930.36
Balau	681.4
Kelat	1242.85
Kapur	1044.81
Gerutu	1613.79
Meranti mix	1641.39
Kedondong	1585.77
Kempas	838.89
Mixed heavy hardwood	959.55
Mixed medium hardwood	1263.36
Mixed light hardwood	1734.46

8 LIFE CYCLE INTERPRETATION

The life cycle interpretation represents the final phase in the LCA process. In this phase, the findings from both the LCI and LCIA were analysed and interpreted within the context of the study's goal and scope definition**.** For this study, Dark Red Meranti was chosen as an example for interpretation. Dark Red Meranti is the largest exported timber group in 2021, making it both a representative and highly relevant choice for evaluating the environmental impact of commonly used timber products in the global market. The contribution analysis for other timber species/groups are listed in Appendix C.

8.1 Identification of Significant Issues

The identification of significant issues was conducted through a contribution analysis of the four main unit processes involved in the production of kiln-dried sawn timber: harvesting, transportation, sawing, and kiln drying. The contributions of each unit process to the potential environmental impacts are summarized in Table 8.1.

Table 8.1: Contribution analysis for 1 m^3 of Dark Red Meranti kiln-dried sawn timber

Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Global warming potential	49	8	17	26
Acidification potential	55	6	17	22
Eutrophication potential	49	6	18	28
Photochemical ozone creation potential	59	5	24	12
Ozone depletion potential	45	7	18	30
Primary energy demand for non-renewable material	50	9	16	25

8.2 Completeness Check

A completeness check was conducted to verify whether the data collected and modelled in the LCI were sufficient to fulfil the goal and scope of the study. This included an assessment of the input and output data coverage for all unit processes. The data were reviewed for consistency in time period (2021–2023), geographical relevance (Peninsular Malaysia), and technological representativeness (current practices in participating facilities). Gaps in data were addressed through follow-up communications with facility personnel, and any remaining gaps were evaluated. Overall, the inventory data is considered sufficiently complete for all key processes, enabling reliable life cycle impact assessment.

8.3 Consistency Check

A consistency check was carried out to ensure that the assumptions, system boundaries, allocation procedures, data sources, and modelling choices remained aligned with the goal and scope of the study. Primary data collection was standardised using structured survey forms, and all background data were sourced from the same LCI database to maintain consistency. Any deviations or assumptions were clearly documented and justified. The consistency check confirms that the LCA results are based on coherent and systematically applied methodologies throughout the study.

8.4 Uncertainty Analysis

In the context of kiln-dried sawn timber, where production processes and input materials can vary significantly between mills, addressing uncertainty is essential to ensure the credibility and robustness of environmental impact results. A preliminary evaluation of uncertainty analysis between mills for the same timber species was performed using statistical method from industry survey data (Table 8.2). The uncertainty analysis for other timber species/groups are listed in Appendix D.

Table 8.2: The Uncertainty Analysis of Dark Red Meranti for selected Parameters

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption in sawmills	kWh	29.64	16.13	11.88	98.02
Diesel consumption for harvesting	L	15.04	11.32	3.84	56.68

The uncertainty analysis reveals the variability in several key input parameters, with the significant parameters are electricity consumption in sawmills and diesel consumption during harvesting activities. This variability of electricity can be attributed to several factors, including sawmill size and capacity, equipment efficiency, and operational practices. Additionally, the type of wood being processed affects energy needs, with denser hardwoods requiring more energy than lighter species. The high variability in diesel consumption during harvesting activities indicates that factors such as machines/equipment and haulage distances can lead to considerable variation in fuel consumption.

8.5 Sensitivity Analysis

Sensitivity analysis was performed to evaluate how variations in key input parameters influence the overall potential environmental impact results.

8.5.1 Electricity Consumption

The ±20% variation in electricity consumption resulted in changes of up to ±13.3% in global warming potential, ±11.4% in acidification potential, ±11.7% in eutrophication potential, ±17.9% in photochemical ozone creation potential, and ±21.1% in ozone depletion potential. These indicate that electricity use is a key driver of potential environmental impact in sawmill operations (Table 8.3). This reflects the significant role of electricity, in shaping the overall potential environmental impacts. The sensitivity analysis demonstrates that changes in electricity usage have a proportional and notable effect on multiple impact categories, underlining the dependence of the system's environmental performance on energy inputs.

