# LIFE-CYCLE ASSESSMENT FOR ENVIRONMENTAL PRODUCT DECLARATIONS OF IPE AND CUMARU DECKING STRIPS PRODUCED IN BRAZIL

# REPORT

**PREPARED FOR**
**INTERNATIONAL TROPICAL TIMBER ORGANIZATION**

**by**

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## Acronyms

| | |
|---|---|
| ANPM | National Hardwood Flooring Association |
| AP | acidification potential |
| CFC11 | trichlorofluoromethane |
| $CO_2$ | carbon dioxide |
| eq. | equivalent |
| EP | eutrophication potential |
| EPD | environmental product declaration |
| FSC | Forest Stewardship Council |
| GJ | gigajoule(s) |
| GWP | global warming potential |
| ISO | International Organization for Standardization |
| ITTO | International Tropical Timber Organization |
| kg | kilogram(s) |
| km | kilometre(s) |
| kVA | 1000 volt amp(s) |
| kW | kilowatt(s) |
| kWh | kilowatt hour(s) |
| l | litre(s) |
| LCA | life-cycle assessment |
| $m^3$ | cubic metre |
| mg | millgram(s) |
| mm | millimetre(s) |
| ODP | ozone depletion potential |
| PCR | product category rule |
| $PO_4$ | phosphate |
| POCP | photochemical ozone creation potential |
| S4S | square four sides |
| $SO_2$ | sulphur dioxide |
| TJ | terajoule(s) |

# 1 Introduction

The world is facing major environmental problems, such as global warming, the depletion of the ozone layer, and waste accumulation (Sharma et al. 2011). There is considerable evidence that the global climate is changing rapidly (EC-JRC-IES, 2010) and will continue to do so for a long time (Fava 2006).

Buildings play an important global role in the consumption of energy and natural resources and the emission of greenhouse gases. According to Sartori and Hestnes (2007), the energy demand of buildings can be both direct (from construction to demolition) and indirect (represented by the energy consumed by materials and in the manufacture of products used in construction and technical installations).

Consumers are increasingly concerned with the social, economic and environmental impacts of the products they use. Life-cycle assessment (LCA) is a tool for systematically analyzing the environmental performance of products and processes over their entire life cycles, including raw-material extraction, manufacturing, use, and end-of-life disposal and recycling.

LCA can be applied to analyze the energy consumption associated with products to be used in buildings (Cabeza et al. 2014). It has been used in the building sector since 1990 (Ortiz et al. 2009) and is an important tool for assessing the environmental impacts of the building industry and of building materials.

LCAs are conducted according to ISO [International Organization for Standardization] 14040 and ISO 14044. The best way to compare different products, however, is to use environmental product declarations (EPDs), which are based on product category rules (PCRs) that specify the parameters to be considered for a given group of products as a way of providing complete and credible data (Gan and Massijaya 2014).

Companies use EPDs to reduce the environmental impact of products and as a strategy for external communication about their environmental credentials (Askhan 2006). EPDs are based on LCAs and contain information on the acquisition of raw materials, energy use, the content of materials and chemical substances, environmental emissions (i.e. into air and water and onto land), and waste generation.

In general, the main parameters used in EPDs are global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP) and ozone depletion potential (ODP) (Gan and Massijaya 2014). Appendix 1 describes each of these parameters.

Because of their capacity to fix carbon, trees play an important role in reducing GWP. Some authors, however, dismiss this role because, ultimately, wood products will be incinerated or placed in landfill (where they will rot), resulting in a neutral or positive carbon dioxide ($CO_2$) balance (Ortiz et al. 2009).

ITTO recognized the growing importance of LCAs and EPDs in the use of tropical wood products in buildings in its Biennial Work Programme 2013–2014, specifying (among other things) the undertaking of an LCA for decking manufactured with ipe (*Handroanthus* spp., syn. *Tabebuia* spp.) and cumaru (*Dipteryx odorata*) lumber as a basis for the development of EPDs for these products. ITTO subsequently commissioned a study on this topic from the National Hardwood Flooring Association (ANPM), in collaboration with the University of São Paulo and Xylema Ltda.

The industry involved in the manufacture of decking using ipe and cumaru in Brazil is highly diverse in its size and technology, log sources and places of processing—all aspects that influence the extent of greenhouse-gas emissions.

Most decking is produced in Brazil in one of two main industrial flows: 1) primary and secondary processing companies in the Amazon region; and (2) primary processing in the Amazon region and secondary processing in the southeast or south of Brazil, involving the long-distance transportation by road of lumber for secondary processing.

A validation meeting held in Brasilia, Brazil, on 11–13 December 2014 agreed that the study would be a cradle-to-gate assessment involving data collection in at least five companies covering the main variations in industrial flow.

# 2 Review

**Ipe**

Ipe is the common name for lumber produced from the *Handroanthus* genus, trees that produce a heavy, hard wood that is brownish in colour and sometimes contains a yellow-to-green substance called ipeina. Ipe species occur naturally throughout South America and in parts of Central America. The principal species in Brazil are *Handroanthus ochraceae*, *H. impetiginosa*, *H. longifolia* and *H. serratifolia*. Other common local names for ipe wood are ipê-amarelo, ipê-do-cerrado, ipê-pardo, ipê-preto, ipê-roxo, ipê-tabaco, ipê-una, ipeúva, pau-d'arco and pau-d'arco-amarelo. Its international names include lapacho, madera negra, guyacan, guayacan plovillo, tachuario, lapacho negro and pui (Flynn and Holder 2001).

The lumber of the principal ipe species is similar in terms of its physical and mechanical characteristics. It is used mainly in heavy structures and flooring, including decking. Ipe lumber is highly suitable as a decking material because of its high resistance to biodeterioration.

**Cumaru**

Cumaru is the common name for lumber produced from *Dipteryx odorata*, a heavy, hard wood with a yellow-to-brownish colour and high mechanical resistance. Cumaru occurs naturally throughout the Brazilian Amazon, as well as in northern countries of South America and in Central America.

Other common names for lumber produced from *Dipteryx odorata* include camaru, camaru-ferro, cambaru, cambaru-ferro, champanha, cumaru-amarelo and cumaru-ferro.

Cumaru has high mechanical resistance and is mainly used in heavy structures and as flooring. Like ipe, cumaru is well-suited for decking because of its high resistance to biodeterioration.

**LCA studies**

Cabeza et al. (2014) evaluated more than 150 LCAs related to buildings, including materials and aspects of construction. They concluded that few LCAs had been conducted on wood-based products, and those that had been conducted were mostly from Europe or North America. The American Wood Council has issued EPDs for redwood decking, softwood lumber, medium-density fibreboard and particleboard. On the other hand, there are few EPD-related studies on tropical lumber and tropical wood products, the most important contributions being studies funded by ITTO (Gan and Massajaya 2014; Adu and Eshun 2014).

# 3 Material and methods

**Goal and scope**
The study applied the LCA (ISO 14040/14044) evaluation method to the ipe and cumaru decking manufacture processes with the goal of analyzing the cradle-to-gate environmental performance of ipe and cumaru decking produced in Brazil. Ultimately, the aim of the study was to provide reliable information on the environmental impacts of those products.

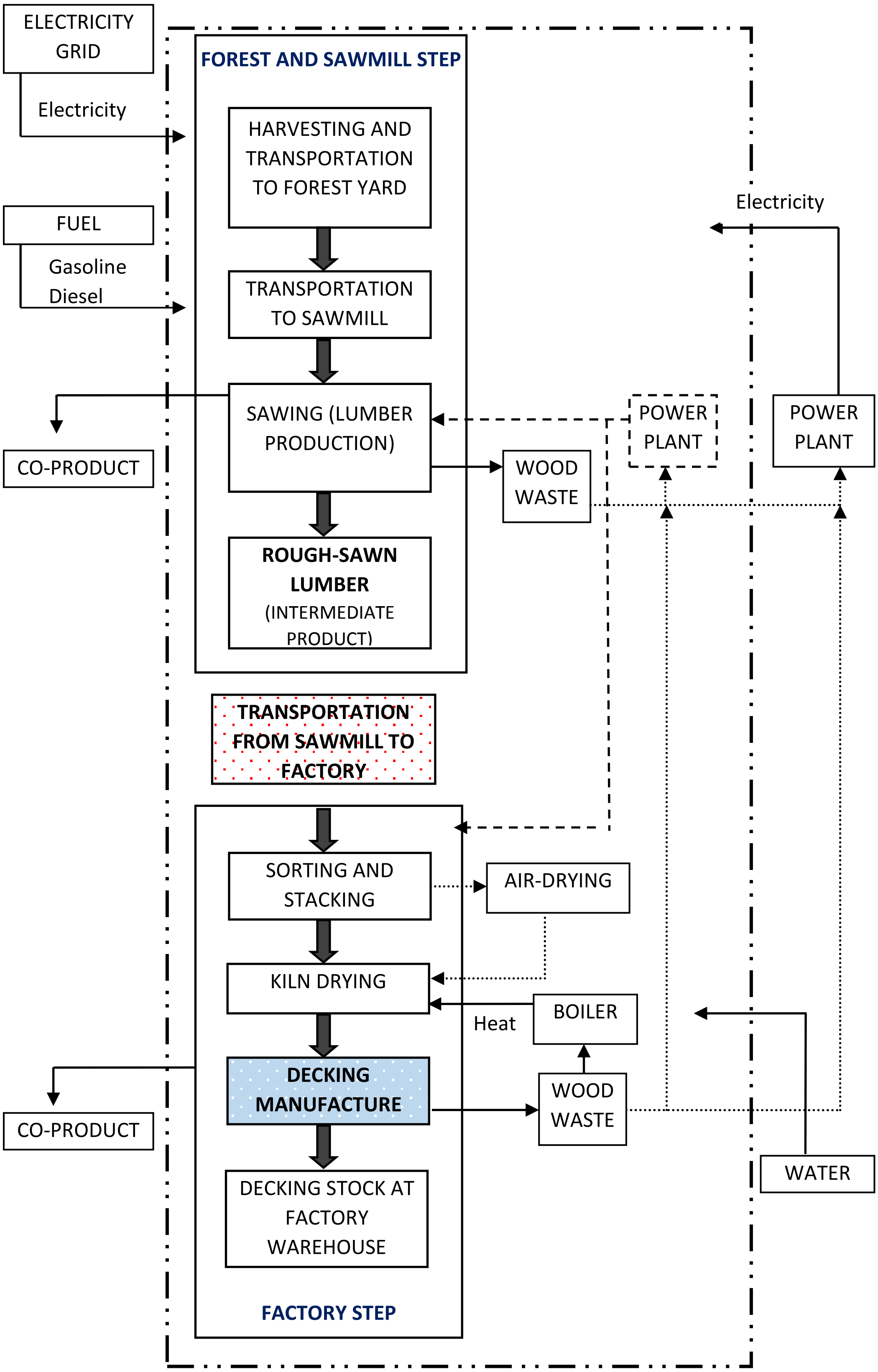
To achieve the goal, the study's main activities were to:

- compile all measurable inputs and outputs of the manufacturing process of ipe and cumaru decking;
- evaluate all potential impacts on the environment;
- assess the carbon footprint according to the PAS2050 methodology; and
- establish the basis for EPDs for each of the two products.

**System description and boundary**
According to ISO 14040, LCA studies may be conducted for "cradle to grave", "cradle to gate" or "gate to gate", with three possible phases:

1) *Manufacturing phase*, which should address all manufacturing activities, from the raw material to the final product, as well as all inputs and outputs related to the manufacturing process.
2) *Use phase*, which includes the transport of the product from the factory to the final consumer, installation, further processing (if applicable) and usage (duration). All inputs and outputs should be considered.
3) *End-of-life phase*, which accounts for the impacts of the product's disposal, reuse or recycling.

**Figure 1: Production stages/activities and boundary, cradle-to-gate assessment**




Note: Dashed and dotted line = system boundary; solid line boxes = foreground processes; dashed line boxes = processes not common to all companies; dotted line = alternate flow.

The boundary of the present study was defined as "cradle to gate"; that is, from the tree in the forest to the product stock in the factory, covering tree harvesting; log extraction and transportation to sawmill; sawing into lumber; transportation to the manufacturing factory; kiln-drying; primary lumber processing (dimensions adjustment); secondary lumber processing (decking manufacture); and internal transportation in the sawmill and factory (Figure 1).

Transportation and distribution from the factory warehouse to intermediate distributors and final consumer, as well as use, re-use and disposal, were excluded from the study because of the huge variation in the operations they involve, which cannot be adequately expressed. Gan and Massajaya (2014) and Adu and Eshun (2014) adopted the same approach in their LCAs of tropical wood products in other regions.

