



**LIFE CYCLE ASSESSMENT FOR ENVIRONMENTAL
PRODUCT DECLARATION OF TROPICAL PLYWOOD
PRODUCTION IN MALAYSIA AND INDONESIA**

REPORT

**PREPARED FOR
INTERNATIONAL TROPICAL TIMBER ORGANIZATION**

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LIFE CYCLE ASSESSMENT FOR ENVIRONMENTAL PRODUCT DECLARATION OF MERANTI PLYWOOD PRODUCED IN MALAYSIA AND INDONESIA

Background

Environmental certifications, eco-labels and environmental claims abound in the market place, creating confusion among companies and consumers alike. Many of these claims focus on one or two product attributes. Others are more comprehensive but may lack commonalities in scope or evaluation methods to allow straight forward comparison of products. Some have no scientific basis. Many claim to make reference to ISO 14040 and ISO 14044 in establishing the environmental impacts through Life Cycle Assessment (LCA). However, in comparison of one product to another using LCA results it is essential that the same attributes be compared within the same family of products to ensure consistency. There are possibilities that LCAs are conducted at different levels and bases making them difficult to be compared. Environmental Product Declarations (EPDs) are based on Product Category Rules (PCR) that specify the parameters to be considered for a given group of products. EPD provides complete, credible data and allows for a fair basis of comparison among products. An EPD is a comprehensive, internationally recognized report that compiles and standardizes technical sustainability information, eliminating the need to wrestle with a dozen or more individual documents. No other single certification or label combines all of these factors. EPDs solve the problems associated with manufacturer of products publishing undifferentiated, selective, unverified, misleading, incomparable and often incomprehensible environmental data derived from non standard methodologies. EPD nowadays is gaining market momentum as a tool that communicates the environmental performance of a product; in this project it is to measure the environmental performance of meranti plywood production.

The important foundation that an EPD is built upon is the Life Cycle Assessment. An LCA compiles and evaluates, according ISO 14040, the inputs, outputs and the potential environmental impacts of a product system throughout the life cycle. Information generated from the process will be relevant, verifiable and comparable. LCA evaluations have been used in many industries and fields of research, and it is helpful to assess building products and assemblies in an integrated design process.

Considering the developments related to EPD and LCA, as well as the increasing international timber markets' requirements for green products (e.g. Green building rating systems like BREEAM in the UK), ITTO has commissioned this study to conduct LCA on meranti plywood where EPD can be established depending on the schemes or Product Category Rules used. The outputs will fill critical gaps in the environmental performance of tropical wood products; and increase market acceptance and specification of tropical/meranti wood products as a green building material.

Introduction

Life Cycle Assessment (LCA) is normally conducted for a product system from cradle-to-grave, by accounting all the environmental impacts from the resource extraction to end-of-product disposal based on a series of LCA standards created by the International Organisation for Standardization (ISO): ISO 14040 and ISO 14044. LCA as defined by ISO 14040 and ISO 14044 is compiling and evaluation of inputs and outputs data, and the potential environmental impacts of a product system during the product's lifetime. The result may then be used for: identifying opportunities to improve the environmental aspects of a product at the various stages in its life cycle, decision making in industry and organization in the selection of products for application, and marketing of the products (e.g. an environmental claim, eco-labelling scheme or environmental products declarations).

There are basically three type of environmental labels or declarations under ISO 14020 series: Type I environmental labelling programme is a voluntary, multi-criteria-based third party programme (ISO 12024:1999(E)), Type II environmental labelling is self-declared environmental claims that may be made by manufacturers, importers, retailers or anyone else who are likely to benefit from such claims (ISO 14021:1999(E)), and Type III environmental declarations that present quantified environmental information on the life cycle of a product to enable comparisons between products fulfilling the same function (ISO 14025:2006). Product Category Rules (PCRs) for product groups are developed for communication of environmental claims (Type III) such as PCR Wood Materials (IBU 2009), Product Category Rules (PCRs) for North American Structural and Architectural Wood Products (UN CPC 31), Sustainability of construction works—Environmental product declarations, and Core rules for the product category of construction products (BS EN 15804:2012). Depending on the schemes or PCRs, the declared environmental impacts are Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Photochemical Ozone Creation Potential (POCP) and Ozone Depletion Potential (ODP) (Appendix 1). Other environmental impacts such as Terrestrial Ecotoxicity Potential (TEP), Human Toxicity Potential (HTP), Freshwater Aquatic Ecotoxicity Potential (FAEP), Marine Aquatic Ecotoxicity Potential (MEP), and Abiotic Depletion Potential (ADP) may also be included. There are also schemes that only deal with GWP or greenhouse gas emission (GHG) in terms of carbon dioxide emission, normally known as carbon footprint (PAS 2050:2011).

There are active developments of LCA tools and applications in Europe, North America and Japan. However, in the tropical timber producing and processing regions in South East Asia, there are very few studies or attempts to conduct LCA on the tropical timber products (Murphy 2004). LCA study of the timber product does not only involve foreground data on timber and the manufacturing processes, but also other local inputs and outputs (background data) to holistically represent the whole product system or life cycle. It requires quality local background datasets that may not be available to assess the whole product system satisfactorily, e.g. local electricity and fuel supply, transportation.

Plywood companies in Malaysia and Indonesia use mainly tropical/meranti timbers supplied from forest concession areas owned by their subsidiary companies or purchased from other suppliers and the plywood is exported and may be further processed by the users. The further processing in some cases, use phase and end-of-product disposal may be varied and are not fixed. For this study on plywood manufacturing, LCA was conducted from cradle-to-gate. Thus the first task was to conduct gate-to-gate life cycle inventory at the plywood companies and then to quantify the environmental impact based on established background databases available for major input materials particularly logs and resin. The upstream operation or log extraction and transportation and resin were based on available local dataset and references. These issues were discussed and agreed at a pre-study workshop with stakeholders representing plywood companies/associations, ITTO representatives and the consultants/researchers. The meeting also agreed to conduct the study at three to four representative plywood companies each in Malaysia and Indonesia.