Table 8.3: Sensitivity analysis for electricity consumption

Electricity consumption (kWh/m^3)	Scenario	GWP	AP	EP	POCP	ODP
		kg CO_2-eq	kg SO_2-eq	kg PO_4-eq	kg ethylene-eq	kg CFC-11-eq
16.34	-10%	47.93	0.587	0.742	0.025	4.680
18.16	Baseline	53.26	0.652	0.824	0.028	5.200
19.98	+10%	58.59	0.716	0.906	0.031	5.720
21.79	+20%	63.91	0.779	0.989	0.034	6.240

8.5.2 Diesel Consumption

A ±20% variation in diesel consumption resulted in an approximate ±9.8% change in global warming potential (from 50.73 to 58.32 kg CO_2-eq), ±10.7% in acidification potential, ±8.6% in eutrophication potential, ±11.1% in photochemical ozone creation potential, and ±16.7% in ozone depletion potential (Table 8.4). This indicates that diesel use, primarily for machinery operation and transportation, has a significant potential environmental impacts.

Table 8.4: Sensitivity analysis for diesel consumption in log harvesting

Diesel consumption (L/m^3)	Scenario	GWP	AP	EP	POCP	ODP
		kg CO_2-eq	kg SO_2-eq	kg PO_4-eq	kg ethylene-eq	kg CFC-11-eq
13.54	-10%	50.73	0.624	0.781	0.027	4.910
15.04	Baseline	53.26	0.652	0.824	0.028	5.200
16.54	+10%	55.79	0.681	0.867	0.029	5.490
18.05	+20%	58.32	0.710	0.910	0.030	5.780

8.6 Assumptions and Limitations

Several assumptions and limitations must be considered when interpreting the results. These limitations stem from constraints related to the methodology used, data gaps, a lack of information, and specific conditions that may influence the findings.

(a) A key limitation relates to the logging in natural forests in Peninsular Malaysia. Logging activities in some states were restricted due to a moratorium (temporary suspension) imposed by the state government. This suspension impacted the states of Pulau Pinang, Selangor, Melaka, Johor, and Perlis, meaning that logging data from these regions were not included in the study.

(b) Another limitation concerns the transportation of logs. The exact distances from the log yard to the checkpoint could not be identified due to limited access to transportation data. To address this, an assumption was made that the distance from the log yard to the checkpoint was 5 km, based on discussions with the Forestry Department. While this assumption is based on the best available information, it introduces a degree of uncertainty, as actual log yard to checkpoint distances may vary depending on specific locations and transportation routes.

(c) The sawing process was also influenced by external factors. In 2021, Malaysia experienced a Movement Control Order (MCO) due to the COVID-19 pandemic, which led to the temporary closure of sawmills for approximately three months. During this period, production was halted, and data from this time could not be included in the study.

(d) For the kiln drying facilities, a further limitation occurred in terms of emission data collection. Specifically, data on on-site emissions, such as VOC and particulate matter (dust and ash), could not be collected due to limitations in measuring equipment. This gap in data means that the full environmental impact associated with kiln drying cannot be accurately assessed in this study. Additionally, the amount of ash produced from combustion during the drying process was minimal, and the ash that was collected was used as fertilizer, which may mitigate its environmental impact.

9 CONCLUSIONS AND RECCOMENDATIONS

The LCA of kiln-dried sawn timber production in Peninsular Malaysia provides a comprehensive analysis of the environmental impacts associated with key stages of production, including log harvesting, log transportation, sawing and kiln drying activities. The study reveals significant potential environmental impacts, particularly in terms of global warming, acidification, eutrophication, ozone depletion and photochemical ozone creation potentials as well as energy consumption, offering a holistic picture of the environmental footprint of timber processing in the region.

One of the most significant findings from the study is that log harvesting activities contributes the most to environmental impacts across all evaluated categories. This is largely due to the emissions from diesel-powered machinery used in felling and transporting logs within forest areas. Kiln drying emerges as energy-intensive phase in the entire process. Although some renewable sources, such as wood waste and biomass, are used in heating systems, the reliance on fossil-based fuels remains high, emphasizing the need for energy optimization in this area.

