PE INTERNATIONAL
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Final Report

Life Cycle Assessment of US Hardwood Veneer

For

AHEC – American Hardwood Export Council

By

PE INTERNATIONAL AG

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ACRONYMS

AHEC	American Hardwood Export Council
AP	Acidification Potential
Bdft	Board foot
C	Carbon
HCFC	Hydrochlorofluorocarbons
cm	Centimetre
CML	Institute of Environmental Sciences of Leiden University (Dutch: Centre for Milieukunde Leiden)
CO_2	Carbon dioxide
CORRIM	Consortium for Research on Renewable Industrial Materials
CPA	Corrugated Packaging Alliance
ECO	Environmental Construction Organisation
ELCD	European Reference Life Cycle Database
EoL	End of Life
EP	Eutrophication Potential
EPA	Environmental Protection Agency
EPD	Environmental Product Declaration
EURO4	European Emission Standard – EURO4
FU	Functional unit
G&S	Goal and Scope
GaBi6	GaBi 6 is a software for Life Cycle Assessment. GaBi stands for ”Holistic balance“ (German: Ganzheitliche Bilanzierung)
GWP	Global Warming Potential
H^+	Hydrogen Ion
Ha	Hectare
HAPs	Hazardous Air Pollutants
HPVA	Hardwood Plywood Veneer Association
IBU	Construction and Environment Institute (German: Institut Bauen und Umwelt e.V.)
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
JRC	European Commission Joint Research Centre
kg	Kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
m^2	Square metre

m^3	Cubic metre
MBF	Thousand board feet. In this study the conversion factor is 2.362 m^3/MBF
MC	Moisture content
MJ	Mega joule
NO_x	Nitrogen Oxides
NREL	National Renewable Energy Laboratory (United States)
ODP	Ozone Depletion Potential
PCR	Product Category Rules
PED	Primary energy demand from renewable resources (net calorific value)
PED nr	Primary energy from non-renewable resources (net calorific value)
PE	Primary Energy
POCP	Photochemical Ozone Creation Potential
ppm	Parts per million
CFC-11	Trichlorofluoromethane (R11)
SO_2	Sulphur dioxide
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
UK	United Kingdom
US	United States of America
US LCI	United States Life Cycle Inventory Database
WC	Water content

1 EXECUTIVE SUMMARY

The goal of this study was to conduct a Life Cycle Assessment (LCA) for US hardwood veneer products. The LCA was completed to (1) better understand the environmental performance of US hardwood veneer products related to cradle-to-gate plus transport to consumer gate (i.e. manufacturers in Europe)[1]; (2) identify the areas of high environmental improvement potential; and (3) respond to customer and public requests for environmental information.

Life Cycle Assessment is a standardized scientific method for systematic analysis of flows (e.g. mass and energy) associated with the life cycle of a specific product, technology, service or manufacturing process system to assess environmental impacts.

The scope of the study is a "cradle-to-gate plus transport[2]" Life Cycle Assessment of US hardwood veneer products. Due to the broad range of products produced with veneer, the use and end-of-life of the final product are excluded from this study. They can be added in product specific studies for a complete life cycle.

The study contains the data on the environmental profile of hardwood veneer with a comprehensive set of environmental impacts. It provides a useful perspective for different stakeholder groups, such as AHEC members and the hardwood industry in general, hardwood veneer consumers, designers and buyers, government agencies, non-governmental organizations, LCA practitioners, and the media.

The main study outcomes can be summarized as follows:

- The main source of environmental impact of hardwood veneer production is energy consumption and the transportation process; Energy consumption is the dominant source of environmental impact for almost all categories. In the base scenario slicer veneer technology (0.5-0.6mm), energy consumption contributes between 42% and 83% along the different impact categories (with exception of total primary energy demand and eutrophication). Thus total primary energy demand (PED) is dominated by primary energy from biomass with 54% of the total impact and the eutrophication (EP) impact category is dominated by transportation with 43% of total impact). Moreover the same is observed in the base scenario rotary veneer (0.6 mm), where power and thermal energy consumption are the highest contributors with between 31% - 84% influence for all analyzed categories with the exception of total primary energy demand (primary energy demand from biomass incorporated in the input logs represents approximately 68% of the total impact). Transportation is another exception for the categories acidification potential (AP) and eutrophication potential

[1] The cradle-to-gate plus transport in this study refers to the assessment of a partial product life cycle from resource extraction (cradle) to the transport to a product manufacture in Europe. The use phase and disposal phase of the product are omitted in this case.

2 The estimated scenario of transportation to a customer in Europe (product manufacture) is 500 km as the large majority of EU cities are located within 500 km of a major seaport.

(EP) contributing with 58 % and 54 % of the total impacts respectively. In contrast, the base scenario rotary (2-2.5mm) shows transportation activities as the highest contributor in all categories with between 62-84 % contribution (with the exception of total primary energy demand, which is dominated by primary energy from biomass with approximately 77% of the total PED). The high impact from transportation is explained by the longer distances reported by companies within this group especially from mill to port of export (up to double the distances of the other companies). Additionally, companies reporting these distances also had a greater influence on the weighted average due to their high production figures. If the veneer is transported overseas, the impact of transportation can be as high as production or become a major source of environmental impact;

- The forestry process is a relatively small contributor to the overall results compared with other processes involved. The only exception is in the category total demand of primary energy (PED). By definition PED includes the energy incorporated in the wood at harvesting (primary energy from biomass) and thus it is mostly defined by the forestry process. Excluding PED, forestry contributes from 3% (POCP) to around 7% (EP) in slicer panel (0.5-0.6 mm thickness), from 5% (AP & POCP) to around 10% (EP & ODP) in rotary panel (0.6 mm thickness) and from 3% (AP, GWP, POCP & PED nr) to around 5% (EP&ODP) in rotary panel (2-2.5 mm thickness). Also the forestry stage does not lead to a dominant contribution due to low intensity forest management and the natural re-growth of the trees;
- On the other hand the forestry process is representing the highest carbon uptake during harvesting. During growth, carbon is stored in the wood via photosynthesis. This biogenic carbon is stored in the veneer and its subsequent products. The carbon stored in biomass will, - sooner or later, be released at the end of the product's life cycle[3] . The end of the product's life cycle is not included in this study. The potential benefits from carbon storage, delayed emissions or the substitution effect can be fully excluded or accounted for differently according to different standards (PAS 2050[4], PEF 2nd draft[5], ISO 14067[6], EN 15804 etc.). To enable study stakeholders to utilise the data for different applications, and to avoid the AHEC communication being perceived as "greenwashing", the stored (biogenic) carbon was clearly quantified in the inventory for transparency in the carbon balance, and treated as a separate element in the report whilst not being subtracted from the Global Warming impact of the product.

[3] Assuming a 100% degradation rate.

[4] PAS 2050 is showing delayed emissions for the treatment of biogenic carbon (British Standard Institute (BSI), 2011).

[5] PEF or Product Environmental Footprint Guide, suggest the inclusion of the biogenic carbon but documenting it separately.

[6] ISO 14067 (2013), suggest the inclusion of the biogenic carbon but documenting it separately.

- There are differences in environmental performance between different hardwood veneer technologies and additionally in some cases, veneer thicknesses has a significant influence. The results show some variation between veneer technology and veneer thicknesses. On a per m^2 basis, the rotary veneer (0.6 mm) shows the lowest environmental impacts in comparison with a similar thickness of slicer veneer (0.5-0.6 mm) or a thicker rotary veneer (2-2.5 mm). This conclusion is based on results for two facilities representing 34% of the total rotary technology production in the US (HPVA, 2013). The thinner rotary veneer companies tended to report the lowest transport distances (nearer to principal port of exports) plus lower energy consumption figures. Environmental Profiles should be communicated on the basis of hardwood technology and veneer thickness;

There are significant improvement potentials in hardwood veneer production (such as energy consumption) and transportation routes ((from factory in the US to consumer (i.e. manufacturer in Europe)) that would have a great influence on the environmental performance of the produced veneer.

2 GOAL OF THE STUDY

AHEC is conducting a programme of Life Cycle Assessment (LCA) in accordance with ISO 14040/44 for American hardwood products. The main goal of the study is to analyse the cradle-to-gate plus transport to consumer gate (i.e. manufacturer in Europe) environmental performance of hardwood veneer production from different companies representative of the industry as a whole and to provide credible scientific evidence for informed decision making in areas related to the environmental profile of American veneer hardwood products.

Therefore AHEC is interested in:

- Compiling life cycle inventory data for hardwood forestry, logging[7] and the veneer production process of selected American hardwood species to facilitate preparation of further LCA studies;
- Compiling a scaled average cradle-to-gate plus transport to consumer gate (i.e. manufacturer in Europe) Life Cycle Assessment of American hardwood veneer (species-mix) production;
- Understanding the environmental impact of hardwood veneer production, specially related to the supply chain and energy consumption;
- Understanding the variability in environmental performance of the different hardwood veneer technologies (rotary or slicer) and products (thicknesses: 0.5- 2.5 mm);
- Identifying areas of high importance to the environmental performance of hardwood products and aspects of high improvement potential to assist in defining further sustainability strategy;
- Supporting AHEC members‘ decision making with reliable information regarding the environmental performance of hardwood veneer;
- Acquiring the data that could be published as inventory datasets in databases like ILCD, ADEME, US LCI;
- Supporting external communication with reliable scientific information in Environmental profiles or Environmental Product Declarations.

The study is intended to be the basis for an EPD or Environmental Profile representing a scaled average US hardwood veneer production for slicer and rotary technology or a so called “manufacturer group declaration” (declaration of average products as an average from several manufacturer´s plants).

The overall goal of an EPD is to provide relevant, verified and comparable information about the environmental impact of goods and services. In this case, the creation of the EPD from this study will follow the EPD programme [8] requirements (i.e. IBU [9] ECO EPD [10] etc.).

[7] The LCI data for hardwood forestry and logging for this study is basing on the same modeling processes included in the AHEC LCA study on Lumber carried out by PE International between 2010-2012.

The intended audience of this study is AHEC staff and their consultants, AHEC members, policy makers in American hardwood export markets as well as architects, other customers, and LCA practitioners. A third party critical review process was undertaken to provide assurance that the study was consistent with the ISO 14040/44 standards for LCA. Publication of the LCA study is foreseen following a successful critical review.

There are multiple approaches in accounting for carbon uptake and storage. To enable study stakeholders to utilise the data for different applications, and to avoid the AHEC communication being perceived as "greenwashing", the biogenic carbon was treated as follows:

- Carbon will be clearly quantified in the inventory for transparent carbon balance;
- Only the carbon that is stored in the final veneer product will be accounted as stored carbon;
- Stored carbon will be treated as a separate element in the report and will not be subtracted from the Global Warming impact of the product.

For more description on carbon storage please refer to section 3.4.4.

Results are not intended to be used in comparative assertions intended to be disclosed to the public.

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[8] At the time of writing this report, it is not known if AHEC will develop an EPD and which precise program it will follow.

[9] Institute Construction and Environment e.V. (IBU) was created out of an initiative of manufacturers of construction products who decided to support the demand for more sustainability in the construction sector. IBU´s environmental product labels were created in close cooperation with construction and environmental authorities in Germany and international standardization processes. IBU is currently the only organization in Germany that certifies EPD consistently based on international standards. In addition to manufacturers, independent experts from research, Germany´s Ministry of Construction, the German Environmental Agency (UBA), and health and environmental experts are involved in audits. The IBU label provides a lot of information, credibility, and acceptance.
See:http://bau-umwelt.de/auctores/scs/imc/fdInf_ID=283b8aXf563a51e82XY7f01=I=96646193/Home.htm

[10] In Brussels, on September 26, 2011 the EPD programs from Germany, Finland, France, Great Britain, Italy, The Netherlands, Norway, Poland, Portugal, Sweden and Spain have signed a Memorandum of Understanding to establish a foundation of an European platform („ECO-platform"). The platform aims at the development of a consistent and Europe wide valid „European core EPD".

3 Scope of the Study

The following section describes the general scope of the study. This includes the identification of products to be assessed, the boundary of the study, the allocation procedures, and the cut-off criteria.

3.1 System Description

The life cycle stages are described in detail in this chapter and shown in Figure 3-1. It is important to note that two technologies were considered for the study; slicer and rotary[11]. Half round technology, a third technology in which hardwood logs are cut; has not been included in the assessment as it was not reported by the companies interviewed. Sometimes half round technology is considered as a slicer technology (although it has more similarity to a peeling technology), probably this is due to the fact that half-round machines are normally operated by flat slicing veneer companies (CHPVA, 2006) (Cassens, FNR-240).

The rotary technology is representing approximately 80-85% of the market (on a value basis more towards 80%, on a volume more towards 85%). Thus sliced veneer is representing 15-20% of the market (HPVA, 2014). As previously explained half round technology is representing a small segment of the sliced market. Those veneers are often sold together with sliced and customers can't distinguish them. It's a very small ("negligible") share of the sliced veneer (HPVA, 2014).

3.1.1 Forest

The forest part of the system includes[12] :

- Felling of trees;
- Skidding trees to landing;
- Processing trees into logs;
- Loading logs on a truck;
- Post-harvest and stand establishment.

Hardwoods in the US are harvested mostly in the eastern half of the US. Appendix E contains a map of the US hardwood harvesting regions.

The great majority of hardwood forest in the US is not planted but is naturally grown /regenerated. No active management is required until the harvest. Hardwood forests

[11] Rotary: the almost whole log or bolt is placed in a giant lathe and continuously turned. The log is "unrolled" much like a carpet. Slicer: logs are cut into halves or quarters (flitch). Each half or quarter is then sliced affected by the species and grain pattern desired. Half round: a half log or flitch is secured in place and turned 360° against a stationary knife. Some difference in production steps, yields and applications are occurring.

[12] The LCI data for hardwood forestry and logging for this study is basing on the same modeling processes carried out for the AHEC LCA study on Lumber.

undergo two main harvests: the commercial thin after 70-72 years of stand establishment and the final harvesting at the end of the rotation period (82 to 120 years depending on the management intensity). With low intensity practice, only the final harvest takes place (CORRIM, 2010, Module A).

The hardwood species in the US are general harvested using manual felling techniques[13]. Medium cable skidders are utilised for skidding, then the stumps are delimbed with chainsaws and loaded on long trucks to be delivered to the sawmill or veneer mill (round logs) or to the chipping mill (pulp logs). Some biomass (limbs, tops and other unmerchantable materials also known as slash[14]) is left in the forest. For the modelled regions no slash reduction activities are mandated for fire risk reduction and the slash is assumed to decay *in situ*.

The Resources Planning Act (RPA) (USDA, 2007) assessment published in 2010 showed that the growing stock of American hardwood has increased constantly over the last 50 years. The US Forest Service forecasts expect an additional increase of American hardwood stock of at least 15% through to 2030. Therefore planting of the seedlings has not been modelled in the present study as natural regeneration is assumed to be sufficient. There is no use of irrigation or fertiliser. The RPA Assessment also indicates that the hardwood forests in the US are maturing which leads to an increased biodiversity.

The two valuable products of the forest processes are round logs and pulpwood logs. The ratio of pulpwood logs to round logs can vary, with round logs representing 33.5% to 44.8% of the total harvest volume (CORRIM, 2010, Module A).

Price data for the co-products was used for economic allocation between pulpwood logs and roundwood logs. The chosen allocation approach follows the requirements of ISO 14040/14044 (2006), EN 15804, PCR for IBU Part B: Requirements on the EPD for solid wood products and is intended to align to the ECO Platform Initiative. These requirements aim to harmonise the LCA methodology choices for European construction products. For details on allocations see chapter 3.6. The alternative allocation approach is evaluated in section 4.4.1.

Please refer to chapter 3.5.1 for a detailed description on forestry data collection, treatment and representativeness.

3.1.2 Transportation from forest to the log yard

This process step includes the conveyance of the logs from forest landing to each veneer mill log yard. Information has been provided by companies and per species. Transportation is modelled taking into account the transportation mode and distance provided by each company.

[13] Hand felling includes felling with axe, saw, or chainsaw.

[14] Slash is the residue, e.g., treetops and branches, left on the ground after logging or accumulating as a result of storm, fire, girdling, or delimbing (*The Dictionary of Forestry*. Society of American Foresters)

3.1.3 Log yard (log receiving and grading)

This process consists of receiving and storing the logs which were transported from the forest to the mill. It includes the following steps:

- Sorting and storage of logs; sorting by grades and sizes and storing either wet or dry depending on the season and species;
- In-yard transportation of logs from the point of unloading to the deck;
- Sprinkling of logs with water arising either from storm water collection system, own wells or mains water;
- In-yard transportation of logs from the storage deck to the debarker and sawmill.

3.1.4 Debarking and saw mill

- Mechanical removal of the bark (log debarking);
- Cutting of the long logs into blocks for peeling (rotary technology only);
- Cutting of the logs into flitches (halves or quarters for slicer technology only) to produce specific grain patterns;
- Saw sharpening and maintenance of all sawmill equipment and yard transportation vehicles;
- Co-products are green bark and some green wood chips mixed with bark which is either landfilled, composted or used as hog fuel input for boilers.

3.1.5 Vat or wood conditioning of flitches and logs;

- Heating the logs or flitches with either water or steam to condition them while increasing temperature and moisture content;
- Conditioning temperatures may vary by species and log diameter. Hardness, density and desired colour reactions are characteristics that define cooking temperature and duration (Danzer, 2012);
- Temperatures can reach 80-100° C for periods between 12 and 72 hours (CHPVA, 2006).

3.1.6 Flitch planeing

- Planeing of the flitches in order to even, clean and smooth them of rough structures (slicer technology);
- Waste generated will include slabs/head planeing material and flitch surface material which have all been reported by the companies.

3.1.7 Slicer and rotary cutting

As previously mentioned, different cutting possibilities exist to obtain veneer panels with a desired grain pattern and end use application. Logs are cut normally 1 hour after being conditioned or soaked (CHPVA, 2006).

Slicer

After cleaning of flitches, these are then held in place by hydraulic dogs or vacuum tables on a metal frame, which move down against a knife in order to obtain the sliced veneer.

Different cutting methods exist in order to obtain the desired grain pattern. The so called plane or flat slice technology offers the highest yield and is generally the least expensive (HPVA, 2004). On the other hand the quarter sliced produces a cut perpendicular to the growth rings and is generally more expensive than plane slicing. In terms of species specific applications, rift cut is generally used only for red and white oak. Because it has the lowest yield per log, it is generally the most expensive slicing method (HPVA, 2004).

The thicknesses with the Slicer can vary but for this study all companies interviewed were reporting it between 0.5 - 0.6 mm (0.019 - 0.023 inches). In order to reduce defects or imperfections veneers are then clipped to size, sorted, measured and graded.

Main outputs will be denoted by sliced green veneer sheets and backing boards.

Peeling

In the rotary process, a rotary lathe slices the softened veneer blocks into thin veneer sheets that have 0.6 mm (0.02 inches) to 2.5 mm average thickness. One company which reported a thickness of 2.5 mm explained that panels will be glued together (5 panels together) for plywood applications. Average panels for this application vary between 1.2 m to 3.12 m long and 1.1 to 1.5 m wide. For other applications such as engineered flooring, veneer panel sizes are typically around 1.2 m long X 1.2 m wide, or 1.5 m long X 1.2 cm wide.

The outputs of this process mainly cover the veneer sheet and wood residues from the process itself such as cores, log trimmings, and other green wood residues. Cores can be employed in the production of pallets while the rest are normally sent to the boiler as hog fuel.

Some companies have reported that after the peeler (rug) there is an additional cut into panels or strips. Furthermore a green clipping process will take place (before going through the dryer) so as to remove defects at this stage.

Half round slicing is a variation of peeling. This technology consists of attaching half a log to a face plate on a lathe and turning it around the centre (Horizon plywood, 2013). This results in a cut slightly across the annular growth rings, and visually shows modified characteristics of both rotary and plain sliced veneer. Half round slicing of wood is used to accentuate the variegated grain in various woods such as burls and other specialty veneers. However, it can also be used to achieve a flat sliced veneer appearance (Veneernet, 2013).

In terms of representativeness, the ten companies participating in this study (see Table 6) have not reported half round slicing within their operations, thus it has been excluded from this study (for more information on representativeness refer to section 0).

3.1.8 Veneer drying

Jet dryers can dry the green veneer sheets down to between 6 to 11 % moisture content (MC). Dryer temperatures and speeds vary by species and thickness. Hardness, density and desired colour reactions are characteristics that define drying delay and drying parameters.

Emissions from the dryer stacks are usually not measured or at least this was found from the interviewed companies. However exhaust measurements carried out in 1998 indicate that the amount of any hazardous air pollutants (HAPs) emissions from dryers is below the regulatory levels (NCASI/HPVA study, 1998).

During the drying process, water is emitted as water vapour. Please refer to the chapter 3.5.2 for a detailed description of the water evaporation data collection and estimation.

Finally, veneer sheets are stacked into bundles of 24 at the end of the drying process. This is done to create an appropriate quantity of veneer that can be clipped at one time. A log may produce 400-1000 sheets or more. Since several grades of veneer are often present, the veneer must be divided evenly for grading/valuation. Generally there isn't much change in appearance through 24 sheets, so this quantity allows for good balance between efficiency and value.

3.1.9 Clipping/trimming

Generally for export markets, the rough edges along the lengths as well as the widths and any other major defects in the sheet are cut out. If a knot is right in the middle of a bundle, it is often clipped in two lengthwise to make what are called quarters. Depending on the positions of the knots and defects as well as quality, the veneer sheet becomes either furniture; panel or door grade.

Each bundle is first edge clipped using a large guillotine or saw blades and then the ends are clipped or just trimmed. Clipping position is according to chalk or crayon marks placed on the veneer by the markers. The surface area of each clipped bundle is measured using a light curtain system. The surface area value is then automatically multiplied by 24 (Danzer, 2013 a).

Overseas customers purchase only clipped veneer sheets thus they do not have to pay a shipping cost for the wood they would have to clip off themselves. On the other hand, unclipped veneers are also sold within the US domestic market with some exceptions to nearby locations such as Mexico and Canada (HPVA, 2013). Co-products will refer to veneer sheet clipping residues or bunched clipped waste.

3.1.10 Splicing

Smaller pieces of panels after the removal of defects will be glued (Purebond) together on the side in order to obtain a wider veneer panel (stock panel) to satisfy customer requirements. These panels are so-called spliced panels.

3.1.11 Crating/packaging

Final product veneer sheets are then bundled into crates and are ready for transport or shipment for the domestic as well as the export market. Common materials reported as inputs within the packaging stage are plastic film and steel banding.

3.1.12 Energy generation

Three main sources provide heat, electricity and mechanical energy for veneer production:

- Thermal energy in the form of steam generated by in-house boilers (gas and biomass) which mainly feed vats and dryers;
- Electricity from the grid which is used for power in all production stages;
- Diesel for on-site transport processes within veneer production (forklifts, conveyors etc.).

Hog fuel refers to the mixture of wood residues arising in veneer production (bark, sheet clipping residues, backing boards, log trimmings or butts, bunch clipped waste, head planeing material, flitch surface material) which are used for combustion in self-operated wood fired boiler facilities.

The thermal energy for veneer drying and vats originates from biomass and natural gas burned onsite. Average energy mix is estimated as 88% biomass and 12% natural gas (assumed in the modelling process US: heat, onsite boiler hardwood mill average NE-NC). The share was derived from primary data of 35 AHEC members evaluated for the previous study carried out by AHEC for lumber and is consistent with CORRIM research findings (modules C and L).

Please refer to the chapter 3.5.2 for a detailed description of veneer data collection, treatment and representativeness.

3.1.13 Transport to export markets and customers

Transportation is modelled taking into account the transportation mode and distances. Primary data, and statistical data from AHEC members and some geographical estimation were proposed to be used to develop a representative transportation scenario for the AHEC veneer model. Please refer to chapter 0 for more details on the transportation data collection, treatment and representativeness.

Transport processes modelled include transportation of the dried packaged veneer to the port of export and hence overseas to the port of import in Europe (only the European export market scenario was considered).

The onward road transportation (assumed) of veneer to customers/consumers in Europe (i.e. manufacturers in Europe) was also included using an average distance of 500 km.

3.1.14 Hardwood species under consideration

The forests of the US include a wide variety of hardwood species that are used for veneer production. Some are less available for commercial purposes, and produced in small volumes for regional use only.

Each company participating in the study reported the mix of species they handle. Thus certain species-specific aspects (density, moisture content and forest-log yard transport distances) were considered in order to obtain scaled average characteristics per species mix in each company. The following species are reported as being handled by the ten companies participating in the study:-

- Ash (*Fraxinus spp.*)
- Basswood (*Tilia americana*)
- Beech (*Fagus grandifolia*)
- Yellow birch (*Betula alleghaniensis*)
- Cherry (*Prunus serotina*)
- American Gum (*Liquidambar styraciflua*)
- Hickory (*Carya spp.*)
- Pecan (*Carya illinoinensis*)
- Hard maple (*Acer saccharum, Acer nigrum*)
- Soft maple (*Acer rubrum, Acer saccharinum*)
- Red oak (*Quercus* spp.)
- White oak (*Quercus* spp.)
- Red elm (*Ulmus rubra*)
- Tulipwood (*Liriodendron tulipifera*)
- Sassafras (Sassafras albidum)
- Black walnut (*Juglans nigra*)

Detailed species-mix profiles per company are shown in Table 1 below.

