TECHNICAL DOCUMENT

LIFE CYCLE ASSESSMENT (LCA) OF PLYWOOD PRODUCTION IN PENINSULAR MALAYSIA

Version 1.0

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PROJECT BACKGROUND

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

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Malaysian Timber Industry Board

Life Cycle Assessment of Plywood Production 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 Technical Working Group members:

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EXECUTIVE SUMMARY

The life cycle assessment (LCA) conducted for plywood production in Peninsular Malaysia is the first comprehensive evaluation aimed at quantifying the environmental performance of the timber industry in the region. This study serves as a crucial step towards developing the first national database for the timber sector in Malaysia, with a primary focus on identifying key areas of environmental impact and proposing strategies to enhance sustainability across the production process. The LCA was conducted in compliance with ISO 14040/44 standards, ensuring transparency and rigor in assessing potential environmental impacts from raw material extraction through to the production of plywood. The main objectives of this LCA study are:

- To assess and quantify the environmental impacts associated with plywood production in Peninsular Malaysia.
- To develop a national database for the timber industry, allowing for more accurate data and future comparisons.
- To identify areas for improvement within the plywood production process to promote greater environmental sustainability.

The LCA results reveal significant environmental impacts linked to various stages of the plywood production process. Key findings include:

- The potential environmental impacts for 1 m^3 of plywood product is for global warming, acidification, eutrophication, photo-oxidant chemical formation and ozone depletion potentials were 433.75 kg CO_2-eq, 1.88 kg SO_2-eq**,** 13.08 kg PO_4-eq**,** 0.18 kg ethylene-eq and 5.35E-06 kg CFC-11-eq, respectively. Non-renewable primary energy demand was 6472.25 MJ.
- The study also assessed the calorific value of renewable energy, showing 4,847.25 MJ, which suggests that renewable energy sources play a significant role in the overall energy demand of plywood production.
- The main environmental impacts associated with plywood production were found to originate from the production stage of the process. This includes energy-intensive activities such as pressing, drying, and processing, which consume significant amounts of electricity and non-renewable resources.

The study identified several key areas where improvements could lead to substantial reductions in environmental impacts:

- Raw material usage: Optimizing the use of raw materials, especially logs and veneers, to minimize waste and improve efficiency.
- Energy efficiency: Improving energy usage in the manufacturing process, especially through better energy management practices and shifting to renewable energy sources.
- Sustainable material alternatives: Exploring the use of alternative, environmentally friendly materials in the production process, such as bio-based resins or recycled wood products.

This LCA study provides a comprehensive and rigorous assessment of the environmental impacts associated with plywood production in Peninsular Malaysia. The findings underscore the significant environmental impacts linked to the production stage and highlight opportunities for improvement in energy efficiency, raw material usage, and the adoption of sustainable practices. By implementing the recommendations outlined in this report, plywood manufacturers can reduce their environmental footprint, enhance sustainability, and contribute to a more environmentally responsible and circular timber industry. Additionally, the creation of a national database for the timber industry in Malaysia will provide a valuable resource for future LCA studies and industry benchmarks, promoting a more sustainable path forward for the sector.

1 INTRODUCTION

Plywood production is a vital component in Malaysia's timber industry, playing a significant role in supporting both markets and international export demands. As sustainability becomes an increasingly critical factor in global markets, transparency and accountability in environmental performance are becoming increasingly important. For the Malaysian plywood industry to remain competitive and aligned with global expectations, it is essential to assess and the potential environmental impacts of its production processes adhering to international standards.

The study on environmental performance of plywood production was carried out to meet these requirements using life cycle assessment (LCA) approach. LCA is a comprehensive tool that evaluates the potential environmental impacts associated with all stages of a product's life, from raw material extraction to production, use and disposal. The LCA concept is widely adopted by the global wood industry, due to its ability to offer a structured, transparent and data-driven foundation for environmental decision-making and product development. This report aims to generate a representative and reliable dataset that reflects plywood production in Peninsular Malaysia, while also supporting alignment with global sustainability goals.

This report adheres to internationally recognized LCA standards and has undergone a structured expert review process to ensure its credibility and accuracy. The review was conducted by two independent experts' reviewers:

(a) Professor Dr Marlia binti Mohd Hanafiah – Universiti Kebangsaan Malaysia
(b) Associate Professor Dr Amir Hamzah bin Sharaai – Universiti Putra Malaysia

Both reviewers were selected based on their expertise and extensive experience in the field of LCA. The review process was conducted over a period of four weeks following the completion of the final LCA draft. All reviewer comments were carefully considered by the project team and addressed in a transparent and systematic manner.

2 GOAL OF THE STUDY

The goal of this study is to conduct a cradle-to-gate LCA of plywood production in Peninsular Malaysia, which begins from log harvesting until the manufacture of plywood. The scope of this study excludes the use and end-of-life phases of plywood products. These phases are not included due to the wide variety of products that can be derived from plywood, which may undergo different uses, treatments, and disposal methods. These stages can be addressed in a more product-specific LCA study to provide a more detailed understanding of its overall environmental footprint.

2.1 Intended Applications

The data generated from this study can be applied as foundational for other LCA studies related to timber and timber-based products, offering a comprehensive and reliable basis for evaluating the environmental impacts of these materials. In addition, the standardized and transparent data can be used for the development of Environmental Product Declarations (EPDs) in line with the guidelines and requirements outlined in the relevant Product Category Rules (PCR). This environmental data will also enable the identification of environmental hotspots within the timber supply chain, allowing stakeholders to make informed decisions and aimed at reducing negative environmental impacts. This helps in shaping long-term strategies for local and global markets and supports on-going improvements in sustainability within the timber industry.

2.2 Intended Audience

The intended audiences 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.

2.4 Standards

The study has been carried out in accordance with the following international standards:

- ISO 14040 (2006) Environmental management – Life cycle assessment – Principles and Framework
- ISO 14044 (2006) Environmental management – Life cycle assessment – Requirements and Guidelines

3 SCOPE OF THE STUDY

The scope of the cradle-to-gate LCA study for plywood production in Peninsular Malaysia is outlined in the following sections.

3.1 Plywood Industry in Peninsular Malaysia

Plywood mills in Peninsular Malaysia are privately owned. These mills source their raw materials either directly from forest concessions, which are regulated areas designated for timber harvesting, or through third-party suppliers that distribute timber from various sources. The geographic distribution of plywood production is concentrated in a few key states. Kedah and Perak are the leading producers, together accounting for approximately 62% of the total plywood output in Peninsular Malaysia. This is followed by Pahang and Pulau Pinang, which contribute around 29% collectively. The remaining production is distributed among Johor, Kelantan, Negeri Sembilan and Selangor.

3.2 Descriptions of Product

Plywood is a wood-based panel consists of multiple layers of wood veneers, which are glued together with the grain of the veneer is arranged perpendicularly to each other. The veneer layers are obtained from logs, mostly from the natural forests and plantations in Peninsular Malaysia. Plywood manufacturers commonly use urea formaldehyde (UF), melamine urea formaldehyde (MUF) and phenol formaldehyde (PF) adhesives to bond the veneers. These adhesives are mostly sourced from local manufacturers. Other materials added with the adhesive are hardener and industrial flour to improve the bonding properties and curing performance of the glue mixture.