Product definition

Meranti or tropical plywood is made using mixed light to medium hardwoods consisting mainly of meranti groups of timbers in Malaysia and Indonesia. The plywood is used widely in the building construction sector as its strength, durability and cost make it a preferred building material. A small volume may be used for furniture manufacture. Plywood is made using veneers composed with wood grain perpendicularly to each other with mainly formaldehyde based resin. Plywood is normally made up of odd number of veneers, e.g. 3, 5, 7, 9, 15. The overall plywood thickness may range from 3 mm up to 28 mm and the sizes are usually 3' x 6' and 4' x 8'. Besides making the main product—plywood, a plywood plant may also sell dried veneer and other products like laminated veneer lumber (LVL) and block board using timber recovered from peeler cores.

Main product standards

Referenced standards used in the plywood plants are,

<u>No</u>	<u>Standards</u>	<u>TITLE</u>
1	MS 228:1991	Specification for Plywood (First Revision)
2	MS 544 : PART 4 : SECTION 1 : 2001	Code of Practice for Structural Uses of Timber: Part 4 : Timber Panel Products: Section 1 – Structural Plywood
3	MS 544 : PART 4 : SECTION 2 : 2001	Code of Practice for Structural Uses of Timber Part 4 : Timber Panel Products : Section 2 – Marine Plywood
4	BS 1088-1: 2003	Marine plywood – Part 1: Requirements
5	BS EN 314-1: 1993	Plywood – Bonding quality Part 1. Test methods
6	BS EN 314-2: 1993	Plywood – Bonding quality Part 2. Requirements
7	JAS MAFF, Notification no 1751, 2008	Japanese Agricultural Standard For Plywood
8	MTIB-CB-PS-01:09/2013	Plywood Certification Standard

Description of the manufacturing companies

The plywood companies in Malaysia and Indonesia are privately owned manufacturing entities that purchase raw materials from forest concession owners. Some companies may also own the concession areas and normally these are operated independently. The plywood companies are usually large, producing more than 5,000 m³/month of various types of plywood. Usually, the plywood plants will use all the wood wastes generated for process heat and co-generation of electricity for their own consumption. Additional electricity requirement is obtained from the national electricity grid. In some places, coal may be used to generate electricity and thermal requirement in the companies.

Raw materials and composition

The main raw materials are tropical timber obtained locally. The common timber species are meranti group (42%), keruing group (7%), kapur (0.5%) and the mixed light hardwoods (50.5%) based on actual data collected. In this region, logs are normally delivered using tug boats. The formaldehyde based resins (urea-formaldehyde, melamine-urea-formaldehyde and phenol-formaldehyde) are supplied by local adhesive companies.

Manufacturing process

Plywood production process in general are the same among the plywood companies. However, they may vary in terms of specific condition based on their raw material condition, equipment/machines, thickness, kind of plywood and the target quality of the produced plywood. Figure 1 describes the meranti plywood manufacturing process in Indonesia and Malaysia.

Brief description of the plywood production process are as follows;

Log yard: Meranti logs as plywood raw material are sorted in log pond or log yard, especially to determine the wood species and log quality. In general, log pond is used for floater wood species and log yard is used for sinker wood species. Figure 2 shows the condition of the meranti log for plywood production.

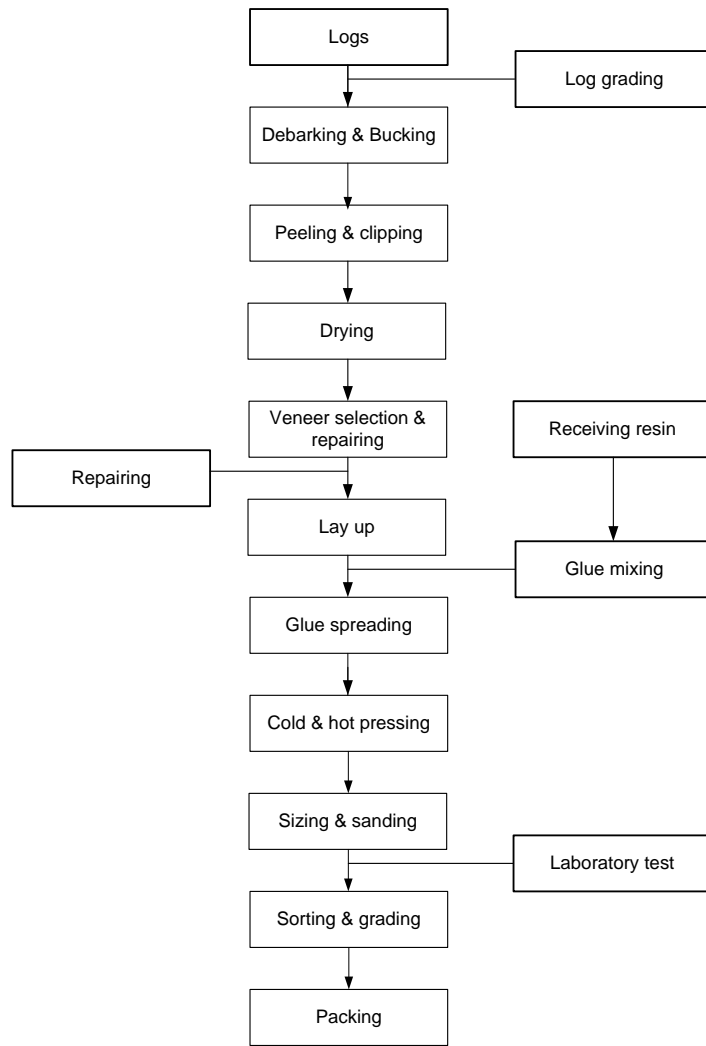


Figure 1. Meranti plywood manufacturing process



Figure 2. Meranti logs for plywood production

The wood species used in the plywood companies sampled were mainly the family of meranti species for face veneer. For core veneer, all wood species are permitted when they do not affect its utilization. Table 1 shows an example of log receiving standard of the plywood industry sampled.