Table 1: Species-mix for per slicer and rotary companies

Species	Company 1	Company 2	Company 3	Company 4	Company 5	Company 6	Company 7	Company 8	Company 9	Company 10
Ash		0.100	0.0003	0.010	0.041	0.014		0.050		
Basswood						0.040				
Beech						0.0002				
Yellow birch	0.003		0.003	0.010	0.006	0.058		0.010		0.568
Cherry	0.127	0.260	0.025	0.350	0.245			0.100		
American gum			0.002				0.040		0.358	
Hickory		0.040	0.025	0.010	0.020		0.040	0.390		
Pecan									0.052	
Hard maple	0.030	0.090	0.107		0.289	0.234				0.432
Soft maple			0.002	0.090		0.008		0.050		
Red oak	0.160	0.250	0.045	0.040	0.310	0.613	0.100	0.340	0.537	
White oak	0.380	0.150	0.348	0.230	0.063		0.040	0.040		
Red elm			0.006							
Tulipwood			0.033	0.050	0.018	0.033	0.780	0.020	0.054	
Sassafras			0.00010							
Black walnut	0.300	0.100	0.344	0.150						
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

The species addressed in this study represent the majority of commercial American hardwood species. More than 95% of the hardwood species harvested in US by volume and more than 95% of the AHEC members export volumes are covered (from AHEC 1998-2009 statistics on hardwood removals and 2006-2010 statistics on export volumes by species).

Important to notice is that LCI profiles in this veneer study have not been calculated per species but rather represent an average of the total species handled per company. Refer to later sections in the report for details.

For more detail on the forestry modelling process refer to section 3.5.1.

3.2 System Boundaries

The system boundaries were defined following the framework and principles of ISO 14040:2006 and ISO 14044:2006.

Hardwood veneer exported by AHEC members is an intermediate product for different applications such as architectural construction, furniture-making, mouldings, panelling, vehicle dashboard applications, and recently electronic design covers. Thus, the use and the EoL (end of life) stages depend highly on the final product application and are out of AHEC members' control. To address the goals stated, the cradle-to-gate plus transport to consumer gate (i.e. manufacturers in Europe) system was chosen.

Subsequently, the European core rules for the product category of construction products (EN 15804, 2012)[15] and IBU's specific PCR for wood materials (IBU, 2013) were also consulted to enable the LCA study results to be used in any later EPD communication for construction products[16] .

AHEC members export veneer to Canada (36%), Europe (33%), China (7%), and other regions (22%). The percentages represent the average share of export volumes in 2012 (HPVA, 2013). As the impact of transportation is an important discussion and communication issue for AHEC products, the system was defined to include the overseas transport of veneer. Europe was chosen as the only final customer destination for this study as it has a significant transportation distance, high share of exports and a market which is interested in environmental aspects (only the analysis of unclipped veneer at the mill will show the impact without the overseas transport to Europe in section 4.4.2).

The product system under study is a cradle-to-gate plus transport to consumer gate (i.e. manufacturers in Europe) gate system covering process steps from the point of forestry and harvesting to the importers yard in Europe. It includes:

- Hardwood forestry management and logging;
- Manufacturing of dried veneer in the US by rotary and slicer technology (green font area as is shown in Figure 3-1);
- Cradle-to-gate production of energy and ancillary materials needed to manufacture the veneer panel;
- Handling of production wastes/co-product generated in the cradle-to-gate system;
- Transportation of hardwood logs and ancillary materials within the cradle-to-gate system;
- Transportation of veneer to the customer yard in Europe.

Elements excluded from the system are the production of capital equipment, human labour and commuting. These elements are traditionally excluded from product LCAs as they are assumed to fall far below the cut-off criteria. Table 2 below gives examples of the industry activities included and excluded in the assessment. See chapter 3.7 for further details on cut-off criteria and flows excluded.

Table 2: System boundary – inclusions and exclusions
Cradle-to-gate plus transport LCA of U.S. hardwood veneer

[15] This European standard EN 15804 provides core product category rules for all construction products and services. It provides a structure to ensure that all Environmental Product Declarations (EPD) of construction products, construction services and construction processes are derived, verified and presented in a harmonized way.

[16] Veneers are not only used as a construction product as they can have other applications Such as for electronics decoration purposes http://www.danzer.com/Danzer-iPad-Cover.3103.0.html

included	examples
Production of raw materials	• Forest logging for veneer manufacturing
Production of auxiliary materials	• Production of lubricants/fuels/saw blades for
Energy production	• Production of electricity and thermal energy needed for veneer manufacturing
Operation of primary production	• Energy and material requirements of veneer mill
Water	• Either from storm water collection system, well or tap water
Transport	• Transport of logs from forest to veneer mill
excluded	examples
Construction of capital equipment	• Different machines and vats. • Construction of veneer mill building
Human labour and employee transport	• Production of food for employees • Employees commuting to work
Use phase and EoL phase	• Production of final product from hardwood veneer • Installation of the final product • Disposal of the product at the EoL

The chosen cradle-to-customer gate system allows the analysis of various products made from veneer at a later stage. The system boundary for the system under investigation is given in Figure 3-1.

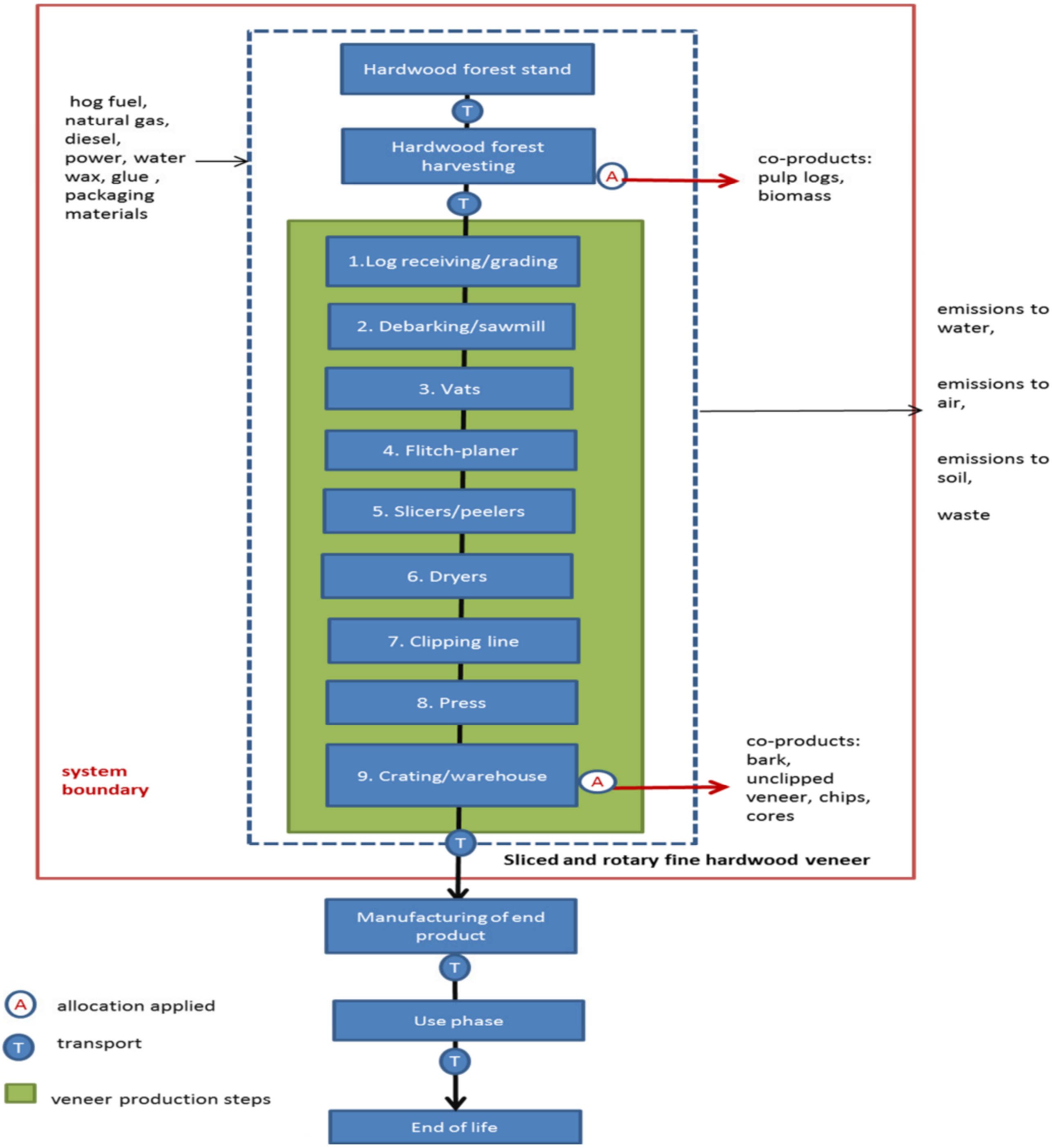

Figure 3-1: Life cycle flow diagram: Simplified system boundary for cradle-to-gate plus transport (LCA of US hardwood Veneer)

3.3 Function and Functional Unit

This chapter describes the veneer characteristics and functional unit (including products covered) selected for the study.

3.3.1 Function

Veneer is an intermediate product further processed into final products to be used for a wide range of applications. There are four major types of markets or uses for face veneers; architectural, secondary manufacturing such as furniture and cabinets, profile-wrapped mouldings and panelling (Cassens, FNR-240).

3.3.2 Functional Unit

The functional unit (FU) quantifies performance/function of a product system for use as a reference unit.

For US hardwood veneer, the chosen functional unit in this report is **1 square metre of US average hardwood (species-mix) dried veneer (10% MC)** generated from both rotary and slicer technology and delivered to the European customer.

Table 3 below describes the range of products considered by the study.

Table 3: Products covered

US Hardwood veneer product range covered	
Species	Mix of hardwood species as handled per company (see 3.1.14)
Thickness	0.5 – 2.5 mm
Density	577 – 728 kg/m^3 (species mix and moisture dependent)
Moisture content on an oven dried veneer	5.5% - 12% MC
Technology	Rotary (peeling) and slicing technology

The FU chosen for veneer products are consistent with ISO 14040/14044 (2006) and the Product Category Rules (PCR) for solid wood products for the IBU[17] and ECO Platform[18] initiative.

[17] Institute Construction and Environment e.V. (IBU) was created out of an initiative of manufacturers of construction products who decided to support the demand for more sustainability in the construction sector. IBU´s environmental product labels were created in close cooperation with construction and environmental authorities in Germany and international standardization processes. IBU is currently the only organization in Germany that certifies consistently based on international standards. In addition to manufacturers, independent experts from research, Germany´s Ministry of Construction, the German Environmental Agency (UBA), and health and environmental experts are involved in audits. The IBU label provides a lot of information, credibility, and acceptance. See:http://bau-umwelt.de/auctores/scs/imc/fdInf_ID=283b8aXf563a51e82XY7f01=l=96646193/Home.htm. For IBU it would be a declared unit.

[18] In Brussels, on September 26, 2011 the EPD programs from Germany, Finland, France, Great Britain, Italy, The Netherlands, Norway, Poland, Portugal, Sweden and Spain signed a Memorandum of Understanding to establish a foundation of an European platform (“ECO-platform“). The platform aims at the development of a consistent and Europe wide valid “European core EPD“.

The reference flows for the respective three FU of the study are shown in Table 4. All cases shown are representing a moisture content of 10%.

Table 4: Reference Flow for the FU 1 m2 US Hardwood veneer products		
Slicer veneer 0.5mm	Weight per surface: 0.35 kg/m2	Scaled thickness: 0.54 mm
Rotary veneer 0.6mm	Weight per surface: 0.45 kg/m2	Scaled thickness: 0.66 mm
Rotary veneer 2-2.5mm	Weight per surface: 1.45 kg/m2	Scaled thickness: 2.20 mm

The study presents results for a 1 m^2 mass weighted average (scaled according to production volumes of the participating companies in each group of technology with respective thickness) hardwood veneer for rotary and slicer technology. Both technologies are representative of the industry and cover the description and data provision by the companies participating.

Only mass weighted average hardwood veneer production process were modelled per company. None of the companies participating could express details on production patterns as per species handled (e.g. there is no energy consumption split per production stage (debarker, cutter, kiln drying) and along species).

In general the average density of the different logs was calculated based on species specific density at determined MC and mass weighted species amounts.

3.4 SELECTION OF IMPACT ASSESSMENT CATEGORIES

3.4.1 Main indicators

A set of environmental impact categories has been investigated and was selected in the same was as was done for the AHEC LCA lumber study. The choice of categories was made based on the recommendations of the ILCD Handbook (ILCD Handbook, 2010) and the choice of indicators was made based on the European EPD rules for construction products (EN 15804, 2012).

The study includes the following environmental impact categories: primary energy demand (total and non-renewable sources), global warming potential, photochemical oxidant creation potential (smog formation), acidification potential, stratospheric ozone depletion and eutrophication potentials. These impact categories have a classification of I (recommended and satisfactory) or II (recommended but in need of some improvements) in the ILCD handbook (2010). Some impact categories with a I/II rating were not included when they were not recommended by the European EPD rules for construction products (EN 15804: 2012). In the selected impact categories the CML indicators were calculated.

The methods and indicators for each category were chosen based on the European EPD rules for construction products (EN 15804:2012). The details of each impact category and its indicator are shown in Table 5. While the indicators chosen for this study are the latest CML indicators in GaBi 6 (CML method from 2001, factors updated 2010), the nomenclature in TRACI[19] is included as well in the table and main results in TRACI units are reported in Appendix D.

Table 5: Life cycle impact assessment categories & indicators

LCIA categories and indicators used in cradle-to-gate plus transport LCA of US hardwood Veneer

Category Indicator	Impact category	Description	Unit	Reference
Primary energy demand (PE) (renewable and non-renewable) [20]		A measure of the total amount of primary energy extracted from the earth. PE is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ	Guinée et al., 2001, factors updated in 2010
Climate Change	Global Warming Potential* (GWP)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.	kg CO_2 equivalent	IPCC, 2007, *100 year GWP is used*
Eutrophication	Eutrophication Potential (CML)	A measure of emissions that cause eutrophying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems	kg Phosphate equivalent	Guinée et al., 2001, factors updated in 2010
	Eutrophication Potential (TRACI)		kg Nitrogen equivalent	Bare et al., 2011
Acidification	Acidification Potential (CML)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight.	kg SO2 equivalent	Guinée et al., 2001, factors updated in 2010
	Acidification Potential (TRACI)		kg H+ equivalent	Bare et al., 2011
Ozone creation in troposphere	Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOC's under the influence of UV light.	kg Ethene equivalent	Guinée et al., 2001, factors updated in 2010
	Smog Air (TRACI)		kg NOx equivalent	Bare et al., 2011
Stratospheric Ozone Depletion	Stratospheric Ozone Depletion	Refers to the thinning of the stratospheric ozone layer as a result of emissions. This effect causes a greater fraction of solar UV-B radiation to reach the surface earths, with potentially harmful impacts to human and animal health, terrestrial and aquatic ecosystems etc. referring trichlorofluoromethane, also called freon-11 or CFC 11	kg CFC-11 equivalent or trichlorofluoro-methane, also called freon-11 or R11	WMO, 1999, factors updated in 2010

[19] Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), EPA US.
[20] PE is not an impact category in CML but has been included in the study. Actually CML refers to abiotic depletion potential (fossil) and does not provide indicators for renewable energy.

	Stratospheric Ozone Depletion (TRACI)	CFC 11 equivalent	WMO, 1999

* The terminology "potential" is defined by ISO and used by CML to clearly indicate that LCIA shows potential impacts in the future. For example for climate change the Global Warming Potential represents the potential impact of GHG emissions related to the reference unit CO_2.

The study is aware on the developments for new life cycle impact assessment methods such as ReCiPe 1.07[21]. However the results of this study will not be shown in ReCiPe 1.07. The main reason for this is in order to maintain consistency with the way of communication of the environmental impacts applied in the lumber study (the lumber study only shows CML categories).

On the other hand, ReCiPe is a newer methodology where results are sometimes quite different than with CML due to changes in the methodological background (e.g. POCP, where NOx is much more relevant compared to VOCs in ReCiPe than in CML).

CML is considered a robust methodology being used worldwide especially in the construction sector (most users today, outside North America (where mostly TRACI is used), use CML (IBU, 2013)). The CML results are stable and are tried and tested in many LCA projects. Furthermore the results carried out with CML are comparable and consistent with many published studies.

Appendix D contains results in TRACI.

3.4.2 Optional elements of LCIA

Optional elements of the ISO 14040/44 (2006), namely, normalisation, grouping, and weighting were not applied as they involve value-choices and were not necessary for the defined goal and scope. The additional LCIA data quality analysis was performed and includes contribution analysis (identification of the greatest contribution to the indicator result), and sensitivity analysis (identification of how changes in data and methodological choices affect the results of the LCIA).

3.4.3 Impacts to be applied with caution

There are other environmental impacts for which the evaluation methodology is less mature. These impacts are classified with II and III in the ILCD handbook (recommended, but to be applied with caution). These impacts include:

- Toxicity
- Land use (occupation)
- Land use change (LUC) (direct and indirect)

[21] The ReCiPe LCA methodology was created by RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft. The group of authors includes the developers of the CML 2001 and Ecoindicator 99 methodologies.

- Water related impacts
- Biodiversity

Refer to Appendix G for a qualitative discussion of these non-considered impacts,

3.4.4 Biogenic carbon

During growth of trees, carbon is stored in the wood via photosynthesis. This biogenic carbon is stored in the veneer and its subsequent products. The carbon stored in biomass will, - sooner or later, be released at the end of the product's life cycle[22] . The end of the product's life cycle is not included in this study. The potential benefits from carbon storage, delayed emissions or the substitution effect can be fully excluded or accounted for differently according to different standards (PAS 2050[23], PEF 2nd draft[24], ISO 14067[25], EN 15804 etc.). To enable study stakeholders to utilise the data for different applications (veneers are regarded as intermediate product), and to avoid the AHEC communication being perceived as "greenwashing", the stored (biogenic) carbon will be clearly quantified in the inventory for transparency in the carbon balance, and treated as a separate element in the report whilst not being subtracted from the Global Warming impact of the product.

Stored carbon that does not end up in the final veneer product, e.g. carbon stored in leftover forest biomass (e.g. small branches, leaves) is not assigned to the veneer FU. It is assumed to be eventually converted back to CO_2 and emitted. Moreover carbon in the forest floor or forest soil is not assigned to the veneer FU. Only the final carbon that is stored in the veneer product is accounted as stored carbon. Thus removals from the atmosphere from biogenic sources are not modelled in this study.

Additionally, biogenic carbon dioxide emissions (e.g. resulting from biomass boilers) are modelled as carbon neutral (no impact on the GWP) as they are being offset by the uptake in biomass.

Not enough data is available on the carbon content in different hardwood species and a conservative value of 46.27% carbon in absolute dry mass was modelled (Lamlom & Savidge, 2003; Thomas & Martin, 2012[26]) as carbon storage for all hardwood species. This is a conservative value reported for hardwoods (Lamlom & Savidge, 2003; Thomas & Martin, 2012) and is consistent with the approach followed by the AHEC lumber study.

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[22] assuming a 100% degradation rate.

[23] PAS 2050 is showing delayed emissions for the treatment of biogenic carbon (British Standard Institute (BSI), 2011).

[24] PEF or Product Environmental Footprint Guide, suggest the inclusion of the biogenic carbon but documenting it separately.

[25] ISO 14067 (2013), suggest the inclusion of the biogenic carbon but documenting it separately.

[26] In all biomes, wood C content varied widely across species ranging from 41.9–51.6% in tropical species, 45.7–60.7% in subtropical/Mediterranean species, and 43.4–55.6% in temperate/boreal species.

3.5 DATA COLLECTION, GENERATION AND TREATMENT

After the preparation of the LCA questionnaires whose aim was to collect the information as per each process step (logyard, vat, cutting, drying, etc.), different companies were contacted with the support of the HPVA[27]. Table 6 below shows the list of all participants and their final status in data collection process.

Table 6: List of participant companies

Company	Location	Technology	Data collection status
Amos Hill	Edinburgh, Indiana	slicer	plausibility ok, finalized with mass balance difference <= 5%
Atlantic veneer corp.	North Carolina	slicer	plausibility ok, finalized with mass balance difference <= 5%
Danzer	Edinburgh, Indiana	slicer	plausibility ok, finalized with mass balance difference <= 5%
Danzer	Williamsport, Pennsylvania	slicer	plausibility ok, finalized with mass balance difference <= 5%
Freeman Slicer	Kentucky	slicer	plausibility ok, finalized with mass balance difference <= 5%
Indiana Veneer	Indianapolis	slicer	no data provision
International veneer company (IVC)	South Hill, Virginia	slicer	no data provision
Armstrong	Pennsylvania	Rotary	plausibility ok, finalized with mass balance difference <= 5%
Columbia Newport	Vermont US	Rotary	plausibility ok, finalized with mass balance difference <= 5%
Columbia Presque Isle	Maine US	Rotary	plausibility ok, finalized with mass balance difference <= 5%
Freeman Rotary	Kentucky	Rotary (2-2,5mm)	plausibility ok, finalized with mass balance difference <= 5%
Mannington	New Jersey	Rotary (2-2,5 mm)	plausibility ok, finalized with mass balance difference <= 5%

The four companies selected for slicer technology, including five facility locations, represent about 40% of total production volume of HPVA members; whereas the four companies with rotary technology and 5 production sites represent more than 60% (HPVA, 2013) of the production volume of HPVA members. See also data representativeness chapter 0. The data collection process took approximately 24 months to be completed.

Some main reasons for the long duration of the data collection process are:

- Registration of power and thermal energy consumption is done on an overall process basis rather than as per process stage (lack of counters and meters per machine);

[27] The Hardwood plywood and veneer association (HPVA) Founded in 1921, the Hardwood Plywood & Veneer Association (HPVA) represents the interests of the hardwood plywood, hardwood veneer, and engineered hardwood flooring industries. HPVA member companies produce 90% of the hardwood plywood stock panels and hardwood veneer manufactured in North America. Located in Reston, VA, near Washington, DC, HPVA offers a wide variety of valuable information and resources on hardwood plywood, veneer, and engineered flooring.

- Lack of measurements on the exact amount of waste residues arising per process stage as well as on respective bulk density figures;
- Lack of measurements on moisture content of the wood along the different process stages, which worsen the determination of the values for wood density as these were also not reported by the companies;
- Lack of weight records; especially for input logs arriving, water evaporation, different emissions, amount hog fuel sent to boilers etc.;
- Lack of measurements on number, diameter and length of logs;
- Difference in mass balances were > 5%;
- Companies only use the Doyle scale to estimate the volume of logs being delivered; this only converts the diameter of a log (without bark) into usable lumber board feet rather than actual volume of logs;
- Rather imprecise way some companies used to determine the yield (typically in m^2/board foot) especially because it does not indicate how much wood was actually lost.

Initially, the intention for data collection was to obtain data on the inputs and outputs per process stage (sawmill, cutting, dryer, clipping etc.). However, in the absence of existing records for power and thermal energy consumption per stage as well as wood residues produced and in order to ease the communication process between companies, the data collection process was revised to a "system process approach". This means that all process stages within veneer production (outside forest) were aggregated into an single overall unit process for analysis and modelling in GaBi 6.

Primary and secondary data collected were provided in a way consistent with GaBi 6 background data. Table 7 summarises the main production steps and the data sources or origins.

Table 7: Data sources overview

Sources overview for cradle-to-gate plus transport LCA of U.S. hardwood veneer

data	data source
Hardwood forest stand establishment and harvesting	CORRIM, adapted with prices from secondary data (industry price reports) and with species-specific densities moisture contents and log transport distances
Slicer veneer production	AHEC members primary data
Rotary veneer production	AHEC members primary data
Transportation	primary data on modes and distances, GaBi 6 data on emissions
Background data (materials, fuels and energy)	GaBi 6 (2013)

3.5.1 Forest

The forest process is a “generic” model for US hardwoods (not species-specific). However and as previously described, certain species-mix aspects such as density, moisture content and transport distances (calculated through a weighted average) were considered and included in the veneer model carried out for this study.

Data for forestry was taken from Consortium for Research on Renewable Industrial Materials (CORRIM) research[28] (CORRIM, Module A, 2011) and reflects the average hardwood logs inventory per cubic metre of hardwood for Northeast/North Central (NE/NC) region of the US. The inventory is a scaled or mass weighted average of three forest management scenarios developed for the region. The module A of the Phase II CORRIM research was taken as the basis for modelling the hardwood forest.

After extensive research at the time of the AHEC LCA lumber study, forestry data from the CORRIM was found to be the only feasible data source for North American hardwood forestry inventory. CORRIM data on forest stocks, location, ownership etc. is based on the Forest Inventory and Analysis (FIA) data for the region. Harvesting production and fuel consumption rates were assimilated from existing studies of harvesting equipment typical of the systems used to harvest sites in the region. These studies included both personal interviews with timber harvesting contractors and published information.