3.3 Plywood Markets

Plywood is one of the main wood-based products manufactured in Peninsular Malaysia, with an annual production of 210,000 m^3 in 2023. It is primarily used in the construction furniture, packaging and interior design sectors. Plywood is highly regarded in international markets for its consistent quality, durability and adaptability, contributing to its strong export performance. The export value in 2003 was about RM 566 million. The three largest importing regions were America (United States as the major importer with 51,000 m^3), Europe (major importer was United Kingdom with 48,000 m^3) and West Asia (major importer was Yemen with 50,000 m^3). Other significant markets include Australia (33,000 m^3), Japan (8,000 m^3) and Singapore (16,000 m^3).

3.4 Dimensions of Plywood

Plywood produced in Peninsular Malaysia typically comes in standard sizes of 914 x 1894 mm (3 x 6 feet) and 1219 x 2438 mm (4 x 8 feet)**,** which are widely used in the industries due to dimensional requirements of most construction and industrial applications. The thickness of the panels generally ranges from 3 mm to 30 mm**,** depending on its applications. The thinner panels are often used for interior linings and packaging, while thicker panels are used for structural purposes. In addition to these standard dimensions, plywood mills also manufacture panels in other sizes, tailored to meet specific requirements from domestic and international buyers.

3.5 Functional Unit

The main product of this study is plywood. Plywood mills in Peninsular Malaysia commonly used volume as the output unit for plywood. Therefore, the functional unit of this study is standardized as 1 m^3 basis of plywood.

3.6 System Boundary

The system boundary for this study is defined according to the cradle-to-gate approach, beginning with log harvesting and ends with the production of plywood. The transportation of materials is accounted for within the system boundary. Figure 3.1 illustrates the system boundary applied in this study. The following elements were excluded within the system boundary based on their relevance to the environmental profiles measured:

- Fixed capital equipment and facilities
- Transportation of plywood manufacturing workers

- All contributions from the production of machinery and infrastructure.

These exclusions are consistent with LCA best practices and are intended to focus the analysis on the most significant contributors to environmental performance within the defined cradle-to-gate scope. This approach ensures the results are representative of the production processes while maintaining methodological transparency.

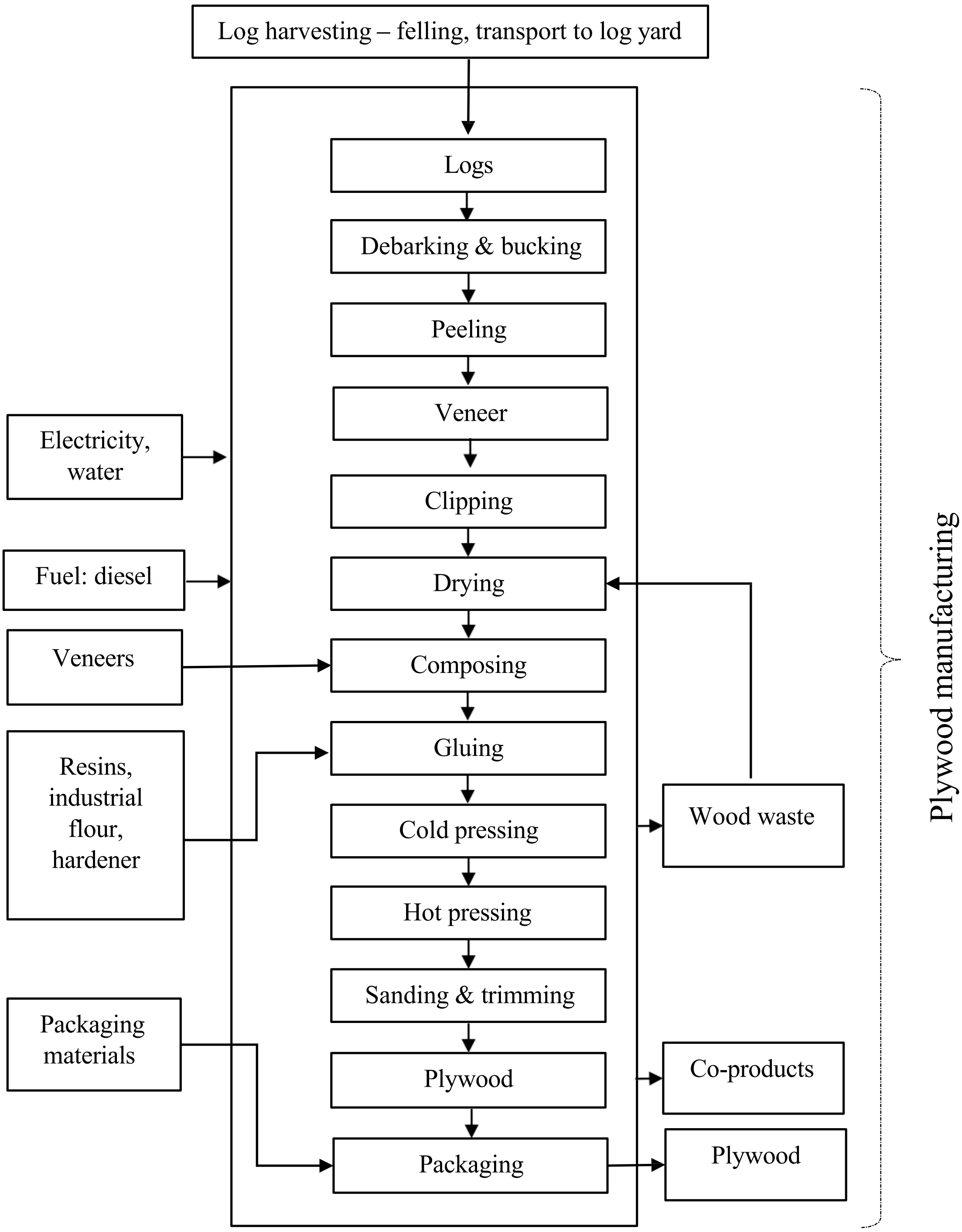

Figure 3.1: System boundary for production of plywood

3.7 Cut-off Rules

No cut-off rules were applied in the impact.

3.8 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. This study models the production of plywood using technologies commonly applied in plywood mills across Peninsular Malaysia. The reference period for this study was 2021–2024, selected to reflect the most recent and representative time window for both primary and secondary data. Primary data were collected within this period from participating plywood mills. When secondary data were used, efforts were made to ensure that the data were as current as possible and fell within the same time frame. Geographical representativeness in this study is based on data collected from plywood mmills located throughout Peninsular Malaysia. 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 clearly documented and justified. Methodological consistency was maintained through standardized data collection templates and the use of a single, reputable secondary data source (Ecoinvent 3.11), enhancing data compatibility. Reproducibility is supported through transparent documentation of all data sources, assumptions, and modelling procedures.

3.9 Allocation Rules

The environmental burdens were distributed between the main product and co-products, where applicable, during the harvesting and plywood production process. A mass allocation approach was applied, in which the inputs and outputs were distributed proportionally in accordance to the mass of each product and co-products.

3.10 Selection of Impact Assessment Categories

The inventory data was translated into several potential environmental impacts in life cycle impact assessment (LCIA) phase, as presented in Table 3.1. These indicators do not determine the severity or absolute significance of the impacts. Rather, they quantify the potential environmental harm based on scientific models and established data. It is important to note that LCIA results are relative expressions. They do not represent actual environmental effects, threshold exceedances, safety margins, or specific 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 3.2.