Table 1. Log receiving standard

No.	Item	For Face Veneer	For Back or Core
1.	Length	300 cm up	100 cm up
2.	Diameter	40 cm up	18 cm up
3.	Crack	Total length of crack on both side log end shall not be more than 10% of the log length.	Total length of crack on both side log end shall not be more than 20% of the log length.
4.	Knot (Sound Knot)	Permitted up to diameter of 10 cm and up to a number of 2 in every 2 m length.	Permitted.
5.	Decay	Permitted up to a depth of one twelfth of the radius of the log	Permitted to up to a depth of one eighth of the radius of the log.
6.	Worm hole	Permitted up to a depth of one twelfth of the radius of the log.	Permitted to up to a depth of one eighth of the radius of the log
7.	Twist of the grain	Permitted up to an angle of 10° of the log's axis.	Permitted up to an angle of 15° of the log's axis.
8.	Ring crack	Permitted if 10 cm^2 from log center.	Permitted if 15 cm^2 from log center.
9.	Others	Permitted if slight	Permitted if slight.

Bucking: Logs emerge from the debarker after having been stripped of its bark (debarking). The meranti logs were transported using hoist to the bucking/cross-cutting section into billets/blocks for peeling. In some plywood companies, meranti logs may have been debarked in the forest concession area, so debarking process in the plywood industry is not necessary. The logs cut to 3, 4, 6 and 8 feet based on the order and the standard used. Figure 3 shows the bucking process.

Log grading and cleaning: The cut logs/billets are then graded and transported to the log washer using conveyor. The logs were cleaned using water spray. The log grading and washing process can be seen in Figure 4.



Figure 3. Log cutting process.



Figure 4. Log grading and cleaning.

Peeling: Log centering before peeling process using laser projection as shown in Figure 5. The block is peeled using rotary lathe. Rotary veneer is the most popular technique in veneer production for ordinary plywood production. The veneer thicknesses for core veneer were 1.3 mm; 1.6 mm; 2.2 mm; 3.6 mm; and 4.0 mm, while the face and back veneer thicknesses were 0.60 mm; 0.65 mm; 0.70 mm; 0.80 mm; 0.85 mm; 1.70 mm. Figure 6 shows the peeling process of meranti log.

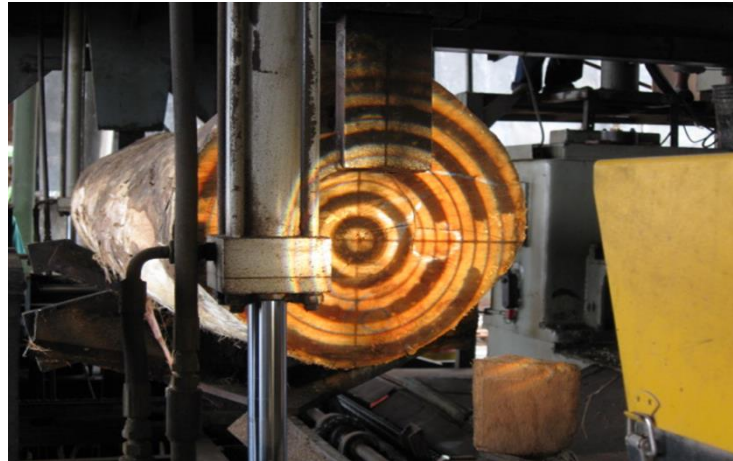


Figure 5. Log centering



Figure 6. Peeling process of meranti log.

Table 2 shows the sample of the veneer peeling common parameters of meranti plywood company in Indonesia and Malaysia.

Table 2. Veneer peeling conditions

Parameter	Veneer Thickness (mm)			
	0.60	1.30	1.40	3.30
Peeling Speed (m/min)	Max 200	Max 200	Max 200	Max 200
Knife Angle (°)	19°30`	19°30`	19°30`	19°30`
Cutting Angle (°)	21°00`	21°00`	21°00`	21°00`
Clearance Angle (°)	0°	0°	0°	0°
Vertical Gap Between Spindle	0~0.6	0~0.6	0~0.6	0~0.6

And Nose Bar (mm)				
Vertical Gap Between knife And Nose Bar (mm)	0.05~0.30	0.05~0.30	0.05~0.30	0.05~0.30
Horizontal Gap Between knife And Nose Bar (mm)	0.45~0.54	1.13~1.17	1.22~1.26	2.95~2.97
Distance Gap Between knife And Nose Bar (mm)	0.54	1.17	1.26	2.97
Maker's Name	Taihei	Meinan	Taihei	Meinan
Model	HYB-NAL-8	HYB-NAL-8	V28-AB-W	HYB-NAL-8

Reeling and unreeling veneer: the produced veneer was reeling using babon and sent to unreeling section using automatic transport machine. Figure 6 shows the reeling and unreeling veneer process.



Figure 6. Reeling and unreeling of veneer

Veneer Drying: Green veneer is dried in steam or electric heated ovens. The veneer is dried in “continuous or batch dryers” to maximum 12 % moisture content for face and back; and maximum 10% for core and centre core. The continuous dryer or roll dryer temperature is 180° C. Drying time range from 10 minutes to 25 minutes depend on veneer thickness, thicker veneer required longer drying time. Figure 7 shows continuous veneer drying process.



Figure 7. Continuous veneer drying.

Table 3 shows an example of veneer drying condition on meranti plywood industry in Indonesia and Malaysia.

Table 3. Dryer operation conditions

Type item		Continuous dryers				Roll Dryer
		No. 1	No.2	No.3	No.4	No.5
Number Sections		18	17	18	17	14
Number of Decks		3	3	3	3	6
Length of Heating Section (m)		36	34	36	34	28
Steam Pressure (kg/cm ²)		10~15	10~15	10~15	10~15	10~15
Temperature (°C)	In	170~190	170~190	170~190	170~190	150~175
	Out	140~180	170~190	140~180	147~190	165~185
Feeding Speed (m/minute)		20-40	20-40	4-18	8-15	4-14
Dry Time (minute)		0.9-1.8	0.8-1.7	2.0-4.5	2.3-4.3	2.0-7.0
Dry Veneer Thickness (mm)		0.80		2.00		
Maker's Name		UROKO	GREENZE BACH	UROKO	GREENZEB ACH	BABCOCK
Model		CD-2.8Mx18Hs=3cs3D	EBD.III 280/34M.k (65)	CD-2.8Mx18Hs=3cs3D	EBD.III 280/34M.k(65)	RD VI 460/28Mk (45) "I"

After dryer, each dried veneer should be separated to face, back and inner layer and proceed to next processing step.