Sawing, while not as energy-demand as drying, still makes a notable impact on certain environmental categories. It plays a significant role in photochemical ozone creation potential, due to emissions related to mechanical processing. This highlights the need for efficient and well-maintained equipment, particularly when processing species that are more difficult to handle. Transportation, though not the primary source of significant potential environmental impacts, contributes moderately to the overall impacts. Its influence varies greatly depending on the distance between the forest and the sawmill, with some transport routes extending over 300 kilometres. The variability in transportation distances introduces inconsistencies in environmental burdens, which could be addressed by developing more localized supply chains or optimizing logistics networks to minimize travel.

A sensitivity analysis further reveals that changes in electricity and diesel consumption significantly influence key environmental outcomes. For example, a 20% fluctuation in electricity usage can result in more than a 13% change in the global warming potential. This indicates that energy management, particularly at the facility level, plays a crucial role in the overall sustainability of the timber production process. Monitoring and optimizing the use of energy inputs, especially electricity in sawing and thermal energy in kiln drying, can yield substantial improvements in environmental performance.

The study also finds that renewable energy sources such as biomass from wood residues and palm oil waste are actively used in kiln drying. However, their environmental benefits are not adequately represented in the conventional impact assessment categories like those of the CML method. This underrepresentation suggests that the contribution of renewable integration is often underestimated, which calls for more inclusive LCA methods that reflect the true environmental advantages of using renewable fuels.

Based on these insights, several recommendations are proposed to enhance the sustainability of kiln-dried sawn timber production. Logging practices should be optimized by improving reduced-impact logging methods and transitioning to fuel-efficient or hybrid machinery. Operator training and proper equipment maintenance can further reduce fuel consumption and emissions during forest operations.

To address the high energy demand of kiln drying, investments in high-efficiency kilns or pre-drying technologies should be considered. Increasing the use of renewable biomass and improving combustion systems would reduce reliance on fossil fuels, while solar thermal technologies could be introduced to preheat kiln air. Similarly, sawmills should aim to improve energy efficiency by upgrading to more efficient motors, redesigning mill layouts to reduce energy losses, and adopting digital monitoring systems to control power usage effectively. In addition, sawmills are encouraged to adopt the use of solar energy as a sustainable alternative to conventional energy sources. This shift not only reduces greenhouse gas emissions but also aligns with national efforts to promote renewable energy use within the wood-based industry.

Finally, policy support is essential to drive change at scale. Government incentives such as subsidies, tax breaks, or carbon credit schemes could motivate companies to adopt sustainable technologies and practices. Additionally, capacity-building programs focused on sustainable forestry and energy management would equip industry workers with the knowledge and skills needed to implement and maintain best practices. Together, these measures would strengthen the environmental sustainability of kiln-dried sawn timber production in Peninsular Malaysia, aligning it with global efforts toward greener industry practices.

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APPENDIX A

LIFE CYCLE INVENTORY DATA COLLECTION SHEET

DATA ON LOG PRODUCTION AND FUEL CONSUMPTION DURING LOG HARVESTING IN PENINSULAR MALAYSIA

Starting month/year:
Ending month/year:
Data collected by:

GENERAL INFORMATION

- All data collected from the participated loggers will be maintained **STRICTLY CONFIDENTIALLY**.
- Data collection shall be carried out on **monthly basis for twelve months** period. Please state the reason IF unable to collect the data for twelve months period.

The survey form is divided into five parts:

Part A : Description of logger/logging area
Part B : Logging processes

Units are generally specified. However, if the logging operator(s) use other units, please cross-off the specified unit and add the unit used.