Table 3.2: The selection of environmental impacts according to timber LCA study

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
Primary energy from renewable material (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
Primary energy from non-renewable material (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

3.11 Interpretation of Results

The results of LCI and LCIA were interpreted according to the goal and scope. The interpretation addresses the following topics:

- Identification of significant issues
- Evaluation of completeness and consistency
- Sensitivity analysis
- Conclusions, limitations and recommendations

3.12 Software and Database

The model for this study was developed using openLCA 2.4, while Ecoinvent 3.11 database was used for the analysis.

3.13 Critical Review

The critical review of the study was performed according to ISO 14044 (2006) and TS 14071 (2014). The critical review process ensured that:

• the methods used to carry out the LCA are consistent with the standards;

• the methods used to carry out the LCA are scientifically and technically valid;

• the data used are appropriate and reasonable in relation to the goal of the study;

• the interpretations reflect the limitations identified and the goal of the study; and

• the study report is transparent and consistent.

The study reviewed by three international expert reviewers:

(a) Professor Dr Marlia binti Mohd Hanafiah – Universiti Kebangsaan Malaysia

(b) Associate Professor Dr Amir Hamzah bin Sharaai – Universiti Putra Malaysia

4 DATA COLLECTION

Primary data related to resources use and outputs were sourced from participating logging contractors and plywood mills manufacturers. Two survey forms were developed for this data collection. One was designed to gather information on harvesting activities (Appendix A), while the other was intended for plywood manufacturing processes (Appendix B). These survey forms were administered by trained LCA practitioners and was reviewed by designated experts. Data collection was carried out across Peninsular Malaysia from 2022 to 2024. Site visits and interviews were carried out with the logging contractors and plywood manufacturers. Direct measurements were taken where necessary, while at the sites, to ensure data accuracy and consistency. Each site visit and interview was conducted over the course of one day per facility, with the presence of officers from the District Forestry Office. Follow-ups communications were made via emails and phone calls to verify the data through cross-checking. All collected data were kept with strict confidentially.

Data for harvesting activities were collected at natural forests and rubber tree plantations. Eighteen harvesting sites were sampled for this study. The officers from State Forestry Department / District Forestry Office identified the harvesting sites of natural forests for data collection, following approval from the Forestry Department Peninsular Malaysia (FDPM). The selection of study locations was based on the previous year's timber production statistics, major producing states and the availability of active logging contractors during the survey period. Meanwhile, rubberwood harvesting sites were selected based on discussions with rubberwood sawmill operators. This survey captured log production of 30% from the total harvesting output in Peninsular Malaysia's for the year 2023. Although the number of surveyed log production may appear limited, the collected data provides a comprehensive overview of the country's harvesting practices, given that the distribution of species, machineries and equipment used, and harvesting methods applied. Information was recorded by trained personnel on log production, the amount of fuel used and types of machinery employed.

The participated plywood mills were surveyed to collect the activity data on material flow and energy consumption associated to plywood manufacturing. The data collection covered activities that begin from the transportation of materials until the production of plywood. The Malaysian Panel-Products Manufacturers Association (MPMA) assisted in identifying the the potential plywood mills for data collection. Three plywood mills participated in this survey, in which altogether accounted for 70.5% of the total plywood production in Peninsular Malaysia for the year 2021.

4.1 Secondary Data

This study primarily relied on data collected from the logging contractors and plywood manufacturers. Additionally, secondary data were also used to complete the cradle-to-gate process and link it with upstream activities, as outlined in Table 4.2. These secondary data were essential for providing a more comprehensive analysis and filling any gaps in the primary data. A thorough data quality assessment was conducted using the Pedigree Matrix approach to ensure the reliability and representativeness of the data used for plywood production, as highlighted in Table 4.2.

Table 4.2: Secondary data use and assessment of data quality

Inputs	LCI data source	Time related coverage	Geographical coverage	Technological coverage	Data quality assessment
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
Adhesive	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1 Geography: 2 Technology: 1
Hardener	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1 Geography: 2 Technology: 1
Industrial flour	Database: Ecoinvent 3.11	2021	Rest of the world	Same technology	Time: 1 Geography: 2 Technology: 1

4.2 Calculation Rules

In Peninsular Malaysia, log volume is reported in hoppus ton. Based on the functional unit of this study, the log volume in hoppus ton was converted into cubic metre (m^3) using the following equation (Eq. 1):

$$1 \text{ Hoppus ton of logs} = 63.66 \text{ ft}^3 = 1.8026474 \text{ m}^3 \quad \text{Eq. 1}$$

The collected data was checked to identify any missing information. The missing data were then verified with plywood manufacturers or logging contractors to determine whether they were omitted intentionally, represented as unknown values or recorded as zeros. In this study, it was identified that missing data is defined as information that was not reported by the plywood manufacturers or logging contractors.

The survey results for each unit process were standardized into production basis. The values reported by every surveyed plywood mill were used to calculate a production-weighted average (Eq. 2). This approach generates a composite representation of the surveyed plywood mills, ensuring that the final result accurately reflects the overall industry while maintaining the confidentiality of individual sawmills (Milota 2015).

$$W = \frac{\sum^{n} w_i X_i}{\sum^{n} w_i} \quad \text{Eq. 2}$$

Where:

W = weighted average
n = number of terms to be averaged
w_i = weights applied to x values
X_i = data values to be averaged

5 LIFE CYCLE INVENTORY (LCI) ANALYSIS

The life cycle inventory analysis presents the inputs and outputs for every unit process on the basis of 1m³ of plywood.

5.1 Log Harvesting

The primary sources of logs for plywood production in Peninsular Malaysia are hardwood logs from natural forests and rubberwood from rubber tree plantations. Harvesting in natural forests is permitted within production forest areas in the Permanent Reserved Forest (PRF), state land and alienated forest that have been licensed for harvesting by the Forestry Department of Peninsular Malaysia (Figure 5.1). The annual cut is established for each state, based on the forest inventory, in line with the principles of Sustainable Forest Management (SFM) under a 30-years cutting cycle.