**Functional unit**

The functional unit adopted for the study was 1 $m^3$ of the final product (either ipe or cumaru decking), packed and stocked in the factory ready for shipping to intermediate distributors and final consumers.

**Software**

Overall system modelling was done using Microsoft Excel. The LCA analysis was done using GaBi6 software.

**Manufacturing process**

Brazil's federal Ministry of Environment, or the equivalent state authority, must approve all harvesting in tropical forests in Brazil, and the process to obtain this approval includes the development of a sustainable forest management plan. Nevertheless, the market does not perceive this legal approval as constituting green origin certification.

The forest certification system of the Forest Stewardship Council (FSC) generally has a high level of credibility worldwide. Most users assume that FSC certification provides evidence that the forest from which the certified product was obtained is under sustainable management, considering environmental, social and economical aspects, but the environmental status of the final product is not considered. FSC chain-of-custody certification shows that the producer is sufficiently organized to ensure that the raw materials can be tracked from the forest to the point of sale.

Decking manufacture in Brazil involves a great diversity of log sources, company sizes and technologies. There are three main industrial flows:

- Medium to large companies located near big cities with easy access and modern machinery. Most such companies have their own forests or state concessions, some with FSC certification.
- Medium-sized (and a few large) companies, some located near big cities with easy access and some located in small cities (near the forest), mixing old and modern

technologies. Most do not have their own forests and instead buy lumber from various suppliers; some may have one main lumber supplier. FSC certification is an exception.

- Small to medium-sized companies, located in small cities near the forest, with some difficulties of access. Old technologies are predominant, and lumber is bought from several suppliers. Sometimes the production is sold to a larger company or to a main resale company.

Forest and sawmill operations (illustrated in figures 2–5), and the equipment required, comprise the following:

- tree felling and delimbing—chainsaw;
- log skidding to temporary yards on secondary roads—skidder and loader;
- transport of logs to main forest yard—loader and truck;
- crosscut to length—chainsaw;
- transport of logs from the forest yard to the sawmill yard—loader and truck;
- unloading of logs at the mill yard—loader;
- transport of logs to band saw—loader;
- log-sawing—band saw;
- sawnwood trimming—circular saw;
- lumber packing for drying or transportation—manual labour; and
- transport of lumber packs to mill sheds or truck—loader.

Figure 2: Felling (left) and extraction

Figure 3: Log yards at the forest (left) and the sawmill

Figure 4: Transport of logs by truck (left) and loader

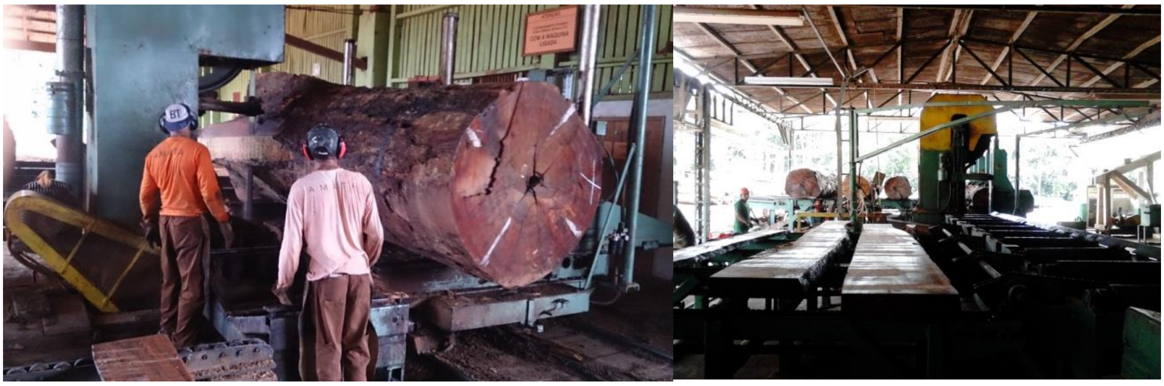


Figure 5: Sawmill operations

In addition to these operations, auxiliary activities include the transportation of workers to and from the forest (by pickup truck or bus); the opening of secondary roads (bulldozer); the opening and maintenance of main roads (bulldozer); and the construction of local facilities, such as forest offices and worker accommodation.

The main inputs are gasoline and diesel (electricity is supplied by diesel-powered generators). The outputs are lumber (intermediate product), useful residues and waste.

Companies produce various types of flooring themselves or supply other flooring manufacturers. Short pieces not used in decking manufacturing are used for other types of flooring. “Waste”, comprising sawdust, bark and very small pieces, is burned to produce energy.

The production steps in the flooring factory, and the equipment used (figures 6–10), are:

- transportation from sawmill to the factory—truck and forklift;
- unloading (forklift) and lumber packing for drying—manual labour;
- primary lumber processing (ripping to size)—multiple band saw (optional operation);
- transporting sawn lumber to air-drying yard or to kilns—forklift and truck;
- kiln-drying—kiln;
- blanking—surface planer;
- moulding to decking profile —multiple head planer; and
- internal transportation between machines and to factory storage facilities—forklift and truck.

Figure 6: Lumber pack ready to be transported to the factory (left), and air-drying yard at the factory

Figure 7: Moving sawn lumber from one processing unit to another


Figure 8: Surface planer (left) and multiple head planer

Figure 9: Useful residues, to be used in other types of flooring

Figure 10: Ipe and cumaru decking stored at factory warehouse

Inputs used in processing are diesel, electricity and water for the kiln-dryer boiler. Sawdust and other process residues are used as fuel for the kiln-dryer boiler. Outputs are wood residues and the final product (decking boards).

**Assumptions**

The study made the following assumptions:

- Data collected for inputs and outputs are representative of the current manufacturing processes used in the production of ipe and cumaru decking in Brazil.
- Default values for emission factors obtained from commercial databases are representative of current knowledge.
- Lumber residues with dimensions adequate to be remanufactured to other products were not sources of emissions in decking production.
- The methodology to integrate production flows is valid for all companies in the study.

# 4 Field study

**Initial survey**
An initial survey of 38 companies was conducted using emails and phone calls to collect data on production capacity, raw-material sources, product specifications and the principal machinery used. Of those 38 companies, eight reported that they produce ipe or cumaru decking; 16 reported that they do not produce ipe or cumaru decking (although some produce decking using other species); and 14 declined to participate in the survey.

Based on data provided by respondents, it was possible to draw the following conclusions:

- Ipe lumber constitutes 0.5–5.0% of total lumber processed in responding companies. Only two companies reported a volume of ipe production higher than 18% of total production.
- Cumaru lumber is used more widely by the responding companies and at higher volumes (1.5–30 times higher) than ipe.
- The dimensions of the final products are 19, 20 and 21 mm thickness; 80, 100, 140 and 145 mm width; and variable lengths starting at 610 mm and increasing in steps of 152.4 mm.

**Selected companies**
Following recommendations made at the validation meeting in December 2014, seven companies were selected for data collection, representing the more common manufacturing practices of lumber and decking production, as follows:

- Three companies (labeled A, B and C in this study) own the forest area in which they harvest their raw materials, or they have a harvesting concession in a public forest, and have a sawmill in which they produce rough-sawn green lumber, which they sell to a manufacturing company.
- Two companies (D and E) own the forest area in which they harvest their raw materials and produce the rough-sawn lumber as well as the final decking product (ipe and cumaru decking).
- The remaining two companies (F and G) purchase rough-sawn lumber from several suppliers and manufacture the final decking product (ipe and cumaru decking).

Table 1 summarizes the production stages or phases of industrial flow of the assessed companies; Figure 11 shows their locations; and Box 1 shows the allocations and cut-off criteria for the study.

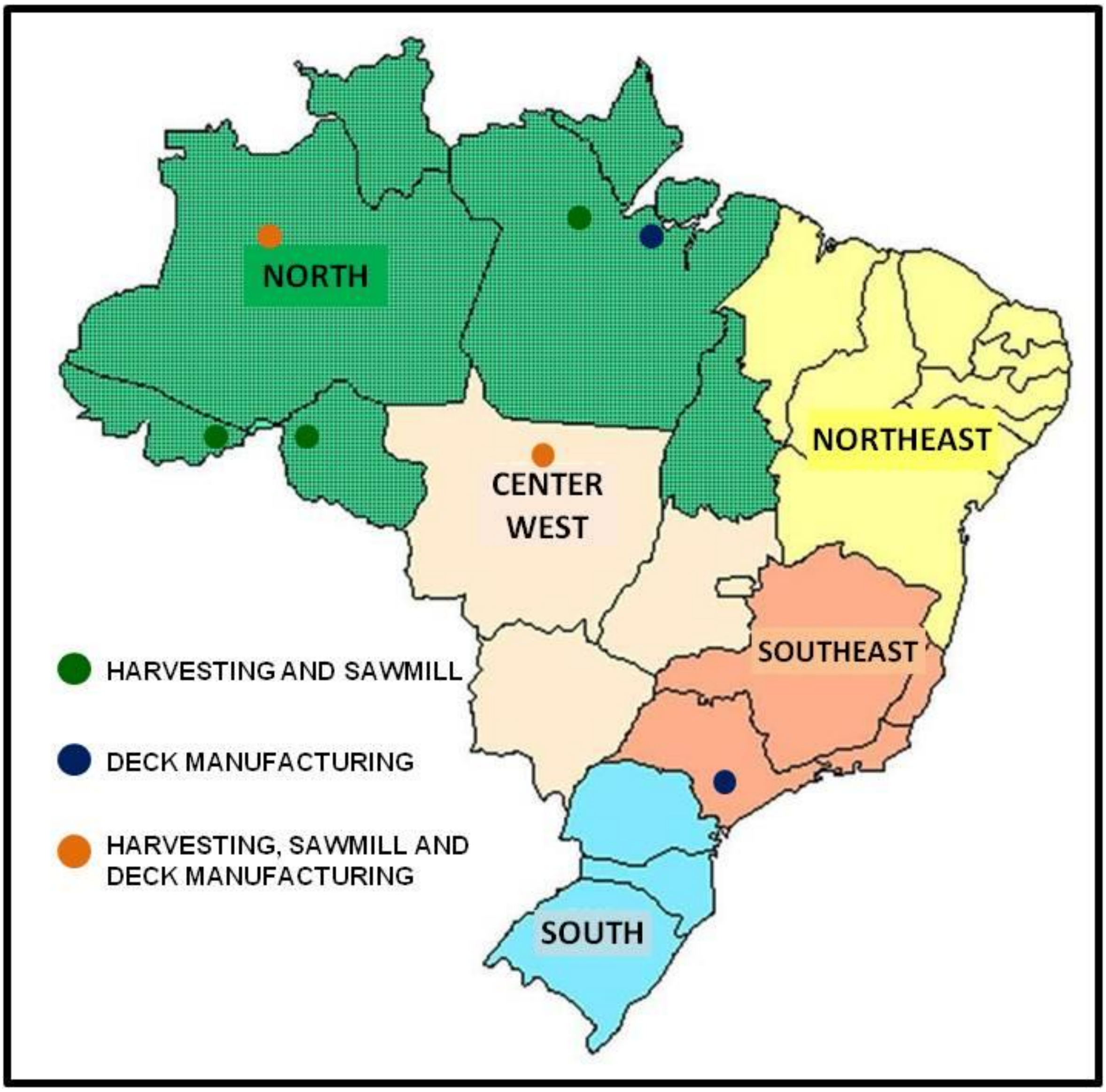
**Box 1: Allocations and cut-off criteria**
*Exclusion*: a flow that contributes to less than 2% of the total cumulative mass or energy.

| *Allocations*: there are no allocations, in accordance with the product category rules published by IBU (2009) and FPInnovations (2013). |
|---|

**Table 1: Production stages of assessed companies**

| **Phase of industrial flow** | | **Company** | |
|---|---|---|---|
| Harvesting and sawmilling | A, B, C | D, E | |
| Transport to company | | D | F, G |
| Manufacturing | | D, E | F, G |

**Figure 11: Approximate locations and nature of companies assessed in the study**



# 5 Results

All data collected from the selected companies were for the entire production in 2014. Table 2 shows the production capacity and Table 3 shows the general characteristics of the selected companies with forest harvesting and sawmill activities to produce ipe and cumaru lumber. Table 4 presents the production capacity and general characteristics of those companies with manufacturing activities to produce ipe and cumaru decking boards. Table 5 shows conversion rates from logs to decking. Tables 6, 7 and 8 present total inputs and outputs in the harvesting, sawmilling and manufacturing phases (respectively) for ipe and cumaru decking production.

Given the limited sample size but large differences among companies in the transportation distances involved in moving lumber from sawmills to factories, diesel inputs in that phase (i.e. lumber transport to manufacturing factory) are presented separately (Table 9).