Conversion units:

Volume of log:	1 hoppus ton = 63.66 ft^3 = 1.803 m^3
Volume of sawn timber:	1 ton = 50 ft^3 = 1.416 m^3
Weight:	1 tonne = 1,000 kg
Power:	1kW = 1.341 HP
	1 HP = 746 W = 0.746 kW
Area:	1 ha = 2.47105 acre
	1 acre = 0.404686 ha
Volume of oil:	1 drum = 200 L
	1 jerry can = 20 L

List of documents used for data collection:

a) Log book / removal pass
b) Fuel purchases record
c) Fuel usage record
d) Others if necessary, please state:

Please complete the survey form as much details as possible. Your cooperation is highly appreciated

Thank you.
Project team

PART A: DESCRIPTION OF LOGGER/LOGGING AREA

SECTION I: DESCRIPTION OF LOGGER/LOGGING ARE	
Name of company / logging contractor	
Address	
Contact person	
Telephone	
Email	

SECTION II: INFORMATION ON LOGGING SITE	
Location:	
Compartment	
Total logging/licensed area	ha / acre
Logged area	ha acre
Forest type	□ Hill forest □ Lowland forest □ Peat swamp forest
Forest status	□ Permanent reserved forest □ State land (land-use conversion)
Distance from logging area to main landing site	km
Duration of logging	Month/year: From to

SECTION IIi: OPERATION OVERVIEW	
Normal operating hours:	
Normal working hours / days:	hr/day days/week
Break	hours/day

Total working days in a month:

M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12

Note: M=month

PART B: LOGGING PROCESSES

SECTION I: LOG PRODUCTION		
Volume of harvested logs by species/group in reporting period of harvesting (for 1 year)		
Species/timber group	**Volume**	
	Hoppus ton	**m^3**
Total volume of logs harvested		
Volume of log/logged area		

SECTION II: MACHINES / EQUIPMENT & FUEL CONSUMPTION								
Machines / Equipment	**Make / model**	**No. of machines In operation**	**Rated power (kW @ HP @ cc)**	**Fuel consumption (L)**	**Hydraulic oil**	**Engine oil (L)**	**Transmission oil (L)**	**Activities**

Machines used		**Activity**
Winched-lorry (San Tai Wong)	Diesel	□ Short-distance haulage between sub-landing and main landing site. Travel distance (one-way): ___________ km Average load for winched-lorry: ton
Excavator	Diesel	Loading, unloading, and stacking of logs □ Main landing site □ Sub-landing site
Wheeled loader (log grabber)	Diesel	Loading, unloading, and stacking of logs □ Main landing site □ Sub-landing site
Bulldozer (Crawler-trator)	Diesel	□ Log skidding □ Road construction □ Road maintenance
Tractor		□ Road construction □ Road maintenance
Chainsaw	Petrol	□ Tree felling □ Bucking □ Delimbing
Genset	Petrol / Diesel	□ Logging camp
Water pump	Petrol / Diesel	□ Logging camp
Pick-up truck (4x4)	Diesel	□ Transportation of workers / logistics
Motorcycle	Petrol	□ Transportation of workers / logistics

APPENDIX B

LIFE CYCLE INVENTORY DATA COLLECTION SHEET		
Date:	State:	Currated by: Name: Organization:

GENERAL INFORMATION

All data collected from the participated mills will be maintained strictly confidentially.

Data collection shall be carried out on monthly basis for a recent twelve months period. Please state the reason IF unable to collect the data for the full twelve months period.

The survey form is divided into five parts:

Part A : Description of sawmill
Part B : Transportation of logs to sawmill
Part C : Sawmill processes
Part D : Kiln drying processes
Part E : Downstream processing

Units are generally specified. However, if the mill(s) use other units, please cross-off the specified unit and add the unit in use by the mill(s).

Blank sheets will be added in the survey form. In the case there are additional observations / clarifications during data collection, please fill in the blank sheets.

Conversion units:

- *Logs : 1 hoppus ton = 63.66 ft^3 = 1.803 m^3*
- *Sawn timber : 1 ton volume = 50 ft^3 = 1.416 m^3*
- *1kW = 1.341 HP*

List of documents useful for this data collection:

(a) Transfer pass
(b) Invoices
(c) Log book
(d) Electricity bills
(e) Data from administration
(f) Others if necessary

Please complete the survey form in as much detail as possible. Thank you.