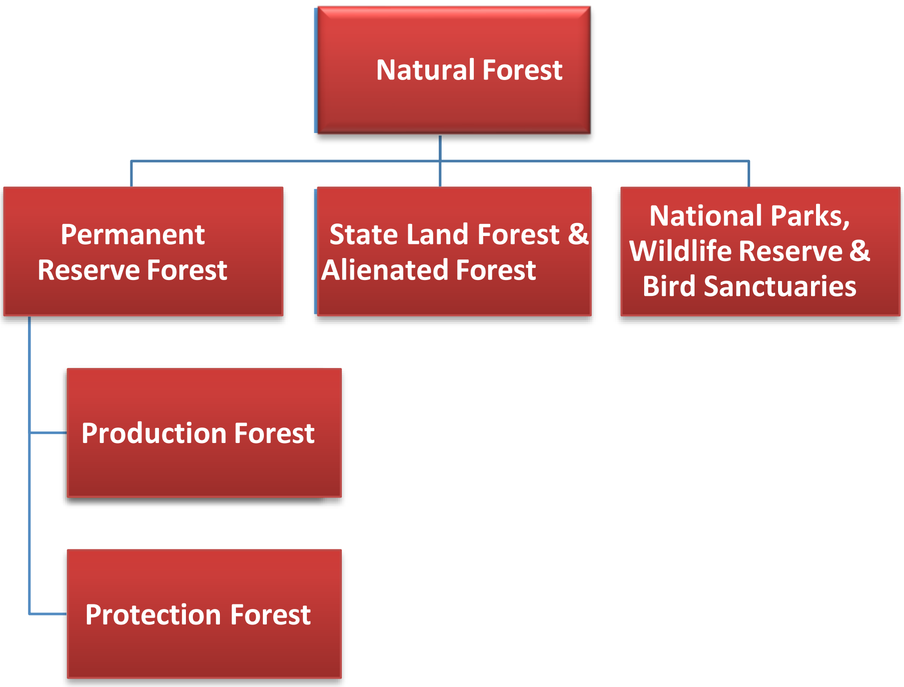

Figure 5.1: Classification of natural forest in Peninsular Malaysia

Harvesting activity begin with the construction and maintenance of forest roads using bulldozers (crawler tractors). Felled trees are delimbed and bucked using chainsaw. The logs are then skidded from the felling site to an intermediate log yard in the forest. The logs are then loaded into the winched lorry using an excavator and haulage between the intermediate and main log yard. A wheeled loader (log grabber) is used for unloading and stacking of logs at the main log yard. The logging operation is included with a logging camp and four-wheel drive pick-up truck for transportation of workers and supplies. Logs are sorted for species and quality, and scaled before being transported to plywood mills. No co-products were generated during harvesting of hardwood logs.

For rubberwood, the whole tree is uprooted by excavator. The felled trees are delimbed and bucked using chainsaw. Rubberwood logs are normally cut into 1.8 m for loading into lorry. An excavator is used to load the logs onto a 5–6 tonne lorry**.** In some cases, logs are loaded onto a winched lorry and hauled to the main log yard before transporting to rubberwood plywood mills by a lorry. During the rubberwood harvesting process, stump logs and chip logs are also generated as co-products. These co-products are sold to other mills. an allocation approach was applied to distribute the environmental burdens among these rubberwood co-products.

Data on the inputs and outputs of harvesting activities are presented in Table 5.1. Inputs include fuel consumption during the harvesting activities, while the outputs comprise of logs produced.

Table 5.1: Inputs and outputs for production of 1 m^3 of harvested logs

Timber species/group	Output	Input		Allocation (%)
	Log volume (m^3)	Fuel consumption (L/m^3)		
		Diesel	Petrol	
Hardwood logs	1	16.33	0.88	100
Rubberwood	1	8.95	0.52	40.98
Stump logs (co-products)	0.89			36.48
Chip logs (co-products)	0.55			22.54

5.2 Transportation of Materials

The primary material for plywood manufacturing is logs, which are delivered to plywood mills using 16-32ton Euro 3 double-axle lorries. These logs are transported either with shorter distances longer distances depending on the location of the harvesting sites relative to the plywood mills. Additional materials required for plywood production are delivered using single-axle lorries. The weighted average transport distances for these materials, are presented in Table 5.2. It is assumed that all lorries return to their point of origin without carrying a load.

Table 5.2: Average distance and diesel consumption for material transportation

Material	Mode of transport	Weighted average distance (km)
Logs	Lorry	58
Veneers	Lorry	87
Resins	Lorry	56

5.3 Plywood Manufacturing

Transported logs from harvesting sites are kept in the log yard. The process begins with debarking the logs using a debarking machine, followed by peeling veneers from the logs using a lathe machine. The veneers are then cut according to the required size and quality, and subsequently dried to a final moisture content of 12% using a dryer. The heat required for the drying process is generated by a steam boiler fuelled by wood residues.

Veneers are sorted based on quality and grouped into face, core and back veneers. Narrow veneers are joined together to obtain the desired dimensions. The face, core, and back veneers are glued and layered together, with the grain direction of each layer oriented perpendicular to the one below it. The lay-up generally consists of an odd number of veneer layers. Participating plywood mills use urea formaldehyde adhesive to produce plywood for dry uses, whereas melamine-urea formaldehyde and phenol formaldehyde adhesives are used for plywood intended for humid environment. The glued veneers undergo cold pressing, followed by hot pressing to cure the adhesive and bond the layers. After pressing, the plywood boards are sanded and trimmed to meet the required specifications.

In addition to plywood, the participating mills also generate wood residues, primarily in the form of off-cuts and sawdust, during the production process. These by-products are either utilized internally as fuel in the mills' steam boilers or sold externally, in which case they are classified as co-products. Furthermore, some mills also produce laminboard as an additional co-product. As these outputs are generated simultaneously with plywood and hold economic and functional value, an allocation procedure was applied to distribute the environmental burdens between the plywood and co-products.

Electricity was used in plywood production to operate the debarker, bucker, lathe, pneumatic and mechanical conveying equipment, fans, hydraulic pumps, and saws throughout the production process. Diesel fuel was consumed for off-road transportation, primarily to power forklifts and log grapples, in order to handle logs and plywood within the mill. Water was used in the steam boiler system, with most of it lost through evaporation during the process. No water emissions were reported from the plywood production activities.

The inputs and outputs for the production of 1 m^3 of plywood are presented in Table 5.3. This table outlines the materials used, energy and water consumption, as well as other ancillary materials involved in the manufacturing process.

Table 5.3: Weighted average of inputs and outputs for producing 1 m^3 plywood

Parameter		Unit	Value	Allocation (%)
Inputs				
Materials	Logs	m^3	1.74	
	Veneers	m^3	0.25	
	Urea resins	kg	36.09	
	Phenolic resins	kg	32.01	
	Industrial flour	kg	8.82	
	Hardeners	kg	0.22	
Fuel & utility	Diesel	L	4.47	
	Electricity	kWh	118.81	
	Water	m^3	0.43	
Outputs				
Product & co-	Plywood	m^3	1	76.58

products	Laminboard	m^3	1.22E-02	0.93
	Off-cuts	kg, OD	206.53	22.41
	Sawdust	kg, OD	0.73	0.08
Boiler	Wood residues	kg, OD	323.15	

5.4 Packaging

Plywood is typically packaged for shipping using plastic strapping and plastic guides. The quantities of these packaging materials used per 1 m^3 of plywood are detailed in Table 5.4. The total amount of packaging materials was fully allocated (100%) to the final product.

Table 5.4: Packaging Inputs for 1 m^3 of kiln-dried sawn timber

Packaging	Unit	Value
Plastic strap	kg	0.85
Serrated clip	kg	0.04

6 LIFE CYCLE IMPACT ASSESSMENT

Table 6.1 presents the potential environmental impacts associated with the production of 1 m^3 of plywood. The total global warming potential (GWP) was estimated at 433.75 kg CO_2-eq, indicating a significant contribution to climate change due to greenhouse gas emissions generated throughout the life cycle. The data reveal that the production phase is the most environmentally intensive stage, accounting for 62.60% of total GWP, suggesting high energy consumption and emissions during manufacturing operations.