Veneer selection and repairing; Dried veneer than selected based on their quality and repaired if necessary. Figure 7 shows veneer selection and repairing process. Table 4 shows an example of face, back, inner veneer selecting standard of meranti plywood industry in Indonesia and Malaysia.



Figure 7. Veneer selection and repairing

Table 4. Face, back, inner/core layer selecting standard

Criteria Item	Face		Back, Inner/core Layer
	Quality 1	Quality 2	
Total number of live knot, dead knots, bark pockets and resin pockets, whose largerst diameters are exceeding 5 mm.	Permitted up to a number of quintuple of the panel area expressed in square meters (if there are fractions below a decimal point add one (1) to integer part).	Permitted up to a number of sextuple of the panel area expressed in square meters (if there are fractions below a decimal point add one (1) to integer part).	Permitted up to a number of sextuple of the panel area expressed in square meters (if there are fractions below a decimal point add one (1) to integer part).
Live knots.	Permitted up to a longer diameter of 25 mm.	Permitted up to a longer diameter of 45 mm.	Permitted up to a longer diameter of 45 mm and widthwise diameter of not exceeding 30 mm.
Dead knots	Permitted up to a longer diameter of 15 mm.	Permitted up to a longer diameter of 25 mm.	Permitted up to a longer diameter of 40 mm and widthwise diameter of not exceeding 30 mm.
Loose knots and holes.	Permitted if loosened off sections or holes are not exceeding 3 mm in longer diameter.	Permitted if loosened off sections or holes are not exceeding 5 mm in longer diameter.	Permitted up to a longer diameter Of 40 mm and widthwise diameter of not exceeding 10 mm.
Pin knots.	Permitting if not affecting appearance.	Permitting if not excessiveaffecting appearance.	Permitting if not excessive affecting appearance.
Bark pocket or resin	Permitted if the longer	Permitted if not	Permitted if not

pocket.	diameter is not exceeding 30 mm.	conspicuous.	conspicuous.
Sound burls or chicken track.	Permitted if slight.	Permitted if not conspicuous.	Permitted if not conspicuous.
Discoloration or stain.	Permitted if slight.	Permitted if not conspicuous.	Permitted if not conspicuous.
Decay	Not permitted.	Permitted if very slight.	Permitted if very slight.
Open splits or chips	Permitted up to a length of 20% of the panel length, up to a width of 1.5 mm and up to a number of two.	Permitted up to a length of 40% of the panel length, up to a width of 4.0 mm and up to a number of three, or up to a length of 20% of the panel length, up to a width of 2 mm and up to a number of six.	Permitted up to a length of 40% of the panel length, up to a width of 6.0 mm.
Cross break	Permitted if slight.	Permitted if slight.	Permitted if slight.
Worm holes.	As to those than linear worm holes are, permitted up to a longer diameter of 1.5 mm, and if they are not dark-rimmed and not located collectively. As to the linear worm holes, permitted up to a longer diameter of 10 mm, and if they are dark-rimmed, and located in the numbers less than quadruple of the panel area expressed in the square meters (if there are fractions below a decimal point, add one (1) to the integer part).	Permitted if not excessive.	Permitted if not excessive.
Rough grain	Permitted if slight.	Permitted if not excessive	Permitted if not excessive
Open joints	Permitted if joint parts are color matched and there is no opening	Permitted if openings of joints are not so noticeable.	Permitted if openings of joints are not so noticeable.

	with the joints.		
Other defects	Permitted if slight.	Permitted if not conspicuous.	Permitted if not conspicuous.

Lay up: The veneer then lay up perpendicular fiber orientation with the adjacent veneer. Table 5 shows an example veneer composition of meranti plywood industry in Indonesia and Malaysia.

Tabel 5. Veneer composition of meranti plywood

Veneer position	Veneer Thickness		
	3 plies	5 plies	7 plies
Face	0.60	1.30	1.50
Core	1.40	3.30	3.30
Center core	-	3.30	3.00
Core	-	-	3.30
Center core	-	-	3.00
Core	-	3.30	3.30
Back	0.60	1.30	1.50
Total veneer thickness	2.60	12.50	18.90
Total plywood thickness	2.40	11.50	17.50

Glue spreading: Glue spreading on core veneer or crossband veneer using glue spreader. The standard glue spread range from 150 g/m² to 300 g/m². Figure 7 shows glue spreading process.



Figure 7. Glue spreading process.

Table 6 shows an example of glue composition of melamine formaldehyde and urea formaldehyde adhesives of meranti plywood industry in Indonesia and Malaysia.

Table 6. Glue composition of Melamine Formaldehyde and Urea Formaldehyde resin.

Resin	Melamine Formaldehyde	Urea Formeldehyde
Melamine formaldehyde	6.5 kg	-
Urea formaldehyde	-	6.5 kg
Flour	1.1 kg	0.7 kg
Melamine powder	0.3 kg	-
Hardener	0.5 kg	0.3 kg
Catcher	0.6 kg	0.6 kg
Total	9.0 kg	8.1 kg
Glue spread amount	150 – 300 g/m ²	150 – 300 g/m ²
Viscosity	3-15	3-15
pH	6 ± 1	6 ± 1

Cold pressing: Cold pressing facilitate the adhesive develop better glue bonding through better glue transfer, wetting and penetration process. The pressure is $8 \pm 1 \text{ kg/cm}^2$ for 30 minutes. Open assembly time 20 to 30 minutes, closed assembly time 240 minutes. Figure 8 shows the cold pressing process and Table 7 lists the cold press settings.



Figure 8. Cold press station

Table 7. Cold pressing standard

Plywood size	Material size (cm)	Pressure Gauge (kg/cm ²)	Unit Pressure (kg/cm ²)	Pressing Time (min)
920 x 1830	960 x 1880	8.0 ± 0.8	10 ± 1	30
1230 x 2440	1270 x 2490	14.1 ± 1.4		

Ø Cylinder (cm) : 37.5
 Size of Platen (cm) : 140 cm x 280 cm
 Open assembly time : 20 ~ 30 minutes
 Closed assembly time : 240 minutes

Hot pressing: Heat and pressure are used to cure the resin, thereby bonding the veneers together to make plywood (pressing). The pressure is $8 + 1 \text{ kg/cm}^2$. The standard average pressing time is 25 second per mm plywood thickness. The pressing tempeture is 110 – 115°C for UF and MF bonded plywood. Figure 8 shows hot pressing process. Table 8 shows an example of hot pressing standard meranti plywood industry in Indonesia and Malaysia.