AHEC wanted the veneer study to be consistent with the previous study; therefore the study on veneer relies entirely on the same background forest process model used in the lumber study. In the US, the hardwood harvesting is split fairly equally between SE and NE/NC regions (Pacific Northwest contributes only a few % to the total of US hardwood manufacturing). The Northeast-North Central regions cover forests from Minnesota to Maine and as far south as Missouri, West Virginia and Pennsylvania. Appendix E contains the map depicting the hardwood harvesting regions as used by AHEC members. The Northeast-North Central region in CORRIM data refers to the Northern, Central and Appalachian regions of hardwood harvesting as used by AHEC members. Based on the hardwood removals statistics by state and information on the location of AHEC members from AHEC, the CORRIM data covers around half of the total existing AHEC members by regional location and where approximately 46% of total US hardwood annual removals take place.

No data on hardwood forestry (at the time the AHEC LCA Lumber study was conducted), was available for the SE region, so the data from NE/NC region was extrapolated to represent all of the US hardwood forestry[29]. It is estimated that this data assumption has very minor impact on the veneer study as (1) the SE region provides a different hardwood

[28] The Consortium for Research on Renewable Industrial Materials (CORRIM) focuses on research and education programs relating to renewable industrial materials. CORRIM’s research guidelines and the detailed reports are available online (www.corrim.org). The unit process LCI datasets developed by CORRIM research are available through the public US LCI database (www.lcacommons.gov/nrel/search) which is maintained by National Renewable Energy Laboratory as a public institution.

[29] CORRIM new releases for 2013 have been checked and there is until now no LCI carried out for SE regions. Other sources reviewed give no much enough detail in order to carry a LCI for SE regions.

species profile, but the LCI for harvesting a cubic metre of hardwood is expected to be very similar to that of the NE/NC region, (2) the impact of forestry on the hardwood veneer environmental impact is relatively small so the differences in forestry practices have small impact on the environmental performance of the hardwood veneer, (3) all companies participating in the veneer study are located within the Northern, Central and Appalachian regions, thus are within the area coverage of CORRIM forestry data. For more discussion on forestry data representativeness please refer to chapter 0.

In general the natural regeneration hardwood forestry process does not involve irrigation, use of fertiliser or planting and thus the inventory is mostly comprised of the harvesting requirements. Harvesting requirements relate to the cubic metres of wood harvested and are not species-specific. However, the harvested logs volume were converted to mass, taking into account the species mix mass weighted average densities (48 - 100% MC) in order to reflect the differences in species mix-mass for transportation (in order to express transport on a tkm basis).

The allocation between hardwood round wood and pulp logs was made based on the average round wood and pulp log prices from 2009-2010 and are not species specific: 43.6 [\$/m³] for round wood logs and 32.7 [\$/m³] for pulp logs (rounded from Timber Mart-South, 2009-2010).

Hardwood pulp log prices do not vary much across species, while the prices for hardwood round wood vary substantially both across species and grades. For example, white oak round wood may cost a third of the same grade of hard maple. Furthermore, round wood prices vary within the species with, for example, hard maple of the lowest grades round wood being 1/3 the price of the highest grade (Northeast Timber Exchange, 2012). To further complicate the issue, wood prices are not very stable with the price relationship of pulpwood to round wood fluctuating over the years.

Species and grade-specific allocation was not performed to avoid over-complication of the report due to too many possible products. The primary energy is extracted from the environment when wood is harvested. For calculation of the primary energy consumption at the wood harvesting stage (net calorific value), the energy incorporated in wood was assumed to be 10.33 MJ per kg of green wood (for all species).

The hardwood forest model was built in the GaBi 6 LCA software, using the CORRIM data on hardwood forestry management and logging together with the aspects of species-specific data discussed above. GaBi 6 datasets on fuels and transportation were used.

3.5.2 Description of inputs and outputs in the hardwood veneer production

The hardwood veneer production analysis is based on primary data from AHEC members; companies own estimations and CORRIM research (CORRIM, Module A 2010). Additionally, AHEC publications were used to reference hardwood species densities (AHEC, 2009).

The veneer production process was analysed as a single, aggregated process based on the so-called 'system process' approach. No differentiation between the highest or lowest production process performances on a per species basis could be observed due to a lack of information and details from the companies. Therefore the analysis carried out in this study represents an "average" for the US hardwood slicer and rotary veneer production process in the sector rather than species-specific analysis.

The following inputs and outputs for slicer and rotary veneer production (data for each technology were collected and analysed separately) have been estimated as follows:

Input logs

All veneer companies record their log volume by using the Doyle log scale in board feet. The board foot is a specialized unit of measure used for estimating the volume of lumber in the US and Canada. It reflects a measurement of one foot wide, 1 foot long and 1 inch thick or its volumetric equivalent. However this unit is not the actual volume of the logs but rather a nominal one. There can be an underestimation of approximately 34-66% of actual volume as found in the study. The error can be greater on small logs and lesser on large ones (email communication Danzer (2013 a) and Amos Hill).

In order to help minimise the weakness of the Doyle Bdft scale to determine actual volumes, four ways were used to estimate log volumes and masses:

- Companies' own specific conversion factor from Bdft to m^3 or kg. This only applies for the average log typically handled by the company; although it is clearly stated as still only a rough estimation;
- Correction of the input volume given in Bdft by a factor of 1.66;
- Own log weight estimations;
- Total number of logs, average diameter and length (as cylinder volume calculation).

Each production facility handles a different mix of hardwood species logs. The modelling per production site reflects this context by means of an estimation of the average weighted density for the species mix and its average particular MC as indicated by the company (see Appendix E for the list of species densities at 12% MC that have been used in the study).

Moisture content of the logs at log yard or delivery area (which range between 48 to 100 %) was provided by the companies.

Input Bark

Normally the way logs are measured at log yard does not include bark. Thus bark was estimated by using the following calculations:

Bark per tree (m^3) =length avg. log (m) x circumference of the avg. diameter (m) x removal bark thickness (m)   **Total Bark (kg) = Bark per tree (m^3) x total number of logs x density for that MC (kg/m^3)**

Companies which do not record figures for length or diameter of logs could not use the above calculations. These normally keep track of trailer loads of bark per year and by noting the percentage of fullness, the dimension of the load compartment and the density, the amount bark was roughly estimated.

From information reviewed, bark represents between 10-11% of total log masses (approx. 0.0127 m removal for an average diameter of 0.4318 m) which seems feasible. Moisture content of the bark was assumed to be the same as the moisture content indicated for logs.

The amount of bark[30] arising as residues during debarking was assumed to be the same as the input bark in logs.

Energy consumption

Hardwood veneer production requires both electrical and thermal energy for processing logs into veneer panels. All thermal energy is produced on-site, whereas electricity is produced off-site from a regional power grid. As previously described, companies participating record power and thermal energy information on an overall base rather than per process or sub-process stage. Therefore the model was set up in order to assess the overall picture (see section 3.1.12 for more detail on energy model)

Results show total electricity consumption of 1.86-4.21 MJ/kg finished slicer veneer and 0.0045-2.36 MJ/kg rotary peeled veneer. In order to validate the figures, several literature review sources were consulted which provide a wide-range of 0.49-4.4 MJ/kg dried veneer (Energie Agentur NRW, 2012) in Germany[31]. The value presented by one rotary company of 0.0045 MJ/kg has been validated 3 times. The person contacted verified it, despite the fact that it shows a much lesser consumption in comparison to another site operated by the same company (2.36 MJ/kg veneer produced)[32].

Green wood residues arising during veneer cutting as well as dried wood residues from clipping and trimming generates the necessary thermal energy for running the veneer

[30] The end destination of bark is variable within the companies analyzed: most companies reported that they sell it or give it for free for mulch (approx. 60% of the companies). Others reported its combustion in their boilers for energy generation.

[31] These figures although fitting a German context can be used to compare with and validate the study figures. Unfortunately only one source of information was found for North America from the National Renewable Energy Laboratory which shows energy consumption figures for a veneer hardwood drying process (power 0,41 MJ/kg dried veneer and thermal energy 7,05MJ /kg dried veneer). They suggest that total amount of power for hardwood veneer production is 7.5 MJ/kg produced hardwood veneer and 9.9 MJ thermal energy/ kg produced hardwood veneer. The system boundaries and description are not very clearly explained www.lcacommons.gov/nrel/process/show/65422ead-9d4c-45f6-9bb7-a00a8909fc0b?qlookup=+++%2Bveneer&max=35&hfacet=&hfacetCat=&loc=&year=&dtype=&crop=&index=7&numfound=57&offset=

[32] The great differences in power consumption could be explained by different technologies in place among several veneer plants (vacuum tables vs. hydraulic dogs, longer dryers, pre-dryers and more fans) (Danzer, 2013b)

production at facilities. Sometimes companies purchase extra wood chips in order to meet the thermal energy production requirements. The thermal energy is typically in the form of steam and is mainly used for vats and dryers. The thermal energy consumption ranges between 7.49-29.02 MJ/kg for slicer technology and between 5.60-13.51 MJ/kg for rotary technology. These values have been compared with available literature and are in agreement with the 6.3 – 29 MJ/kg given by Energy Agency NRW (2012) and Environmental, Climate and Energy Ministry of Baden and Württemberg (2012) (2.3 MJ/kg dry veneer produced power consumption and 19.8 MJ/kg dry veneer produced of thermal energy).

Furthermore, diesel is reported as the main fuel employed to move machines, transport equipment and materials within and outside the facility. A US diesel combusted (in industrial equipment) process from GaBi 6 has been taken in order to model the fuel consumption and emissions by different machines.

Water input

Water use mainly comprises sprinkling of logs at log yard and steaming vats and boiler make-up water. Water figures were provided by the companies and represent three key sources; storm water collection system, own wells and mains water.

Other Inputs

*Other minor inputs such as wax, glue and packaging materials have been provided by the companies and are also included in the modelling.

Veneer final product

Final production figures are all derived from annual sales reports computed by each company. A distinction arises between clipped and unclipped final product for slicer technology. Only clipped veneer material is considered as final product or FU of thisstudy.Unclipped veneer sheets are treated as co-products and this is considered further in a sensitivity analysis.

Moisture content on an oven dry basis of final sheets ranges from 5.5 % to 12 % with average weighted density figures according to species-mix of 577-728 kg/m^3. Furthermore, the average thickness of panels can vary from 0.5 to 2.5 mm. A special type of rotary veneer panels are the ones showing the greater thicknesses (2-2.5 mm). These are produced in the case of a company (rotary technology) that produces also veneer that goes into 12.5 mm thick hardwood plywood production (the production figures have been considered and adjusted in order to reflect only that segment of the system under investigation in this study).

Water evaporation

This output is covered by the study in a simple manner (consistent with basic data quality requirements) because a ‘water footprint’ or other water analysis is not a priority objective of the study. The final product can be dried between 5.5% to 12% MC on an oven dry basis depending on species which affects the drying times and subsequently the energy consumption. During the drying process, wood shrinks and up to 37% of moisture can be lost depending on the species.

Some companies provided water evaporation calculations based on the yield before veneer is clipped (veneer measured as it is coming out of the dryer (m^2/Bdft) and the input to the drier in Bdft. By means of these figures, they were able to calculate the total panel area obtained. By applying the respective thickness and density at that MC condition, a total input mass was calculated. Additionally, the shrinkage will determine the loss in thickness after drying. Following the same procedure a total mass output will be calculated. The difference between both will give total water evaporation in mass. The weighted average shrinkage for the respective species-mix was assumed to be 6.4 to 7.6% (based on average radial and tangential shrinkage from the USDA Forest Service).

For the majority of companies it was difficult to estimate water evaporation as no measurement of the yield before clipping (after drying) and volumes going in and out of the dryer are recorded. Those companies just determined water evaporation amounts as a difference resulting from total mass input (estimated MC) minus final product (MC is measured) and total co-products generated (in many cases MC has to be estimated as actual measurements are not carried out).

Co-products

Wood co-products are recognised through different names along a slicer and a rotary technology. Nevertheless, most companies have provided them by just differentiating between bark, wood chips and veneer sheet clipping residues. All the types found and reported by the companies are described below:

Backing boards: are solely associated to slicer technology. After the cutting is completed; the remaining piece is called the backing board. Normally there are two backing boards per log which have the same size of a log diameter^ (see Figure 3-2). Calculations below show the backing board volume quantification as well as the total backing board in mass, as it was estimated by the companies.

Backing board per tree (m^3) =2 (number backing board per log) x length avg. log (m) x diameter (m) x thickness (m)

Total Backing board (kg) = Backing board per tree (m^3) x total number of logs x density at that MC (kg/m^3)

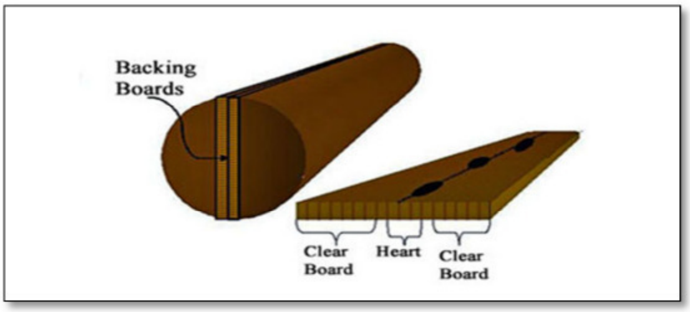


Figure 3-2 View of the backing board on a log [33]

Most of the backing boards generated are burned in the boilers (68-75%). The typical MC reported lies between 65-69%.

Bark: the amount of bark arising as residue during normal debarking was assumed to be the input bark contained in the logs. Moreover, bark can be used either at the wood fired boilers for energy generation, or transferred to outside vendors for mulching or composting (sold or given free and accordingly modeled using economic allocation and additionally compared with mass allocation).

Bunch clipped waste: were only reported by a rotary technology and refer to the residues arising when panels all set in a "bunch" are being simultaneously cut in order to remove defects. Bunch clipped residues will share the same MC figure as the final product (dried residues). After being cut into small chips they will be collected through the general waste stream system feeding into the boiler while a minor percentage can be sold.

Cores: are solely associated with a rotary technology and refer to solid cylinders which remain after the peeling process. After the cutting process is completed; the remaining piece of the log is termed the core (green waste with approx. 66 % MC as reported). Calculations below show the cores volume quantification as well as the total core in mass as estimated by the companies.

Cores volume (m^3) = 3.14159 x length avg. core (m) x (avg. core diameter (m)/2)^2*removal flitch thickness (m)

Total cores (kg) = cores volume (m^3) * total number of logs* density at that MC (kg/m^3)

One company reported that approximately 80% of cores are sold and used to make pallets for finished goods and the rest is given away for free to employees.

Flitch surface material: flitch surface material occurs during the planeing of flitches in order to even and reduce roughness. The table below shows the flitch material volume quantification by using the circumference formula of an average log diameter. Then total

33 http://www.stemwood.com/about%207.htm

mass of flitch material is calculated from the flitch material volume and the total number of logs by species-mix density for that respective MC as reported by the companies.

Flitch material volume (m^3) = length avg. log (m) x circumference of an avg. log diameter (m) x removal flitch thickness (m)

Total flitch material (kg) = Flitch material volume (m^3) x total number of logs x density at that MC (kg/m^3)

Normally a 3.18 mm has been considered as the flitch removal thickness. This material is all reused in the boiler for energy generation. Typical MC reported is around 60%.

Logs trimmings or butts: lateral left overs of the original log which are generated during the cutting of the log in order to fit to the size of the cutter before the peeling takes place. Subsequently these green residues will be chipped to feed the boiler (80% are used for energy generation (boilers) and the rest is given freely to employees).

Slabs/head planning material: generated during the planning process in order to even and reduce roughness and were just reported by few companies. These materials are normally chipped and all used for combustion at the boilers.

Veneer sheet clipping residue (clipping, trimmings): are generated during the clipping or trimming of the panel in order to reduce defects. Companies know roughly the size that is cut per panel and per side thus by following some simple calculations with the area, thickness and density these were closely estimated. Veneer sheet clipping residues will share the same MC figure as the final product. After being cut into small chips they are collected through the general waste stream system and feed to the boiler for energy generation.

Prices of veneer mill co-products were provided by the different companies. Some initial cross checking has been carried out in order to check plausibility. An average price for a specific MC has been calculated in order to characterize suitably each co-product for allocation. If the co-product from a company is representing a different MC, this is adjusted in order to reflect the correct price in the model.

Table 8, Table 9, Table 10 summarise the inputs and outputs of the veneer process and prices used for economic allocation. Unallocated tables including amounts of co-products are shown in Appendix B.

Table 8: Hardwood veneer inventory for 1 m2 slicer veneer & co-product prices (for respective MC assumed in the model)

Inventory data from a 1 m^2 slicer veneer in cradle-to-gate (based on species mix).

INPUTS	amount	Price [USD/kg]

Roundwood with bark, hardwood, green, kg	1.22E+00	n/a
Wax (synthetic), kg	1.98E-04	n/a
Electricity, MJ	9.88E-01	n/a
Thermal energy, onsite boiler, MJ	6.41E+00	n/a
Diesel, combusted in industrial equipment, m³	3.35E-06	n/a
Lubricating oil, kg	1.55E-04	n/a
Water (tap water), kg	2.84E+00	n/a
Water (well), kg	1.42E+00	n/a
Water (rain), kg	2.10E-02	n/a
Steel banding kg	2.89E-03	n/a
Knives (Steel hot rolled), kg	2.98E-04	n/a
Polyethylene-film, packaging, kg	6.05E-05	n/a
OUTPUTS	amount	Price [USD/kg]
Hardwood veneer clipped (10% MC), kg	3.54E-01	4,25
Hardwood veneer unclipped (10% MC), kg	0.00E+00	3,17
Backing boards (69% MC), kg	0.00E+00	0,191
Bark, hardwood green (60% MC), kg	0.00E+00	0,0109
Bunch clipped waste (8,6 % MC) , kg	0.00E+00	0,0244
Cores (66,6% MC), kg	0.00E+00	0,0285
Flitch surface material (69% MC), kg	0.00E+00	0,0221
Log trimmings (81,8% MC), kg	0.00E+00	0,022
Logs for sale	0.00E+00	0,63
Slabs (69% MC), kg	0.00E+00	0,01
Veneer sheet clipping residue (10% MC) , kg	0.00E+00	0,0869
Wood chips (15% MC) (as total wood waste residues), kg	0.00E+00	0,0848
Sheet residues (Trim)	0.00E+00	0,0259
Water vapor, kg	3.61E-01	n/a
Packaging waste (plastic), kg	7.14E-05	n/a

Steel waste, kg	2.56E-04	n/a
Waste (unspecified), kg	0.00E+00	n/a
Sludge, kg	2.62E-04	n/a
Waste water, kg	4.28E+00	n/a
Acetaldehyde, kg	5.52E-06	
Acetone, kg	8.38E-06	
Acrolein,kg	7.20E-06	
Formaldehyde,kg	5.50E-07	
Hazardous air pollutants[34],kg	1.45E-05	
Hydrocarbons,kg	2.67E-04	
Methanol,kg	7.80E-06	
Methyl isobutyl ketone kg	7.16E-06	

Table 9: Hardwood veneer inventory for 1 m^2 rotary veneer (0,6mm) & co-product prices (for respective MC assumed in the model)

Inventory data from a 1 m^2 rotary veneer (0,6mm) in cradle-to-gate (based on species mix).

INPUTS	amount	Price [USD/kg]
Roundwood with bark, hardwood, green, kg	1.62E+00	n/a
Wax (synthetic), kg	8.66E-04	n/a
Electricity, MJ	4.86E-01	n/a
Thermal energy, onsite boiler, MJ	4..61E+00	n/a
Diesel, combusted in industrial equipment, m^3	1.79E-06	n/a
Lubricating oil, kg	2.36E-04	n/a
Water (tap water), kg	1.66E+00	n/a
Water (well), kg	0.00E+00	n/a
Water (rain), kg	4.03E+00	n/a
Steel banding kg	0.00E+00	n/a
Knives (Steel hot rolled), kg	1.57E-04	n/a
Polyethylene-film, packaging, kg	3.22E-04	n/a
OUTPUTS	amount	Price [USD/kg]

[34] This category includes hazardous air pollutants, as listed in Section 112 of the U.S. Clean Air Act (1970) and Clean Air Act (1990). The complete list is found in on Wikipedia at National Emissions Standards for Hazardous Air Pollutants, and on EPA. http://en.wikipedia.org/wiki/National_Emissions_Standards_for_Hazardous_Air_Pollutants

Hardwood veneer clipped (10% MC), kg	4.54E-01	4,25
Hardwood veneer unclipped (10% MC), kg	0.00E+00	3,17
Backing boards (69% MC), kg	0.00E+00	0,191
Bark, hardwood green (60% MC), kg	0.00E+00	0,0109
Bunch clipped waste (8,6 % MC) , kg	0.00E+00	0,0244
Cores (66,6% MC), kg	0.00E+00	0,0285
Flitch surface material (69% MC), kg	0.00E+00	0,0221
Log trimmings (81,8% MC), kg	0.00E+00	0,022
Logs for sale	0.00E+00	0,63
Slabs (69% MC), kg	0.00E+00	0,01
Veneer sheet clipping residue (10% MC) , kg	0.00E+00	0,0869
Wood chips (15% MC) (as total wood waste residues), kg	0.00E+00	0,0848
Sheet residues (Trim)	0.00E+00	0,0259
Water vapor, kg	3.80E-01	n/a
Packaging waste (plastic), kg	3.21E-05	n/a
Steel waste, kg	0.00E+00	n/a
Waste (unspecified), kg	0.00E+00	n/a
Sludge, kg	4.85E-03	n/a
Waste water, kg	5.69E+00	n/a
Acetaldehyde, kg	6.35E-06	
Acetone, kg	9.65E-06	
Acrolein,kg	8.29E-06	
Formaldehyde,kg	6.34E-07	
Hazardous air pollutants,kg	1.67E-05	
Hydrocarbons,kg	3.08E-04	
Methanol,kg	8.97E-06	
Methyl isobutyl ketone kg	8.23E-06	

Table 10: Hardwood veneer inventory for 1 m2 rotary veneer (2-2,5mm) & co-product prices (for respective MC assumed in the model)

Inventory data from a 1 m2 rotary veneer (2-2,5mm) in cradle-to-gate (based on species mix).

INPUTS	amount	Price [USD/kg]
Roundwood with bark, hardwood, green, kg	5.20E+00	n/a
Wax (synthetic), kg	4.72E-05	n/a
Electricity, MJ	2.71E+00	n/a
Thermal energy, onsite boiler, MJ	8.97E+00	n/a
Diesel, combusted in industrial equipment, m^3	3.07E-04	n/a
Lubricating oil, kg	6.00E-05	n/a
Water (tap water), kg	1.27E+00	n/a
Water (well), kg	0.00E+00	n/a
Water (rain), kg	1.58E-01	n/a
Steel banding kg	0.00E+00	n/a
Knives (Steel hot rolled), kg	9.78E-05	n/a
Polyethylene-film, packaging, kg	4.25E-04	n/a
OUTPUTS	amount	Price [USD/kg]
Hardwood veneer clipped (10% MC), kg	1.45E+00	4,25
Hardwood veneer unclipped (10% MC), kg	0.00E+00	3,17
Backing boards (69% MC), kg	0.00E+00	0,191
Bark, hardwood green (60% MC), kg	0.00E+00	0,0109
Bunch clipped waste (8,6 % MC) , kg	0.00E+00	0,0244
Cores (66,6% MC), kg	0.00E+00	0,0285
Flitch surface material (69% MC), kg	0.00E+00	0,0221
Log trimmings (81,8% MC), kg	0.00E+00	0,022
Logs for sale	0.00E+00	0,63
Slabs (69% MC), kg	0.00E+00	0,01
Veneer sheet clipping residue (10% MC) , kg	0.00E+00	0,0869
Wood chips (15% MC) (as total wood waste residues), kg	0.00E+00	0,0848

Sheet residues (Trim)	0.00E+00	0,0259
Water vapor, kg	1.74E+00	n/a
Packaging waste (plastic), kg	6.37E-06	n/a
Steel waste, kg		n/a
Waste (unspecified), kg	2.94E-03	n/a
Sludge, kg	4.56E-04	n/a
Waste water, kg	1.43E+00	n/a
Acetaldehyde, kg	6.-55E-06	
Acetone, kg	9.97E-06	
Acrolein,kg	8.55E-06	
Formaldehyde,kg	6.54E-07	
Hazardous air pollutants,kg	1.73E-05	
Hydrocarbons,kg	3.17E-04	
Methanol,kg	9.26E-06	
Methyl isobutyl ketone kg	8.49E-06	

Drying emissions: During the drying process VOCs are emitted because compounds present in the wood are given off with water. One might detect 25 or 30 compounds in the dryer exhaust; mostly these emissions are from the terpene family but also other VOCs like formic or acetic acid. These emissions are currently not measured and the literature data from NCASI (1998) was adopted in the model. The VOC emissions from kiln drying are species, temperature, thickness and moisture dependent.