Similar trends are evident across other impact categories. The acidification potential, at 1.88 kg SO_2-eq, reflects the emission of acidifying substances that may lead to soil and water degradation. Eutrophication potential, calculated at 13.08 kg PO_4^{3-}-eq, is particularly high relative to other categories, indicating a strong potential for nutrient pollution that could impact aquatic ecosystems. Photo-oxidant formation, at 0.18 kg ethylene-eq, signifies the release of substances that contribute to ground-level ozone and smog formation, which affect air quality and human health. Finally, the ozone depletion potential is minimal, at 5.35×10^{-6} kg CFC-11-eq, suggesting a limited role of ozone-depleting substances in this life cycle.

The production of 1 m^3 of plywood consumes approximately 6,472.25 MJ of non-renewable primary energy, highlighting a significant dependence on fossil-based energy sources such as coal, natural gas, and petroleum. This figure reflects the energy-intensive nature of plywood manufacturing, particularly in processes like log processing, veneer drying, resin application, and hot pressing, all of which require substantial thermal and electrical energy inputs.

Table 6.1: Potential environmental impacts of 1m^3 plywood production

Inputs	Log harvesting	Transportation of materials	Production activities	Total
Global warming potential (kg CO_2-eq)	110.61	51.61	271.53	**433.75**
Acidification potential (kg SO_2-eq)	0.61	0.21	1.06	**1.88**
Eutrophication potential (kg PO_4-eq)	0.23	0.08	12.78	**13.08**

Photochemical oxidant formation potential (kg ethylene-eq)	0.07	0.02	0.09	**0.18**
Ozone depletion potential (kg CFC-11-eq)	1.13E-06	5.23E-07	3.69E-06	**5.35E-06**
Energy resources: non-renewable (MJ)	1360.59	704.99	4406.65	**6472.25**
Renewable energy (MJ)			4847.25	**4847.25**

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 plywood production. In particular, this LCA accounts for 4,847.25 MJ of renewable energy per cubic meter of plywood, which is derived from wood residues generated on-site. This renewable energy is utilized predominantly in the veneer drying process, one of the most energy-intensive stages in plywood manufacturing.

The use of 4,847.25 MJ of renewable energy per functional unit indicates a substantial reliance on on-site biomass combustion, such as burning bark or off-cuts, to generate heat for veneer drying operations. This practice is common in plywood mills and serves both environmental and economic purposes. Key implications of this renewable energy use include:

- Lower net carbon emissions, since biomass is considered carbon-neutral under most LCA conventions, as the CO_2 released during combustion is offset by CO_2 absorbed during tree growth;
- Enhanced energy self-sufficiency, as mills that utilize their own residues for thermal energy reduce their dependence on purchased fossil fuels;
- A clear pathway for further emissions reductions, as increasing the share of biomass or integrating additional renewable sources (e.g., solar-assisted drying) can displace even more non-renewable energy.

7 INTERPRETATION

The life cycle interpretation is conducted based on the results from the LCI and LCIA, in alignment with the goal and scope defined for this study.

7.1 Identification of Significant Issues

The identification of significant environmental issues in this study was achieved through a comparative assessment of the potential environmental impacts associated with the three primary unit processes: log harvesting, transportation of materials and plywood manufacturing. This analysis forms a critical part of the Life Cycle Assessment (LCA) framework, which aims to evaluate the environmental burdens at different stages of a product's life cycle. The purpose was to identify environmental hotspots, those stages that contribute disproportionately to overall potential environmental impacts across multiple impact categories. By quantifying and comparing the contributions of each unit process to impact categories, this study provides a clear understanding of where environmental performance improvements are most urgently needed (Figure 7.1).

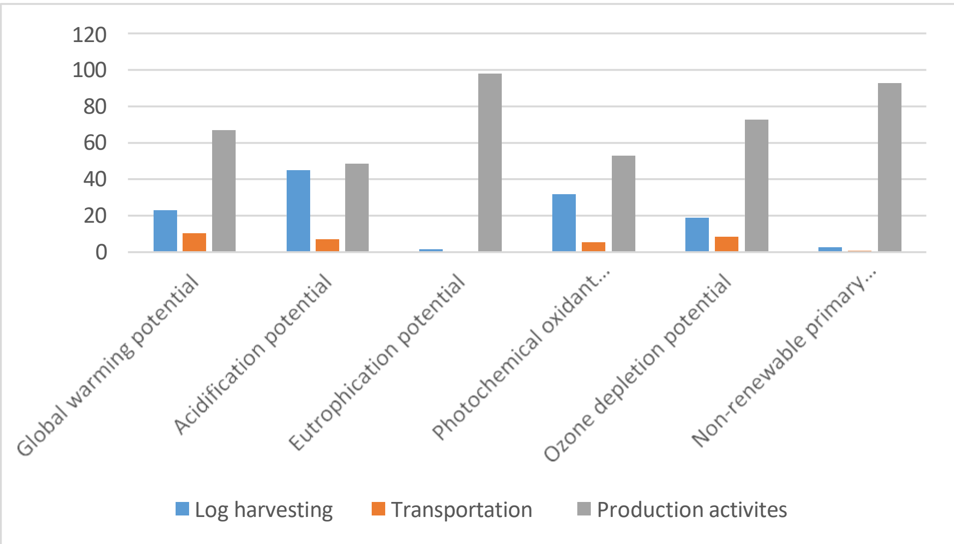

Figure 7.1 : The contribution analysis of 1m^3 of plywood production

Global Warming Potential

The production stage is the largest contributor to global warming potential, accounting for approximately 62.60% of total emissions. This is largely attributed to fossil fuel-based energy consumption in production processes. Log harvesting contributes 25.50%, mainly from diesel-powered equipment used in forest operations. Transportation accounts for 11.90%, primarily due to fuel combustion during raw material and product transport.

Acidification Potential

Production activities contribute 56.38% of total acidifying emissions, primarily from sulfur and nitrogen oxide emissions linked to fuel combustion. Log harvesting is also a significant contributor at 32.45%, resulting from machinery emissions and potential soil acidification due to forest disturbance. Transportation contributes 11.17%, stemming from emissions during logistics operations. Addressing acidification impacts will require attention to cleaner fuel use and improved combustion controls.

Eutrophication Potential

Eutrophication potential is overwhelmingly dominated by the production phase, contributing 97.71% of the total. This impact is driven by nutrient-rich wastewater discharges and chemical inputs such as resins and adhesives used during manufacturing. Log harvesting and transportation have minimal contributions, at 1.76% and 0.53%, respectively. Mitigation should focus on improving wastewater management and reducing nutrient-containing emissions at the production stage.

Photochemical Oxidant Formation Potential

The production stage is responsible for 50% of emissions contributing to ground-level ozone formation, primarily from volatile organic compounds (VOCs) emitted during resin application and combustion processes. Log harvesting contributes 38.89%, possibly from combustion equipment and VOC release from felled biomass. Transportation adds 11.11%. Reducing VOCs and adopting low-emission technologies are key strategies to address this category.

Ozone Depletion Potential

Ozone depletion is most strongly associated with production activities, which contribute 68.97% of the total. This is likely linked to the use or release of refrigerants from facility equipment. Log harvesting and transportation contribute 21.12% and 9.91%, respectively. Controlling refrigerant use and preventing leaks will be essential to mitigate these impacts.

Non-Renewable Primary Energy Use

Production activities are by far the largest consumer of non-renewable energy, accounting for 68.09% of total use. This reflects high energy demands for pressing, and other heat-intensive processes, predominantly fuelled by fossil energy sources. Log harvesting (21.02%) and transportation (10.89%) represent smaller shares.