To apply the LCA inventory (see below) to the entire industrial flow from cradle to gate, it was necessary to integrate data from forest harvesting and sawmilling with data from the manufacturing phase. The following methodology was adopted:

- Due to differences in production capacity, product recovery, energy supply and equipment, a weighted mean rather than the arithmetic mean was used to calculate average values for the forest harvesting and sawmill component.
- Total consumption inputs (diesel and gasoline) in the harvesting phase (Table 6) were calculated for ipe and cumaru using the following equation:

  *Total input consumption = (total quantity used/total log output) * ipe or cumaru log output*

- For each of the five companies with forest and sawmilling operations (A, B, C, D and E) the inputs needed to produce 1 $m^3$ of sawnwood were calculated using the following conversion factor relating log volume input to sawnwood output:

$$\frac{\textit{Input}}{m^3 \textit{ of sawnwood}} = \left\{\frac{\textit{Input}}{m^3 \textit{ of log}} \times \frac{\textit{Total log volume}}{\textit{Total sawnwood volume}}\right\} + \frac{\textit{Total input sawnwood}}{\textit{Total sawnwood volume}}$$

- The average value for input per $m^3$ of sawnwood, calculated using data from companies A, B, C, D and E, was used as the lumber input value for the four companies with manufacturing activities (D, E, F and G). The conversion factor relating lumber volume input and decking volume output was calculated in the same way:

$$\frac{\textit{Input}}{m^3 \textit{ of decking}} = \left\{\frac{\textit{Input}}{m^3 \textit{ of lumber}} \times \frac{\textit{Total lumber volume}}{\textit{Total decking volume}}\right\} + \frac{\textit{Total input decking}}{\textit{Total decking volume}}$$

Table 10 presents the results obtained using this method to integrate the two industrial phases of decking manufacturing. Table 11 shows the estimated diesel input for the transportation from sawmill to manufacturing factory.

**Table 2: Production capacity and general characteristics of companies with forest activities to harvest ipe and cumaru logs**

| Characteristic | Unit | Company | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| Log production | | | | | | | | |
| Total | $m^3$ | 26 080 | 20 000 | 92 080 | 9 600 | 117 852 | | |
| Ipe | $m^3$ | 200 | 200 | 1 104 | 2 820 | 80 | | |
| Cumaru | $m^3$ | 5 940 | 400 | 1 564 | 670 | 3 543 | | |
| Distance (forest to factory) | km | 180 | 40 | 680 | 80 | 45 | | |
| Transport | - | Truck | Truck | Ferry-boat | Truck | Truck | | |
| Fuel | - | Diesel | Diesel | Diesel | Diesel | Diesel | | |
| Facilities in forest | - | Yes | Yes | Yes | Yes | Yes | | |
| Electricity generation | - | Yes | Yes | Yes | Yes | Yes | | |
| Output | kVA | 25 | 25 | 80 | 5 | 45 | | |
| Fuel | - | Diesel | Diesel | Diesel | Diesel | Diesel | | |

Note: Production data are for 2014.

**Table 3: Production capacity and general characteristics of selected companies with sawmill activities to produce ipe and cumaru lumber**

| Characteristic | Unit | Company A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Log input | | | | | | | | |
| Total | $m^3$ | 26 080 | 20 000 | 50 000 | 9 600 | 110 676 | | |
| Ipe | $m^3$ | 200 | 200 | 600 | 2 820 | 80 | | |
| Cumaru | $m^3$ | 5 940 | 400 | 850 | 670 | 3 543 | | |
| Saw power | kW | 397.2 | 89.8 | 294 | 184 | 336 | | |
| Electricity source | - | Power plant | Power plant and grid[1] | Power plant and grid[1] | Power plant[2] | Power plant[2] | | |
| Internal transport | | | | | | | | |
| Stacker | - | ▯ | ▯ | ▯ | ▯ | ▯ | | |
| Forklift | - | - | ▯ | - | - | ▯ | | |
| Fuel | - | Diesel | Diesel | Diesel | Diesel | Diesel | | |
| Conversion rate | | | | | | | | |
| Ipe | % | 27 | 30 | 45 | 42 | 22 | | |
| Cumaru | % | 40 | 30 | 48 | 42 | 21.2 | | |
| Lumber output | $m^3$ | 10 954 | 8 000 | 26 000 | 4 800 | 23 574 | | |
| Ipe | $m^3$ | 54.0 | 60 | 270 | 1,184 | 18.1 | | |
| Cumaru | $m^3$ | 2 376 | 120 | 408 | 281 | 752 | | |
| Residue generation | tonne | 18 152 | 14 400 | 28 800 | 5,760 | 104 523 | | |
| Ipe | tonne | 181 | 174 | 409 | 2,028 | 76.7 | | |
| Cumaru | tonne | 4 455 | 350 | 552 | 486 | 3 489 | | |
| Residue use | - | Biofuel | Co-product Biofuel | Co-product Biofuel | Co-product Biofuel | Biofuel | | |

Note: Production data are from 2014.

1 = 70% from grid and 30% from power plant.

2 = Company supplies biofuel to power plant and receives electricity.

**Table 4: Production capacity and general characteristics of the selected companies with manufacturing activities to produce ipe and cumaru decking**

| Characteristic | Unit | Company | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| Lumber input – ipe | m³ | | | | 1 184.4 | 18.1 | 2 100.0 | 1 296.0 |
| Lumber input – cumaru | m³ | | | | 281.4 | 752.3 | 3 280.0 | 910.0 |
| Distance (sawmill to factory) | | | | | | | | |
| Ipe | km | | | | 500 | 0.0 | 2 900 | 60 |
| Cumaru | km | | | | 500 | 0.0 | 2 000 | 60 |
| Transport | - | | | | Truck | Forklift/stacker | Truck | Truck |
| Fuel | - | | | | Diesel | Diesel | Diesel | Diesel |
| Internal transport | - | | | | Stacker | Stacker /forklift | Forklift/truck | Forklift |
| Fuel | - | | | | Diesel | Diesel | Diesel | Diesel |
| Lumber drying | - | | | | | | | |
| Type of drier/quantity | - | | | | Hot air/6 | Kiln/12 | Kiln/17 | Kiln/3 |
| Drier output | kW | | | | 14.3 | 29.4 | 19.3 | 22.7 |
| Power of manufacturing machines | kW | | | | 125.0 | 173.0 | 89.0 | 25.0 |
| Electricity source | - | | | | Power plant | Power plant[1] | Grid | Grid |
| Conversion rate – ipe | % | | | | 36.0 | 60.6 | 45.2 | 70.1 |
| Conversion rate – cumaru | % | | | | 36.8 | 61.4 | 49.9 | 68.0 |
| Decking output – ipe | m³ | | | | 426.4 | 11.0 | 949.2 | 908.5 |
| Decking output – cumaru | m³ | | | | 103.6 | 461.9 | 1,636.7 | 618.8 |
| Residue generation – ipe | tonne | | | | 773.18 | 7.27 | 1,173.82 | 395.25 |
| Residue generation – cumaru | tonne | | | | 190.29 | 310.71 | 1,758.31 | 311.58 |
| Residue use | | | | | Co-product Biofuel | Biofuel | Co-product Biofuel | Biofuel |

Note: Production data are for 2014.
1 = Company supplies biofuel to power plant and receives electricity.

**Table 5: Conversion rates from log input to decking output, ipe and cumaru**

| Characteristic | Unit | Company | | | | | | | Weighted mean | Conversion | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | | | |
| Log input | | | | | | | | | | | |
| Ipe | m³ | 200 | 200 | 600 | 2 820 | 80 | | | | 1 | **4.926** |
| Cumaru | m³ | 5 940 | 400 | 850 | 670 | 3 543.5 | | | | 1 | **5.364** |
| Conversion rate | | | | | | | | | | | |
| Ipe | % | 27 | 30 | 45 | 42 | 22 | | | **0.4068** | | |
| Cumaru | % | 40 | 30 | 48 | 42 | 21 | | | **0.3453** | | |
| Lumber output | | | | | | | | | | | |
| Ipe | m³ | 54 | 60 | 270 | 1 184.4 | 18.1 | | | | 0.407 | 2.004 |
| Cumaru | m³ | 2 376 | 120 | 408 | 281.4 | 752.3 | | | | 0.345 | 1.852 |
| Lumber input | | | | | | | | | | | |
| Ipe | m³ | | | | 1 184.4 | 18.1 | 2 100 | 1 296 | | 0.407 | 2.004 |
| Cumaru | m³ | | | | 281.4 | 752.3 | 3 280 | 910 | | 0.345 | 1.852 |
| Conversion rate | | | | | | | | | | | |
| Ipe | % | | | | 36.0 | 60.6 | 45.2 | 70.1 | **0.4991** | | |
| Cumaru | % | | | | 36.8 | 61.4 | 49.9 | 68.0 | **0.5400** | | |
| Decking output | | | | | | | | | | | |
| Ipe | m³ | | | | 426.4 | 11.0 | 949.2 | 908.5 | | **0.203** | 1.000 |
| Cumaru | m³ | | | | 103.6 | 461.9 | 1,636.7 | 618.8 | | **0.186** | 1.000 |

Note: Production data are for 2014.

**Table 6: Total inputs and outputs in the harvesting phase of ipe and cumaru decking production**

| Input/output | Unit | Company | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| Log harvesting (diesel)[1] | l | 70 000 | 105 420 | 411 300 | 38 500 | 1 144 333 | | |
| Log harvesting (gasoline)[2] | l | 6 260 | 4 200 | 26 200 | 2 000.0 | 27 566 | | |
| Log harvesting (diesel)[1] | kg | 59 290 | 89 290.7 | 348 371.1 | 32 609.5 | 969 250.1 | | |
| Log harvesting (gasoline)[2] | kg | 4 607.4 | 3 091.2 | 19 283.2 | 1 472.0 | 20 288.6 | | |
| Transport to mill (diesel) | l | 121 800 | Included in log harvesting operations | 510 000 | 58 240.0 | Included in log harvesting operations | | |
| Transport to mill (diesel) | kg | 103 164.6 | Included in log harvesting operations | 431 970 | 49 329.3 | Included in log harvesting operations | | |
| | | Total gasoline consumption | | | | | | |
| Ipe | kg | 35.3 | 30.9 | 231.2 | 432.4 | 13.8 | | |
| Cumaru | kg | 1 049.4 | 61.8 | 327.5 | 102.7 | 610 | | |
| | | Total diesel consumption | | | | | | |
| Ipe | kg | 1 245.8 | 892.9 | 9 356 | 24 069.5 | 657.9 | | |
| Cumaru | kg | 37 000.8 | 1 785.8 | 13 254.3 | 5 718.6 | 29 142.7 | | |
| | | Log output | | | | | | |
| Total | $m^3$ | 26 080 | 20 000 | 92 080 | 9 600 | 117 851.9 | | |
| Ipe | $m^3$ | 200 | 200 | 1 104 | 2 820 | 80 | | |
| Cumaru | $m^3$ | 5 940 | 400 | 1 564.0 | 670.0 | 3 543.5 | | |

Note: Data are for 2014.

1 = Includes the diesel used by electricity generator.

2 = Includes gasoline in the sawmill yard to adjust log length.

**Table 7: Total inputs and outputs in the sawmill phase of ipe and cumaru decking production**

| Input/output | Unit | Company A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Log input at sawmill | m³ | 26 080 | 20 000 | 50 000 | 9 600 | 110 676.3 | | |
| Ipe | m³ | 200 | 200 | 600 | 2 820 | 80 | | |
| Cumaru | m³ | 5 940 | 400 | 850 | 670 | 3 543.5 | | |
| Internal transport (diesel) | l | 30 360 | 36 000 | 112 000 | 15 832 | 122 950 | | |
| Internal transport (diesel) | kg | 25 714.9 | 30 492 | 94 864 | 13 409.7 | 104 138.7 | | |
| Electric energy (grid) | kWh | 0.0 | 143 823.7 | 310 557.5 | 0.0 | 0.0 | | |
| Electric energy (power plant) | kWh | 884 259.3[1] | 0.0 | 0.0 | 232 921.6[2] | 3 270 938.88[2] | | |
| Electric energy (grid) | TJ | 0.0 | 0.740 | 1.597 | 0.0 | 0.0 | | |
| Electric energy (power plant) | TJ | 3.183 | 0.000 | 0.000 | 0.839 | 11.775 | | |
| Diesel for power plant | l | 0.0 | 12 000 | 30 000 | 0.0 | 0.0 | | |
| Diesel for power plant | kg | 0.0 | 10 164 | 25 410 | 0.0 | 0.0 | | |
| Lumber output | | | | | | | | |
| Ipe | m³ | 54.0 | 60.0 | 270.0 | 1 184.4 | 18.1 | | |
| Cumaru | m³ | 2 376 | 120.0 | 408.0 | 281.4 | 752.3 | | |
| Co-products output (other kind of flooring and biofuel) | | | | | | | | |
| Ipe | tonne | 181 | 101.7 | 409.2 | 2 028.1 | 76.7 | | |
| Cumaru | tonne | 4 455 | 205.0 | 552.5 | 485.8 | 3 489.0 | | |
| Waste output | | | | | | | | |
| Ipe | tonne | 0.0 | 71.9 | 0.0 | 0.0 | 0.0 | | |
| Cumaru | tonne | 0.0 | 145.0 | 0.0 | 0.0 | 0.0 | | |

Note: Data are for 2014. Total inputs of diesel and electric energy are the quantities used to sawn the total log input at sawmill.
1 = Electric energy from biofuel (power plant).
2 = Company supplies biofuel to power plant and receives electricity.