The estimated formaldehyde release per square metre of veneer in this study is assumed to be 6.84E-07 kg. Emissions from dryers included by the NCASI[35] study (1998) comprise acetaldehyde, acetone, acrolein, formaldehyde, methanol, methyl isobutyl ketone, total hydrocarbons and total HAPs (hazardous air pollutants). If direct-fired units are used, products of combustion such as carbon monoxide (CO), carbon dioxide (CO2), and nitrogen oxides (NOx), are also emitted. The condensed PM and a portion of the VOCs leave the dryer stack as vapour but condense at normal atmospheric temperatures to form liquid particles or mist that creates a visible blue haze. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows an average of emissions emitted in kg per square metre veneer produced.

Both the VOCs and condensable PM are primarily compounds evaporated from the wood, with a minor constituent being combustion products. Quantities emitted are dependent on wood species, dryer temperature, fuel used, and other factors including season of the year.

[35] The National Council for Air and Stream Improvement (NCASI) is an independent, non-profit research institute that focuses on environmental and sustainability topics relevant to forest management and the manufacture of forest products. In 1998 they carried out measurements on different dryers for different wood hardwood species from the veneer industry in the US.

Table 11 Emissions from dryer measurements carried out by NCASI in 1998

	AVERAGE (kg/m^2)
Acetaldehyde	6,85E-06
Acetone	1,04E-05
Acrolein	8,95E-06
Formaldehyde	6,84E-07
Methanol	9,68E-06
MIBK (methyl isobutyl ketone)	8,89E-06
Total hydrocarbons (as carbon)	3,32E-04
Total HAPs	1,81E-05

In order to add these emissions into the three veneer models, the following was undertaken:

-an average value from measurements shown by NCASI (kg/m^2) was obtained;

-those average values were inserted in the GaBi models;

-total emission amounts according to total production figures were calculated in each respective model per company (parameters were added in order to make calculations in the GaBi software straightforward); These were then recalculated by GaBi in order to reflect the FU of a 1 square meter per company model;

-the GaBi software then calculates automatically values per FU when an economic allocation takes place;

- verifications were carried out in order to control that the mass weighted approach model per technology also is reflecting the background emission values from NCASI (values in Table 8, Table 9 and Table 10 are reflecting the sum of the individual values obtained per each company model after the mass weighted approach was inserted in the model).

3.5.3 Transport

Average transportation distances and modes (container ship and truck,) are provided by AHEC and member companies. Fuel use and the associated emissions were calculated using pre-configured transportation models from the GaBi 6 database 2013. The transportation models for truck transport were based on the GaBi 6 database using emission standards and factors for trucks in the US and EU. The fuel used for transport was modelled according to the respective geography, fuel type, sulphur content and share of biogenic fuel.

The mass of transported wood across the LCA model reflects the species mix-average density and the moisture content at the respective transportation stage.

Primary data from AHEC members analysed suggests that transportation distances from forest to veneer mill range from 96 to 740 km (60 to 462 miles) and the transport mode is 100% truck.

Transportation from veneer mill to port of export was modelled taking into account the specific veneer mill location and its main export port (distances were provided by companies participating and range from 273 km to 2703 km).

Average shipping distance from export port in the US to a port in Europe is 7753 km. It is calculated as an average for all US hardwood lumber exports to Western Europe, weighted according to ports of import and export during the period 2003-2009. The same was assumed for veneer.

The estimated scenario of transportation to a customer in Europe is 500 km as the large majority of EU cities lay well within 500 km of a major seaport.

The US truck dataset is modelled based on the US Census Bureau Vehicle Inventory Use Survey (VIUS) and US Department of Transportation and Environmental Protection Agency (EPA) fuel efficiency and emissions data. The biogenic (non-fossil) fraction of fuel is determined by the 2011 EPA Renewable Fuel Standard, which specifies a renewable fuel content of 8% in 2011. Veneer truck transport is assumed to have 57% utilization ratio (average in US for log/roundwood trucks) and the amount of sulphur in US diesel is assumed to be 15 ppm (US ultra-low sulphur fuel standard 2007).

The container ship dataset is modelled on the International Maritime Organization Study and IPCC emission factors (Second IMO GHG Study, Final report, April 2009. Emission factors go back to IPCC 2006 and EMEP/EEA). The container ship consumes heavy fuel oil with 0% biogenic carbon and 2.7 weight percent sulphur. Capacity utilization ratio was assumed to be 48% (conservative assumption as the range for ships is 45-70%).

For the European truck, the Euro 4 emission standard was used, the biogenic carbon share is 5% and sulphur content is 10 ppm. For the European truck transport is assumed to have 85% utilization ratio. Table 12 summarizes the transport distances, modes and parameters used.

National averages for fuel inputs and regional US electricity grid mixes were used from the GaBi 6 database 2013. GaBi databases are updated on a yearly basis.

The GaBi datasets used for this study are based on the data from 2009/2011-2014.

Table 12: Transport distances, modes and parameters

Transport modelled in cradle-to-gate plus transport LCA of US hardwood veneer to customers (Europe)

Transport	Mode	Average Distance [km]	Share of biogenic carbon [%]	Sulphur content in fuel	Utilization ratio [%]

Logs from forest to veneer mill	US Truck, diesel driven (truck for pole, logging, pulpwood, or pipe transport), 9 t payload capacity	96-740	8	15 ppm	57
Veneer mill to US overseas port	US Truck, diesel driven (truck for pole, logging, pulpwood, or pipe transport), 9 t payload capacity	273-2703	8	15 ppm	57
US overseas port to European overseas port	Container ship ocean with 27500 dead weight tons (dwt) pay load capacity, heavy fuel oil driven	7735	0	2.7 wt % (27000 ppm)	48
Europe port to final product manufacturer	Truck, diesel driven, Euro 4. 27 t payload capacity	500	5	10 ppm	85

3.6 Co-product Allocation

Forestry and veneer production unit processes generate co-products in a way that it is not feasible to split the process into sub-processes (each producing only one product), so allocation is necessary. Due to the high difference in the co-product prices, mass allocation (or any other physical mean allocation) does not capture the underlying revenue intention of the production process. Therefore economic allocation was chosen as a basis to distribute the environmental impact of the process between co-products.

Price data for co- products were used for the economic allocation in forestry and veneer production. The allocation approach follows the requirements of the core rules for EPD's for construction products in Europe and complies with the ISO 14044 standard. Weighted average prices for veneer co-products across all companies, normalized to a common MC per co-product group, are reported in Table 8, Table 9, and Table 10.

As mentioned before, the prices are subject to change due to variation within years, species and grades. Sensitivity analysis (Chapter 4.4) includes an evaluation of a mass allocation approach. Stored carbon was allocated on stoichiometry (46.27% C (dry weight basis) assumed in all US hardwood products and co-products) not on price (see chapter 3.4.4).

The background data underlying the model was also explored via different allocation approaches; it includes for example energy content allocation; price allocation etc. appropriate to the process. Allocation is documented in the GaBi 6 datasets documentation [GaBi 6].

3.7 CUT-OFF CRITERIA

Generally the decision on the exclusion of materials, energy and emissions data is made on the following basis (according to ISO 14040[36]):

Mass – If a flow is less than 2% of the cumulative mass of the respective gate-to-gate model inventory, it may be excluded, providing its environmental relevance is not a concern;

Energy – If a flow is less than 2% of the cumulative energy of the model, it may be excluded, providing its environmental relevance is not a concern;

Environmental relevance – If a flow meets the above criteria for exclusion, yet it is thought potentially to have a significant environmental impact, it will be included. Material flows which leave the system (emissions) and whose environmental impact is greater than 2% of the whole impact of an impact category that has been considered in the assessment must be covered. This judgment will be made based on experience and documented as necessary.

The sum of the neglected material flows must not exceed 5% of mass, energy or environmental relevance of the system inventory.

Table 2 in chapter 3.2 contains the list of elements excluded from the system boundary (like buildings or human labour). There is almost no disposal of used knives as they are re-sharped as many times as possible and therefore were excluded from the study.

Further excluded flows are listed in Table 13, Table 14 Table 15 with an estimation of their relevance.

Table 13: Cut off - excluded flows (Slicer)

Flow	Description	Estimated amount in kg per m2 of veneer
oil waste handling	Thin non-treated wooden strips are used in the drying to create space between individual lumbers for better air flow. The strips are reusable.	0.000194774
steel banding waste	Companies reported that steel banding waste is sold back to a metal recycler	0.000339989
grinding waste	Grinding waste resulting from sharping knives is disposed in a landfill.	0.000809862
water use for boiler refill	Most of the veneer mills have a boiler onsite. Water in the boiler requires refills.	5.98139E-06

Total mass of excluded flows per product FU is estimated to be less than 0.00004% of the total inputs and 0.02% total outputs.

[36] According to DIN EN 15804, the cut off criteria shall be below 1%. But this study followed ISO 14044 rules of cut-off.

Table 14: Cut off - excluded flows (Rotary 0.6 mm)		
Flow	**Description**	**Estimated amount in Kg per m2 of veneer**
oil waste handling	Thin non-treated wooden strips are used in the drying to create space between individual lumbers for better air flow. The strips are reusable.	4.79242E-05
glue	Glue is used to paste veneer panels together in order to make them bigger	0.000231766
grinding waste	Grinding waste resulting from sharping knives is disposed in a landfill.	0.000168824
water use for boiler refill	Most of the veneer mills have a boiler onsite. Water in the boiler requires refills.	7.6819E-06
Total mass of excluded flows per product FU is estimated to be less than 0.002% of the total inputs and 0.003% total outputs.		

Table 15: Cut off - excluded flows (Rotary 2.5 mm)		
Flow	**Description**	**Estimated amount in Kg per m2 of veneer**
oil waste handling	Thin non-treated wooden strips are used in the drying to create space between individual lumbers for better air flow. The strips are reusable.	0.000168576
water use for boiler refill	Most of the veneer mills have a boiler onsite. Water in the boiler requires refills.	2.45516E-05
Total mass of excluded flows per product FU is estimated to be less than 0.0001% of the total inputs and 0.003% total outputs.		

3.8 OVERALL DATA QUALITY AND REPRESENTATIVENESS

The study relies on primary data from AHEC members together with assumptions or estimations carried out by them, and on data from the GaBi 6 databases and CORRIM.

Collected primary data have gone through intense and iterative quality and plausibility checks (especially for mass balances, energy consumption, yield), and all unreliable data points have followed a triple verification or proof with the contact person per E-mail or telephone. Simultaneously, some literature values were confirmed by primary data collected by some of the members.

As previously stated, the aim of the study is to represent an average slicer and rotary veneer production (species-mix) in the US. Each company´s production is modelled and its influence is revealed by the mass weighted approach (based on final production figures (clipped veneer amounts for slicer and veneer for rotary)). Thus, companies with higher production volumes have a proportionately higher influence on the overall results than companies with smaller production volumes. For the study limitations related with data gaps and weaknesses please refer to section 3.5.

3.8.1 Precision and completeness

All relevant foreground data is either primary data directly measured or estimated by the AHEC member participants. An extensive and comprehensive questionnaire was used to survey the industry participating. Primary mill data were collected for the year 2011-2012 from facilities across the eastern US that represents nearly 40% of total slicer technology and over 60% of rotary. All upstream processes were taken from the GaBi databases which have been well documented (see GaBi 6 documentation).

3.8.2 Consistency and reproducibility

In order to ensure consistency only primary data of the same level of detail and upstream data from GaBi 6 database (2013) was used. The reproducibility is given for internal use since the models in GaBi 6 are stored and available only in a database owned by PE. For the external audience no full reproducibility in any degree of detail will be possible.

While building up the model, validations concerning the plausibility of mass and energy flows were continuously conducted. Conversion rates from incoming logs into dry veneer and energy consumption figures have been cross checked and compared with available public sources. The veneer companies show some variation on energy consumption figures; but these are consistent with the wide range reported by few available literature sources (refer to section 3.5.2 for more detail on energy figures). In general the system process approach adopted allows for a simplified understanding and communication process than a more disaggregated, multi-units process.

3.8.3 Geographical coverage and representativeness

The geographical coverage of this study represents the cradle to gate hardwood veneer production processes carried out in the US with a further transportation step to Europe.

CORRIM data was utilised to represent hardwood forest stand establishment and harvesting and covers North-eastern and North Central (NE/NC) forests; where roughly half of the US hardwood forests are harvested and where roughly half of the AHEC members are located (see also chapter 3.5.1 on forestry data discussions).

Veneer production data for slicer and rotary technology was built on direct measurements and estimations by the AHEC member participants. Veneer production figures cover the north, central and Appalachian region of the US (see Appendix E for a map of the US with each region), where most of the veneer manufacturing takes place.

Transportation distance and mode data is primarily data from AHEC members and is representative for American Hardwood products exported to the European market (see also chapter 0 on transport data).

Background GaBi 6 datasets were chosen to represent the US geography for veneer transport and production and EU geography for inland EU transportation.

The geographical coverage achieved is considered to be representative for overall production of hardwood veneer panels in the US with further distribution to major consumer markets in Europe.

3.8.4 Time coverage and representativeness

The study aims to assess the cradle-to-gate life cycle of veneer panels currently being produced by AHEC members. To achieve the representation of the current technology state, the most accurate data available was chosen for the study:

- Data for hardwood forestry management comes from the CORRIM reports published in 2005-2010.
- Veneer production data for slicer and rotary technology was gathered from AHEC members for the years 2011 and 2012.
- Veneer production figures covering the north, central and Appalachian region of the US, where most of the veneer manufacturing is taking place is representative for the 2011/2012 timeframe and covers co-product prices, transportation distances and modes, fuel mix, processing inventories, and on-site energy generation inventories.
- The background data on energy and fuels were obtained from the GaBi 6 database 2013 and are representative of the years 2009/2011-2014.
- The time coverage is considered representative for the current production technology and distribution practices of AHEC members. It is estimated that the study up to the veneer production ‘factory’ gate is representative for the next 10 years. On the other hand transportation should be reviewed after 2015 as new regulations on shipping fuels and emissions are expected to be adopted in 2015.

3.8.5 Technological Coverage and representativeness

The forestry data is a weighted average of available management scenarios and harvesting equipment utilised thus representing the current technology state.

Veneer production data represents the conventional slicer/rotary technology practices which reflect the current state-of-the-art in the US.

Energy and transportation datasets from GaBi 6 database 2013 are representative of the years 2009/2011-2014.

The hardwood veneer production is a relatively mature industry and it is estimated that the study will stay representative of the US hardwood veneer production for the next 10 years. Therefore the time validity is representative for the current production technology and distribution practices of AHEC members.

3.9 Assumptions and Limitations

- As part of the CORRIM protocol for ensuring data quality, an overall wood mass balance is required to fall within 5% from material input to material output (Bergman, Bowe 2012).
- This LCI study covered one full year during the period 2011-2012 and depended on when an operational (fiscal) year started at each company. The geographical area covered the eastern region as previously described.
- Most of the surveyed sites are medium- to large-size facilities. Unfortunately some of the larger facilities with high technology didn't contribute to the study.
- Primary data indicated that until now major species represented are red and white oaks (*Quercus spp*.), hard and soft maples (*Acer spp*.), hickory (*Carya spp*.), yellow poplar (*Liriodendron tulipifera*), ash (*Fraxinus spp*.), sweetgum (*Liquidambar styraciflua*), black walnut (*Juglans nigra*), cherry (*Prunus serotina*) and yellow birch (*Betula alleghaniensis*).

3.9.1 Potential Limitations Related to System Boundary

The aforementioned system boundaries (chapter 3.2) may have some limitations on the applicability of the study, its results, and the interpretation of its findings. Therefore this study is stated to be applicable only to the specific conditions stated in the chapters above. The results of this assessment are to be used according to the defined goal and scope only.

3.9.2 Potential Limitations Related to Impact Indicator Choice

The omission of certain life cycle impact categories may result in an incomplete picture of the overall performance of the studied products. For instance, social and economic indicators are not covered in this life cycle assessment so trade-offs between environmental, social and economic factors could not be evaluated. Some potentially relevant environmental issues are not covered by the selected impact categories due to the lack of mature and consistent methodology. Biodiversity impacts of hardwood production should be revisited in the future as new and reliable methodologies become available. Also water footprint, toxicity and land use could be included in future studies.

As already mentioned, the choice of categories was made based on the recommendations of the ILCD Handbook (ILCD Handbook, 2010) and the choice of indicators was made based on the European EPD rules for construction products (EN 15804, 2012). In the selected impact categories the CML indicators were calculated (CML method from 2001, factors updated 2010). On the other hand the newer methodology ReCiPe has not been included (refer to section 3.4 for more detail on the reasons behind).

As the veneer study falls within a North American context where TRACI is the dominant methodology in use, the main results of the study are reported also in TRACI units in Appendix D.

3.9.3 Potential Limitations Related to Allocation

Allocation approaches based on price were chosen following the guidelines for European EPD on construction products (EN 15804, 2012). While the approach is legitimate and complies with respective ISO standards, the results could be different should mass allocation be used instead. Thus allocation based on mass was included in the sensitivity assessment.

3.9.4 Potential Limitations Related to Forest Model

The underlying model of wood production from CORRIM (CORRIM, 2010) does not cover the forest in the SE region that represents roughly half of the US hardwood forest production. Nevertheless no principal differences are expected in the SE hardwood harvesting and all companies participating in the veneer study are located within the Northern, Central and Appalachian regions, thus within the regional coverage of CORRIM forestry data

3.9.5 Potential Limitations Related to Transport Distances

The modes and distances of transportation are modelled based on primary data (provided by companies) and assumed average distances. The impacts of the transportation to customers could be much lower if exported to Mexico or much higher if delivered to China.

3.9.6 Potential Limitations Related to Carbon Uptake

Embodied energy in wood and carbon storage (based on carbon content in dry mass) in products (see chapter 3.2 for details) are modelled assuming the same for all species and do not reflect any differences between them. These are data gaps as the values are not collected or measured (refer to section 3.4.4 for more detail on references used). As the lower values of carbon content were taken for all species, refined data will probably improve the assessed environmental performance of hardwood veneer, if carried out per species in future studies.

3.9.7 Potential Limitations Related to Veneer Production and Data

Species-mix

The inventory of the veneer production for slicer and rotary technology reflects an average hardwood veneer manufacturing in the US and is not species specific. Although vat duration, drying temperatures and cutting speeds will vary by species and thickness, the target for the study was an analysis of an average mass weighted production (slicer and rotary veneer) from several manufacturers' plants. Moreover, companies register resources and energy consumption on a general basis, thus the identification on a per species basis would not have been possible at this time. However, further specific measurements and analysis in the future could enable this.

Log volume measurements

As previously explained companies used different ways to express the actual volume of logs.

An actual Bdft which conceptually equals 144 cubic inches (1 foot by 1 foot by 1 inch) or also represents $0.00236m^3$ was not an easy unit to be processed in the study. A 10 inch diameter by 10 foot log length has a volume of 22.5 Bdft (3168 cubic inches lumber), or for example a 20 inches by 10 foot log gives 160 Bdft (23040 cubic inches lumber)[37].

Both examples above do not reflect real or actual volume but are a crude estimation of how much lumber can be cut out of the log. The actual geometric volumes of the examples above are 9425 cubic inches and 37699 cubic inches. Thus for the 10 inch diameter log, the Doyle Bdft volume calculation only gives 34% of its geometric volume whereas for the 20" diameter log, the Bdft volume calculation gives 61% of the geometric volume.

Some companies used their own conversion factors. Unfortunately these are also just rough estimations which only suit the dimensions of the average log they handle.

Actual volume figures are therefore only predictions based on estimations due to the way logs are measured in practice at the veneer mills in the US.

Final veneer product amount and thickness

Some companies estimate the final product quantity by using the Bdft volume (which reflects lumber volume) and multiply it by an average yield (the amount in square feet from each Bdft) rather than an exact average yield representing all species handled. Furthermore, there exists a distinction in slicer technology for clipped and unclipped veneer yield.

[37] The Doyle Bdft formula is:

(Diameter (inches) - 4) ^2 * (Length (foot) /16).

Estimations for final production figures will get even harder when an exact average final thickness is unknown[38]. Over the years companies have tried to improve thickness consistency and yield in order to ensure meeting the thickness (nominal) specified by customer. However, they still try to be conservative and always exceed the specified thicknesses (the customer never wants it below nominal, but above is okay). Today they are still above, but it is unknown by exactly how much. The problem relates to a lack of technology to enable the measurement electronically, in real-time in order to control the slicers accordingly.

Moisture content tracking

Unfortunately, there is no track or measurement of the MC of the different wood chip material generated (e.g. backing boards, cores, trims etc.), thus these were roughly estimated by the companies participating in the study. Furthermore, logs arriving at the mill from the forest are also rarely measured for MC; thus, MC of the input material is hard to identify precisely.

Emissions

None of the companies participating were able to provide emissions data either from the boilers or the drying processes. Emissions data from the year 1998 have been found (NCASI, 1998) and were used to represent emissions from the drying process.

Yield

The overall yield is normally determined by the average yield for clipped veneer (amount in square feet or square metre of the final product obtained per each Bdft), multiply by total logs delivered as input and measured in Bdft. Consequently, those calculations will be affected due to the Bdft accuracy issues as already explained: yield factors are built up on estimated lumber volume rather than actual log input mass or volume. Furthermore, the average yield is not an exact yield weighted precisely for all species.

In terms of plausibility, yields represent another concern. From information reviewed, rotary (26-54% lost in dry mass) and slicer companies (41-67% lost in dry mass) are showing higher losses (% lost in dry mass). The rule of thumb explains that the thinner the panel is, the higher the loss expected (from total amount of log input) during its production. With values varying across the rotary and slicer companies analyzed, it is hard to observe a uniform pattern. Two producers of thinner rotary veneers (0.6 mm) are giving 49 and 52% lost dry mass while three thicker rotary companies (2-2.5mm) show 26%, 53% and 54% lost in dry mass.

[38] Average thickness figures will be required in order to calculate total veneer production volumes when total production figures in area are given (surface area * thickness = volume, volume*density= kg of veneer).

Information has been once more verified especially for the lowest value showed by one particular company (26% lost, which doesn't align with other values shown); nevertheless the company has ratified this production figure.

Water input and emissions

There is a lack of measurements of water vapor occurring during the drying and vat processing. Some companies had difficulties in reporting accurately the total amount of water consumed for sprinkling, and used in vats and boilers. Furthermore there is a wide variation across the values reported on water consumption per kg final product (1.2 - 25 kg/kg final veneer).

3.10 Software and Database

The LCA model was created using the GaBi 6 Software system for life cycle engineering, developed by PE International. The GaBi database provided the life cycle inventory data for fuels and energy obtained from the background system.

The final veneer modelling for slicer and rotary technologies was built up in GaBi 6 which follows the rules of the relevant PCR documents; thus fitting with new IBU and EN 15804 (advisory board meeting 2013-01-07) requirements for water and waste flow indicators.

3.11 Modelling

After data was collected, a model was created in GaBi 6 and respective data per company was inserted. In order to be show average results for the production of 1 m^2 veneer in the US, a weighted averaging procedure by mill volume and veneer technology type according to final total veneer production figures for all mills/technologies was carried out in GaBi 6.

A weighted average[39] of the values reported by each of the mills was applied. This represents the fraction of that mill´s value to total production evaluated. Each model per company is a compilation of all applicable inputs and outputs as collected for that company during the survey. Three modelling scenarios to represent different veneer technology and thicknesses were created in GaBi:

- Slicer with 0.5-0.6 mm veneer thickness;
- Rotary with 0.6 mm veneer thickness;
- Rotary with 2-2.5 mm veneer thickness.

3.12 Interpretation approach

Interpretation was performed by:

[39] The mass weighted average in this study is used to calculate the average value of a particular set of production figures with different levels of relevance. The relevance of each number is called its weight. The weights should be represented as a percentage of the total relevancy. Therefore, all weights should be equal to 100%, or 1.

- Identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
- An evaluation that considers completeness, sensitivity and consistency checks;
- Consideration of conclusions, limitations, and recommendations.

3.13 Reporting

The technical report will not be published but can be made accessible to interested audiences upon request to AHEC.

The results of the study will be made available as LCI datasets in the GaBi 6 commercial database. The results will be provided to AHEC members and LCI datasets could also be made available in public databases like ILCD, ADEME and the US LCI.

AHEC and AHEC members may use this report to prepare and provide information based on this study, e.g. a technical summary of the report, a flyer addressing the major outcomes of the study etc.

3.14 Critical Review

The review panel was:

Prof. Dr. Matthias Finkbeiner (panel chair), Chair of Sustainable Engineering, Department of Environmental Technology,Technische Universität Berlin.

Prof. Dr. Richard Murphy. Professor of Life Cycle Assessment, Centre for Environmental Strategy, University of Surrey, Guildford, UK; Distinguished Research Fellow, Imperial College London; Director & Senior LCA Practitioner, LCA works Ltd..

Pankaj Bhatia. Director, GHG Protocol, World Resources Institute.

The review was performed according to Clause 7.3.3 of ISO 14040 (2006) and Clause 6.3 of ISO 14044 (2006).