7.2 Completeness Check

A completeness check was conducted to verify whether the data collected and modelled in the life cycle inventory (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 relevant unit processes, namely log harvesting, transportation, and plywood manufacturing. The data were reviewed for consistency in time period (2021–2023), geographical relevance (Peninsular Malaysia), and technological representativeness (current practices in participating facilities). Co-products, energy use, and emissions were included as per system boundary. Gaps in data were addressed through follow-up communications with facility personnel, and any remaining gaps were evaluated for their influence on results. Overall, the inventory data is considered sufficiently complete for all key processes, enabling reliable life cycle impact assessment.

7.3 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. The same methodological framework was consistently applied across all unit processes, including log harvesting, transportation, and plywood production. Primary data collection was standardised using structured survey forms, and all background data were sourced from the same LCI database to maintain consistency. Allocation methods, such as mass-based allocation for co-products, were uniformly applied. 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.

7.4 Uncertainty Analysis

Uncertainty is an inherent aspect of LCA and production modeling, arising from multiple sources such as data variability, model assumptions, methodological choices, and system boundaries. In the context of plywood manufacturing, 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 was performed using statistical method from industry survey data. Table 7.1 presents the uncertainty for inputs on log consumption, purchased veneers, phenolic resin, electricity consumption, diesel consumption in logging activities and UF resin.

Table 7.1: Survey data statistics for selected parameters

Materials	Unit	Weighted average	Std. Deviation	Mean	Min.	Max.
Log consumption	m^3	1.74	0.33	1.60	1.24	1.89
Purchased veneers	m^3	0.25	0.31	0.38	0.08	0.71
Phenolic resin	kg	32.01	18.52	27.38	14.52	48.60
Electricity	kWh	118.81	49.34	98.24	45.04	142.50
Diesel consumption	L	13.12	11.98	23.20	3.84	52.78
UF resin	kg	36.09	8.62	12.03	3.51	20.74

The analysis revealed notable differences in uncertainty levels across the various input materials and energy sources. These differences are summarized below:

- Log consumption exhibited the low uncertainty. This suggests that raw log inputs are stable and consistently used throughout the production process, likely due to standardization in log sizing or consistent sourcing practices.

- Purchased veneers showed the highest relative variability. This high variability could be attributed to differing thicknesses, types, or qualities of purchased veneers depending on market availability or operational needs.
- UF resin indicated significant inconsistency in usage. This may result from batch-based processing differences, inconsistent formulation, or variable adhesive demands depending on the type of product being manufactured.
- Phenolic resin highlight
- substantial uncertainty. Variations in phenolic resin usage might stem from shifts between production lines or substitutions in resin types.
- Electricity and diesel reflected high uncertainty. These energy-related inputs may fluctuate due to factors such as equipment efficiency, operational schedules, or differing energy sources across production sites.

7.5 Sensitivity Analysis

In situations where uncertainty could influence decision-making, conducting a sensitivity analysis is highly recommended. A sensitivity analysis was performed to assess how incremental changes in log consumption impact the environmental performance of plywood production. This approach enhances the transparency and credibility of the LCA, providing decision-makers with a clearer understanding of potential outcomes. It also helps prioritize areas for improvement and risk mitigation, enabling more informed and effective decision-making.

7.5.1 Log Consumption

A sensitivity analysis was conducted to evaluate how incremental changes in log consumption affect the environmental performance of plywood production. The base case assumes a log usage of 1.74 m^3 per cubic meter of plywood, based on average values reported by participating mills. To assess system responsiveness, log input was varied by ±10% and ±20%, representing realistic operational fluctuations due to process efficiency or material wastage (Table 7.2).

Table 7.2: Impact of different log consumption

Log usage (m^3)	Scenario	Global warming potential (kg CO_2-eq)	Acidification potential (kg SO_2-eq)	Eutrophication potential (kg PO_4^{3}-eq)	Photo-oxidant formation potential (kg C_2H_4-eq)	Ozone depletion potential (kg CFC-11-eq)
1.392	–20%	46.47	0.522	0.659	0.023	4.160
1.566	–10%	49.86	0.587	0.742	0.025	4.680
1.740	0%	53.26	0.652	0.824	0.028	5.200
1.914	+10%	56.65	0.717	0.906	0.031	5.720
2.088	+20%	60.04	0.782	0.988	0.034	6.240

A 20% reduction in log usage results in a 12.8% decrease in global warming potential, while a 20% increase causes a 12.7% rise, indicating a fairly linear relationship. This suggests that global warming potential is proportionally sensitive to changes in log consumption. Acidification and eutrophication potentials also show consistent trends. A 20% decrease leads to reductions of 20.0% and 20.0%, respectively, while a 20% increase results in increases of 19.9% and 19.9%, demonstrating near-linear sensitivity. Similarly, photo-oxidant formation and ozone depletion potential increase by 21.4% and 20.0%, respectively, when log usage rises by 20%, and decrease by comparable amounts when usage is reduced.

7.5.2 Purchased Veneers

A sensitivity analysis was conducted on purchased veneers on the environmental performance of plywood production. The base case assumes a veneer consumption of 0.25 m^3 per cubic meter of plywood. To assess system responsiveness, veneer input was varied by ±20% and +40%, reflecting fluctuations in material availability and usage (Table 7.3).

Table 7.3: Impact of different purchased veneers

Purchased veneer (m^3)	Scenario	Global warming potential (kg CO_2-eq)	Acidification potential (kg SO_2-eq)	Eutrophication potential (kg PO_4-eq)	Photo-oxidant formation potential (kg ethylene-eq)	Ozone depletion potential (kg CFC-11-eq)
0.20	-20%	51.53	0.615	0.798	0.027	4.890
0.25	Base	53.26	0.652	0.824	0.028	5.200
0.30	+20%	55.42	0.689	0.875	0.029	5.510
0.35	+40%	57.58	0.725	0.926	0.030	5.820

A 20% reduction in veneer usage results in a 3.2% decrease in global warming potential, while a 40% increase leads to an 8.1% rise, showing a mild non-linear sensitivity. Although the impacts are less dramatic compared to resin or diesel, increases in veneer consumption still lead to noticeable environmental burdens. Acidification and eutrophication potentials follow a similar trend. A 20% reduction in veneer usage results in decreases of 5.7% and 3.2%, respectively, while a 40% increase causes rises of 11.2% and 12.4%. Photo-oxidant formation and ozone depletion potential are also affected, with small but measurable changes. At a 40% increase, photo-oxidant formation rises by 7.1%, and ozone depletion by 11.9%.

7.5.3 Phenolic Resin

A sensitivity analysis was conducted for phenolic resin, with a base consumption of 32.01 kg per cubic meter of plywood. The analysis varied resin input by ±20% and +40%**,** reflecting variations due to material substitutions, supplier changes, or process inefficiencies (Table 7.4).