**Table 8: Inputs and outputs in the industrial manufacturing phase of ipe and cumaru decking production**

| Input/output | Unit | Company | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| Lumber input at company – ipe | m³ | | | | 1 184.4 | 18.1 | 2 100 | 1 296 |
| Lumber input at company – cumaru | m³ | | | | 281.4 | 752.3 | 3 280 | 910 |
| Internal transport (diesel) | | | | | | | | |
| Ipe | l | | | | 2 487.2 | 40.6 | 4 693.5 | 933.1 |
| Cumaru | l | | | | 590.9 | 1,687.3 | 7 330.8 | 655.2 |
| Ipe | kg | | | | 2 106.7 | 34.4 | 3 975.4 | 790.3 |
| Cumaru | kg | | | | 500.5 | 1 429.1 | 6 209.2 | 554.9 |
| Kiln drying (electricity) | | | | | | | | |
| Ipe | kWh | | | | 32 606.5 | 3 831.4 | 295 491 | 113 646.2 |
| Cumaru | kWh | | | | 7 746.9 | 159 246.9 | 460 971.2 | 79 707.9 |
| Ipe | GJ | | | | 117.38 | 13.79 | 1 063.77 | 409.13 |
| Cumaru | GJ | | | | 27.89 | 573.29 | 1 659.50 | 287.27 |
| Kiln drying (water) | m³ | | | | 0.0 | | | |
| Decking manufacturing (electric energy) | | | | | | | | |
| Ipe | kWh | | | | 61 186.1 | 1 020.5 | 85 260 | 25 971.8 |
| Cumaru | kWh | | | | 14 846.7 | 42 414.7 | 136 940 | 18 236.4 |
| Ipe | GJ | | | | 220.27 | 3.67 | 306.94 | 93.50 |
| Cumaru | GJ | | | | 53.45 | 152.69 | 492.98 | 65.65 |
| Decking output | | | | | | | | |
| Ipe | m³ | | | | 426.4 | 11.0 | 949.2 | 908.5 |
| Cumaru | m³ | | | | 103.6 | 461.9 | 1,636.7 | 618.8 |
| Co-product output (another kind of flooring) | | | | | | | | |
| Ipe | tonne | | | | 169.13 | 0.00 | 398.41 | 0.00 |
| Cumaru | tonne | | | | 43.66 | 0.00 | 603.65 | 0.00 |
| Co-product output (biofuel) | | | | | | | | |
| Ipe | tonne | | | | 604.04 | 7.27 | 775.40 | 395.25 |
| Cumaru | tonne | | | | 146.63 | 310.71 | 1 154.66 | 311.58 |

| | | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| Waste generation | | | | | | | | |
| Ipe | tonne | | | | 0.0 | 0.0 | 0.0 | 0.0 |
| Cumaru | tonne | | | | 0.0 | 0.0 | 0.0 | 0.0 |

Note: Data are for 2014. Inputs of diesel and electric energy are the quantities used to manufacture the total lumber input of each species.

**Table 9: Distance from sawmill to manufacturing factory and diesel consumption to transport total lumber of each species**

| Input | Unit | Company | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G |
| Distance from sawmill to factory | | | | | | | | |
| Ipe | km | | | | 500 | 0.0 | 2 900 | 60 |
| Cumaru | km | | | | 500 | 0.0 | 2 000 | 60 |
| Transport to factory (diesel consumption) | | | | | | | | |
| Ipe | l | | | | 13 372.3 | 0.0 | 208 336.0 | 2 217.5 |
| Cumaru | l | | | | 3 177.1 | 0.0 | 224 620.0 | 1 557.0 |
| Ipe | kg | | | | 11 326.3 | 0.0 | 176 460.6 | 1 878.2 |
| Cumaru | kg | | | | 2 691.0 | 0.0 | 190 253.1 | 1 318.8 |

Note: Data are for 2014.

**Table 10: Inputs per 1 m³ of logs, sawnwood and decking, in the production of ipe and cumaru decking**

| Input | Unit | Company | | | | | | | Weighted mean |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | |
| Gasoline/m³ log – ipe | kg/m³ | 0.18 | 0.15 | 0.21 | 0.15 | 0.17 | | | **0.169** |
| Gasoline/m³ log – cumaru | kg/m³ | 0.18 | 0.15 | 0.21 | 0.15 | 0.17 | | | **0.178** |
| Diesel/m³ log – ipe | kg/m³ | 6.23 | 4.46 | 8.47 | 8.54 | 8.22 | | | **8.225** |
| Diesel/m³ log – cumaru | kg/m³ | 6.23 | 4.46 | 8.47 | 8.54 | 8.22 | | | **7.172** |
| Diesel/m³ sawnwood – ipe | kg/m³ | 3.65 | 6.78 | 5.35 | 3.33 | 4.16 | | | **3.052** |
| Diesel/m³ sawnwood – cumaru | kg/m³ | 2.47 | 6.78 | 5.01 | 3.33 | 4.43 | | | **3.596** |
| Electricity (grid)/m³ sawnwood – ipe | GJ/m³ | 0.000 | 0.123 | 0.071 | 0.000 | 0.000 | | | **0.027** |
| Electricity (grid)/m³ sawnwood – cumaru | GJ/m³ | 0.000 | 0.123 | 0.067 | 0.000 | 0.000 | | | **0.031** |
| Electricity (power plant)/m³ sawnwood – ipe | GJ/m³ | 0.452 | 0.000 | 0.000 | 0.208 | 0.470 | | | **0.179** |
| Electricity (power plant)/m³ sawnwood – cumaru | GJ/m³ | 0.305 | 0.000 | 0.000 | 0.208 | 0.501 | | | **0.211** |
| Diesel/m³ decking–- ipe | kg/m³ | | | | 4.94 | 3.14 | 4.19 | 0.87 | **3.009** |
| Diesel/m³ decking – cumaru | kg/m³ | | | | 4.83 | 3.09 | 3.79 | 0.90 | **3.082** |
| Electricity (grid)/m³ decking – ipe | GJ/m³ | | | | 0.000 | 0.000 | 1.444 | 0.553 | **0.816** |
| Electricity (grid)/m³ decking – cumaru | GJ/m³ | | | | 0.000 | 0.000 | 1.315 | 0.570 | **0.888** |
| Electricity (power plant)/m³ decking – ipe | GJ/m³ | | | | 0.792 | 1.592 | 0.000 | 0.000 | **0.155** |
| Electricity (power plant)/m³ decking – cumaru | GJ/m³ | | | | 0.785 | 1.572 | 0.000 | 0.000 | **0.286** |
| Water/m³ decking | | | | | | | | | |
| Ipe (river) | l/m³ | | | | 0.0 | 120.3 | 0.0 | 0.0 | **0.6** |
| Ipe (municipal) | l/m³ | | | | 0.0 | 0.0 | 151.9 | 87.2 | **97.3** |
| Cumaru (river) | l/m³ | | | | 0.0 | 120.4 | 0.0 | 0.0 | **19.7** |
| Cumaru (municipal) | l/m³ | | | | 0.0 | 0.0 | 155.2 | 85.3 | **108.8** |

Note: Data are for 2014. Excludes diesel consumption in transporting lumber from sawmill to manufacturing factory.

**Table 11: Diesel input per 1 $m^3$ of ipe and cumaru decking, for the transport of lumber from sawmill to manufacturing company**

| Diesel input (lumber transport from sawmill to factory) | Unit | Company | | | | | | | Arithmetic mean |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | |
| Ipe | kg | | | | 26.6 | 0.0 | 185.9 | 2.1 | 53.6 |
| Cumaru | kg | | | | 26.0 | 0.0 | 116.2 | 2.1 | 36.1 |

Note: Data are for 2014.

**Table 12: Life-cycle inventory inputs to produce 1 $m^3$ of ipe and cumaru decking**

| Input | Unit | Company | | | | | | | Weighted mean |
|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | |
| Inputs – ipe decking | | | | | | | | | |
| Log | $m^3$ | | | | 6.825 | 4.057 | 5.436 | 3.505 | **4.924** |
| Diesel | kg | | | | 69.6 | 41.5 | 55.6 | 34.1 | **49.6** |
| Gasoline | kg | | | | 1.2 | 0.7 | 0.9 | 0.6 | **0.8** |
| Electricity – grid | GJ | | | | 0.1 | 0.0 | 1.5 | 0.6 | **0.9** |
| Electricity – power plant | GJ | | | | 1.3 | 1.9 | 0.4 | 0.3 | **0.5** |
| Water – river | l | | | | 0.0 | 120.3 | 0.0 | 0.0 | **0.6** |
| Water – municipal | l | | | | 0.0 | 0.0 | 151.9 | 87.2 | **97.3** |
| Inputs – cumaru decking | | | | | | | | | |
| Log | $m^3$ | | | | 7.870 | 4.717 | 5.804 | 4.259 | **5.363** |
| Diesel | kg | | | | 71.0 | 42.8 | 52.6 | 36.7 | **48.2** |
| Gasoline | kg | | | | 1.4 | 0.8 | 1.0 | 0.8 | **1.0** |
| Electricity – grid | GJ | | | | 0.1 | 0.1 | 1.4 | 0.6 | **0.9** |
| Electricity – power plant | GJ | | | | 1.4 | 1.9 | 0.4 | 0.3 | **0.7** |
| Water – river | l | | | | 0.0 | 120.4 | 0.0 | 0.0 | **19.7** |
| Water – municipal | l | | | | 0.0 | 0.0 | 155.2 | 85.3 | **108.8** |

Note: Data are for 2014. Integrated flow excluding diesel consumption in transporting lumber from sawmill to manufacturing factory.

Of the seven companies assessed, only two had sufficiently organized monthly production data to be used in the study; all others were only able to provide annual data. The field survey was carried out after the harvesting period (usually from June to November, which is the dry season in the Amazon region), thereby allowing sufficient data to be collected.

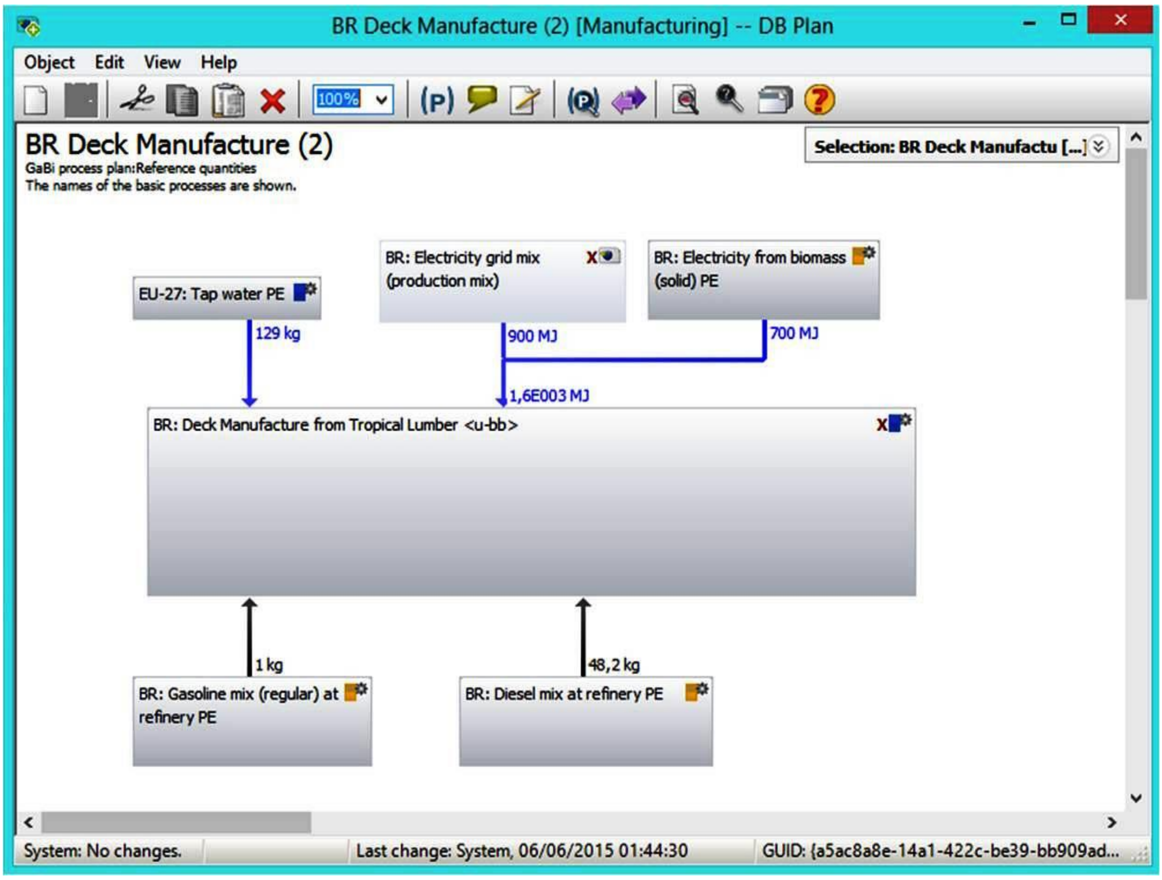
**Life-cycle inventory data**

The life-cycle inventory inputs to produce 1 $m^3$ of ipe and cumaru decking were calculated for companies D to G according to the method described above for cradle (forest) to gate (factory warehouse). These inputs are shown in Table 12, excluding diesel consumption for transport from sawmill to factory, which is shown in Table 11.