Members of the committee are not engaged or contracted as official representatives of their organizations and act as independent expert reviewers. The analysis or verification of individual datasets is outside the scope of this review.

The Critical Review Panel's Review Statement can be found in Appendix G, at the end of this document.

4 RESULTS

The following section describes, discusses and presents the results in terms of their contributing factors (gravity analysis) and stability (scenarios). All results refer to 1 m^2 of weighted average US hardwood slicer (0.5-0.6 mm) and two rotary veneer production models (0.6 mm and 2-2.5) with manufacture in the US and delivery to the customer in the EU. The results do not include use or EoL phases of the final product.

For the discussion on the selection of impact indicators please refer to section 3.4. Table 16 below summarises the main impact categories used in the life cycle impact assessment and provides the abbreviations and units used in the following graphs and tables. For the description of the indicators (which environmental issue they measure) please refer to Table 2. Appendix A describes the LCIA categories in more detail.

Table 16: Impact measured, short names and units

Impact indicator	Short name	unit
CML2001 - Nov. 2010, Acidification Potential	AP	[kg SO_2-Equiv.]
CML2001 - Nov. 2010, Eutrophication Potential	EP	[kg Phosphate-Equiv.]
CML2001 - Nov. 2010, Global Warming Potential	GWP	[kg CO_2-Equiv.]
CML2001 - Nov. 2010, Ozone Layer Depletion Potential	ODP	[kg CFC-11-Equiv.]
CML2001 - Nov. 2010, Photochemical Ozone Creation Potential	POCP	[kg Ethene-Equiv.]
Primary energy demand from renewable resources (net calorific value)[40].	PED	[MJ]
Primary energy from non-renewable resources (net calorific value)	PED nr	[MJ]
Potential carbon storage in product	CS	[kg CO_2-Equiv.]

4.1 RESULTS FOR 1 M^2 SLICER VENEER PANEL

<u>Base Scenario</u>

The default product used as a base scenario in the study is a 0.5-0.6 mm thick slicer veneer with 10 % MC. Six slicer companies fit into this range of thickness (as shown in Table 6). Table 17 contains the summary of main results associated with production and transportation of 1 m^2 of slicer veneer panel with a thickness of 0.5-0.6 mm. Results were calculated in GaBi using an economic allocation for co-products.

[40] The abbreviation PED is referring only to the amount of primary energy demand from renewable resources. PE will be used to refer to total primary energy demand (PED + PEDnr)

Table 17: LCIA of 1 m^2 of slicer veneer with 0.5-0.6 mm thickness and 10% MC

Impact	AP	EP	GWP (excl. biogenic)	ODP	POCP	PED	PED nr	CS
	[kg SO_2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO_2-Equiv.]	[kg R-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO_2-Equiv.]
	3.33E-03	3.85E-04	4.83E-01	2.24E-10	3.79E-04	1.63E+01	6.79E+00	-0,54

One square meter of 0.5-0.6 mm thick slicer veneer with a MC of 10% at the customer yard generates the following environmental impacts shown in Table 17

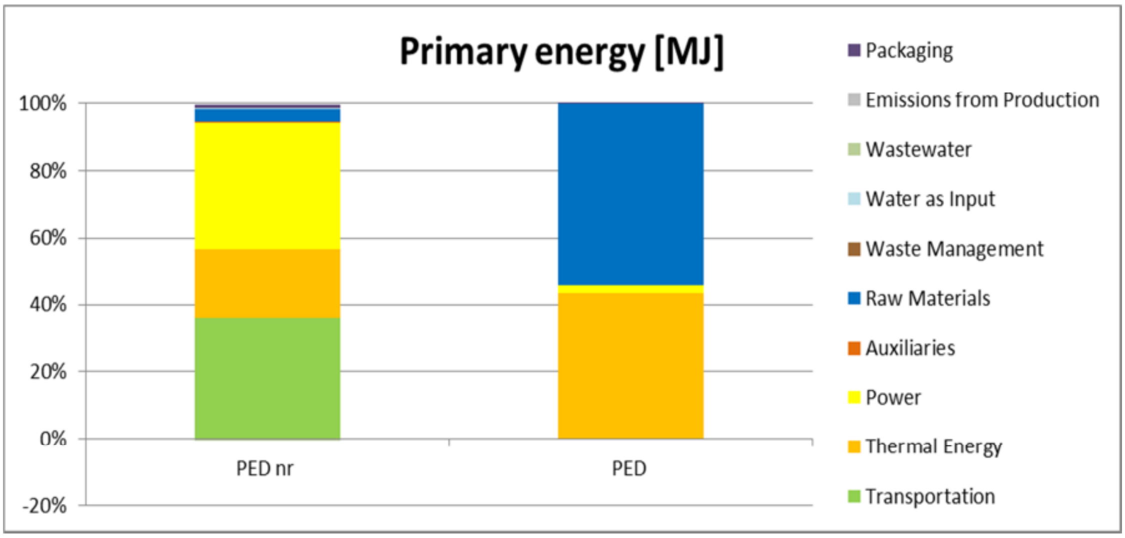
Total demand of primary energy from renewable resources (PED) was 1.63E+01 MJ. This includes the energy incorporated within the wood itself. Approximately 6.79E+00 MJ of the total PE demand was primary energy consumed from non-renewable resources.

One square meter of slicer veneer with 10% MC contains biogenic carbon that represents a removal of 0.54 kg of carbon dioxide from the atmosphere. This value is written in grey text to highlight that this is an area of potential storage that would be likely to be released back to the atmosphere at the end-of-life for the final product.

General comment on handling carbon

In the opinion of the authors, the carbon storage value should not be subtracted from the GWP value unless the complete carbon account of removals and releases are taken into account on the basis of the full product life cycle, otherwise the stored carbon should be explicitly shown separately.

Figures below utilize contribution analysis (identification of the greatest contribution to the indicator result) to show LCIA results. The following contributing elements were identified: transportation (forest to mill, transport from mill to customer in Europe), thermal energy as input, electrical power as an input, auxiliary materials (oil, knives), raw materials (logs, wax), waste management practices within production, water as an input, emissions from production itself, and packaging.



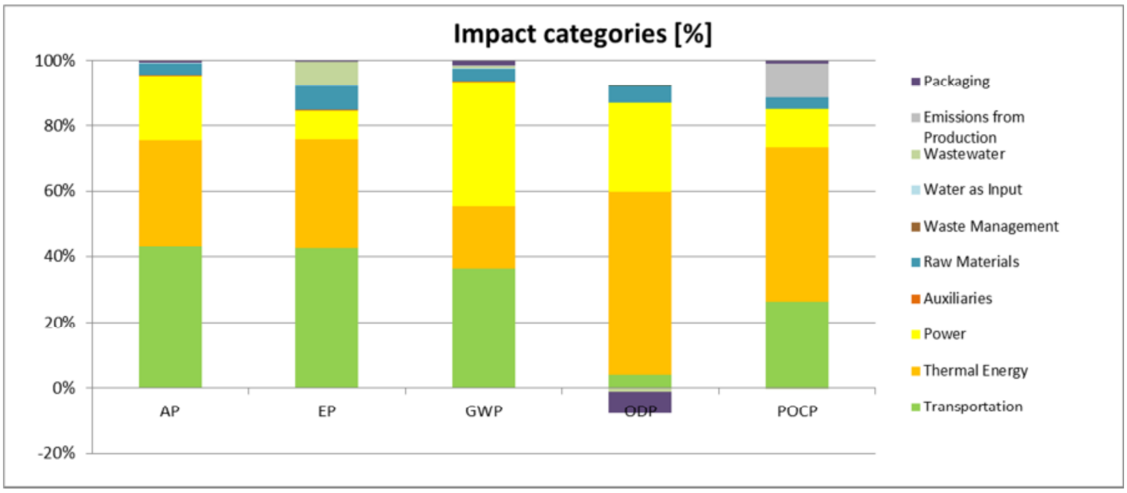


Figure 4-1: Contribution analysis - base scenario 1 m^2 of slicer veneer panel at customer with 10% MC; thickness 0,5-0,6 mm

Contribution analysis suggests that most impact to PEDnr comes from the electricity supply (coal, natural gas etc., consumed to produce electricity) used in the veneer processing. The next big non-renewable resource is from transport to customer, where crude oil is extracted to produce diesel and heavy fuel oil utilized by trucks and container ships. Total primary energy demand (PED) (primary energy from renewables) is dominated by the energy incorporated within wood - both contained within the actual wood raw material making up the veneer and as thermal energy coming from the combustion of wood residues obtained during the processing of logs into the veneer products.

POCP impact is dominated by emissions during thermal energy production; namely by VOCs and a mix of organic and inorganic emissions resulting from biomass and fuel burning in on-site boilers. POCP impact is also contributed to by emissions during transportation, electrical power use and emissions from the drying process taking place during production of the veneer.

ODP impact is driven by the halogenated organic emissions to air (chlorofluoromethanes) released in the thermal energy and power supply chain. ODP shows a negative impact for packaging (-1.82E-11). This is due to the scrap material being used as an input in the steel banding production (‘credit’ against virgin steel production[41]).

GWP is dominated by the greenhouse gases emitted during electricity production followed by the greenhouse gases emitted during transportation to the customer.

EP and AP are heavily dominated by the emissions generated during transportation and thermal energy production, namely nitrogen oxides for EP and nitrogen and sulphur dioxides/ nitrogen oxides for AP.

Sulphur dioxide (SO_2) emissions are directly related to the sulphur content of the fuel. The sulphur content of marine fuel is currently under discussion in regard to a future limit of 0.1 weight percent (currently for ocean transport a world average of 0.27 weight percent sulphur is assumed). It also should be mentioned that the main location for emissions contributing to AP and EP (SO_2 and NO_x) is not in populated areas or forestry but over the ocean.

Auxiliaries, water as an input, waste management practices, emissions from production and packaging contribute to a lesser extent to all the main environmental impacts of slicer veneer after transportation, electrical power and thermal energy use.

4.2 Results for 1 m² Rotary veneer Panel (0.6 mm)

Base Scenario

The default product used as a base scenario is a 0.6 mm thick rotary veneer with 9% MC. Two rotary companies which provided data meet this range of thicknesses (as shown in Table 6). Table 14 contains the summary of the main environmental impacts associated with production and transportation of 1 m^2 of rotary veneer panel with a thickness of 0.6 mm. Results were calculated in GaBi using an economic allocation for co-products.

Table 18: LCIA of 1 m^2 of rotary veneer with 0,6 mm thickness and 9% MC

Impact	AP	EP	GWP (excl. biogenic)	ODP	POCP	PED	PED nr	CS

[41] The „value of scrap” regards the methodology of the international steel association “Worldsteel” represents the theoretic environmental profile of the steel scrap. This is the result from the difference between primary steel production (theoretical value on the basis of blast furnace, no scrap input) and secondary steel production (100% scrap input of electrical arc furnace, EAF). The ODP value is dependent on power consumption and based on, herewith, the share of nuclear power in the power mix. In the EAF route, electricity is mostly used as energy carrier, whereas fossil fuels (e.g. coal) are used in blast furnace, this adds to the EAF power mix has higher share of nuclear power than the blast furnace power mix (varying upon the country in which the power mix is generated). The use of the value scrap dataset results in negative value in the ODP category.

	[kg SO_2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO_2-Equiv.]	[kg R-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO_2-Equiv.]
	2.98E-03	3.55E-04	3.35E-01	1.65E-10	3.15E-04	1.63E+01	4.70E+00	-0.71

One square meter of 0.6 mm thick rotary veneer panel with a MC of 9% at the customer yard generates the following environmental impacts shown in Table 18:

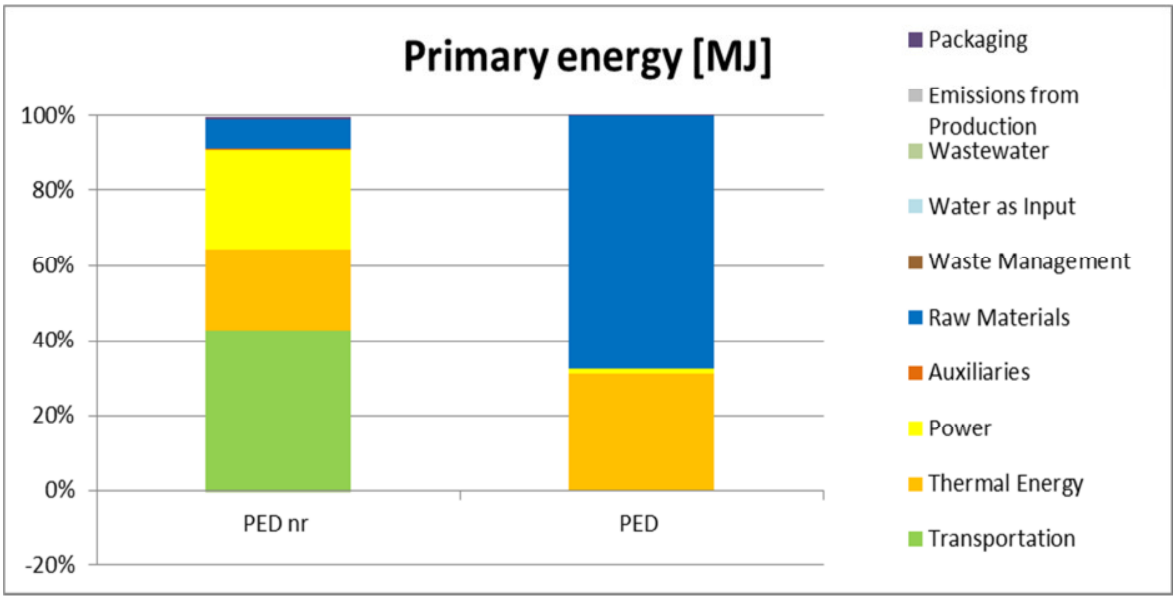
Total demand of primary energy (PED) from renewables equals 1.63E+01 MJ. This includes the energy incorporated within the wood itself. Around a third of PE is represented by the primary energy consumed from non-renewable resources equaling 4.70E+00 MJ.

One square meter of rotary veneer (0.6 mm thick) with 9% MC contains biogenic that represents a removal of 0.71 kg of carbon dioxide from the atmosphere. This value is written in grey text to highlight that this is an area of potential storage that would be likely to be released back to the atmosphere at the end-of-life for the final product.

General comment on handling carbon

In the opinion of the authors, the carbon storage value should not be subtracted from the GWP value unless the complete carbon account of removals and releases are taken into account on the bases of the full product life cycle otherwise the stored carbon should be explicitly shown separately.

The figure below utilizes contribution analysis (identification of the greatest contribution to the indicator result) to show LCIA results. The following contributing elements were identified: transportation (forest to mill, transport from mill to customer in Europe), thermal energy as input, electrical power as an input, auxiliary materials (oil, knives), raw materials (logs, wax), waste management practices within production, water as an input, emissions from production itself, and packaging.



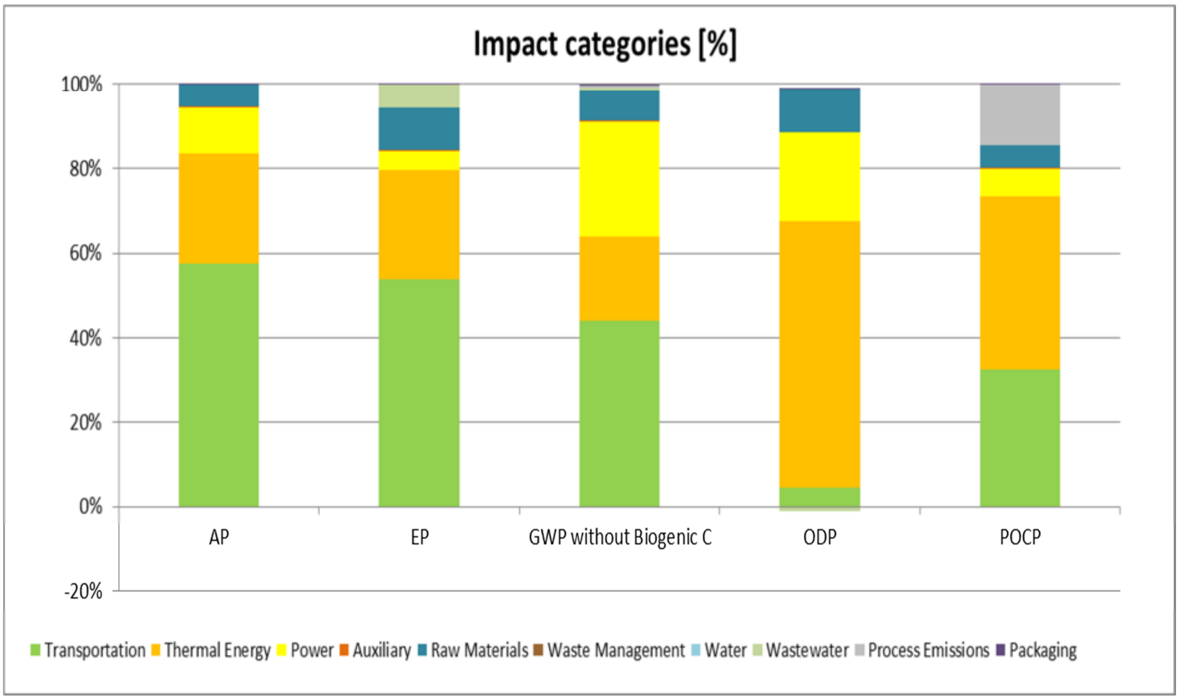


Figure 4-2: Contribution analysis - base scenario 1 m^2 of rotary veneer at customer with 9% MC; thickness 0,6 mm

Contribution analysis suggests that most impact to PED nr are coming from the transport of logs from forest to mill and transport of veneers to customer in Europe. Here crude oil is mined to produce diesel and heavy fuel oil utilized by trucks and container ships. The next big non-renewable resource is the electricity supply chain (coal, natural gas etc, consumed to produce electricity) required for processing the log into final veneer. Total primary energy demand (primary energy from renewables) is dominated by the energy incorporated in wood (assigned to forestry).

POCP impact is dominated by emissions during thermal energy production; namely VOCs and mix of organic and inorganic emissions emerging from biomass and fuel burning in on-site boilers. POCP impact is followed by emissions emerging during transportation, emissions from production and emissions from power supply and; namely SO_2, NO_x, NMVOC and other emissions from overseas transport.

ODP impact is driven by the halogenated organic emissions to air (chlorofluoromethanes) released predominantly during the thermal energy supply chain followed by power generation.

GWP is dominated by the greenhouse gases emitted during transportation followed by electricity supply and thermal energy production in on-site boilers.

EP and AP are heavily dominated by the emissions generated during transportation, namely nitrogen oxides for EP and nitrogen and sulphur dioxides/ nitrogen oxides for AP.

SO_2 emissions are directly related to the sulphur content of the fuel. Sulphur content of marine fuel is currently under discussion to be further limited up to 0.1 weights percent (currently for the ocean transport a world average of 0.27 weight percent S is assumed). It also should be mentioned that the main location for emissions contributing to AP and EP (SO_2 and NO_x) is not in populated areas or forestry but over the ocean.

Auxiliaries, water as input, waste management practices, emissions from production and packaging contribute in a lesser extent to all main environmental impacts than transportation, power and thermal energy.

4.3 Results for 1 m^2 Rotary veneer panel (2-2.5 mm)

Base Scenario

The default product used as a base scenario for the second rotary analysis comprises a veneer layer with a thickness between 2-2.5 mm and 9% MC. Three rotary companies provided data and meet this range of thickness (as shown in Table 6). Table 19 contains the summary of the main environmental impacts associated with production and transportation of 1 m^2 of 2 – 2.5mm rotary veneer. Results were calculated in GaBi using an economic allocation for co-products.

Table 19: LCIA of 1 m^2 of rotary veneer with 2-2.5 mm thickness and 9% MC

Impact	AP	EP	GWP (excl. biogenic)	ODP	POCP	PED	PED nr	CS

	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg R-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO2-Equiv.]
	1.62E-02	2.58E-03	2.49E+00	1.22E-9	1.59E-03	4.82E+01	3.47E+01	-2.26

One square meter of 2-2.5 mm thick rotary veneer panel with a MC of 9% at the customer yard generates the following environmental impacts shown in Table 19.

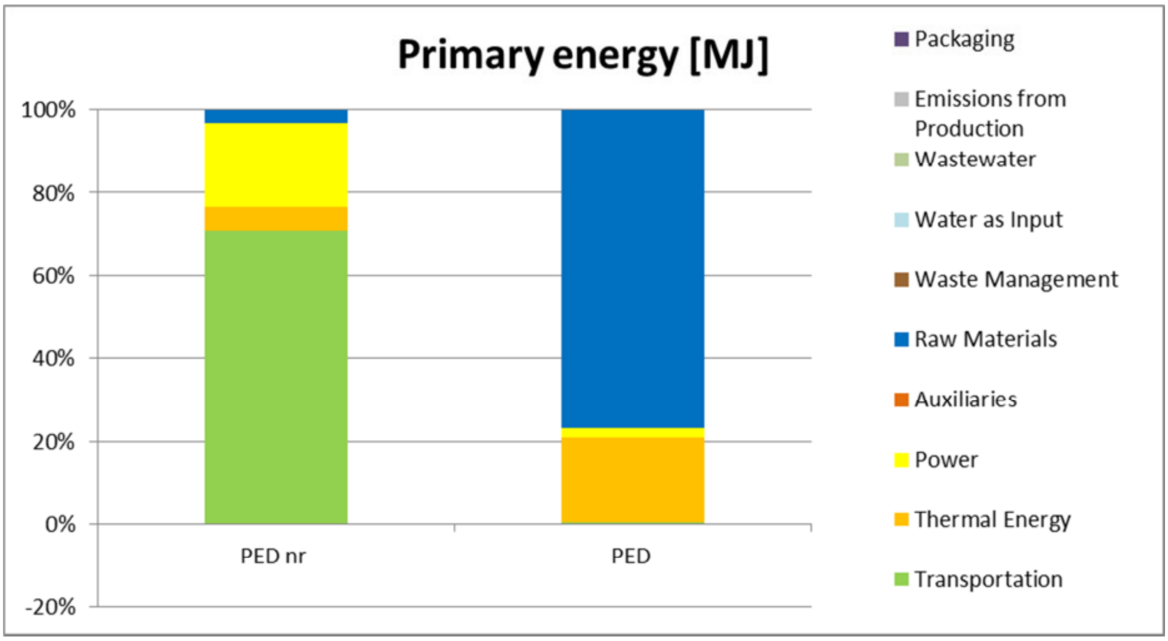
Total demand of primary energy (PED) equals 4.82E+01 MJ. This includes the energy incorporated within the wood itself. Approximately 3.47E+01 MJ of the total PE demand was primary energy consumed from non-renewable resources.

One square meter of rotary veneer with 9% MC contains biogenic carbon that represents a removal of 2.26 kg of carbon dioxide from the atmosphere. This value is written in faded color to highlight that this is an area of potential storage that would be likely to be released back to the atmosphere at the end-of-life for the final product.

General comment on handling carbon

In the opinion of the authors, the carbon storage value should not be subtracted from the GWP value unless the complete carbon account of removals and releases are taken into account on the basis of the full product life cycle otherwise the stored carbon should be explicitly shown separately.

The figure below utilizes contribution analysis (identification of the greatest contribution to the indicator result) to show LCIA results. The following contributing elements were identified: transportation (forest to mill, transport from mill to customer in Europe), thermal energy as input, electrical power as an input, auxiliary materials (oil, knives), raw materials (logs, wax), waste management practices within production, water as an input, emissions from production itself, and packaging.



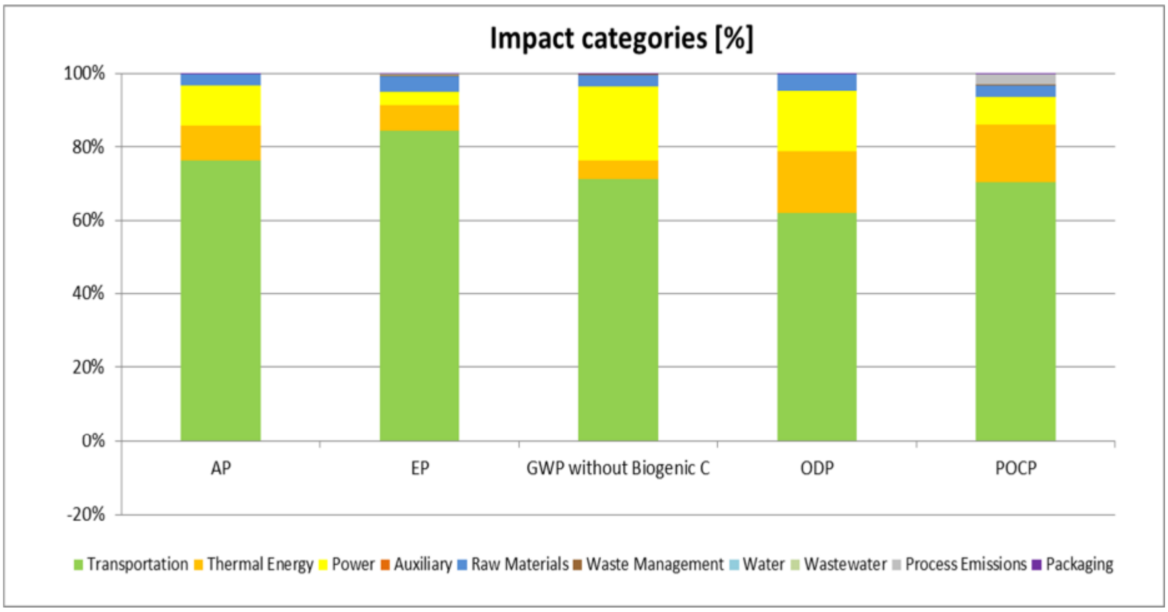


Figure 4-3: Contribution analysis - base scenario 1 m^2 of rotary veneer panel at customer with 9% MC; thickness 2-2.5 mm

Contribution analysis suggests that most impact to PED-nr is coming from the conveyance steps to transport logs from forest to mill and transport of dry ready veneer to the customer in Europe. Here crude oil is extracted to produce diesel and heavy fuel oil utilized by trucks and container ships. The next big non-renewable resource contributor is the electricity supply chain (coal, natural gas etc., consumed to produce electricity) required for processing the log into final veneer. Total primary energy demand (primary energy from renewables) is dominated by the energy incorporated in wood (assigned to forestry).