Table 7.4: Impact of phenolic resin usage

Phenolic resin (kg)	Scenario	Global warming potential (kg CO_2-eq)	Acidification potential (kg SO_2-eq)	Eutrophication potential (kg PO_4-eq)	Photo-oxidant formation potential (kg ethylene-eq)	Ozone depletion potential (kg CFC-11-eq)
25.61	-20%	45.46	0.560	0.711	0.024	4.290
32.01	Base	53.26	0.652	0.824	0.028	5.200
38.41	+20%	60.06	0.743	0.936	0.031	6.110
41.61	+40%	64.28	0.790	1.013	0.033	6.510

For global warming potential, a 20% reduction in resin usage leads to a 14.6% decrease, while a 40% increase results in a 20.7% rise, indicating a non-linear sensitivity, with higher resin usage causing disproportionately greater environmental impacts. Acidification and eutrophication potentials also exhibit similar non-linear trends. A 20% reduction leads to decreases of 14.1% and 13.7%, respectively, while a 40% increase results in increases of 21.1% and 22.9%. These categories, particularly eutrophication potential, are notably sensitive to changes in resin usage. Photo-oxidant formation and ozone depletion potential show less dramatic changes for small increases, but rise significantly at higher usage levels—by 17.9% and 25.2%, respectively, when resin usage increases by 40%.

7.5.4 Electricity Consumption

Electricity is a key input in the plywood manufacturing process, influencing environmental impacts across multiple categories due to the energy-intensive nature of pressing, and other mechanical operations. The sensitivity analysis for electricity consumption was conducted with a base value of 118.81 kWh per cubic meter of plywood. The analysis varied electricity consumption by ±10% and +20%, reflecting fluctuations in electricity use due to plant operational efficiency or changes in energy sources (Table 7.5).

Table 7.5: Impact of electricity consumption

Electricity consumption (kWh)	Scenario	Global warming potential (kg CO_2-eq)	Acidification potential (kg SO_2-eq)	Eutrophication potential (kg PO_4-eq)	Photochemical ozone formation potential (kg ethylene-eq)	Ozone depletion potential (kg CFC-11-eq)
06.93	-10%	49.58	0.601	0.755	0.026	4.680
118.81	Base	53.26	0.652	0.824	0.028	5.200
130.69	+10%	56.94	0.703	0.893	0.029	5.720
142.50	+20%	60.61	0.754	0.961	0.031	6.240

For global warming potential, a 10% decrease in electricity consumption results in a 6.9% reduction, while a 20% increase leads to a 13.7% rise, demonstrating the non-linear sensitivity of global warming potential. Larger increases in electricity consumption cause disproportionately higher impacts on global warming. Similarly, acidification and eutrophication potentials exhibit non-linear relationships. A 10% decrease in electricity consumption results in a 7.8% reduction in acidification and 8.4% reduction in eutrophication, while a 20% increase causes increases of 15.7% and 16.6%, respectively. Eutrophication potential is particularly sensitive to increases in electricity consumption. Photochemical ozone formation and ozone depletion potential also follow a similar trend, with moderate increases at 10%, but showing more significant changes when electricity consumption rises by 20%.

7.5.5 Diesel Consumption

A sensitivity analysis was conducted for diesel consumption, with a base value of 13.12 L/m³ per cubic meter of plywood. The analysis varied diesel usage by ±10% and +30%, reflecting variations in fuel consumption due to operational factors and process efficiencies (Table 7.6).

Table 7.6: Impact of diesel consumption in log harvesting

Diesel consumption (litres)	Scenario	Global warming potential (kg CO_2-eq)	Acidification potential (kg SO_2-eq)	Eutrophication potential (kg PO_4-eq)	Photochemical ozone formation potential (kg ethylene-eq)	Ozone depletion potential (kg CFC-11-eq)
1.81	-10%	49.92	0.602	0.750	0.025	4.560
13.12	Base	53.26	0.652	0.824	0.028	5.200
14.43	+10%	56.51	0.703	0.897	0.030	5.710
17.11	+30%	62.81	0.780	1.005	0.033	6.300

For global warming potential, a 10% decrease in diesel consumption results in a 6.4% reduction, while a 30% increase leads to a 17.9% rise, highlighting the non-linear sensitivity. Larger increases in diesel consumption cause disproportionately higher impacts on GWP. Similarly, acidification and eutrophication potentials exhibit non-linear responses, with 10% changes resulting in moderate increases or decreases, while 30% increases lead to larger environmental burdens. Eutrophication potential, in particular, shows a marked increase with higher diesel consumption. Photochemical oxidant chemical formation and ozone depletion potential show less sensitivity to small changes in diesel usage but experience more substantial increases when consumption rises by 30%. Overall, the analysis indicates that environmental impacts grow disproportionately with higher diesel usage, suggesting that reducing diesel consumption could lead to significant environmental benefits.

7.5.6 UF Resin

This sensitivity analysis investigates the effect of varying UF resin usage on environmental impacts across five major categories. The analysis compares the environmental impacts at different levels of UF resin usage. We use the base level (36.09 kg) as a reference point and assess the percentage change in environmental impacts when the resin usage is decreased by 10%, increased by 10%, or increased by 30%. This allows us to observe how changes in resin consumption affect the environmental burden (Table 7.7).

Table 7.7: Impact of UF resin

UF resin (kg)	Scenario	Global warming potential (kg CO_2-eq)	Acidification potential (kg SO_2-eq)	Eutrophication potential (kg PO_4-eq)	Photochemical ozone formation potential (kg ethylene-eq)	Ozone depletion potential (kg CFC-11-eq)
32.48	-10%	49.45	0.594	0.748	0.026	4.880
36.09	Base	53.26	0.652	0.824	0.028	5.200
39.70	+10%	57.06	0.710	0.899	0.029	5.510
46.93	+30%	64.87	0.790	1.013	0.033	6.060

The sensitivity analysis of UF resin usage across various environmental impacts shows that global warming potential, acidification potential, eutrophication potential, photochemical ozone formation, and ozone depletion potential are all significantly affected by changes in resin usage. For global warming potential, a 10% decrease in resin results in a 7.1% reduction, while a 30% increase leads to a 21.9% rise, highlighting the non-linear sensitivity, with larger increases causing disproportionately higher impacts. Similarly, acidification and eutrophication potentials exhibit non-linear responses, with 10% changes resulting in moderate increases or decreases, while 30% increases lead to larger environmental burdens. Eutrophication, in particular, is highly sensitive to increased resin usage.

Photochemical ozone formation and ozone depletion potential show a less pronounced sensitivity to small changes in resin usage, but both categories experience substantial increases when usage rises by 30%. Overall, the analysis indicates that environmental impacts grow disproportionately with higher resin usage, suggesting that efforts to reduce resin consumption could lead to significant environmental benefits.

7.6 Assumptions and Limitations

This study is subject to several assumptions and limitations due to constraints in methodology, data gaps, lack of information, and other specific conditions that may affect the interpretation of results. These are outlined as follows:

1. **Logging in Natural Forests:**
   Logging activities were not conducted in all states within Peninsular Malaysia due to a moratorium (temporary suspension). The affected states include Pulau Pinang, Selangor, Melaka, Johor, and Perlis.
2. **Transportation of Logs:**
   The precise distance from logging log yards to checkpoints, and further to plywood mills, could not be accurately identified. Based on discussions with the Forestry Department, the distance from the log yard to the checkpoint was assumed to be 5 km.
3. **Impact of COVID-19 Pandemic:**
   Plywood mills experienced a three-month closure during the Movement Control Order in 2021, when the Malaysian government implemented nationwide quarantine measures to curb the spread of COVID-19.
4. **Veneer Dryer Emissions:**
   Data on-site emissions from the veneer drying process, such as volatile organic compounds (VOCs) and dry particulate matter (dust and ash), could not be collected due to the unavailability of suitable measuring equipment. However, the small quantity of ash generate during combustion was repurposed as fertilizer.
5. **Data gaps and their significance** :
   Due to the lack of Malaysia-specific data on environmental emissions, characterization factors, and other inputs, this study relied on the most relevant available data from sources suited to the Malaysian context or internationally recognized databases.