Figure 12 shows a generic model of the decking manufacture process created using GaBi6 software; this model was used to integrate the data for all companies.

Environmental impacts were analyzed using GaBi6 LCIA-CML 2001 (Nov. 10). All generic databases were obtained from GaBi6.

**Figure 12: Generic decking manufacturing model, generated by GaBi6, showing processes and flows**




**Impact assessment results**

The potential environmental impacts—GWP, AP, EP, ODP and POCP—are analyzed for three scenarios:

1) five companies with forest harvesting and sawmilling operations;

2) four decking-manufacturing companies, integrating forest and mill activities; and
3) the impact of long-distance lumber transportation.

*Forest harvesting and sawmilling operations*

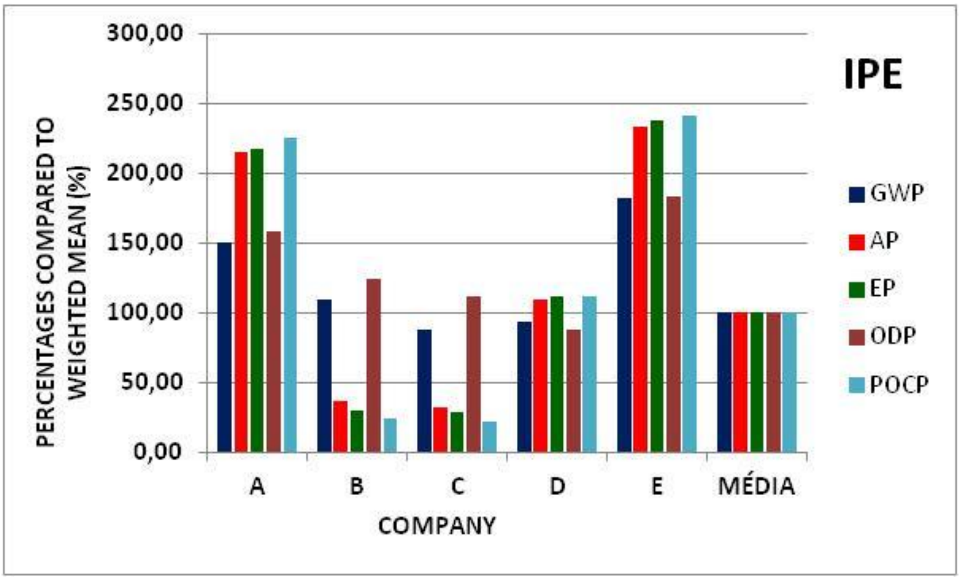
Table 13 shows the environmental impacts estimated for companies A to E, and Figure 13 depicts these results in relation to the weighted average of the five companies.

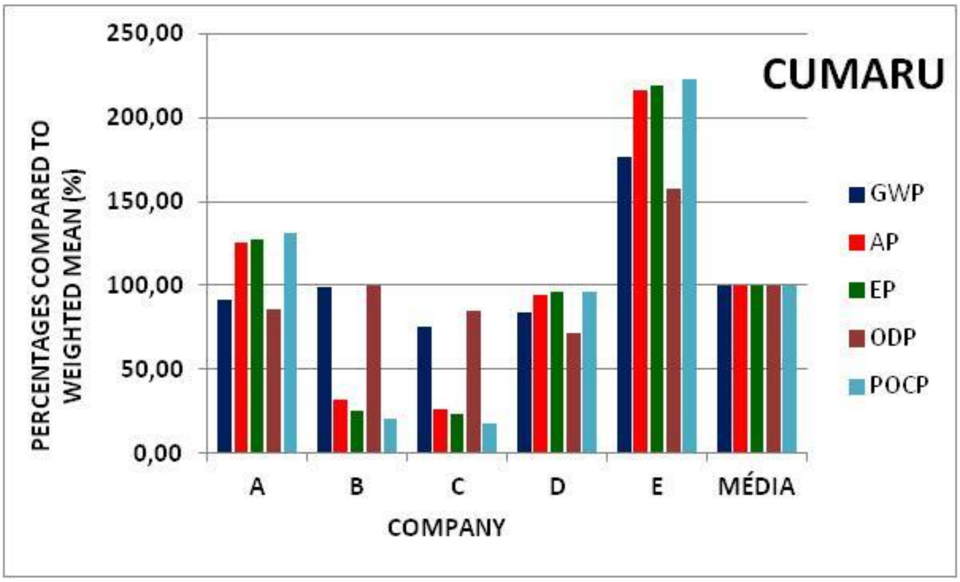
**Table 13: Environmental impact potential for the production for 1 $m^3$ of ipe and cumaru decking (forest and sawmill operations)**

| **Impact category** | **Unit** | **Company** | | | | | Weighted average |
|---|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** | **E** | |
| **Ipe decking** | | | | | | | |
| GWP 100 years | kg $CO_2$-eq. | 46.5 | 33.9 | 27.3 | 29.0 | 56.5 | **31.0** |
| AP | kg $SO_2$-eq. | 1.40 | 0.24 | 0.21 | 0.71 | 1.52 | **0.65** |
| EP | kg $(PO_4)$-eq. | 0.23 | 0.03 | 0.03 | 0.12 | 0.26 | **0.11** |
| ODP | mg CFC11-eq. | 0.98 | 0.77 | 0.702 | 0.553 | 0.115 | **0.628** |
| POCP | kg ethylene-eq. | 0.28 | 0.03 | 0.03 | 0.14 | 0.30 | **0.13** |
| **Cumaru decking** | | | | | | | |
| GWP 100 years | kg $CO_2$-eq. | 28.3 | 30.7 | 23.3 | 26.1 | 54.8 | **31.1** |
| AP | kg $SO_2$-eq. | 0.86 | 0.22 | 0.18 | 0.64 | 1.48 | **0.68** |
| EP | kg $(PO_4)$-eq. | 0.14 | 0.03 | 0.03 | 0.11 | 0.25 | **0.11** |
| ODP | mg CFC11-eq. | 0.607 | 0.706 | 0.598 | 0.502 | 0.111 | **0.706** |
| POCP | kg ethylene-eq. | 0.17 | 0.03 | 0.02 | 0.13 | 0.30 | **0.13** |

Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide. Weighted average = sum of inputs consumed by companies divided by the sum of the decking produced by those companies.

**Figure 13: Relative environmental impact categories, compared with mean values, for companies with forest harvesting and sawmilling operations**




Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide. Weighted average = sum of inputs consumed by companies divided by the sum of the decking produced by those companies.

In all impact categories, company E recorded the highest potential impact, followed by company A. Both these companies use electricity generated from biomass, and their relatively poor performance is due mainly to low sawmill recovery. Company B has relatively high values for GWP and ODP due to its use of electricity from the grid (this situation may change, however, when the company's power plant starts operation).

The average GWP for forest and sawmill operations is 31.0 kg $CO_2$-eq. per $m^3$ for ipe decking (ranging from 27.3 to 56.5 kg $CO_2$-eq. per $m^3$), and 31.1 kg $CO_2$-eq. per $m^3$ for cumaru decking (ranging from 23.3 to 54.8 kg $CO_2$-eq. per $m^3$). Given that 1 $m^3$ of ipe and cumaru decking contain about 500 kg of carbon, even the worst GWP rating represents a good overall result. Nevertheless, it is important that companies improve their sawing operations to increase lumber recovery.

**Integrated manufacturing companies**

Table 14 presents the estimated environmental impacts of companies D to G, and Figure 14 depicts these results in relation to the weighted average of the four companies. These data represent the integrated flow from forest to factory but do not including the diesel consumption involved in transporting the lumber from the sawmill to the factory.

**Table 14: Environmental impact potential for the production of 1 $m^3$ of ipe and cumaru decking (integrated flow from forest to companies, excluding diesel consumption for lumber transportation)**

| Impact category | Unit | Company | | | | Weighted average |
|---|---|---|---|---|---|---|
| | | D | E | F | G | |
| Ipe decking | | | | | | |
| GWP 100 years | kg $CO_2$-eq. | 71.1 | 72.4 | 147.0 | 67.0 | **101.0** |
| AP | kg $SO_2$-eq. | 1.98 | 2.67 | 1.35 | 0.76 | **1.20** |
| EP | kg $PO_4$-eq. | 0.326 | 0.443 | 0.159 | 0.101 | **0.162** |
| ODP | mg CFC11-eq. | 0.893 | 0.526 | 0.679 | 0.449 | **0.601** |
| POCP | kg ethylene-eq. | 0.397 | 0.551 | 0.193 | 0.122 | **0.196** |
| Cumaru decking | | | | | | |
| GWP 100 years | kg $CO_2$-eq. | 74.3 | 80.6 | 138.0 | 67.7 | **107.0** |
| AP | kg $SO_2$-eq. | 2.13 | 2.71 | 1.30 | 0.77 | **1.47** |
| EP | kg $PO_4$-eq. | 0.351 | 0.446 | 0.156 | 0.103 | **0.206** |
| ODP | mg CFC11-eq. | 1.04 | 0.601 | 0.752 | 0.597 | **0.749** |
| POCP | kg ethylene-eq. | 0.428 | 0.556 | 0.190 | 0.124 | **0.252** |

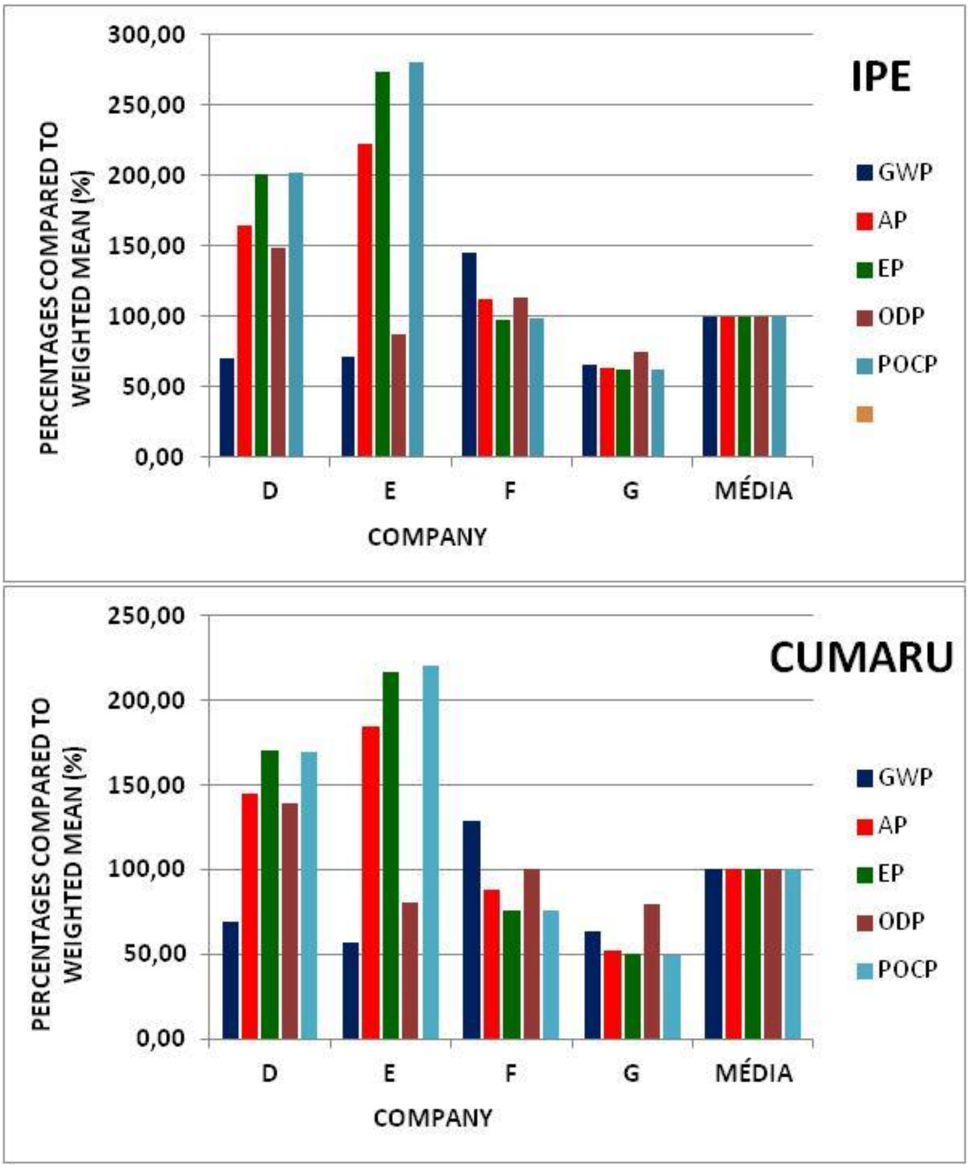
Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide. Weighted average = sum of inputs consumed by companies divided by the sum of the decking produced by those companies.