POCP impact is dominated by emissions during transportation; namely VOCs and a mix of organic and inorganic emissions. POCP impact is also caused by emissions arising during thermal energy production in on-site boilers.

ODP impact is driven by halogenated organic emissions to air (chlorofluoromethanes) released predominantly during the transportation and thermal energy supply chain resulting from power generation.

GWP is dominated by the greenhouse gases emitted during transportation followed by the electricity supply chain and thermal energy production in on-site boilers.

EP and AP are heavily dominated by the emissions generated during transportation, power supply and thermal energy production in on-site boilers, namely nitrogen oxides for EP and nitrogen and sulphur dioxides/ nitrogen oxides for AP.

Sulphur dioxide emissions are directly related to the sulphur content of the fuel. Sulphur content of marine fuel is currently under discussion to be limited to 0.1 weight percent (currently for ocean transport a world average of 0.27 weight percent S is assumed). It also should be mentioned that the main location for emissions contributing to AP and EP (SO_2 and NO_x) is not in populated areas or forestry but over the ocean.

Auxiliaries, water as input, waste management practices, emissions from production and packaging contribute to a lesser extent to all main environmental impacts after transportation, power and thermal energy.

The high impact of transportation within all categories is explained by the long distances reported by the companies (between 898 and 2703 km) from the track to port of export. These distances differ considerably from the ones reported by slicer companies (273-1152 km) and rotary companies with 0.6 mm thickness (349-465 km).

4.4 SENSITIVITY ANALYSIS

In this section various scenarios are presented. The sensitivity analysis provides insight on the sensitivity of the results in relation to various parameters. The sensitivity analysis has been performed on the base scenario average models using economic allocation; slicer with 0.6 mm thick, rotary with 0.6 mm thickness and rotary with 2-2.5 mm thickness.

4.4.1 Allocation (mass allocation to main product only)

The economic allocation was performed in the forest and the production mill site. As discussed in section 3.6 the prices of the co-products can fluctuate and species-specific and grade-specific prices were not taken into account as they are challenging to determine and companies do not differentiate between them.

To address this uncertainty, a scenario analysis for mass allocation was carried out. The table and graph below depict the environmental impacts of hardwood veneer for one extreme allocation scenario: mass allocation in which the impacts are allocated between co-products based on their share in the mass output. This gives the same result as when all the products have the same price during economic allocation. This is a favorable scenario for veneer, as it distributes the environmental burden evenly through the outputs, with for example, a kg of bark taking the same burden as a kg of veneer.

Results of the allocation scenario assessment in Table 20 suggest that mass allocation would lower the impact result for slicer veneer 0.5-0.6 mm thick by 58% for total primary energy demand and 55% for ozone depletion potential. For the other impact categories the scores are reduced by between 35-47%.The scenario for rotary with 0.6 mm thickness also shows significant lower impact results for primary energy demand and ozone depletion (64 % and 63% reduction of impacts respectively) and for the other impact categories (29-48%). Finally in the scenario for rotary 2-2.5 mm thickness an allocation by mass would lower the impact result for veneer by 53% in total primary energy demand and in ozone depletion by 52%. All other impacts would lower results between 35-41%.

As can be observed, all categories are very sensitive to the allocation approach used. Veneer production (either slicer or rotary technology) incurs significant amounts of residue production, meaning that there is a significant amount of co-products or materials generated as 'waste' in relation to the amount of high-value veneer final product, which reduces the impacts compared to when the high price for veneer is the main allocation driver as in economic allocation used in the base case. The amount of log raw material 'lost' to residue was:

- Slicer 0.5-0.6mm thickness shows 40-67 % lost dry mass amongst all slicer companies participating;
- Rotary 0.6mm thickness shows 26-54 % lost dry mass amongst all rotary companies participating; and
- Rotary 2-2.5 mm thickness shows 49-52 % lost dry mass amongst all rotary companies participating.

Furthermore, PED was highly sensitive to the mass allocation scenario because of the fact that it is the only indicator where log mass (from the forestry process) dominates the impact (absorption of solar primary energy during biomass harvesting to give the feedstock energy). A lower log mass input (reallocated due to a mass allocation instead of an economic allocation where highest priced-clipped veneer leads) will reduce the absorption of solar energy thus PED impact during harvesting.

Table 20: Impact of allocation for base scenario slicer 0.5-0.6 mm

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO_2-Equiv.]	[kg Phosphate -Equiv.]	[kg CO_2-Equiv.]	[kg R11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]

economic allocation (base scenario)	3.33E-03	3.85E-04	4.83E-01	2.24E-10	3.79E-04	1.63E+01	6.79E+00
mass allocation	2.17E-03	2.45E-04	2.59E-01	9.91E-11	2.04E-04	6.89E+00	3.61E+00
change of impact from reference to mass allocation	-35%	-36%	-46%	-55%	-46%	-58%	-47%

Table 21: Impact of allocation for base scenario rotary 0.6 mm

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO_2-Equiv.]	[kg Phosphate -Equiv.]	[kg CO_2-Equiv.]	[kg R11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
economic allocation (base scenario)	2.98E-03	3.55E-04	3.35E-01	1.65E-10	3.15E-04	1.63E+01	4.70E+00
mass allocation	2.12E-03	2.40E-04	1.81E-01	6.17E-11	1.68E-04	5.98E+00	2.49E+00
change of impact from reference to mass allocation	-29%	-33%	-46%	-63%	-47%	-64%	-48%

Table 22: Impact of allocation for base scenario rotary 2-2.5 mm

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO_2-Equiv.]	[kg Phosphate -Equiv.]	[kg CO_2-Equiv.]	[kg R11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
economic allocation (base scenario)	1.62E-02	2.58E-03	2.49E+00	1.22E-9	1.59E-03	4.82E+01	3.47E+01
mass allocation	1.06E-02	1.53E-03	1.53E+00	5.84E-10	9.49E-04	2.28E+01	2.14E+01
change of impact from reference to mass allocation	-35%	-41%	-39%	-52%	-41%	-53%	-39%

4.4.2 Unclipped veneer

As previously described, slicer companies produce clipped and unclipped veneer - the main difference is the fact that unclipped veneer has not removed the defects on the borders or sides and is mainly sold in the US domestic market with some small export to Canada or Mexico.

In order to see the impact of the unclipped veneer, a calculation was carried out. The scenario for this is a 0.5-0.6 mm thick slicer unclipped veneer with 10 % MC and no export route to European market (transport distance to export market in Europe were modelled as zero). Table 19 below contains the summary of the main results associated with production and transportation (up to port of export (if exported) of 1 m^2 of slicer veneer unclipped panel with a thickness of 0.5-0.6 mm. Results for the slicer veneer unclipped scenario were calculated in GaBi using an economic allocation for co-products

One square meter of 0.5-0.6 mm thick slicer unclipped veneer with a MC of 10% generates the following environmental impacts shown in Table 23.

Total demand of primary energy (PED) from renewables equals 1.21E+01 MJ. This includes the energy incorporated within the wood itself. Around a third of the PE is represented by the primary energy consumed from non-renewable resources equaling (4.93E+00 MJ).

One square meter of slicer veneer with 10% MC contains biogenic carbon that represents a removal of 0.53 kg of carbon dioxide from the atmosphere. This value is written in grey text to highlight that this is an area for potential storage that would be likely to be released back to the atmosphere at the end-of-life for the final product.

General comment on handling carbon

The carbon storage value should not be subtracted from the GWP value unless the complete carbon account of removals and releases are taken into account on the basis of the full product life cycle. Otherwise the stored carbon should be explicitly shown separately.

Table 23: LCIA of 1 m^2 of slicer veneer (unclipped) with 0.5-0.6 mm thickness and 10% MC

Impact	AP	EP	GWP (excl. biogenic)	ODP	POCP	PED	PED nr	CS
	[kg SO_2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO_2-Equiv.]	[kg R-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO_2-Equiv.]
Unclipped slicer veneer	1.56E-03	1.81E-04	3.45E-01	1.67E-10	2.37E-04	1.21E+01	4.93E+00	-0,53

4.4.3 Best and worst case scenario

A best and worst case scenario was defined for every veneer technology/thickness group analyzed in order to carry out further examination of the environmental impacts from US hardwood veneer production.

The best scenario is characterized by the lowest production loss (%) in dry mass, lowest energy consumption per square meter veneer (taken from the company with lowest consumption), lowest water consumption, lowest packaging material consumption etc. On the other hand the worst case scenario is defined by the highest consumption figures and highest production loss (%) in dry mass.

Slicer veneer 0.5-0.6 mm thick with 10% MC

In general, veneer energy consumption, transportation and forestry are the main drivers for PED, PED (nr) and GWP (see Figure 4-4, Figure 4-5 and Figure 4-6).

The reported energy figures from AHEC members participating ranged between 1.86E+00-4.21E+00 MJ for electrical power and 7.49E+00-29.02E+00 MJ for thermal energy per kg clipped veneer manufactured. This is somewhat consistent with information found that give a wide-range of energy consumption per kg dried veneer manufactured of 0.49E+00-4.40E+00 MJ for electrical power (Energie Agentur NRW, 2012) in Germany. The same is observed for thermal energy which is reported to range from 6.30E+00 – 29.00E+00 MJ/kg veneer (Energy Agency NRW, 2012).

High energy consumption for the worst scenario will be represented by 29.00E+00 MJ of thermal energy and 4.20E+00 MJ of electricity per kg produced clipped veneer. Low energy consumption figures for the best scenario are characterized by 1.90E+00 MJ of electricity and 7.00E+00 MJ of thermal energy per kg produced clipped veneer.

Shortest and longest distances from company sources were also selected in order to define the best and worst case scenario. The best and worst scenarios were modeled using economic allocation.

The impact to PED by raw materials in Figure 4-4 is related to the input logs (absorption of solar primary energy during biomass harvesting to give the feedstock energy) which in the worst scenario will show the highest contribution, followed by the base scenario.

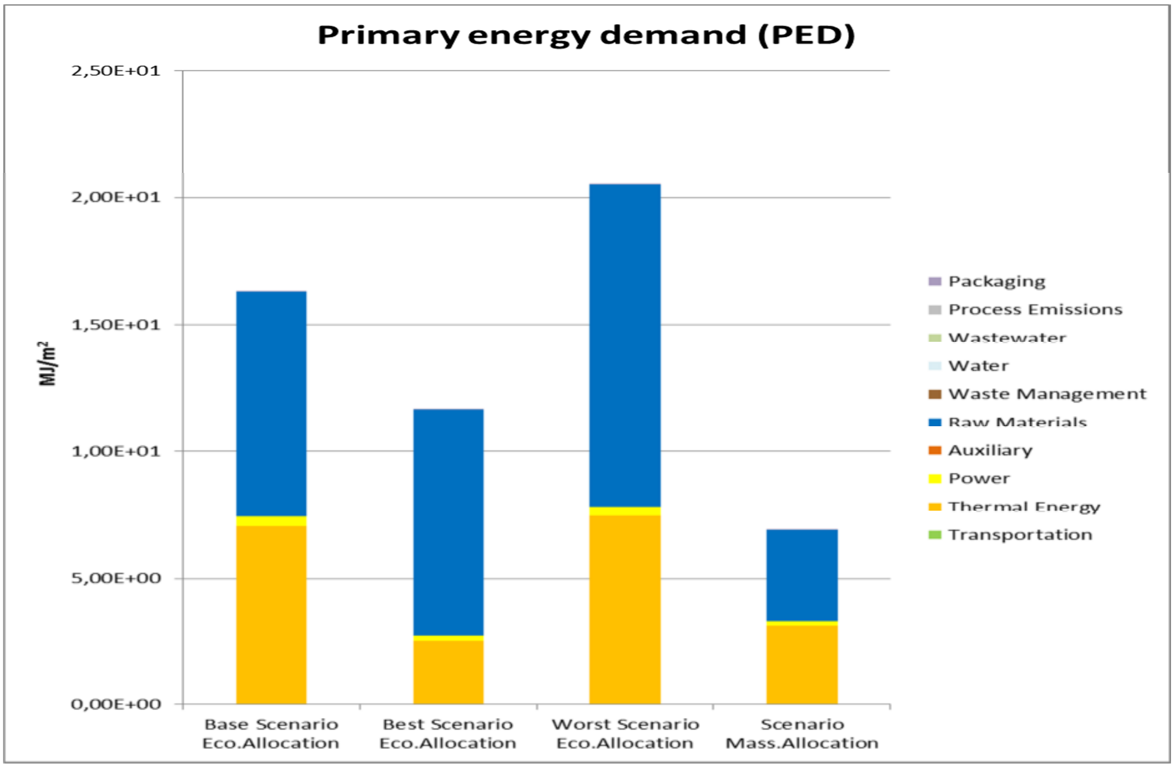


Figure 4-4: PED for base scenario (eco. allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 slicer veneer

The scenario analysis shown in Figure 4-5 and Figure 4-6 suggest that the impact assessment results for veneer are sensitive to the power consumption and transportation (longest distances for worst scenario vs. shortest for best scenario). The lowest reported impacts for PED (nr) and GWP shown in Figure 4-5 and Figure 4-6 are for the mass allocation and best-case scenarios (mass was 2% lower than the best-case scenario which in effect means they are very similar).

The mass allocation scenario value is only 56% of the PED nr value for the worst case scenario. Additionally the mass allocation scenario value is only 55% of the GWP value for the worst case scenario.

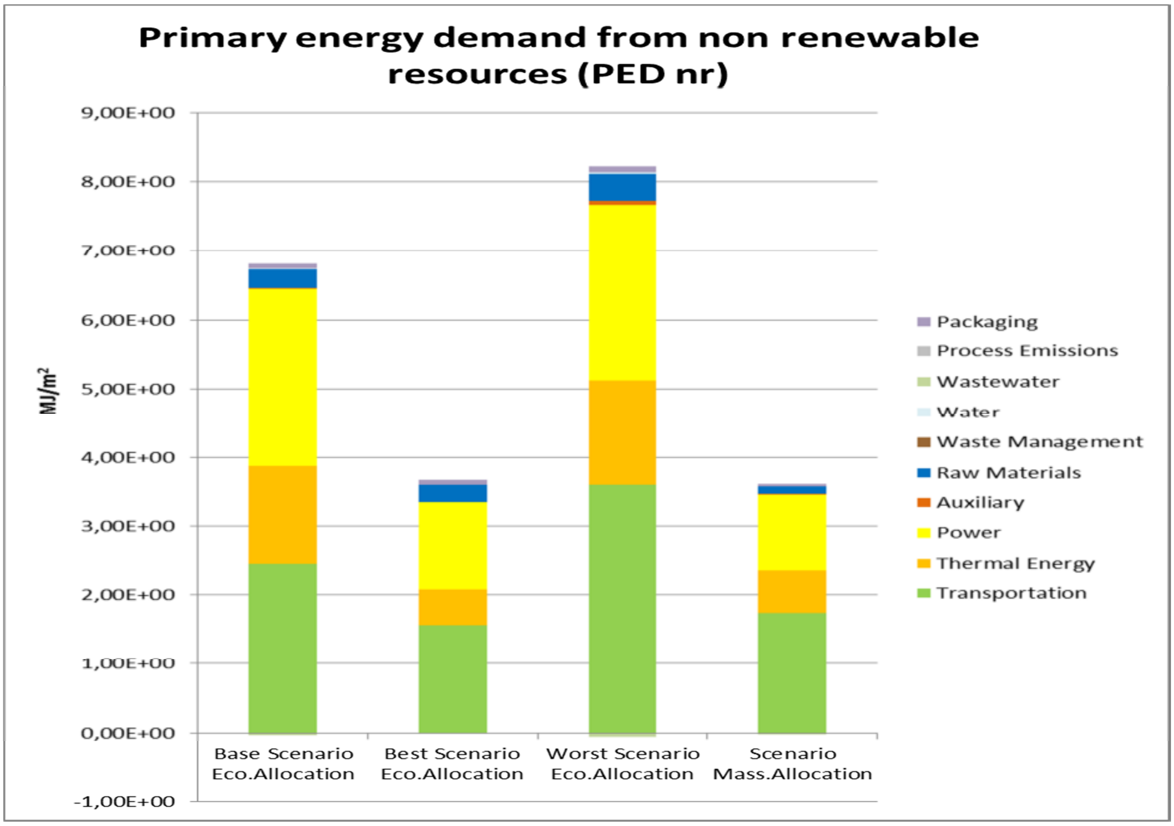


Figure 4-5: PED (nr) for base scenario (eco.allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 of slicer veneer

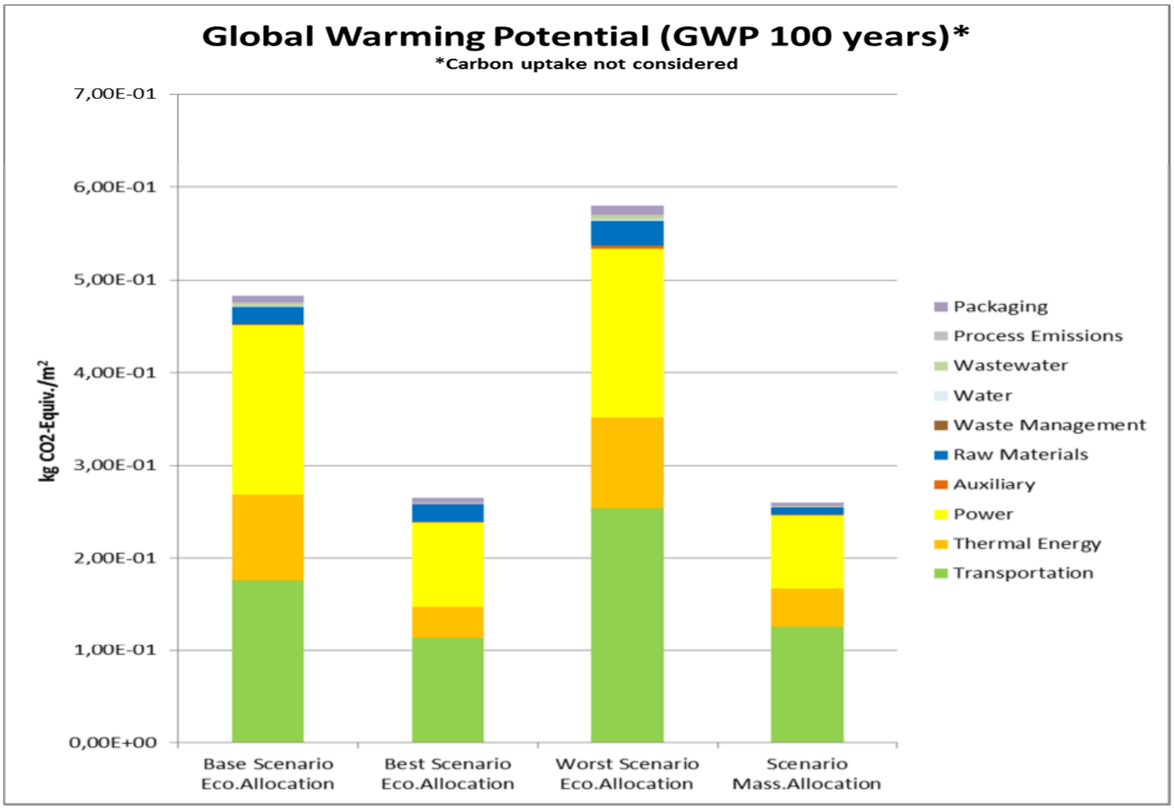


Figure 4-6: GWP base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 of slicer veneer

Results for all other impact categories are given in Appendix B.

Rotary veneer 0.6 mm thick with 9% MC

As already described, this group only covers two rotary companies which register production figures of thin rotary veneer of 0.6 mm.

Veneer raw materials (log forestry), energy consumption and transportation are the main drivers for PED, PED (nr) and GWP (see Figure 4-7, Figure 4-8 and Figure 4-9).

Highest energy consumption for the worst scenario will be represented by 13.51E+00 MJ of thermal energy and 2.36E+00 MJ of electricity per kg produced veneer. Lowest energy consumption for the best scenario is taking 4.5E-03 MJ of electricity and 8.60E+00 MJ of thermal energy per kg produced veneer.

Shortest and longest distances from company sources were also selected in order to define the best and worst case scenario. Furthermore, best and worst scenarios have been modeled based on economic allocation.

The definition of the best and worst scenarios relies on the % lost dry mass which for the best case scenario will be around 49% lost dry mass vs. 52% for the worst scenario.

The impact to PED by raw materials in Figure 4-7 is related to the input logs (absorption of solar primary energy during biomass harvesting to give the feedstock energy) which in the best scenario will show the highest contribution with 12.00E+00 MJ (highest input logs) in comparison to the worst scenario which has 10.00E+00 MJ. However the lowest reported impact for PED as is shown in Figure 4-7 is for the scenario mass allocation. As described above, lower thermal energy consumption in best scenario contributes to an overall lower impact as shown in Figure 4-7.

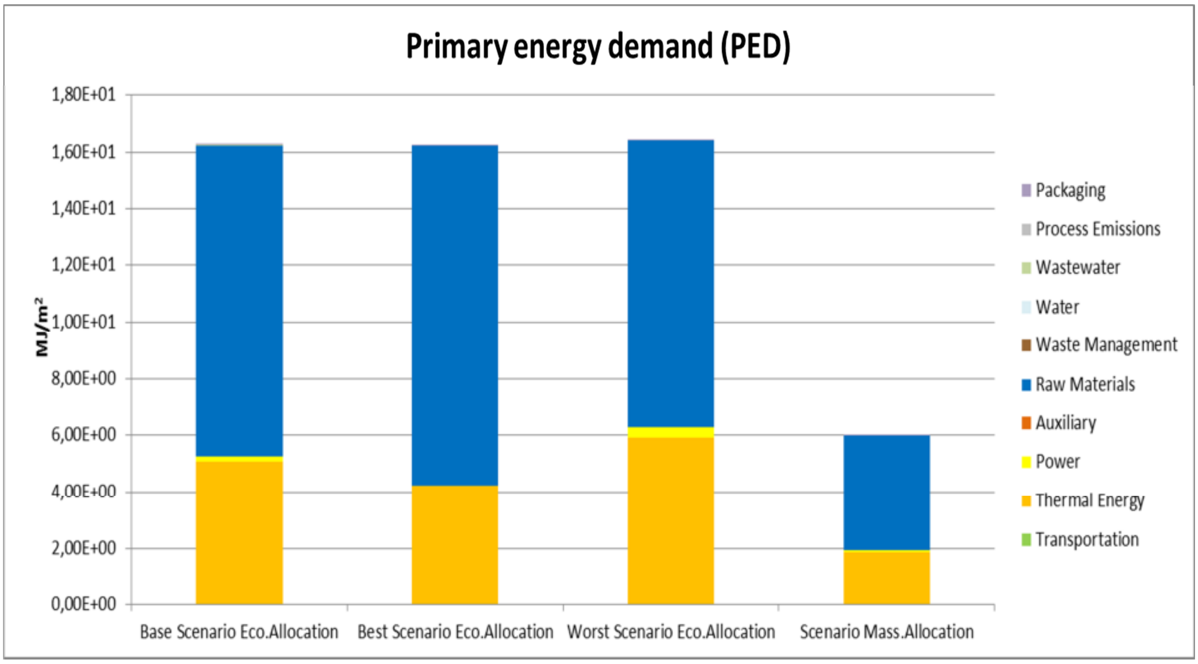


Figure 4-7: PED for base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 rotary veneer 0.6 mm

The scenario analysis shown in Figure 4-8 suggests that the impact assessment results for veneer are sensitive to the power consumption and transportation (longest distances for worst scenario vs. shortest for best scenario). The lowest reported impact for PED (nr) and GWP as is shown in Figure 4-8 and Figure 4-9 are for the scenario mass allocation with, 18% and 16% lower impact than the best-case scenario.