8 CONCLUSIONS

The LCA of plywood production in Peninsular Malaysia provides a comprehensive analysis of the environmental impacts associated with key stages of production, including log harvesting, material transportation, and plywood manufacturing. The study reveals significant environmental impacts, particularly in terms of global warming potential (GWP), acidification, eutrophication, and energy consumption.

A significant portion of the environmental impacts is driven by the plywood manufacturing process, which accounts for more than 70% of the total emissions, primarily due to electricity consumption and the energy-intensive nature of the production activities. Log harvesting and transportation also contribute to environmental burdens, but to a lesser extent. The results indicate that reducing electricity consumption, improving energy efficiency, and optimizing material use can substantially mitigate the environmental impact of plywood production.

The sensitivity and uncertainty analysis highlight the importance of key inputs, such as log consumption, purchased veneers, phenolic and UF resins, diesel usage, and electricity consumption. Notably, the sensitivity of environmental impacts to changes in material and energy consumption suggests that strategic adjustments in these areas can lead to significant reductions in environmental burdens. For instance, reducing the usage of phenolic and UF resins, which have a high non-linear sensitivity to environmental impacts, could provide notable benefits in terms of global warming, acidification, and eutrophication potentials. Based on the study findings it is recommended that:

- Energy Efficiency Improvements: Since the plywood manufacturing process relies heavily on electricity, especially in energy-intensive operations like pressing, drying, and cutting, it is recommended to invest in energy-efficient technologies and renewable energy sources. A shift towards renewable energy (such as solar or biomass) could significantly reduce the impacts of production.

- Reduction of Resin Usage: The sensitivity analysis clearly shows that both phenolic and UF resins have a substantial impact on environmental performance, especially in terms of global warming potential and eutrophication. Manufacturers should explore opportunities to reduce resin consumption through process optimization, use of alternative resins, or improving adhesive efficiency.

- Optimization of Material Usage: Reducing material waste and optimizing the usage of logs and purchased veneers can lead to reduced environmental impacts. Implementing better sourcing strategies and increasing the recycling of wood by-products can minimize waste and contribute to a circular economy.

- Sustainable Transportation Practices: Since transportation contributes to emissions, optimizing logistics by reducing transport distances, utilizing fuel-efficient vehicles, or shifting to lower-carbon transportation options can further reduce environmental burdens.

- Uncertainty Reduction: To enhance the accuracy of future LCA studies, it is recommended that data variability be further reduced by gathering more local, site- specific data. Conducting more detailed surveys and engaging in long-term data collection would provide a more accurate reflection of environmental impacts, particularly in the context of local manufacturing practices and regional energy mixes.

- Adoption of Green Certifications and Standards: To promote sustainable practices in the plywood industry, manufacturers should consider obtaining certifications such as Forest Stewardship Council (FSC) and others that emphasize environmentally responsible production. Such certifications could lead to more sustainable sourcing of raw materials, reducing deforestation and promoting better forest management.

- Continuous Monitoring and Evaluation: Regular updates to the LCA model should be undertaken as new data becomes available, especially regarding energy consumption patterns, material sourcing, and technological advances in production. Incorporating the results of future studies and incorporating technological innovations can help further reduce the environmental footprint of plywood production.

By following these recommendations, the plywood industry in Peninsular Malaysia can reduce its environmental impacts while maintaining production efficiency. Additionally, these actions will help align the industry with global sustainability trends, enhancing its competitive edge in environmentally-conscious markets.

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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 sawntimber:	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:
8.5.6.1 Log book / removal pass
8.5.6.2 Fuel purchases record
8.5.6.3 Fuel usage record
8.5.6.4 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:	Curated 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.* *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 = 1.8027 m^3* • *Sawn timber : 1 ton = 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: FACTORY INFORMATION
Plywood information is divided into two sections:

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

SECTION I: COMPANY PROFILE	
Name	
Address	
Contact person	
Telephone	
Email	

SECTION II: OPERATION OVERVIEW	
1	Year: 2021 Production in that year: ________________ton or volume
2	Production output: ☐ Plywood ☐ Others, Name:_____________________________
3	Do you have any downstream production? ☐Yes ☐ No
4	Factory normal operating hours:

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

5 Total working days per month:

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

6	Do you operate during MCO? ☐ Yes ☐ No If **yes**, please fill on the factory operating hours: No. of hours per day : _______hours No. of days per week : _______hours Break : _______hours If **no**, how long factory was closed? ____________months/days

PART B: MACHINE/EQUIPMENT USED IN PLYWOOD MANUFACTURE

	Machines / Equipment	Number	How many in the operation?	Rated power (kW/HP)	Normal capacity e.g. per day

1.	Debarker				
2.	Peeler/ lathe				
3.	Drier				
4.	Resin spreader				
5.	Cold press				
6.	Hot press				
7.	Sander				
8.	Dust extractor				
9.	Air compressor				
10.	Knife grinder				
11.	Composer				
12.	Sizer				
13.	Boiler – electric, diesel, waste				
14.	Vehicle				
	- Forklift			-	-
	- Log grabber			-	-
15.	Others				

PART C: UTILITIES/ENERGY

	Utility/Energy	Consumption
1.	Electricity (purchased) (kWh/year)	
2.	Generate own electricity (Co-Gen)	
3.	Public water (litre/year)	
4.	Diesel (litre/year)	
5.	Petrol (litre/year)	
6.	Others	

PART D: WOOD INPUT – TRANSPORTATION, VOLUME

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

Log/veneer source e.g. matau, port	distance to factory (km)	Species	Volume (m^3)	Fuel consumption (l)

PART E: CHEMICAL/ADDITIVES USED – TRANSPORTATION, VOLUME
Including resins, hardener, wood putty, insecticide, industrial flours.

Input	Source e.g. produce factory, port	distance to factory (km)	Volume (m^3)	Fuel consumption (l)

PART F: OUTPUT
Products produced such as plywood, laminboard, veneer, waste sold.

Product	Volume (m^3)

PART G: PACKAGING MATERIALS USED – TRANSPORTATION, VOLUME
Items used in packaging such as strapping band, tape, plastic sheet.

Input	**Source e.g. produce factory, port**	**distance to factory (km)**	**Volume (m^3)**	**Fuel consumption (l)**

PART H: MILL RESIDUES					
Types of residue	**Sold**	**Internally Used (Fuel)**	**Internally Used (Other)**	**Landfilled**	
	metric ton / kg	**metric ton / kg**	**metric ton / kg**	**metric ton / kg**	
Sawdust					
Off-cuts					
Bark					
Slab					
Others: ___________					
Others: ___________					
Others: ___________					

PART I: BOILER PROCESS				
Diesel (Litre)	**Sawdust (Tonne metric)**	**Off-cuts (Tonne metric)**	**Water (litre)**	**Other:** ___________

-End of question. Thank you for your feedback-

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