Figure 8. Hot pressing of plywood

Table 8. Hot pressing process settings

Plywood size (mm)	Material Size (cm)	Pressure gauge (kg/cm ²)	Unit pressure (kg/cm ²)	Temperature (°C)	Steam pressure	Pressing time (min)
920 x 1,830	96 x 188	82 ± 8	10 ± 1	110 - 120	0.1 + 0.05 MPa	2.4 = 70

1230 x 2440	127 x 249	143 ± 14				11.5=430
						17.5=620

Ø Cylinder : 37.5 cm

Size of Platen : 137 x 270 cm

Sizing/cutting: After hot pressing, the plywood panels are cut to the standard size 122 cm x 244 cm or based on the order size

Putty process: The defects were minimized by putty process. Figure 9 shows the plywood putty process.



Figure 9. Plywood putty process.

Sanding process: The outer layers of plywood (face and back) are sanded using sander machine. The standard sanding speed depend on the plywood thickness. For 2.40 mm plywood thickness, the standard sanding speed is 58 + 3 m/min. Sand paper grits standard depend on the plywood thickness. For 2.4 mm plywood thickness, the sand paper grit standard for head no.1, 2, and 3 are 150, 180, and 240, respectively. Figure 10 shows sanding of plywood.



Figure 10. Plywood sanding process.

Sorting/grading: the produced plywood is then sorted and graded based on the national or international standard. Table 9 shows an example of standard for finishing meranti plywood in Indonesia and Malaysia.

Table 9. Standard for finishing meranti plywood

Item	Requirement for acceptance
Degree of adhesion	Should conform to the criteria of type I or II. An average value of wood failure ratio and shear strength shall not be less than the values provided in the using standard.
Moisture content	Should stand the moisture content test. An average moisture content of the meranti plywood not be more than 14%.
Formaldehyde emission	The average and the maximum amounts of the formaldehyde emission of the sample plywood shall be equal to or less than the values of 0.3 mg/l (average) and 0.4 mg/l (maximum) for F**** class of performance, and less than the values of 0.5 mg/l (average) and 0.7 mg/l (maximum) for F*** class of performance
Face quality	Quality of face and back should be fulfill the standard quality of face and back veneer.
Core overlap	Ermitted up to a number of two and up to length of 150 mm. Concerning those with surface quality grade 2, up to a number of 3 (three).
Finish of sides and end	There shall not be any scuffing.
Warping or twisting	Permitted up to a warping or twisting length of 50 mm (if the marked thickness is no less than 7.5 mm, up to 30 mm). Or when pressing by hand, the plane of plywood shall touch a horizontal plane. When putting 10 kg weight on (if the market thickness is not less than 7.5 mm, 15 kg), the plane of plywood shall touch a horizontal plane.
Bend of edges (straightness)	Permitted up to larges bending of 1 mm.
Dimensions	Dimensions of the meranti plywood should fulfill the standard use for grading. A difference between lengths of diagonals shall be not more than 2 mm.
Matters to be marked	The meranti plywood should be marked collectively. The information should be including nome of product, dimension, bonding quality, quality of face, formaldehyde emission amount, name of manufacturer and species name of veneer.

Packing: The plywood is packed and marked based on the standard. Number of plywood per pack/crate for plywood thickness 2.40 mm, 11.50 mm, and 17.50 mm are 250, 50, and 35 pieces, respectively. The following matters should be marked collectively: name of product, dimensions, bonding quality, quality of face, formaldehyde emission amount, and name of manufacturer. If a species name of veneer is marked, other those stipulated above, the species name shall be marked collectively in a group. Figure 11 shows plywood packing process.



Figure 11. Packing of plywood for storage/shipment

Goal and Scope

The goal of this study was to determine the cradle-to-gate Life Cycle Impact Assessment on the manufacturing of meranti plywood in Malaysia and Indonesia. The results will be used to gauge the environmental load of the meranti plywood manufactured in this region.

System boundary

LCA may be conducted for cradle-to-grave, cradle-to-gate or gate-to-gate depending on the purpose and need of the study. Cradle-to-grave assessment includes resource extraction, processing, transportation/delivery, use-phase and final product disposal. For primary products, such as plywood, normally the use-phase and final product disposal are not fixed and it will be more appropriate to conduct the assessment up to the gate. For this study, the system boundary was set for cradle-to-gate assessment (Figure 12). In this case, cradle-to-gate LCA includes log extraction, resin production, manufacturing of plywood and transportation within these phases.

Functional unit

One cubic meter (1 m³) of industry–standard size plywood of 914 x 1829 mm (3 x 6 ft) or 1219 x 2438 mm (4 x 8 ft).

Software

Microsoft Excel was used for modelling the overall system. GaBi 6 software—System and database for Life Cycle Engineering, GaBi Life Cycle Inventory databases for fuel and Malaysia electricity database by SIRIM Berhad.

Assumptions

- The data collected on inputs and outputs were representative of the current manufacturing practices of meranti plywood in Malaysia and Indonesia.
- Default values for emission data were obtained from commercial databases and published reports considered as representative of the current scenario.