The mass allocation scenario value is only 39% of the PED nr value for the worst case scenario. Additionally the mass allocation scenario value is only 40% of the GWP value for the worst case scenario.

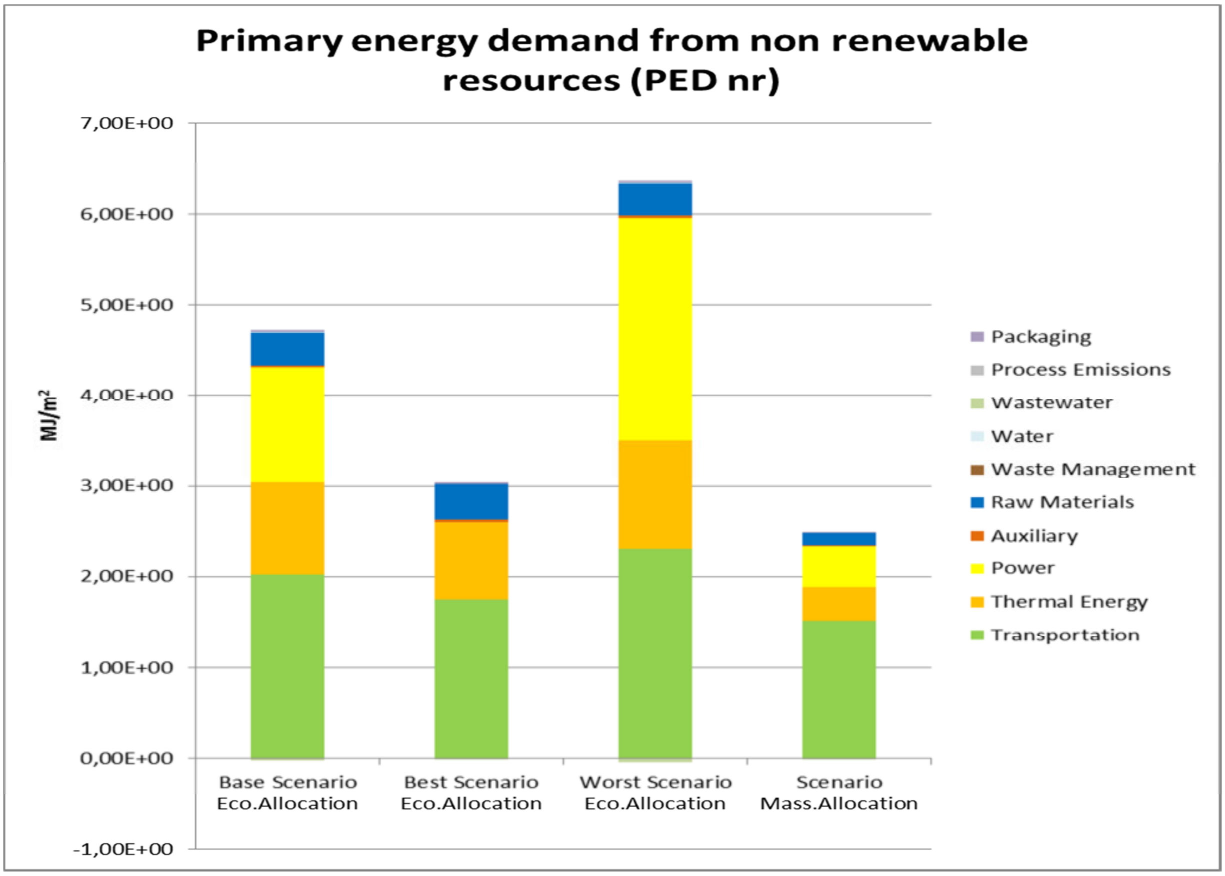


Figure 4-8: PED (nr) for base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 rotary veneer 0.6 mm

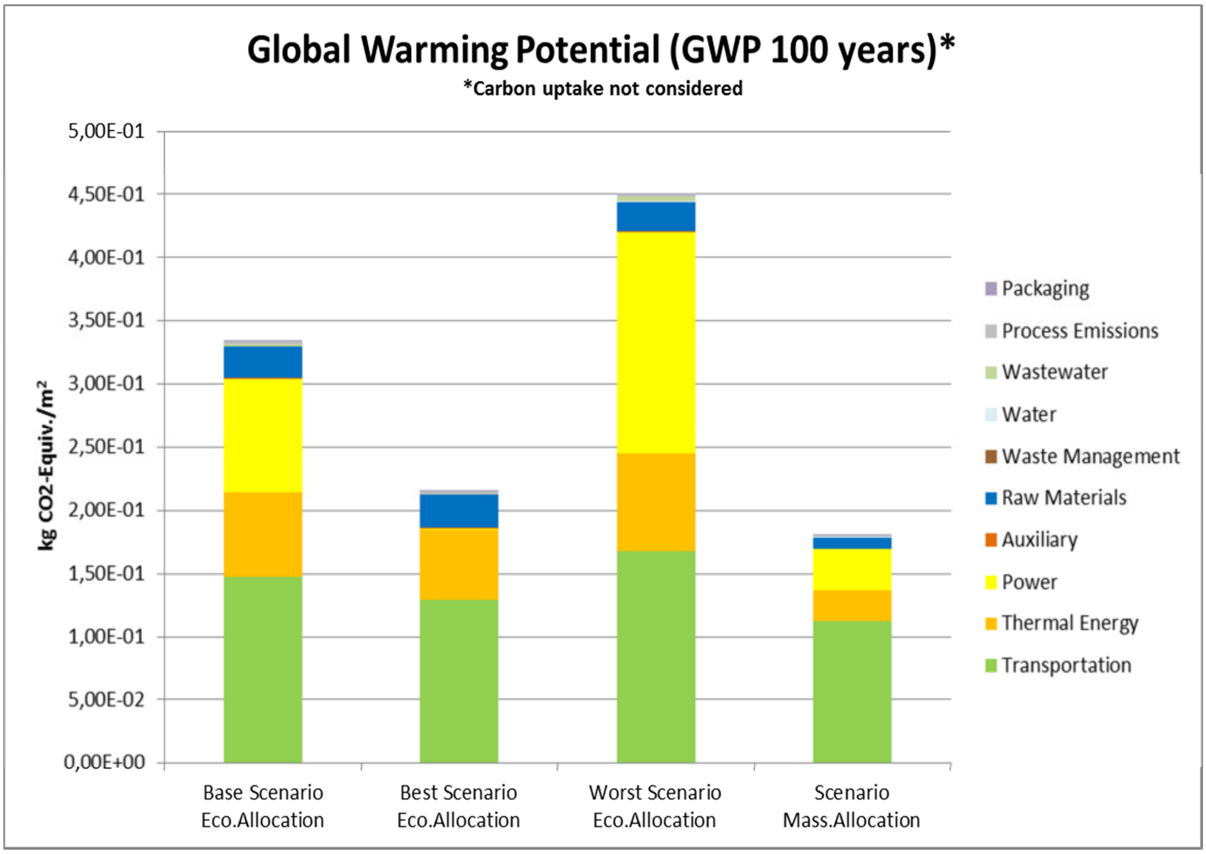


Figure 4-9: GWP for base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 of rotary veneer 0.6 mm

Results for all other impact categories are given in Appendix B.

Rotary veneer 2-2.5 mm thick with 9% MC

Veneer raw materials (log forestry), transportation and power consumption are the main drivers for PED, PED (nr) and GWP (see Figure 4-10, Figure 4-11 and Figure 4-12).

The reported energy figures from rotary companies producing layers with 2-2.5mm thickness range from 1.62E+00-2.34E+00 MJ for power and 5.60E+00-7.19E+00 MJ for thermal energy per kg veneer produced. This is somewhat consistent with the information found that provided a wide-range of values per kg dried veneer manufactured of 0.49E+00-4.40E+00 MJ for power (Energie Agentur NRW, 2012) in Germany. The same is observed for thermal energy whicjh is reported to range from6.30E+00 – 29.00E+00 MJ/kg veneer (Energy Agency NRW, 2012).

High energy consumption for the worst scenario will be represented by 7.19E+00 MJ of thermal energy and 2.34E+00 MJ of electricity per kg produced veneer. Low energy consumption for the best scenario is 1.62E+00 MJ of electricity and 2.34E+00 MJ of thermal energy per kg produced veneer.

Shortest and longest distances from company sources were also selected in order to define the best and worst case scenarios. The best and worst case scenarios were modeled using economic allocation.

The impact to PED by raw materials in Figure 4-10 is related to the input logs (absorption of solar primary energy during biomass harvesting to give the feedstock energy) with the highest impact (37 MJ) by the base scenario followed by worst scenario. The base scenario shows the highest results due to a slightly heavier figure in kg/m^2 produced veneer, thus more logs are required (8-9% more than in worst scenario). It is important to note that the base scenario represents a mass weighted average model from three companies, where one of them (not representing either best or worst scenario figures for wood masses) shows the highest share (dominance) due to its higher production figures in comparison to other two.

The scenario analysis also suggests that the impact assessment results for rotary veneer are sensitive to transportation (longest distances for worst scenario vs. shortest for best scenario) and power consumption. The lowest reported impacts for PED (nr) and GWP shown in Figure 4-11 and Figure 4-12 are for the best scenario and mass allocation. The best scenario value is only 34% of the PED nr value for the worst case scenario. Additionally the best scenario value is only 33% of the GWP value for the worst case scenario.

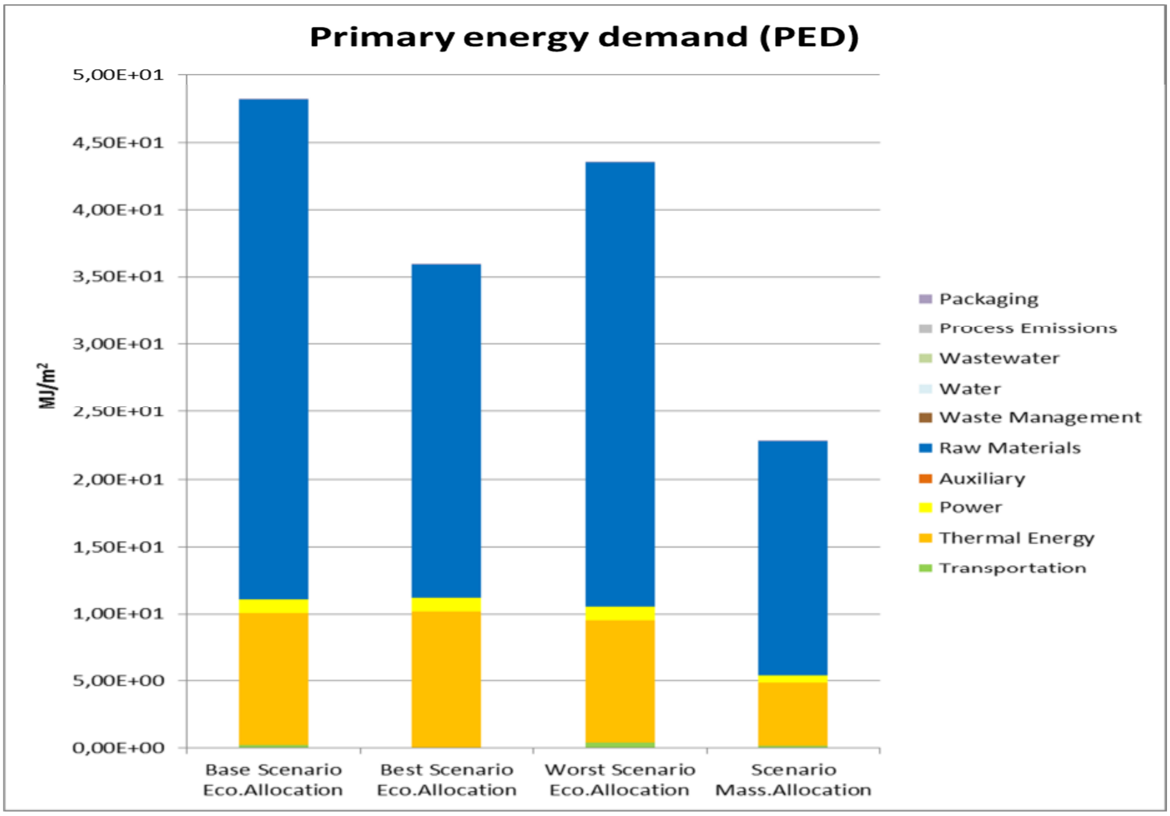


Figure 4-10: PED for base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 rotary veneer 2-2.5 mm

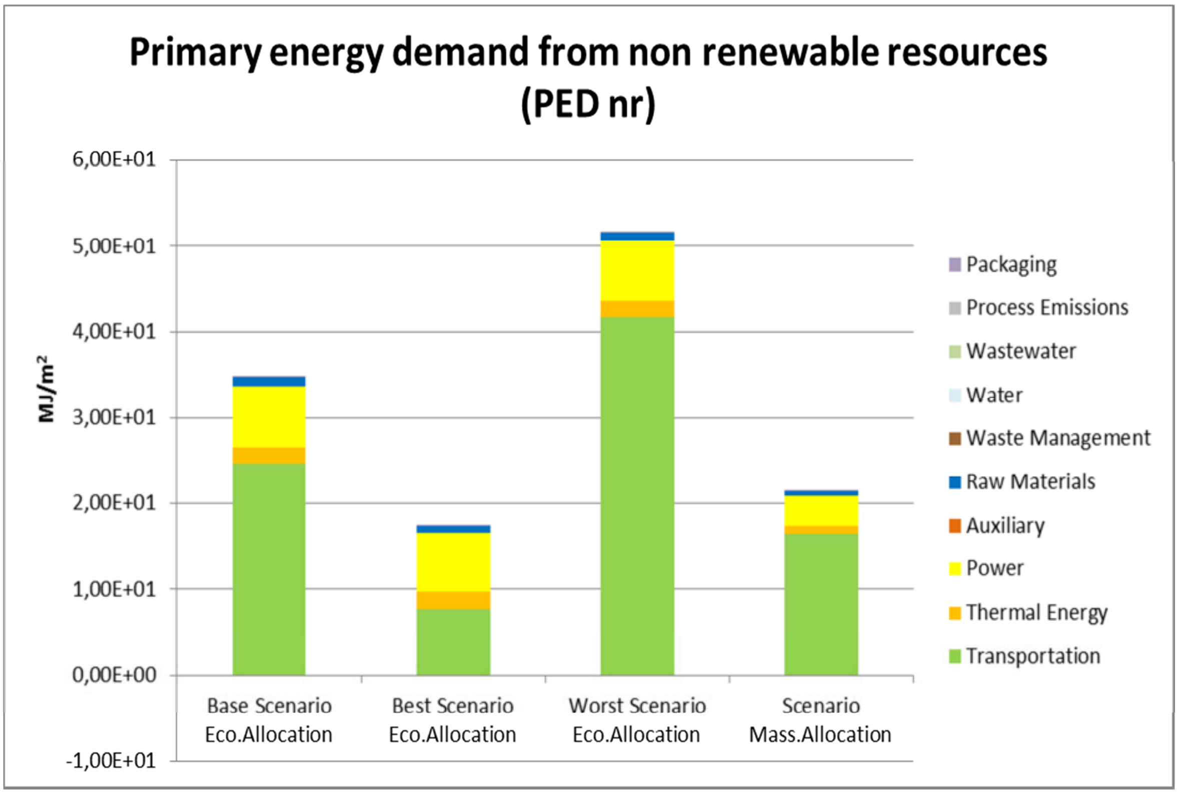


Figure 4-11: PED (nr) for base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 rotary veneer 2-2.5 mm

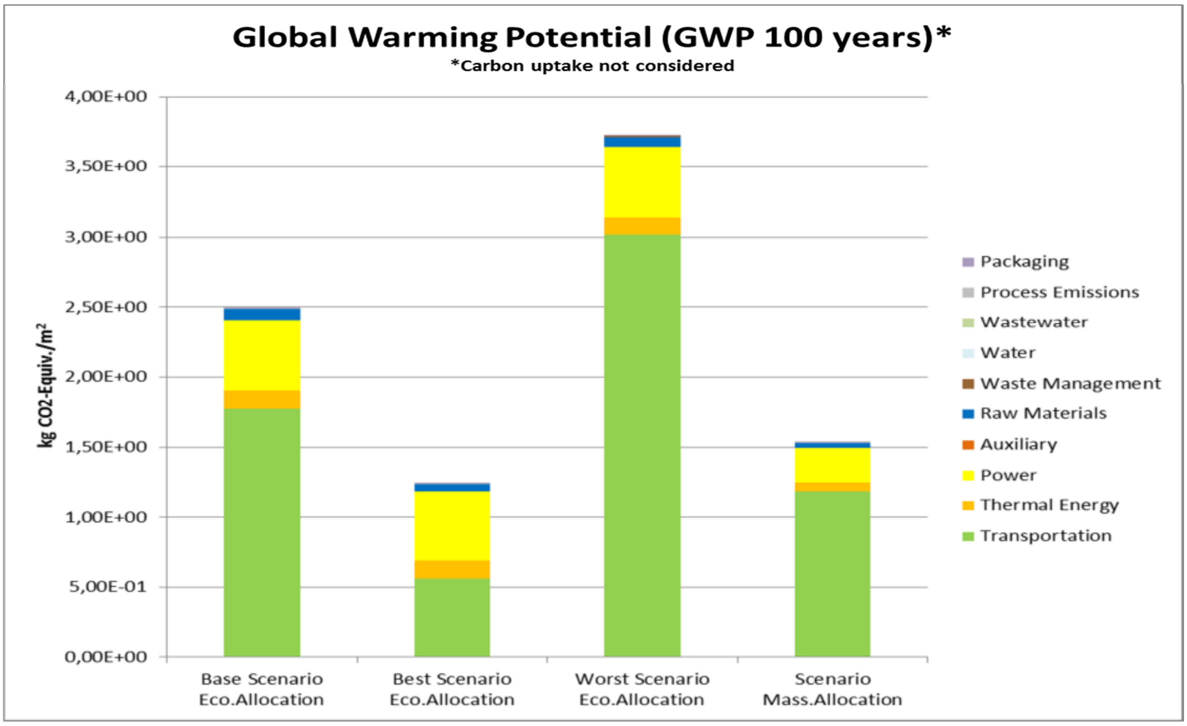


Figure 4-12: GWP for base scenario (eco allocation) vs. best scenario (eco. allocation) vs. worst case scenario (eco. allocation) vs. mass allocation of 1 m^2 of rotary veneer 2-2.5 mm

Results for all other impact categories are given in Appendix B.

5 LIFE CYCLE INTERPRETATION

According to the goal and scope of the study, a Life Cycle Assessment (LCA) for US hardwood veneer products was conducted. The scope of the study included a “cradle-to-gate plus transport to customer (product manufacturer)” assessment of the US hardwood veneer products and did not cover the use and end-of-life phases.

The following chapter summarizes the study and presents the key findings.

5.1 IDENTIFICATION OF SIGNIFICANT ISSUES

The Life Cycle Impact Assessment showed that the environmental impacts were dominated by energy consumption and transportation to customer in the EU. For the base scenario slicer US hardwood veneer (0.5-0.6 mm), energy consumption (power and thermal energy) contributed between 52% and 98% for all analyzed impact category scores with the exception of total primary energy demand which was dominated by primary energy from biomass (absorption of solar primary energy during biomass harvesting to give the feedstock energy) with 54% of the total PED score. Transport activity dominated the category EP with 43% of total EP impacts.

For the base scenario rotary US hardwood veneer (0.6 mm), energy consumption (power and thermal energy) was the highest contributor accounting for between 46% - 86% of all analyzed impact category scores with the exception of total primary energy demand which was again dominated by primary energy from biomass (absorption of solar primary energy during biomass harvesting to give the feedstock energy) which represented approximately 68% of the total PED score. Moreover, transportation showed two exceptions for the categories AP and EP; contributing 58% and 54% of the total impact respectively.

It is interesting to observe that the base scenario rotary US hardwood veneer (2-2.5mm) shows transportation activities as the highest contributor in all categories with 62 - 84 % contribution, with the exception of total primary energy demand, dominated by primary energy from biomass (absorption of solar primary energy during biomass harvesting to give the feedstock energy) at approximately 77% of the total PED. The reason for this high impact from transportation is explained by the longer distances reported by companies within this group, especially from the segment mill to port of export (reaching even double the distances from the other companies). Also companies reporting such longer distances had a greater share in weighted average score, due to their high production figures.

The absolute contribution of transportation to final customer is directly related to the location of the target market and the sulphur content of the used fuel for container ships. There is currently discussion to further limit the sulphur content of marine fuels to 0.1 weight percent (currently for ocean transport a world average of 2.7 weight percent is assumed). It also should be mentioned that the main location for emissions related to container ships contributing to AP and EP (SO_2 and NO_x) is not in populated areas or forestry but over the ocean.

5.2 Completeness, Sensitivity and consistency

Completeness checks were carried out throughout the study especially to check the totality of different inputs and outputs of the veneer production reported by the different companies. For more detail on cut-off discussion refer to Section 3.7.

Consistency in mass balances (unit measurements (section 3.5.2) and MC) of the wood input material, product and co-products were carefully checked in order to achieve a good reliability of the study. Furthermore the reported energy input figures were cross-checked with available literature sources (see 3.5.2.) Also these were validated with data provided by one of the company's operation facility in Europe.

Modeling approaches chosen are consistent with the AHEC LCA study on Lumber (2010-2012). For more detail please refer to section 3.4.1 on impact categories and 3.4.4 on biogenic carbon. Furthermore, the economic allocation approach follows the requirements of the core rules for EPD's for construction products in Europe and complies with the ISO 14044 standard. Weighted average prices for veneer co-products across all companies, normalized to a common MC per co-product were calculated and inserted in the model (more detail refers to Section 3.6).

A sensitivity analysis was carried out for mass allocation, best and worst case scenarios and for unclipped veneer (only for the slicer model). The findings are presented in chapter 4.4.

In general an extensive literature review was undertaken in order to find similar studies in the US region or worldwide. Unfortunately all LCA studies found (only laminated lumber or engineering wood flooring studies) did not reveal much for the intermediate veneer portion. AHEC tried to connect PE International with some authors of similar studies, but unfortunately PE International was never contacted back.

5.3 Conclusions and recommendations

Life cycle assessment was used to evaluate the environmental performance of the US hardwood veneer products including two different technologies and three different thicknesses. The results presented here are considered to be a good representation for the average species mix for these types of US hardwood veneer. Individual company specific profiles within this overall average differ due to specific practices, especially during drying as well as because of different transport distances.

The results show some variation between veneer technology and veneer thicknesses. On a per m^2 basis, the rotary veneer (0.6 mm) shows the lowest environmental impacts in comparison with a similar thickness of slicer veneer (0.5-0.6 mm) or a thicker rotary veneer (2-2.5 mm). This conclusion is based on results for two facilities representing 34% of the total rotary technology production in the US (HPVA, 2013). The thinner rotary veneer companies tended to report the lowest transport distances (nearer to principal port of exports) plus lower energy consumption figures.

The study has revealed that across all products the main sources of environmental impacts are:

- Energy consumption (power and thermal energy) and
- Transportation to customer.

The forestry process is a relatively small contributor to the overall results compared with other processes involved. The only exception is in the category total demand of primary energy (PED). By definition PED includes the energy incorporated in the wood at harvesting (primary energy from biomass) and thus it is mostly defined by the forestry process. Excluding PED, forestry contributes from 3% (POCP) to around 7% (EP) in slicer panel (0.5-0.6 mm thickness), from 5% (AP & POCP) to around 10% (EP & ODP) in rotary panel (0.6 mm thickness) and from 3% (AP, GWP, POCP & PED nr) to around 5% (EP&ODP) in rotary panel (2-2.5 mm thickness). On the other hand the forestry process is representing the highest carbon uptake during harvesting. During growth, carbon is stored in the wood via photosynthesis. This biogenic carbon is stored in the veneer and its subsequent products. The carbon stored in biomass will, - sooner or later, be released at the end of the product's life cycle[42] . The end of the product's life cycle is not included in this study. The potential benefits from carbon storage, delayed emissions or the substitution effect can be fully excluded or accounted for differently according to different standards (PAS 2050[43], PEF 2nd draft[44], ISO 14067[45], EN 15804 etc.). To enable study stakeholders to utilise the data for different applications, and to avoid the AHEC communication being perceived as "greenwashing", the stored (biogenic) carbon was clearly quantified in the inventory for transparency in the carbon balance, and treated as a separate element in the report whilst not being subtracted from the Global Warming impact of the product.

Stored carbon that does not end up in the final veneer product, e.g. carbon stored in leftover forest biomass (e.g. small branches, leaves) is not assigned to the veneer FU. It is assumed to be eventually converted back to CO_2 and emitted (stays in the forest). Moreover carbon in the forest floor or forest soil is not assigned to the veneer FU. Only the final carbon that is stored in the veneer product is accounted as stored carbon. Thus removals from the atmosphere from biogenic sources are not modelled in this study. Only biogenic carbon dioxide emissions (e.g. biomass boilers) are modelled as carbon neutral (no impact on the GWP) as they are being offset by the uptake in biomass.

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[42] assuming a 100% degradation rate.