PART A : SAWMILL INFORMATION

Sawmill information is divided into two sections:

Section I : Company profile *Section II : Operation overview*

SECTION I: COMPANY PROFILE	
Name of sawmill	
Address	
Contact person	
Telephone	
Email	

SECTION II: OPERATION OVERVIEW

1 Year: 2021
Production in that year: _______________ ton or volume

2 Production output:
☐ Air dried sawn timber
☐ Kiln dried sawn timber

3 Number of bandsaws in the factory: _________ unit

4 Do you have any downstream production?
☐Yes ☐ No

5 Sawmill normal operating hours:

No. of hours per day	
No. of days per week	
Break	

6. Total working days per month:

Jan	Feb	Mac	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec

7. Do you operate during MCO?
☐ Yes ☐ No
If **yes**, please fill on the sawmill operating hours:
No. of hours per day : ______ hours
No. of days per week : ______ hours
Break : ______ hours

If **no**, how long sawmill was closed? ___________ months/days

8. Machines / Equipment used in sawmill:

	Machines / Equipment	Number in mill	How many in the operation?	Rated power (kW / HP)
1.	Band saw			

2.	Circular saw / cross-cut saw			
3.	Dust extractor			
4.	Treatment plant			
5.	Air compressor			
6.	Chainsaw			
7.	Saw doctoring equipment Side dresser (band saw) Sharpener (band saw) Sharpener (circular saw)			
9.	Pony saw			
10.	Others (please specify)			

PART B : TRANSPORTATION OF LOGS TO SAWMILL

Please use removal passes (pas memindah) for data calculation on transportation of logs to sawmill.

Location (matau)	Travel distance to sawmill (km)	Log species	Volume (m^3)	Fuel consumption (l)

PART C : SAWMILL
Data collection for sawmill is divided into six sections: *Section I - Material Flow* *Section II - Mill residues* *Section III - Energy* *Section IV - Water consumption* *Section V - Chemical usage* *Section VI - Fuel consumption*

SECTION I: MATERIAL FLOW		
Log species	**Log number (hoppus ton)**	**Sawn timber volume (ton volume)**

SECTION II : MILL RESIDUES					
Types of residue	**Sold**	**Internally Used (Fuel)**	**Internally Used (Other)**	**Landfilled**	**Selling price**
	metric ton / kg	**metric ton / kg**	**metric ton / kg**	**metric ton / kg**	**RM /ton RM/kg**

Sawdust					
Off-cuts					
Bark					
Slab					
Others:					

SECTION III: ENERGY		
Electriciy (purchased) (kWh/year)		
Generate own electricity (Co-Gen)		
Types of fuels *(e.g. diesel / wood residues)*	Unit	

SECTION IV: WATER CONSUMPTION	
Water use (litre per year)	

SECTION V : CHEMICALS USAGE	
Materials (e.g. boron / CCA / fungicide)	**Amount (litre or kg)**

SECTION VI - FUEL CONSUMPTION					
Amount (litre)	**Machines / Equipment Used**				
	Forklift	**Loader**	**Log Grabber**	**Chainsaw**	Other: ______
Diesel:					
Petrol:					
Lubricants:					

Other:					

PART D : KILN DRYING
Data collection for sawmill is divided into five sections: *Section I - System overview* *Section II - Transportation sawn timber to kiln drying facility* *Section III - Energy* *Section IV - Water consumption* *Section V - Fuel consumption by boiler* *Section VI - Fuel consumption (transportation within KD)* *Section VII - Drying Process* *If sawmill has its own KD, please omit section II and section III*

SECTION I - SYSTEM OVERVIEW		
1	Fan size (cm or inch)	
2	Fan rated power (kW or HP)	
3	Number of fans	
4	Number of drying chambers	
5	Chamber capacity (m^3 or ton volume)	
6.	Target MC	

SECTION V - TRANSPORTATION SAWN TIMBER TO KILN DRYING MILL					
No	**Destination (from/to)**	**Common Name**	**Volume of timber (m^3/ton volume)**	**Amount of fuel (litre)**	**Distance (km)**

SECTION III: ENERGY		
Electriciy (purchased) (kWh/year)		
Generate own electricity (Co-gen)		
Types of fuels *(e.g. diesel / wood residues)*	Unit	

SECTION IV: WATER CONSUMPTION	
Water use (litre per year)	