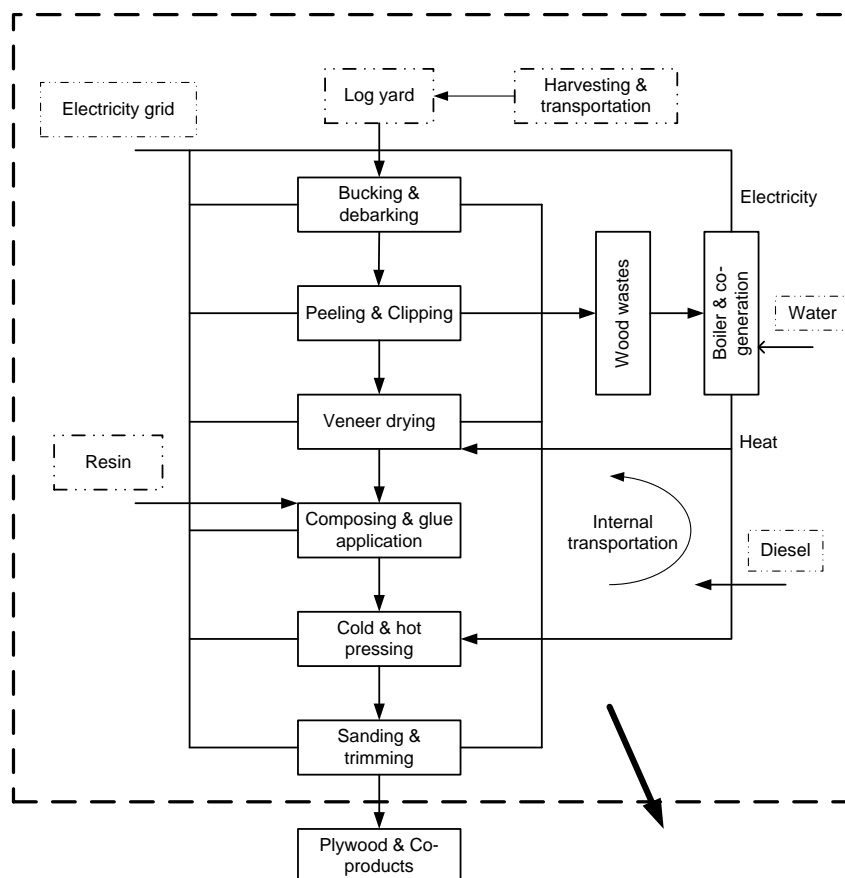


Figure 12. System boundary for cradle-to-gate assessment—dashed line. Solid-line boxes are foreground processes and broken-line boxes are background databases/processes

Life Cycle Inventory Data

Field briefing and survey were conducted in seven plywood companies. However, one company did not provide any data and another returned incomplete dataset and were excluded in the assessment. The general profiles of the remaining five plywood companies assessed in this study are listed in Table 10. Twelve monthly datasets were collected and calculated to provide the input and output data of materials and energy for one cubic meter of plywood produced (Table 11). Data for both unit process approach and overall or black-box approach were collected. However, there were significant difficulties for the plywood companies to provide data at unit process levels and thus incomplete data and high discrepancies. Thus, only the overall data or black box approach was collated and analyzed.

Table 10. Profiles of plywood companies engaged in this study (Companies A, B and C were based in Indonesia, and D and E in Malaysia)

	Unit	Company				
		A	B	C	D	E
Monthly log input	m ³	11,322	15,314	21,164	40,000	24,849
Monthly plywood production	m ³	6,702	10,495	11,249	22,272	15,042
Co-products		Blockboard, veneer	Blockboard, lamineboard	Blockboard, Veneer	LVL	Veneer
<u>Electricity</u>						
National grid		✓	✓	✓	✓	✓
Co-generation		-	-	-	✓	✓
Coal power plant		✓	✓	-	-	-

Table 11. LCI Inputs to produce a unit (one cubic meter) of plywood

	Unit	Company				
		A	B	C	D	E
<u>Inputs</u>						
<u>Raw materials</u>						
Log	m ³	1.69	1.46	1.88	1.84	1.76
Resin: Urea formaldehyde	kg	134	103	73	66	83
Hardener	kg	17	11	10	11	17
<u>Energy/Water</u>						
Electricity – grid	kWh	16.0	9.7	150.9	17.7	92.0
Electricity – co-generation	kWh	-	-	-	264.3	46.0
Electricity – coal	kg	44.7	38.1	-	-	-
Diesel	litre	0.135	0.130	0.941	5.635	5.790

Water (river water)	m ³	7.69	5.72	0.00	4.88	4.89
Water (municipal)	m ³	0.57	0.34	1.23	0.92	0.00

Life Cycle Inventory Analysis

Cut-off criteria

Exclusion: A flow that contributes to less than 2% of the total cumulative mass/energy.

Allocation for co-products

When there were co-products, the allocation of the input and output were based on mass.

Life Cycle Impact Assessment data sources

The environmental impacts were based on LCIA-CML 2001 (Nov. 10) of GaBi 6. Details of background databases used are listed in Table 12.

Table 12. Background databases used for Life Cycle Impact Assessment

Database	Data source
Electricity grid mix	SIRIM MY
Electricity from biomass	GaBi 6
Electricity from hard coal	GaBi 6
Thermal energy from biomass	GaBi 6
Thermal energy from hard coal	GaBi 6
Diesel	GaBi 6
River water source	GaBi 6
Municipal water source	GaBi 6
Resins: Urea formaldehyde, UF	Wilson (2010)
Logs	Gan & Zairul (2013)
Emissions to air and freshwater	GaBi 6

A generic model (Figure 13) of the plywood manufacture was created using GaBi 6 and the data from five companies were analysed.

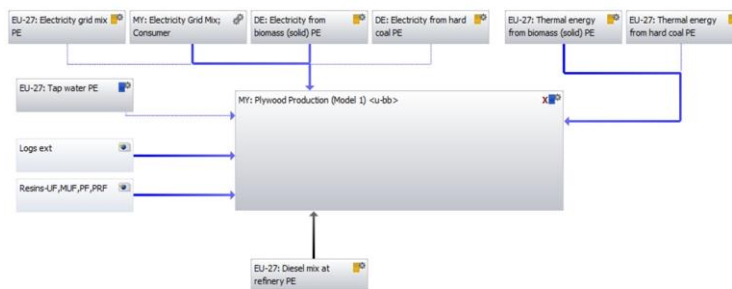


Figure 13. Plywood manufacturing model created using GaBi 6 showing connected processes/flows

Impact Assessment Results

The overall environmental impacts for cradle-to-gate manufacturing of meranti plywood in terms of Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP) and Photochemical Ozone Creation Potential (POCP) (Appendix 1) for the five plywood companies are shown in Table 13. These results may be used to compare the various environmental impacts of the different companies for consideration to improve their manufacturing processes and technology.