Table 14 shows that company F has a very high GWP compared with companies D, E and G (for example, it is more than double the GWP of those companies for the manufacture of ipe decking). Company F's relatively high GWP can be attributed to high electricity inputs and low decking recovery.

A specific characteristic of company F is the wide range of flooring it produces, making it more difficult to purchase lumber with the appropriate dimensions for decking production. The company buys lumber as rough-sawn boards with sufficiently large dimensions to enable their use in various types of flooring. This lumber is kiln-dried and then planed to decking profiles. The first planer, which transforms the rough-sawn lumber to S4S [square four sides] lumber, must be a strong machine because it needs to remove relatively large amounts of dry wood and adjust the S4S dimensions to make it easier for the multiple head planer.

On the other hand, company G recorded the lowest scores in all impact categories for both ipe and cumaru. This company is located near the sawmill, and it buys its lumber in blocks with appropriate dimensions for decking manufacture. The first cut—to transform the green blocks to slabs—is done in a multiple gig saw, which requires a relatively low electricity input. The slabs are then dried in kilns, followed by the final moulder cut. The electricity input is relatively low and the decking recovery is higher because of the efficient adjustment of rough-sawn lumber dimensions.

**Figure 14: Relative environmental impact categories, compared with mean values, for the manufacturing companies, integrated flow from forest to factory (without diesel consumption for lumber transportation)**




Note: AP = acidification potential; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; POCP = photochemical ozone creation potential; ODP = ozone depletion potential. Weighted average = sum of inputs consumed by companies divided by the sum of the decking produced by those companies.

## Companies with complete flow

This scenario analyses the impacts of companies D and E, which are involved directly in the complete cradle-to-gate production chain. Table 15 presents the estimated environmental impacts of companies D and E, and Figure 15 depicts these results in relation to the mean of the two companies. These data do not including the diesel consumption involved in transporting the lumber from the sawmill to the factory.

Table 16 compares the environmental impact potential of companies D and E, estimated for the complete cradle-to-gate production chain and using the methodology described above to integrate forest and manufacturing activities.

**Table 15: Environmental impact potential for the production of 1 $m^3$ of ipe and cumaru decking, comparing companies D and E (complete industrial flow, without diesel consumption for lumber transportation)**

| Impact category | Unit | Company | | Arithmetic mean |
|---|---|---|---|---|
| | | D | E | |
| **Ipe decking** | | | | |
| GWP 100 years | kg $CO_2$-eq. | 65.3 | 97.2 | **82.8** |
| AP | kg $SO_2$-eq. | 2.29 | 3.42 | **2.79** |
| EP | kg $PO_4$-eq. | 0.38 | 0.57 | **0.47** |
| ODP | mg CFC11-eq. | 0.746 | 0.972 | **0.848** |
| POCP | kg ethylene-eq. | 0.47 | 0.70 | **0.57** |
| **Cumaru decking** | | | | |
| GWP 100 years | kg $CO_2$-eq. | 65.9 | 98.3 | **81.1** |
| AP | kg $SO_2$-eq. | 2.08 | 3.43 | **2.71** |
| EP | kg $PO_4$-eq. | 0.35 | 0.57 | **0.45** |
| ODP | mg CFC11-eq. | 0.745 | 0.972 | **0.863** |
| POCP | kg ethylene-eq. | 0.42 | 0.71 | **0.56** |

Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide. Weighted average = sum of inputs consumed by companies divided by the sum of the decking produced by those companies.

Of the two companies, company E recorded the higher values in all impact categories. This is due mostly to its low lumber recovery and its higher energy consumption in the harvesting and sawmill phases. Company E consumed 29% more diesel and 33% more electricity than company D to produce 1 $m^3$ of lumber.

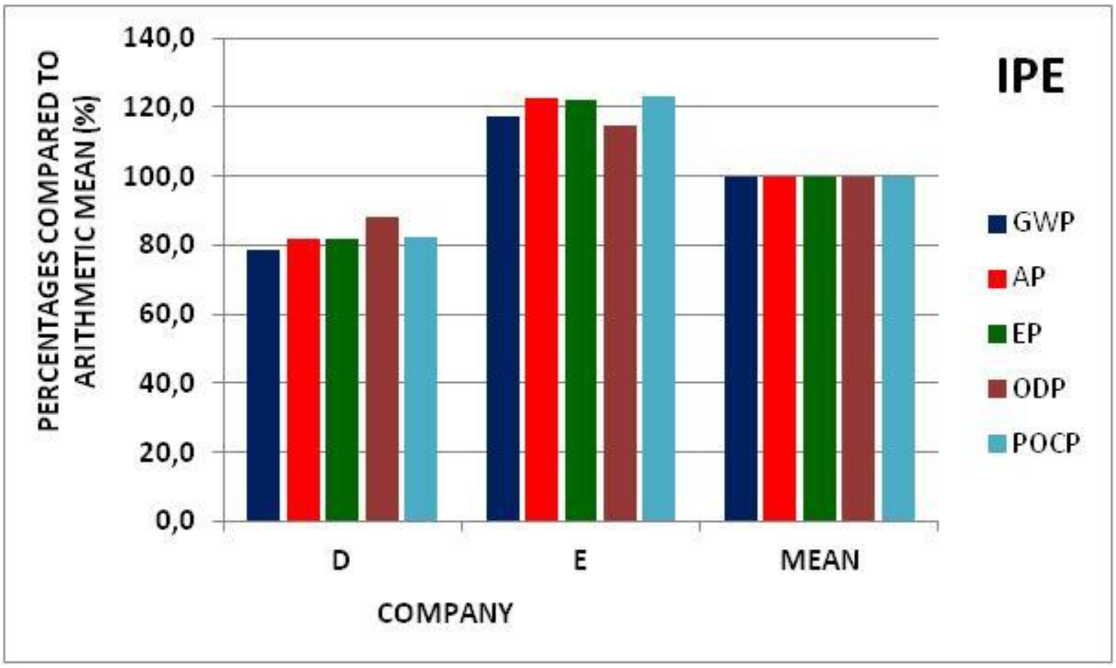
**Table 16: Mean values for companies D and E, comparing results from the complete industrial flow (Table 15) with results obtained using the methodology for integrating harvesting and manufacturing activities (Table 14, integrated flow)**

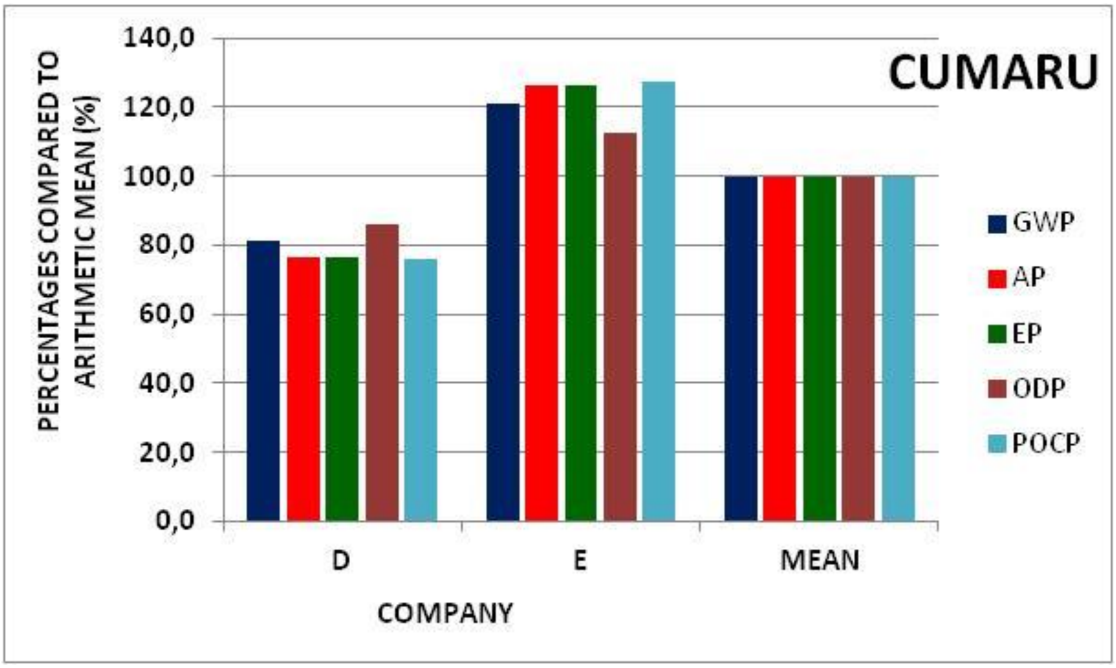
| Impact category | Unit | Company D | | Company E | |
|---|---|---|---|---|---|
| | | Complete flow | Integrated flow | Complete flow | Integrated flow |
| **Ipe decking** | | | | | |
| GWP 100 years | kg $CO_2$-eq. | 65.3 | 71.1 | 97.2 | 72.4 |
| AP | kg $SO_2$-eq. | 2.29 | 1.98 | 3.42 | 2.67 |
| EP | kg $PO_4$-eq. | 0.38 | 0.33 | 0.57 | 0.44 |
| ODP | mg CFC11-eq. | 0.746 | 0.893 | 0.972 | 0.526 |
| POCP | kg ethylene-eq. | 0.47 | 0.40 | 0.70 | 0.55 |
| **Cumaru decking** | | | | | |
| GWP 100 years | kg $CO_2$ eq. | 65.9 | 74.3 | 98.3 | 80.6 |
| AP | kg $SO_2$-eq. | 2.08 | 2.13 | 3.43 | 2.71 |
| EP | kg $PO_4$-eq. | 0.35 | 0.35 | 0.57 | 0.45 |
| ODP | mg CFC11-eq. | 0.745 | 1.04 | 0.972 | 0.601 |
| POCP | kg ethylene-eq. | 0.42 | 0.43 | 0.71 | 0.56 |

Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide. Weighted average = sum of inputs consumed by companies divided by the sum of the decking produced by those companies.

A comparison of the environmental impact values calculated using the complete flow and the integration methodology indicates that, for company E, the integrated flow methodology resulted in an overestimate of GWP and ODP for company D and an underestimate of GWP and ODP for company E. This suggests a need to improve the adopted methodology.

**Figure 15. Relative environmental impact categories, comparing companies D and E (complete industrial flow, without diesel consumption for lumber transportation)**




Note: AP = acidification potential; EP = eutrophication potential; GWP = global warming potential; POCP = photochemical ozone creation potential; ODP = ozone depletion potential.

### Impact of long-distance lumber transport

Tables 17 and 18 show, for ipe and cumaru decking respectively, the distances from sawmill to manufacturing factory for companies D–F, the diesel inputs for transport, and the environmental impact potential of this transportation. Figure 16 shows the GWP values for this transportation for ipe and cumaru decking.