SECTION V - FUEL CONSUMPTION BY BOILER				
Amount of fuel				
Diesel (Litre)	**Sawdust (Tonne metric)**	**Off-cuts (Tonne metric)**	**EFB (Mass)**	**Other:** ____________

SECTION VI - FUEL CONSUMPTION (transportation within KD)					
Amount (litre)	**Machines / Equipment Used**				
	Forklift	**Loader**	**Log Grabber**	Other: ________	Other: ________
Diesel:					
Petrol:					
Lubricants:					
Other:					

SECTION VII - DRYING PROCESS					
No.	**Common Name**	**Dimensions of timber (Thickness x Width x Length)**	**Input (Tonnes)**	**Output (Tonnes)**	**Drying duration (day)**

PART E : DOWNSTREAM PROCESSING
Data collection for sawmill is divided into three sections: *Section I - Operating hours* *Section II – Working days per month* *Section III - Generate own electricity (co-gen)* *Section IV - Energy consumption*

SECTION I - OPERATING HOURS	
No. of hours per day	
No. of days per week	
Break	

SECTION II - WORKING DAYS PER MONTH					
M1		M5		M9	
M2		M6		M10	
M3		M7		M11	
M4		M8		M12	

SECTION III: GENERATE OWN ELECTRICITY (CO-GEN)		
Generate own electricity (Co-gen)		
Types of fuels *(e.g. diesel / wood residues)*	Unit	

SECTION IV - ENERGY CONSUMPTION				
Downstream activities	**Machine(s) used in downstream processing mill**			
	Name of machine(s)	**Rated Power (kWh)**	**No. of machine**	**No. of machine in operation**
☐ Moulding				
☐ Furniture				
☐ Finger Joint				
☐ Other:				

APPENDIX C

CONTRIBUTION ANALYSIS

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Light Red Meranti	Global warming potential	47	9	23	21
	Acidification potential	52	7	22	18
	Eutrophication potential	47	7	24	22
	Photochemical ozone creation potential	59	6	23	11
	Ozone depletion potential	44	8	24	24
	Non renewable primary energy use	47	10	22	20

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Rubberwood	Global warming potential	33	7	36	25
	Acidification potential	31	5	44	19
	Eutrophication potential	21	3	56	20
	Photochemical ozone creation potential	42	5	18	35
	Ozone depletion potential	30	7	17	46
	Non renewable primary energy use	32	8	36	24

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Keruing	Global warming potential	50	11	13	26
	Acidification potential	55	10	13	22
	Eutrophication potential	50	9	14	27
	Photochemical ozone creation potential	67	8	12	13
	Ozone depletion potential	46	11	14	29
	Non renewable primary energy use	50	13	13	24

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Merbau	Global warming potential	47	9	21	22
	Acidification potential	52	7	22	19
	Eutrophication potential	47	7	43	3
	Photochemical ozone creation potential	62	7	21	11
	Ozone depletion potential	43	8	22	27
	Non renewable primary energy use	48	10	22	20

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Balau	Global warming potential	50	5	20	26
	Acidification potential	56	4	20	21
	Eutrophication potential	50	3	22	26
	Photochemical ozone creation potential	22	4	61	14
	Ozone depletion potential	46	4	20	30
	Non renewable primary energy use	51	5	19	25

Kelat	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
	Global warming potential	53	5	23	18
	Acidification potential	58	4	22	15
	Eutrophication potential	52	4	24	20
	Photochemical ozone creation potential	71	3	17	9
	Ozone depletion potential	49	5	25	21
	Non renewable primary energy use	54	6	23	18

Kapur	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
	Global warming potential	34	9	31	27
	Acidification potential	39	7	31	23
	Eutrophication potential	31	14	30	26
	Photochemical ozone creation potential	43	8	34	15
	Ozone depletion potential	26	19	28	27
	Non renewable primary energy use	34	10	31	26

Gerutu	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
	Global warming potential	55	3	25	17
	Acidification potential	60	3	24	13
	Eutrophication potential	55	2	26	17
	Photochemical ozone creation potential	67	2	21	9
	Ozone depletion potential	52	3	26	19
	Non renewable primary energy use	56	4	24	16