Table 13. The environmental impact potential for the production of a unit (one cubic meter) of meranti plywood

Impact category	Unit	Company					Average
		A	B	C	D	E	
GWP 100 years	kg CO ₂ -Equiv.	592	485	411	329	411	446
AP	kg SO ₂ -Equiv.	1.70	1.35	2.08	2.11	2.30	1.91
EP	kg Phosphate (PO ₄)-Equiv.	0.253	0.197	0.333	0.383	0.391	0.311
ODP	kg CFC11-Equiv.	8.95x10 ⁻⁹	6.74x10 ⁻⁹	1.84x10 ⁻⁸	1.66x10 ⁻⁸	1.90x10 ⁻⁸	1.40x10 ⁻⁸
POCP	kg Ethylene-Equiv.	0.188	0.147	0.247	0.250	0.285	0.223

Generally, the average environmental impacts for one cubic meter of meranti plywood were for GWP, 446 kg-CO₂-Equiv (range 329 to 592); for AP, 1.91 kg SO₂-Equiv; for EP, 0.311 kg Phosphate (PO₄)-Equiv; for ODP, 1.40 x 10⁻⁸ kg CFC 11-Equiv and for POCP, 0.223 kg Ethylene-Equiv.

It may be difficult to compare the emissions in Table 13 due to the different units used for the various impact categories. In the following discussion, the average results for all the five companies were used as a reference for comparison (Figure 14). Company D used a high percentage of electricity from wood wastes co-generation installed within its facility and had the lowest GWP value compared with the other four companies. However, for the other impact categories, companies A and B, which used coal for electricity generation, showed lower emission levels for AP, EP, ODP and

POCD. These could be attributed to the lower diesel consumption both within the manufacturing facility and lower contribution from diesel used in the energy mix for grid electricity generation.

In this study, the global warming potential (GWP) was strongly related to the use of fossil fuel and electricity. Company D used only a small portion (6.2%) of its electricity need from the national grid and the rest was generated using co-generation of wood wastes within the company. Co-generation using wood wastes/biomass is considered biogenic fuel and the carbon dioxide released is not considered as emission. Generally, the GWP increased with increased use of electricity from the national grid for companies C and E. However, the CO₂ emissions for companies A and B were a few folds higher as these companies generated electricity from coal. The efficiency for coal generated electricity was about 30% (Anonymous 2014). Companies using coal for process heat and generation of electricity should consider using biogenic fuel as they are close to waste wood or biomass resources.

Carbon footprints for products or services are the greenhouse gas (GHG) emissions associated with the manufacturing of a product or delivery of a service. It is normally reported in CO₂-equiv. In the guidelines, these emissions are categorized as Types 1, 2 and 3 emissions. Type 1 emissions are associated with direct emissions through the burning of fossil fuel on-site. Type 2 emissions are associated with purchased energy such as electricity and heat where the emissions occur off site. Whereas, Type 3 emissions are associated with consumption of materials or services where the emissions occur in the manufacture of the materials or services. The CO₂ emissions for determining the carbon footprint of a product may be obtained from a full LCA study. In this study the average GWP of 446 kg CO₂-Equiv./m³ may be taken as the carbon footprint for one cubic meter of tropical plywood. This average represented 37.0%, 26.6% and 36.4% respectively the CO₂ emissions associated with plywood production, logs and resin used. The formaldehyde resin contributed a high percentage towards the overall CO₂ emissions for the plywood.

Figure 15 shows the proportions of GWPs contributed by the main input materials and the manufacturing processes (gate-to-gate) for meranti plywood. The plywood manufacturing stage or gate-to-gate GWP was lowest for company D which used more than 90% of electricity from co-generation using wood waste. The average gate-to-gate (or plywood manufacturing processes only) GWP for the five plywood companies was 159 kg-CO₂-Equiv./m³. This is comparable to the GWPs for softwood plywood productions in the Pacific Northwest and Southeast (production centres of softwood plywood in United States) which were 152.15 and 222.18 kg-CO₂-Equiv respectively, reported by Wilson and Sakimoto (2005).

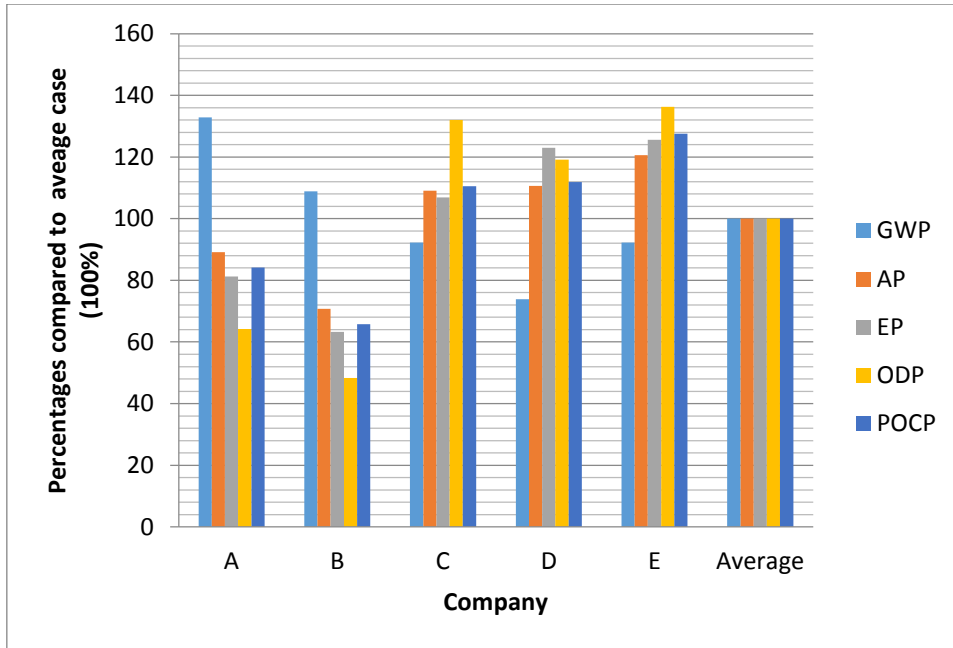


Figure 14. Relative environmental impact categories based on the average values of all the five plywood companies