**Table 17: Distance from sawmill to manufacturing factory, diesel consumption for 1 $m^3$ of ipe decking, and environmental impact potential of this transportation**

| Impact category | Unit | Company | | | | Arithmetic mean | |
|---|---|---|---|---|---|---|---|
| | | D | E | F | G | Total | (minus company F) |
| Distance | km | 500 | 0 | 2 900 | 60 | **865.0** | **186.7** |
| Diesel input | kg | 26.6 | 0 | 185.9 | 2.1 | **53.6** | **9.6** |
| GWP 100 years | kg $CO_2$-eq. | 8.8 | 0.0 | 61.5 | 0.7 | **17.7** | **3.2** |
| AP | kg $SO_2$-eq. | 0.076 | 0.000 | 0.501 | 0.006 | **0.146** | **0.027** |
| EP | kg $PO_4$-eq. | 0.013 | 0.000 | 0.091 | 0.001 | **0.026** | **0.005** |
| ODP | mg CFC11-eq. | 0.000067 | 0.000 | 0.00047 | 0.0000052 | **0.00014** | **0.000024** |
| POCP | kg ethylene-eq. | 0.011 | 0.000 | 0.074 | 0.001 | **0.021** | **0.004** |

Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide.

**Table 18: Distance from sawmill to manufacturing company, diesel consumption for 1 $m^3$ of cumaru decking, and environmental impact potential of this transportation**

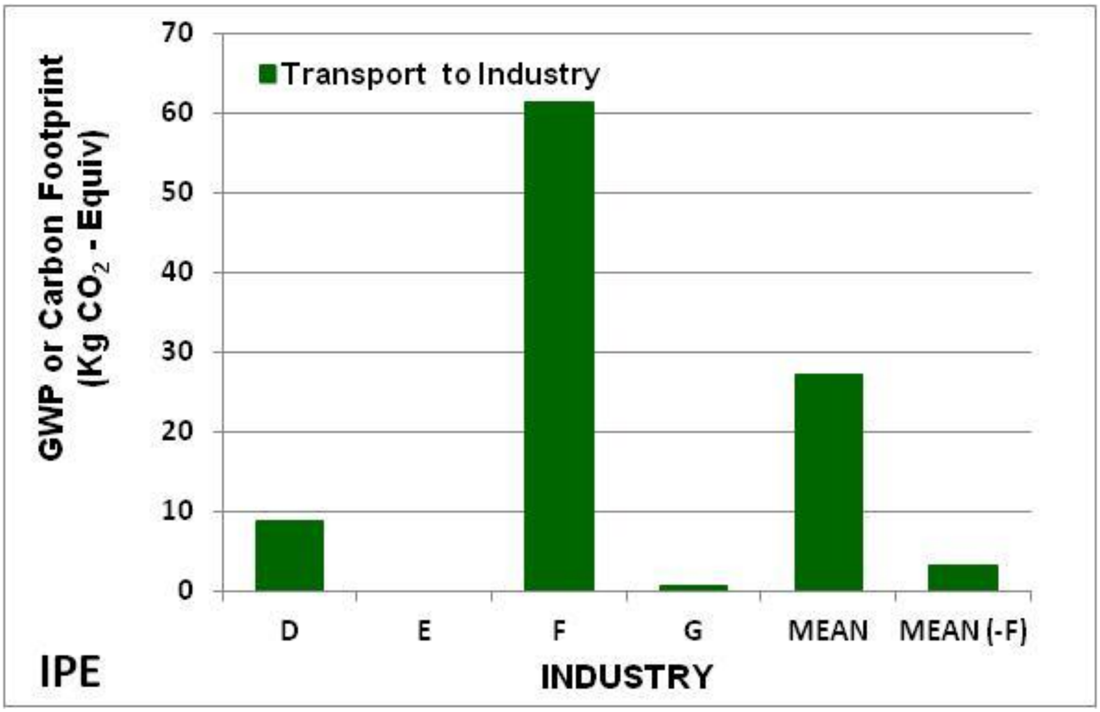
| Impact category | Unit | Company | | | | Arithmetic mean | |
|---|---|---|---|---|---|---|---|
| | | D | E | F | G | Total | (minus company F) |
| Distance | km | 500 | 0 | 2 000 | 60 | **640.0** | **186.7** |
| Diesel input | kg | 26.0 | 0 | 116.2 | 2.1 | **36.1** | **9.4** |
| GWP 100 years | kg $CO_2$-eq. | 8.6 | 0.0 | 38.4 | 0.7 | **11.9** | 3.1 |
| AP | kg $SO_2$-eq. | 0.070 | 0.000 | 0.314 | 0.006 | **0.097** | 0.025 |
| EP | kg $PO_4$-eq. | 0.013 | 0.000 | 0.057 | 0.001 | **0.018** | 0.005 |
| ODP | mg CFC11-eq. | 0.000065 | 0.000 | 0.00029 | 0.0000054 | **0.000091** | 0.000024 |
| POCP | kg ethylene-eq. | 0.010 | 0.000 | 0.046 | 0.001 | **0.014** | 0.004 |

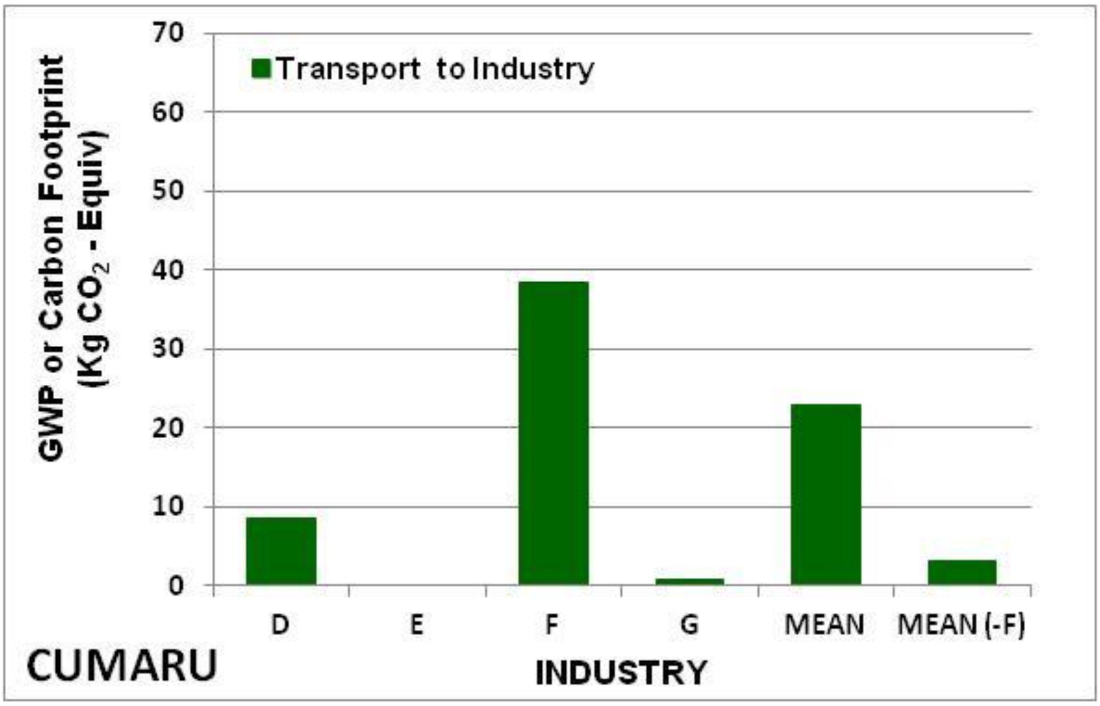
Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide.

Company F is the only company of the seven located in Brazil's Southeast Region, and the distance from it to lumber suppliers ranges from 2000 to 2900 km, implying high inputs of diesel for lumber transport. For company F, the potential impact of transporting the lumber is higher than the potential impact of its harvesting and sawmill activities.

Brazil is a large country on a continental scale, and the distance from the North Region (where the trees grow and the lumber is produced) to the South and Southeast regions (where some big manufacturing companies are located) is 2000–4000 km. In Brazil, therefore, LCAs and EPDs are highly dependent on the proximity of manufacturing factories to the forest.

**Figure 16: Global warming potential related to the transport of lumber to sawmill to manufacturing factory, expressed as kg $CO_2$-eq., for the production of 1 $m^3$ of ipe and cumaru decking**




Note: AP = acidification potential; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; POCP = photochemical ozone creation potential; ODP = ozone depletion potential.

Tables 14, 17 and 18 show that the potential environmental impact of company F is 3–4.5 times higher when the manufacturing phase and lumber transport are considered together (as previously indicated, this is due to the higher input of electricity from the grid and the long-distance transportation of the lumber).

In summary: LCAs and EPDs are strongly influenced by the lumber transportation distance; of the seven companies assessed, six are in northern Brazil and one (company F) is in southeast Brazil. In addition to its transportation component, company F has the highest electricity inputs in the manufacturing phase. It was considered, therefore, that the best approach to analyzing the results was to withdraw company F. Data from companies A, B, C, D, E and G are more homogeneous and give a better picture of decking manufacturing practices in northern Brazil.

**GWP emissions and carbon footprint**

Table 19 presents GWP values for companies D, E and G (integrated industrial flow) and Figure 17 shows these graphically for the forest and sawmill, lumber transport and manufacturing phases.

The forest and sawmilling phase makes the largest contribution to GWP in company D. In companies E and G, on the other hand, the manufacturing process contributes most to GWP. As stated by Gan and Massijaya (2014) in their LCA study for tropical plywood manufacturing in Malaysia and Indonesia, GWP is strongly influenced by the consumption of fossil fuels and electricity (where this is generated using fossil fuels).

**Table 19: Global warming potential, expressed as kg $CO_2$-eq., for the production of 1 $m^3$ of ipe and cumaru decking (integrated flow from forest to factory), by harvesting and sawmill, lumber transport, and manufacturing phases**

| Phase of industrial flow | Company | | | Arithmetic mean |
|---|---|---|---|---|
| | D | E | G | |
| **Ipe decking** | | | | |
| Harvesting and sawmilling | 42.2 | 25.1 | 21.7 | 29.7 |
| Lumber transport | 8.8 | 0.0 | 0.7 | 3.2 |
| Factory manufacturing | 28.5 | 47.4 | 45.3 | 40.4 |
| **Total** | 79.5 | 72.5 | 67.7 | 73.2 |
| **Cumaru decking** | | | | |
| Harvesting and sawmilling | 45.7 | 27.4 | 24.7 | 32.6 |
| Lumber transport | 8.6 | 0.0 | 0.7 | 3.1 |
| Factory manufacturing | 28.5 | 53.1 | 43.2 | 41.6 |
| **Total** | 82.8 | 80.5 | 68.6 | 77.3 |

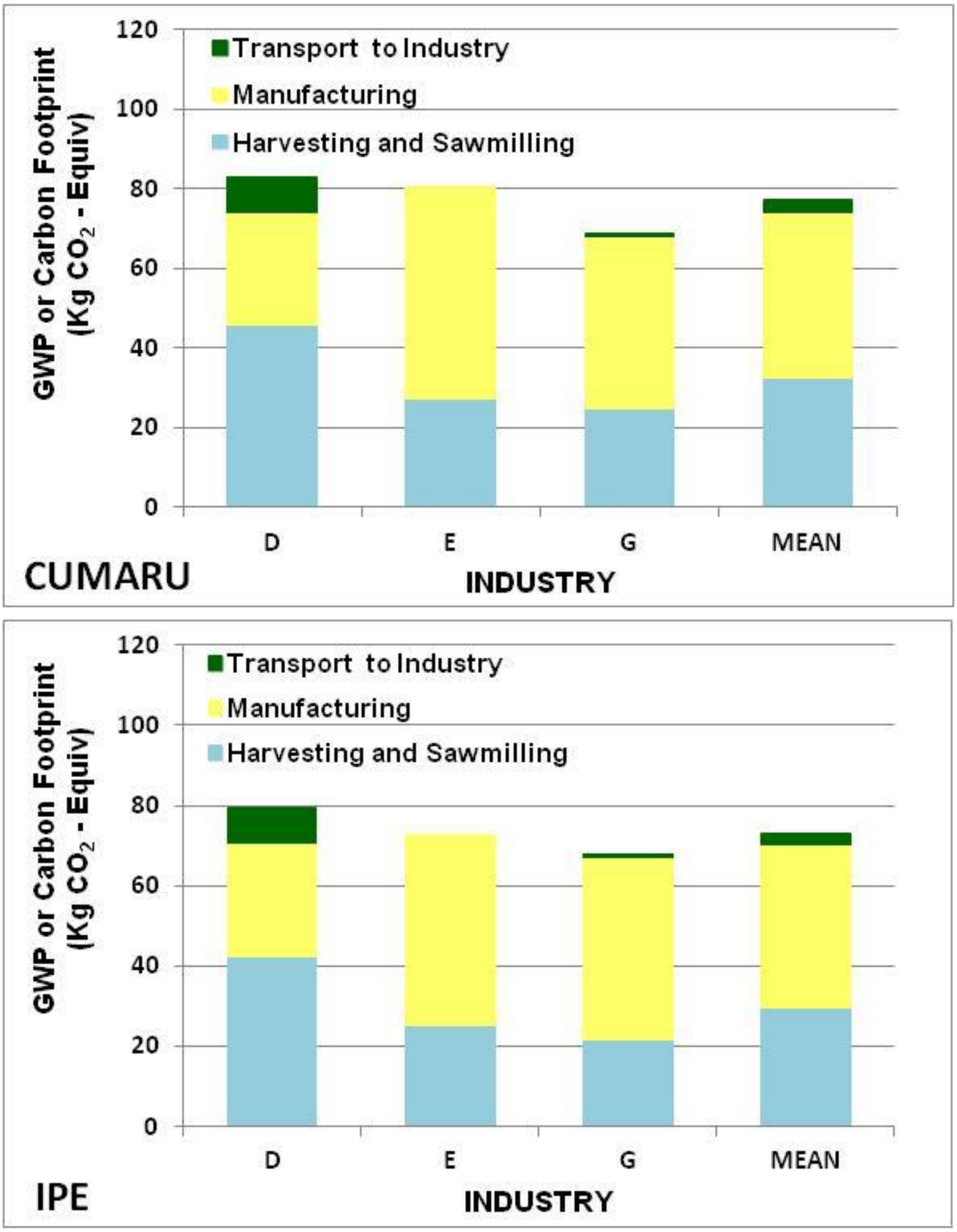
We assume that the values in Table 19 represent all companies that manufacture ipe and cumaru decking in Brazil's North Region (the tropical or Amazon forest region). The average value for each environmental impact category, shown in Table 20, should therefore form the basis of ipe and cumaru decking EPDs. For reference only, Table 21 lists the values for company F in the various impact categories.