Meranti Mix	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
	Global warming potential	53	9	18	20
	Acidification potential	59	8	17	16
	Eutrophication potential	53	7	19	20
	Photochemical ozone creation potential	69	6	15	10
	Ozone depletion potential	49	9	20	23
	Non renewable primary energy use	53	10	17	19

Kedondong	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
	Global warming potential	54	4	27	15
	Acidification potential	60	3	25	12
	Eutrophication potential	53	3	29	15
	Photochemical ozone creation potential	65	3	24	8
	Ozone depletion potential	49	3	31	17
	Non renewable primary energy use	55	4	27	14

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Kempas	Global warming potential	52	6	30	12
	Acidification potential	57	5	28	10
	Eutrophication potential	51	4	33	12
	Photochemical ozone creation potential	66	4	24	6
	Ozone depletion potential	47	6	34	13
	Non renewable primary energy use	52	7	29	12

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Mixed heavy hardwood	Global warming potential	48	6	21	25
	Acidification potential	54	5	20	21
	Eutrophication potential	47	5	23	25
	Photochemical ozone creation potential	62	5	18	15
	Ozone depletion potential	43	6	23	28
	Non renewable primary energy use	49	7	20	24

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Mixed medium hardwood	Global warming potential	55	6	16	23
	Acidification potential	60	5	16	19
	Eutrophication potential	55	5	16	24
	Photochemical ozone creation potential	62	4	23	12
	Ozone depletion potential	52	6	16	27
	Non renewable primary energy use	55	7	16	22

	Potential environmental impacts	Harvesting	Transportation	Sawing	Kiln drying
Mixed light hardwood	Global warming potential	54	0.27	28	18
	Acidification potential	58	0.22	27	15
	Eutrophication potential	54	0.19	28	18
	Photochemical ozone creation potential	65	0.20	25	9
	Ozone depletion potential	52	0.26	28	20
	Non-renewable primary energy use	55	0.31	27	17

APPENDIX D

UNCERTAINTY ANALYSIS

Light Red Meranti

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	20.25	15.56	6.46	68.34
Diesel consumption (harvesting)	L	13.12	0.86	0.03	3.05

Rubberwood

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	32.02	27.38	12.78	74.73
Diesel consumption (harvesting)	L	8.95	6.10	5.28	15.10

Keruing

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	15.52	17.40	14.19	69.58
Diesel consumption (harvesting)	L	16.24	0.96	0.01	3.71

Merbau

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	21.18	18.42	12.58	78.10
Diesel consumption (harvesting)	L	1.31	0.53	4.33	

Balau

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	30.29	28.65	10.08	118.83
Diesel consumption (harvesting)	L	25.92	2.52	0.07	6.38

Kelat

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	37.53	22.18	9.54	107.53
Diesel consumption (harvesting)	L	21.37	0.94	0.41	3.15

Kapur

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	28.26	28.75	16.51	109.16

Gerutu

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	35.94	22.58	12.66	99.88
Diesel consumption (harvesting)	L	33.01	5.60	0.49	14.23

Mix Meranti

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption (sawmills)	kWh	23.15	14.95	8.29	57.79
Diesel consumption (harvesting)	L	16.32	1.48	0.29	5.31

Kedondong

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption in sawmills	kWh	47.58	23.02	7.79	99.88
Diesel consumption	L	21.58	1.49	0.14	5.02

Kempas

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption in sawmills	kWh	54.96	22.00	14.02	110.18
Diesel consumption	L	15.88	0.84	0.15	2.79

Mixed heavy hardwood

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption in sawmills	kWh	45.88	31.01	14.94	129.27
Diesel consumption	L	20.28	2.54	0.10	9.51

Mixed medium hardwood

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption in sawmills	kWh	33.87	25.03	10.85	109.16
Diesel consumption	L	20.56	0.91	0.16	3.10

Mixed light hardwood

Inputs	Unit	Weighted average	Standard deviation	Min.	Max.
Electricity consumption in sawmills	kWh	29.23	21.03	10.91	93.47
Diesel consumption	L	16.68	0.78	0.31	2.49

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