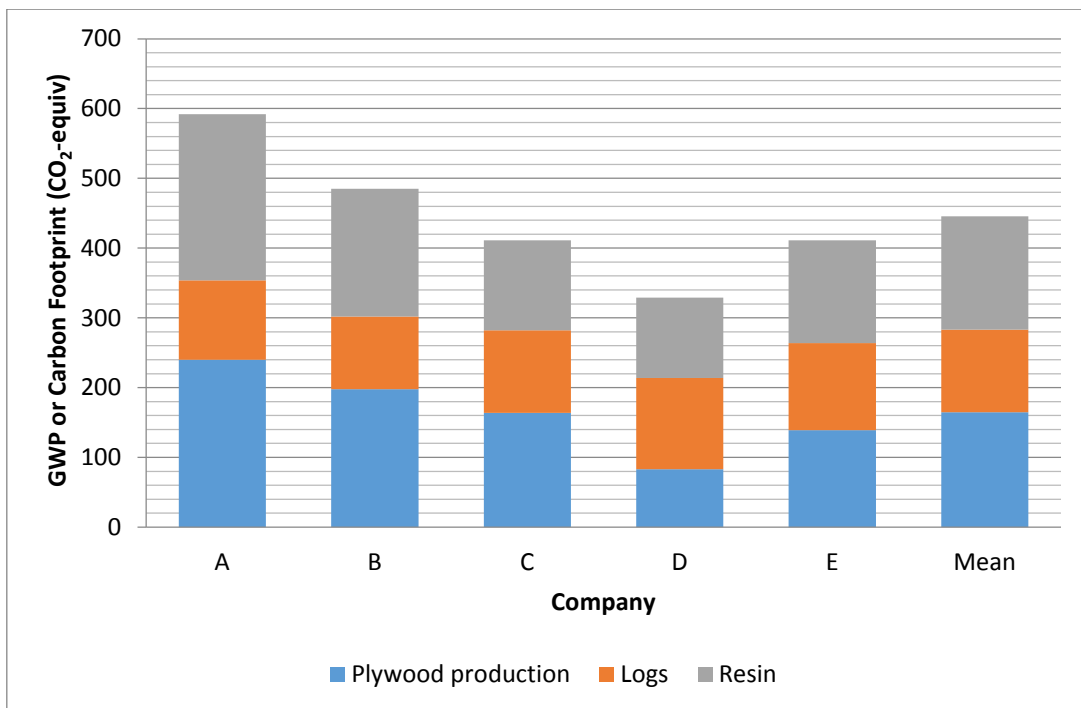


Figure 15. Contributions of GWPs or Carbon footprint by the main inputs (logs and resin) and plywood production (gate-to-gate)

Identification of significant issues

The environmental impact in terms of GWP was strongly associated with the use of input materials (logs and resin), electricity and diesel. Consumption of logs per unit plywood or recovery influenced the GWP associated with log extraction and transportation to the logyard. At the gate-to-gate stage the GWP was greatly influenced by the thermal and electricity use. For companies using co-generation from wood waste, the GWPs were increasingly lower as the percentage of electricity from co-generation increased. For companies using coal generated electricity, the environmental load, particularly GWP value, may be more than double.

For other environmental impact categories, the lower consumption of diesel per unit production had led to lower EP, AP, ODP and POCP.

Conclusion

Life Cycle Assessment was used to evaluate the environmental performance of meranti plywood made using tropical timber harvested from sustainably managed forest and urea-formaldehyde resin. The results are representative of the selected export orientated plywood companies in Indonesia and Malaysia. The company profiles differ due to specific practices such as capacity, recovery, co-products, co-generation and fuel used. The study reveals that the main sources of environmental impacts are raw material consumptions and electrical energy sources. To improve the environmental performance of meranti plywood, companies could:

- i) improve the recovery of log input
- ii) conduct co-generation using biomass for thermal and electricity needs in the manufacturing process
- iii) use optimum amounts of resin for the targeted quality
- iv) improve material flow in the manufacturing process to reduce internal transportation.

This may be adjusted for Environmental Product Declaration use based on the selected scheme or Product Category Rules.

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Environmental Impact Categories

The five environmental impact categories reported are:

i. Global Warming Potential (GWP)

Greenhouse gas effect is a natural mechanism where reflected infrared radiation is absorbed by greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect on the earth surface. An increase in greenhouse gases from anthropogenic activities will enhance the warming effect. Greenhouse gases are carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, nitrogen trifluoride, perfluorocarbons and hydrofluorocarbons. The global warming potentials of these gases are calculated in terms of carbon dioxide equivalents.

ii. Acidification Potential (AP)

Transformation of air pollutants such as sulphur dioxide and nitrogen oxide into acids will lead to a decrease in the pH-value of rainwater. This acidification will damage the ecosystems. The acidification potential is given in sulphur dioxide equivalents (SO₂-Eq).

iii. Eutrophication Potential (EP)

Eutrophication is the enrichment of nutrients in aquatic or terrestrial media. In water, it accelerates the growth of algae that may cause a reduction of oxygen concentration in water that eventually destroy the eco-system. In soil, it is known to affect plant health and stability. The eutrophication potentials are calculated in phosphate equivalents.

iv. Ozone Depletion Potential (ODP)

Ozone layer in the stratosphere is created by the disassociation of oxygen atoms that are exposed to short-wave UV-light. Ozone absorbs the short-wave UV-radiation and releases it in longer wavelengths. Only a small proportion of short-wave UV-radiation reaches the earth. This is essential for life on earth. Anthropogenic emissions that deplete ozone are categorized into two groups: those that are due to the fluorine-chlorine-hydrocarbons (CFCs) and those due to the nitrogen oxides (NO_x). In this study, the ozone depletion potentials are calculated from the different ozone relevant substances and reported in CFC 11 equivalents.

v. Photochemical Ozone Creation Potential (POCP)

Photochemical ozone production is also known as summer smog which may damage vegetation and materials. High concentrations of ozone are also toxic to humans. In LCA, photochemical ozone creation potentials (POCPs) are quantified in terms of ethylene-equivalents.