**Table 20: Environmental impact potential for the production of 1 $m^3$ of ipe and cumaru decking in Brazil's North Region**

| Impact category | Unit | Wood species | |
|---|---|---|---|
| | | Ipe | Cumaru |
| GWP 100 years | kg $CO_2$-eq. | 73.2 | 77.3 |
| AP | kg $SO_2$-eq. | 1.83 | 1.90 |
| EP | kg $(PO_4)$-eq. | 0.30 | 0.31 |
| ODP | mg CFC11-eq. | 0.623 | 0.746 |
| POCP | kg ethylene-eq. | 0.361 | 0.373 |

Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide.

**Figure 17: Global warming potential, expressed as kg $CO_2$-eq., for the production of 1 $m^3$ of ipe and cumaru decking (integrated flow from forest to factory), by harvesting and sawmill, lumber transport, and manufacturing phase**




Note: $CO_2$ = carbon dioxide; GWP = global warming potential.

**Table 21: Environmental impact potential for the production of 1 $m^3$ of ipe and cumaru decking, company F**

| Impact category | Unit | Wood species | |
|---|---|---|---|
| | | Ipe | Cumaru |
| GWP 100 years | kg $CO_2$-eq. | 208.0 | 177.0 |
| AP | kg $SO_2$-eq. | 1.85 | 1.61 |
| EP | kg $PO_4$-eq. | 0.25 | 0.21 |
| ODP | mg CFC11-eq. | 0.679 | 0.752 |
| POCP | kg ethylene-eq. | 0.268 | 0.24 |

Note: AP = acidification potential; CFC11 = trichlorofluoromethane; $CO_2$ = carbon dioxide; EP = eutrophication potential; eq. = equivalent; GWP = global warming potential; $PO_4$ = phosphate; POCP = photochemical ozone creation potential; ODP = ozone depletion potential; $SO_2$ = sulphur dioxide.

LCAs can be used to calculate the Type 3 Carbon Footprint (greenhouse-gas emissions, expressed in kg of $CO_2$-eq.). The carbon footprint is estimated at 73.2 kg $CO_2$-eq./$m^3$ (i.e. the average GWP, as estimated in this study) for ipe decking and 77.3 kg $CO_2$-eq. ; for cumaru decking, both produced in Brazil's North Region.

The GWPs for ipe and cumaru decking compare favourably with those reported for other wood-based products (Gan and Massijaya 2014; Adu and Eshum 2014) and other types of wood flooring (Nebel 2006). Adu and Eshum (2014) reported a GWP of 253.1 kg $CO_2$-eq./$m^3$ for kiln-dried *Khaya* lumber produced in Ghana, which is more than three times higher than the value calculated in this study for ipe and cumaru decking produced in northern Brazil, the difference attributed mainly to the source and quantity of electricity used. Adu and Eshum (2014) reported that the companies surveyed in Ghana obtained their electricity from the grid, 50% of which is generated using coal, implying relatively high emissions of $CO_2$-eq. compared with the Brazil case. In northern Brazil, most (85–90%) electricity obtained from the grid is generated by hydropower, and decking manufacturers obtain their electricity either solely from the grid or both from the grid and using their own biomass. Adu and Eshum (2014) also reported an input of 1.36 GJ for each $m^3$ of kiln-dried *Khaya* lumber, which is about 70% higher than the mean electricity input found in this study (0.79 GJ per $m^3$ of kiln-dried ipe lumber).

It is a well known that kiln-drying requires the highest input of electricity of the various elements of wood-based manufacturing (Jankowsky 2009). Total electricity consumption depends on kiln design and efficiency, kiln schedule, the drying control system, and kiln operator knowledge and experience; it is likely that the operational conditions in Ghana differ from those in Brazil.

In comparing the two studies, two other aspects should be noted:

1) The present study used only the GaBi6 database, whereas Adu and Eshum (2014) used the best background data available in the literature considered most representative of Ghanaian conditions.
2) In both studies, the number of assessed companies was small, and it is possible that company personnel made errors in their supply of basic information.

The GWPs for ipe and cumaru decking are considerably higher than those estimated for redwood decking according to the EPD published by the American Wood Council and California Redwood Association (2013). That EPD used the PCRs for North American Structural and Architectural Wood Products, which consider all energy from biomass-burning to be free of emissions and also allow the carbon sequestered by trees in the forest and still present in the finished product to be deducted from the carbon footprint. As a result, GWP of redwood decking is -648 $kgCO_2/m^3$ (cradle-to-gate). If the LCA for ipe and cumaru decking had used this PCR, their GWP values would also undoubtedly have been negative.

# 6 Conclusions

LCA was used to evaluate the environmental performance of ipe and cumaru decking produced in Brazil's North Region, where both species are harvested in sustainably managed tropical forests. The evaluated companies showed differences in their environmental profiles due to differences in capacity, lumber and decking manufacture recovery, distance from the raw-material source, and use of residues. There were also differences related to the production chain: some companies do their own harvesting in the forest and produce sawnwood or lumber; other companies buy their lumber from several suppliers and only manufacture the decking; and a few companies encompass the complete production chains from the forest to the finished product. It was possible to integrate the different companies and to obtain representative data for the manufacturing phases used in the production of ipe and cumaru decking in northern Brazil. The environmental indicators resulting from this study suggest that both ipe and cumaru decking perform well environmentally compared with other wood-based products. The study also reveals that the main sources of environmental impacts are electricity from the grid and the use of fossil fuels (especially diesel used for transport). The data obtained from one company in southeast Brazil was withdrawn from the analysis because of the high diesel consumption associated with transporting the lumber over the very long distances involved and with electricity obtained from the grid.

Companies can improve their environmental performance by:

- increasing recovery from logs and lumber;
- improving the efficiency of lumber transportation (e.g. with newer vehicles, better vehicle maintenance and the pre-drying of lumber to decrease weight);
- investing in new processing machines to reduce electricity demand;
- improving material flows in the manufacturing process;

- investing in cogeneration systems using biomass to produce thermal energy and electricity; and
- establishing information management systems to provide high-quality data for LCA studies and production management.

**General comments**

This study permitted the collection of valuable data and experience in LCA research in Brazil. Based on this experience, the following general comments can be made:

- No studies exist on LCAs for tropical forest harvesting, and they are needed to provide a solid basis for LCAs on tropical wood-based products.
- The study showed the influence of long-distance lumber transportation on environmental impacts. Because Brazil is a continental-scale country, it is important to extend the present research to cover more companies, especially those in the South and Southeast regions of the country.
- The interpretation of LCAs can differ depending on the PCRs adopted. It is important to develop PCRs specifically for tropical timber and its manufactured products.
- ITTO has an important strategic leadership role to play in promoting research on LCAs and EPDs for tropical timber and products.

# 7 Bibliography

Adu, G.A. & Eshum, J.F. 2014. *Life cycle assessment for environmental product declaration of tropical African mahogany (Khaya) lumber produced in Ghana*. Report prepared for the International Tropical Timber Organization, Yokohama, Japan.

Askham, N.C. 2006. Excel for calculating EPD data for Concrete. In: *SETAC Europe 13th LCA case study symposium proceedings with focus on the building and construction sector, Stuttgart, Germany*.

BS EN 15804:2012. Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products. BSI Standards Publication.

Cabeza, L.F. et al. 2014. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review. *Renewable and Sustainable Energy Reviews* 29: 394–416.

EC-JRC-IES 2010. *International reference life cycle data system (ILCD) handbook*. General guide for life cycle assessment. Detailed guidance. First edition. European Commission Joint Research Centre Institute for Environment and Sustainability.

Fava, J.A. 2006. Will the next 10 years be as productive in advancing life cycle approaches as the last 15 years? *International Journal of Life Cycle Assessment* 1: 6–8 (SPEC.ISS.).

Flynn Jr., J.H. & Holder, C.D. 2001. *A guide to useful woods of the world*. Second edition. Forest Products Society, Madison, USA.

FPInnovations 2013. Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD) for North American Structural and Architectural Wood Products (version 1.1, UN CPC31, NAICS 321). Vancouver, USA. (Available at: https://fpinnovations.ca/Extranet/Pages/)

GaBi 6. PE: GaBi 6 software-System and database for Life Cycle Engineering. Copyright. TM. Stuttgart, Echterdingen 1992-2014.

Gan, K.S. & Massijaya, M.Y. 2014. *Life cycle assessment for environmental product declaration of tropical plywood production in Malaysia and Indonesia*. Report prepared for the International Tropical Timber Organization, Yokohama, Japan.

Gustavsson, L. & Sathre, R. 2006. Variability in energy and carbon dioxide balances of wood and concrete building materials. *Building and Environment* 41(7): 940–951.

IBU 2009. Institut Bauen und Umwelt e.V., PCR Wood Materials. Rules for Environmental Product Declarations (November 2009).

IPT. www.ipt.br/informacoes_madeiras/10.htm.2014.

IPT. www.ipt.br/informacoes_madeiras/38.htm.2014.

ISO 14021: 1999. Environmental labels and declarations—Self-declared environmental claims (Type II environmental labeling). International Organization for Standardization (ISO), Geneva. 23 pp.

ISO 14024: 1999. Environmental labels and declarations—Type I environmental labeling—Principles and procedures. International Organization for Standardization (ISO), Geneva. 11 pp.

ISO 14025: 2006. Environmental labels and declarations—Type III environmental declarations—Principles and procedures. International Organization for Standardization (ISO), Geneva. 25 pp.

ISO 14040, 2006. Environmental management – life cycle assessment – Principles and framework. International Organization for Standardization (ISO), Geneva. 32 pp.

ISO 14044, 2006. Environmental management – life cycle assessment – Requirements and guidelines. International Organization for Standardization (ISO), Geneva. 46 pp.

Jankowsky, I.P. 2009. Metodologia simplificada para a indicação de programas de secagem. 2009. Tese (Livre Docência) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba.

LPF/SFB. Database of Brazilian woods (available at: http://sistemas.florestal.gov.br/madeirasdobrasil/features.php?ID=289&caracteristica=178).

Nebel, B., Zimmer, B. & Wegener, G. 2006. Life cycle assessment of wood floor coverings: a representative study for the German flooring industry. *International Journal of Life Cycle Assessment* 11(3): 172–182.

Ortiz, O., Castells, F. & Sonnemann, G. 2009. Sustainability in the construction industry: a review of recent developments based on LCA. *Construction and Building Materials* 23: 28–39.

Sartori, I. & Hestnes, A.G. 2007. Energy use in the life cycle of conventional and low-energy buildings: a review article. *Energy and Buildings* 3: 249–57.

Sharma, A., Saxena, A., Sethi, M. & Shree, V. 2011. Life cycle assessment of buildings: a review. *Renewable and Sustainable Energy Reviews* 1: 871–875.

# Appendix: Environmental impact categories

Reproduced from Gan and Massijaya (2014)

### Global warming potential (GWP)

The 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.

### 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).

### 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.

### 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 wave-lengths. 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 (NOx). In this study, the ozone depletion potentials are calculated from the different ozone relevant substances and reported in CFC 11 equivalents.

### 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.