[43] PAS 2050 is showing delayed emissions for the treatment of biogenic carbon (British Standard Institute (BSI), 2011).

[44] PEF or Product Environmental Footprint Guide, suggest the inclusion of the biogenic carbon but documenting it separately.

[45] ISO 14067 (2013), suggest the inclusion of the biogenic carbon but documenting it separately.

Not enough data is available on the carbon content in different hardwood species and a low value from literature with 46.27% carbon content in absolute dry mass was modelled (Lamlom & Savidge, 2003; Thomas & Martin, 2012[46]) as carbon storage for all hardwood species. This is a conservative value reported for hardwoods (Lamlom & Savidge, 2003; Thomas & Martin, 2012).

Energy consumption is the dominant source of environmental impact for almost all categories. In the base scenario slicer veneer technology (0.5-0.6mm), energy consumption contributes between 42% and 83% along the different impact categories (with exception of total primary energy demand and eutrophication). Thus PED is dominated by primary energy from biomass with 54% of the total impact and the EP impact category is dominated by transportation with 43% of total EP impacts).

Moreover the same is observed in the base scenario rotary veneer (0.6 mm), where power and thermal energy consumptions are the highest contributors with between 31% - 84% influence for all analyzed categories with the exception of total primary energy demand (primary energy demand from biomass incorporated in the input logs represents approximately 68% of the total impact). Transportation is another exception for the categories AP and EP contributing with 58% and 54 of the total impacts respectively. In contrast, the base scenario rotary (2-2.5mm) shows transportation activities as the highest contributor in all categories with between 62-84 % contribution (with the exception of total primary energy demand, which is dominated by primary energy from biomass with approximately 77% of the total PED). The high impact from transportation is explained by the longer distances reported by companies within this group especially from mill to port of export (up to double the distances of the other companies). Additionally, companies reporting these distances also had a greater influence on the weighted average due to their high production figures.

Based on results obtained in the sensitivity analysis for unclipped veneer (only valid for slicer technology), an unclipped veneer panel which isn't exported to Europe (and has a slightly cheaper price ~ influence of economic allocation) will reduce impacts by 26 to 53% in all categories in comparison with a slicer clipped veneer of the same thickness if all other product properties are the same. For the veneer products exported overseas a significant share of impact is added to veneer, mostly from carbon and sulphur dioxides emitted during container shipping.

Results of the sensitivity analysis of allocation approach (economic vs mass) suggest that use of a mass allocation approach gives lower impact results for slicer veneer 0.5-0.6 mm thick by 58% in total primary energy demand and 55% in ozone depletion potential. Other impact category results are reduced by between 35-47%. In the same comparison rotary veneer (0.6 mm thickness) shows lower impact results for primary energy demand and ozone depletion (64 % and 63% reduction of impacts respectively). Finally rotary veneer (2-

[46] In all biomes, wood C content varied widely across species ranging from 41.9–51.6% in tropical species, 45.7–60.7% in subtropical/Mediterranean species, and 43.4–55.6% in temperate/boreal species.

2.5 mm thickness) allocation on a mass rather than economic basis would have lower impact results by 53% in total primary energy demand and 52% for ozone depletion. For all other impacts it would lower results between 35-41%. The LCIA results for all impact categories are clearly sensitive to the choice of an economic or mass allocation approach. Veneer production (either slicer or rotary technology) incurs a substantial production of residues, meaning that there is a large amount of co-products or materials generated in relation to the veneer final product, which reduces the impacts compared to when the price for veneer is applied for economic allocation. Furthermore, PED shows a high sensitivity to the mass allocation scenario because it is the only indicator where forestry (logs) dominates the impact (reflecting the absorbed solar primary energy in biomass). A lower log mass input (reallocated due to a mass allocation instead of an economic allocation where highest priced-clipped veneer leads) will reduce the absorption of solar energy thus PED impact during the harvesting.

In general, the environmental profile of veneer can be improved. Primary data indicated a range of energy consumption rates suggesting that there is room for improvement for most of the mills (e.g. GWP and non-renewable resource consumption are 14% lower for the veneer produced by mills with lower energy demand; rotary with 0.6 mm thickness).

The biomass widely used in veneer mills as energy source results in improved global warming potential impact and resource consumption (primary energy demand from non-renewable resources) in comparison to natural gas boilers; but at the same time increases emissions contributing to Acidification, Eutrophication and Photochemical Ozone Creation impacts. Further increases in biomass share in the energy mix would reduce greenhouse gases emissions but would increase some other emissions. Based on the study findings it is recommended that AHEC:

- Continues efforts to find more detail on the real differences between veneer technology, thicknesses, and species influence etc. Prepare and publish the EPDs on key US hardwood products (veneer with different thicknesses and technologies, hardwood engineer flooring, hardwood laminated lumber);
- Focus the effort on veneer production improvement on:
    - energy efficiency measures to reduce energy consumption,
    - new possible transportation routes,
    - real knowledge on water consumption,
    - measurements on logs, MC, specific thicknesses of final layer, water consumption etc.
- Initiate additional data collection on process steps (vats, cutting, drying unit processes) to better understand the environmental implications;

- Keep track of prices for hardwood forest and veneer mill hardwood co-products as these data are relevant for calculation of the hardwood veneer environmental impacts;
- Utilize the developed LCA model in the hardwood veneer industry to inform producers about the environmental implications of their decisions;
- Broader the analysis in order to include/discuss quantitatively further relevant environmental impact categories (toxicity, land use (occupation), land use change (LUC) (direct and indirect), water related impacts, biodiversity).
- Promote efforts for data collection within companies in order to reflect specific veneer production patterns and environmental impacts per hardwood specie.
- Investigate options for optimization of the logistics across the transport; routes;
- It is highly recommended that the environmental profile of the hardwood veneer is developed and communicated on the basis of the veneer production technology used and the particular veneer thickness.

6 REFERENCES

AHEC, 2009	American Hardwood Export Council. Sustainable American Hardwoods. A guide to species, 2010 (?, no date in publication, but later than 2008)
AHEC, 2012	American Hardwood Export Council, Life Cycle Assessment of Rough Kiln-dried Hardwood Lumber, 2012 (Final report).
Ananias et al, 2009	Rubén A. ANANIAS, Laurent CHRUSCIEL, André ZOULALIAN, Carlos SALINAS-LIRA and Eric MOUGEL, Overall Mass-Transfer Coefficient for Wood Drying Curves Predictions, 2009
Bare et al., 2011	Bare (2011). TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental impacts 2.0, Clean Techn Environ Policy. Retrieved from http://dx.doi.org/10.1007/s10098-010-0338-9
Bayart et al., 2010	Bayart, J.B.; Bulle, C.; Koehler, A.; Margni, M.; Pfister, S.; Vince, F.; Deschenes, L. (2010). A framework for assessing off-stream freshwater use in LCA, Int J Life Cycle Assess 15, 439–453
Berger, Finkbeiner, 2010	Berger, M. & Finkbeiner, M.(2010). Water Footprinting: How to address water use in LCA? Sustainability 2010, 2(4) Retrieved from http://www.mdpi.com/2071-1050/2/4/919/
Berger, Finkbeiner, 2012	Berger, M.; Finkbeiner, M. (2012). Methodological challenges in volumetric and impact oriented water footprints. J. Ind. Ecol. 2012, DOI: , DOI: 10.1111/j.1530-9290.2012.00495.x
Bergman, Bowe, 2010	Bergman, R. & Bowe, S. (2010). Life-cycle inventory of manufacturing prefinished engineered wood flooring in the eastern United States. Final report to the national wood flooring association.
British Standard Institute (BSI), 2011	Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050:2011)
Cassens, FNR-240	Cassens, D. (FNR-240). Manufacturing fine hardwood face veneer. Purdue University Department of Forestry and Natural Resources, West Lafayette, IN 47907.
CHPVA, 2006	Canadian Hardwood plywood and veneer association (2006). From the bark to the heart. Temoin Production.
CML, 2001	An operational guide to the ISO-standards (Guinée et al.) Centre for Milieukunde (CML), Leiden 2001.
Colnes et al., 2012	Colnes A; Doshi K; Emick H; Evans A; Perschel R; Robards T; Saah D; Sherman A; Carr D; Palola E; Rambo F; Sibbing J; Biomass supply and carbon accounting for southeastern forests, 2012
CORRIM , 2010, Module A	CORRIM (2010). Phase II Final Report. Module A: Life-Cycle Impacts of Inland Northwest and Northeast/North Central Forest Resources. *As published in Wood and Fiber Science, CORRIM SPECIAL ISSUE, SECOND REPORT MARCH 2010 Vol. 42: 144-16.* Retrieved from http://www.corrim.org/pubs/reports/2010/swst_vol42/144.pdf
CORRIM, 2008, Module C	CORRIM (2008). Phase II Final Report. Module C: Life-Cycle Inventory of Hardwood Lumber Manufacturing in the Northeast and North Central United States. Prepared by

	Richard D. Bergman, Scott A. Bowe. Retrieved from http://www.corrim.org/pubs/reports/2010/phase2/Module_C.pdf
CORRIM, 2010, Module L	CORRIM (2010). Phase II Final Report. Module L: Life-Cycle Inventory of Hardwood Lumber Manufacturing in the Southeastern United States. Prepared by Richard D. Bergman, Scott A. Bowe. Retrieved from http://www.corrim.org/pubs/reports/2010/phase2/Module_L.pdf
CORRIM, 2010, Module N)	CORRIM (2010). Phase I Final Report. Module N: Tracking carbon from sequestration in the forest to wood products and substitution. Prepared by John Perez-Garcia, Bruce Lippke, Jeffrey Comnick and Carolina Manriquez.
European Commision, 2012	Product Environmental Footprint (PEF) Guide, 2nd Draft
EN 15804, 2012	EN 15804 (2012). Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products.
Energy Agency NRW (North Rhine-Westphalia)	Energy Agency from North Rhine-Westphalia (2012) Energieeffizienz in der Holzbe- und verarbeitenden Industrie http://www.energieagentur.nrw.de
Environmental, Climate and Energy Ministerial of Baden and Württemberg	Environmental, Climate and Energy Ministerial of Baden and Württemberg (2012) Furniere (Veneer) http://www.umweltschutz-bw.de/?lvl=1588
Danzer, 2013 a	Email communication Mr Will Waldstein. 10. March 2013
Danzer 2013 b	Email communication Mrs Cathy Danzer. 03. May 2013
Danzer, 2012	Email communication Mrs Kami Ervin. 11. July 2012
Freeman, 2012	Email communication Mr George Freeman. 25. 04 2013
GaBi 6	PE: GaBi 6 software-System and Database for Life Cycle Engineering. Copyright, TM. Stuttgart, Echterdingen 1992-2012. Retrieved from www.gabi-software.com
Goetzl et al, 2008	Goetzl A., Ellefson P., Guillery P., Dodge G., Berg S., (2008) Assessment of Lawful Harvesting & Sustainability of US Hardwood Exports. Executive summary. Seneca Creek Associates, LLC. Retrieved from http://www.americanhardwood.org/fileadmin/docs/Seneca_Creek_Study/Seneca_Creek_Study_-_Executive_Summary.pdf
Guinée et al., 2001	Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; Wegener Sleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J (2001). Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, 692 pp., Dordrecht
Hardwood publishing, 2011	Data from The Hardwood Review index Sept 2010- Sept 2011. Email communication with Dan Meyer, Editor, Hardwood Publishing Co., Inc.
Hauschild, 2008	Hauschild et al (2008). Building a Model Based on Scientific Consensus for Life Cycle Impact Assessment of Chemicals: The Search for Harmony and Parsimony, Environ. Sci. Technol. 42, 7032–7037

Horizon plywood INC, 2013	Horizon plywood INC, (2013) Veneer cutting methods http://www.hrzn.net/Grading/veneer_cutting_methods.htm
HPVA, 2014	Email communication with Mr. Kip Howlett. President of the Hardwood Plywood and Veneer Association
HPVA, 2013	Telephone communication with Mr. Kip Howlett. President of the Hardwood Plywood and Veneer Association
HPVA, 2004	Hardwood plywood and veneer association (HPVA) (2004) Hardwood plywood handbook. Editor Curt Alt.
IBU, 2013	Institut Bauen und Umwelt e.V., Part B: Requirements on the EPD for solid wood products, Rules for Environmental Product Declarations (November 2003). Retrieved from Online access link
IPCC, 2006	Intergovernmental Panel on Climate Change (2006) Guidelines for National Greenhouse Gas Inventories. Retrieved from http://www.ipcc-nggip.iges.or.jp/
ISO 14040, 2006	ISO 14040 (2006), Environmental management - Life cycle assessment - Principles and framework, International Organisation for Standardisation (ISO), Geneva
ISO 14044, 2006	ISO 14044 (2006), Environmental management - Life cycle assessment - Requirements and guidelines, International Organisation for Standardisation (ISO), Geneva. Available at www iso.ch
ISO/TS 14067, 2013	Greenhouse gases-Carbon footprint of products- Requirements and guidelines for quantification and communication (ISO/TS 14067:2013).
JRC, 2011	European Commission Joint Research Centre, Institute for Environment and Sustainability (2011). ILCD Handbook. Recommendations for Life Cycle Impact Assessment in the European Context. First edition. Retrieved from Online access link
Lamlom & Savidge, 2003	Lamlom, S.H., Savidge R.A. (2003), A reassessment of carbon content in wood: variation within and between 41 North American species. Biomass and Bioenergy 25 (2003) 381 – 388.
Lindfors et al., 2012	Lindfors, Lars-Gunnar; Ekvall Tomas; Eriksson Elin; Jelse Kristian; Rydberg Tomas. The ILCD Handbook in a Nutshell, A Brief Analysis of the ILCD Handbook and the Draft Guidance on Product Environmental Footprint (2012)
NCASI, 1998	The National Council for Air and Stream Improvement (1998) Wood products MACT study Mill 400 Report.
Northeast Timber Exchange, 2012	Northeast Timber Exchange, LCC. March 2012 price list Retrieved from Online access link
Rice & Erich, 2006	Rice, R.W. and Erich, M.S. (2006). Estimated VOC Losses During the Drying of Six Eastern Hardwood Species. Forest Prod. J. Vol. 56, No. 10. pp. 48-51
Rosenbaum, 2008	USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment, Int J Life Cycle Asses (2008) 13:532–546
Smith et al., 2009	Smith, W. Brad, tech. coord.; Miles, Patrick D., data coord.; Perry, Charles H., map coord.; Pugh, Scott A., Data CD coord. (2009). Forest Resources of the United States, 2007. Gen. Tech. Rep. WO-78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 336 pp. Retrieved from http://www.treesearch.fs.fed.us/pubs/17334
Thomas & Martin,	Thomas, S.C., Martin A.R. (2012), Carbon Content of Tree Tissues: A Synthesis. Forests

2012	2012, 3, 332-352; doi: 10.3390/f3020332
Timber Mart-South, 2009-2010	Timber Mart-South Market News Quarterly, 2009-2010. Retrieved from: http://www.timbermart-south.com
USDA, 2007	United States Department of Agriculture (2007): Interim Update of the 2000 Renewable Resources Planning Act Assessment
USDA, 2008	United States Department of Agriculture (2008): DRAFT National Report on Sustainable Forests – 2010. Retrieved from http://www.fs.fed.us/research/sustain/2010SustainabilityReport
USDA, 2000	Denig, Joseph; Wengert, Eugene M.; Simpson, William T. 2000. Drying hardwood lumber. Gen. Tech. Rep. FPL–GTR–118. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 138 p.
Veneernet, 2013	Veneernet.com http://www.veneernet.com/halfround.html

Appendix A : Description of Impact Categories in CML 2001

Primary energy demand

Primary energy demand is often difficult to determine due to the various types of energy source. Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e. the energy content of the raw material). For renewable resources, the energy-characterised amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). As aggregated values, the following primary energies are designated:

The total **"Primary energy demand from non-renewable resources (PED nr)"**, given in MJ, essentially characterises the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil have been used both for energy production and as material constituents e.g. in plastics. Coal has been primarily used for energy production. Uranium has only been used for electricity production in nuclear power stations.

The total **"Primary energy demand from renewable resources (PED)"**, given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy and biomass.

It is important that the delivered energy (e.g. 1 kWh of electricity) and the primary energy used are not confused with each other; otherwise the efficiency for production or supply of the delivered energy will not be accounted for.

The energy content of the manufactured products will be considered as feedstock energy content. It will be characterised by the net calorific value of the product. It represents the still usable energy content.

Global Warming Potential (GWP)

The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects are also occurring on a global scale. The occuring short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth's surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activites. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane and CFCs. Figure A 1 shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider the possible long term global effects.

The global warming potential is calculated in carbon dioxide equivalents (CO2-Eq.). This means that the greenhouse potential of an emission is given in relation to CO2 Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

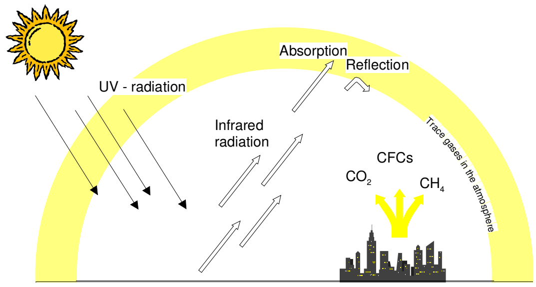


Figure A 1: Greenhouse effect

Acidification Potential (AP)

The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H_2SO_4 und HNO_3) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact.

Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate.

When analysing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary. Figure A 2 displays the primary impact pathways of acidification.

The acidification potential is given in sulphur dioxide equivalents (SO2-Eq.). The acidification potential is described as the ability of certain substances to build and release H+ - ions. Certain emissions can also be considered to have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulpher dioxide.

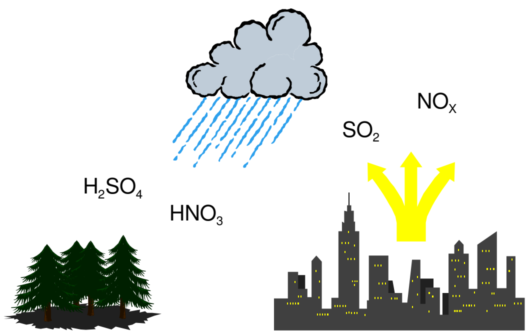


Figure A 2: Acidification Potential

Eutrophication Potential (EP)

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, waste water and fertilisation in agriculture all contribute to eutrophication.

The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulphide and methane are thereby produced. This can lead, among others, to the destruction of the eco-system.

On eutrophicated soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the nutrification level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water.

Nitrate at low levels is harmless from a toxicological point of view. However, nitrite, a reaction product of nitrate, is toxic to humans. The causes of eutrophication are displayed in Figure A 3. The eutrophication potential is calculated in phosphate equivalents (PO4-Eq). As with acidification potential, it's important to remember that the effects of eutrophication potential differ regionally.

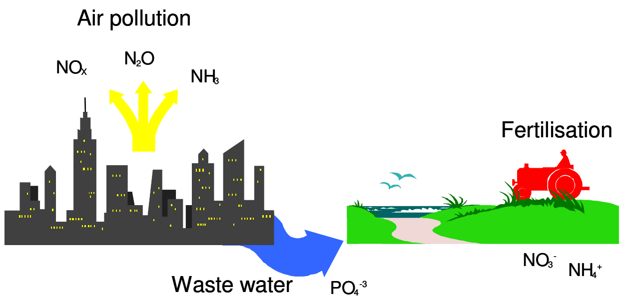


Figure A 3: **Eutrophication Potential**

Photochemical Ozone Creation Potential (POCP)

Despite playing a protective role in the stratosphere, at ground-level ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans.

Radiation from the sun and the presence of nitrogen oxides and hydrocarbons incur complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels.

Hydrocarbon emissions occur from incomplete combustion, in conjunction with petrol (storage, turnover, refuelling etc.) or from solvents. High concentrations of ozone arise when the temperature is high, humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons. Today it is assumed that the existance of NO and CO reduces the accumulated ozone to NO_2, CO_2 and O_2. This means, that high concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less NO and CO (Figure A 4).

In Life Cycle Assessments, photochemical ozone creation potential (POCP) is referred to in ethylene-equivalents (C2H4-Äq.). When analyzing, it's important to remember that the actual ozone concentration is strongly influenced by the weather and by the characteristics of the local conditions.

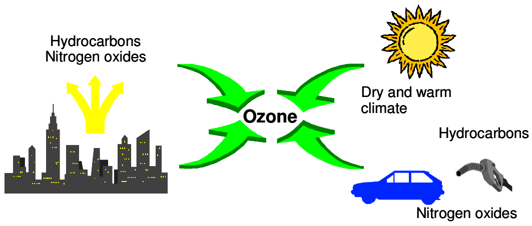


Figure A 4: Photochemical Ozone Creation Potential

Ozone Depletion Potential (ODP)

Ozone is created in the stratosphere by the disassociation of oxygen atoms that are exposed to short-wave UV-light. This leads to the formation of the so-called ozone layer in the stratosphere (15 - 50 km high). About 10 % of this ozone reaches the troposphere through mixing processes. In spite of its minimal concentration, the ozone layer is essential for life on earth. Ozone absorbs the short-wave UV-radiation and releases it in longer wavelengths. As a result, only a small part of the UV-radiation reaches the earth.

Anthropogenic emissions deplete ozone. This is well-known from reports on the hole in the ozone layer. The hole is currently confined to the region above Antarctica, however another ozone depletion can be identified, albeit not to the same extent, over the mid-latitudes (e.g. Europe). The substances which have a depleting effect on the ozone can essentially be divided into two groups; the fluorine-chlorine-hydrocarbons (CFCs) and the nitrogen oxides (NOX). Figure A 5 depicts the procedure of ozone depletion.

One effect of ozone depletion is the warming of the earth's surface. The sensitivity of humans, animals and plants to UV-B and UV-A radiation is of particular importance. Possible effects are changes in growth or a decrease in harvest crops (disruption of photosynthesis), indications of tumors (skin cancer and eye diseases) and decrease of sea plankton, which would strongly affect the food chain. In calculating the ozone depletion potential, the anthropogenically released halogenated hydrocarbons, which can destroy many ozone molecules, are recorded first. The so-called Ozone Depletion Potential (ODP) results from the calculation of the potential of different ozone relevant substances.

This is done by calculating, first of all, a scenario for a fixed quantity of emissions of a CFC reference (CFC 11). This results in an equilibrium state of total ozone reduction. The same scenario is considered for each substance under study whereby CFC 11 is replaced by the quantity of the substance. This leads to the ozone depletion potential for each respective substance, which is given in CFC 11 equivalents. An evaluation of the ozone depletion potential should take into consideration the long term, global and partly irreversible effects.

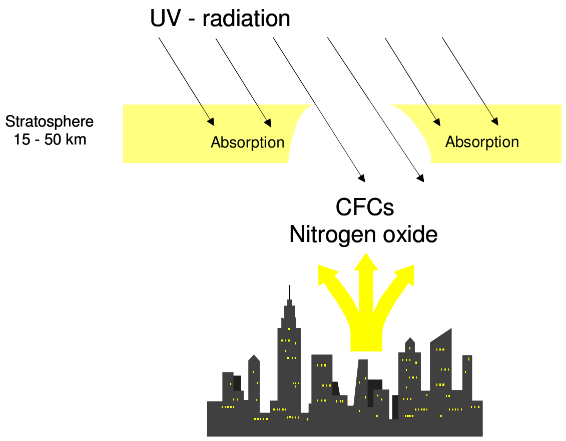


Figure A 5: **Ozone Depletion Potential**

Appendix B : Unallocated Tables for 1m2 Veneer Production

Table A: Hardwood veneer inventory for 1 m² slicer veneer & co-product prices (for respective MC assumed in the model)

Inventory data from a 1 m² slicer veneer in cradle-to-gate (based on species mix).

INPUTS	Amount	Price [USD/kg]
Roundwood with bark, hardwood, green, kg	1.54E+00	n/a
Wax (synthetic), kg	2.28E-04	n/a
Electricity, MJ	1.24E+00	n/a
Thermal energy, onsite boiler, MJ	7.93E+00	n/a
Diesel, combusted in industrial equipment, m³	3.39E-06	n/a
Lubricating oil, kg	2.06E-04	n/a
Water (tap water), kg	3.36E+00	n/a
Water (well), kg	1.68E+00	n/a
Water (rain), kg	3.00E-02	n/a
Steel banding kg	3.50E-03	n/a
Knives (Steel hot rolled), kg	3.91E-04	n/a
Polyethylene-film, packaging, kg	8.40E-05	n/a
OUTPUTS	Amount	Price [USD/kg]
Hardwood veneer clipped (10% MC), kg	3.54E-01	4,25
Hardwood veneer unclipped (10% MC), kg	1.06E-01	3,17
Backing boards (69% MC), kg	4.28E-02	0,191
Bark, hardwood green (60% MC), kg	1.58E-01	0,0109
Bunch clipped waste (8,6 % MC) , kg	0.00E+00	0,0244
Cores (66,6% MC), kg	0.00E+00	0,0285
Flitch surface material (69% MC), kg	2.49E-02	0,0221
Log trimmings (81,8% MC), kg	0.00E+00	0,022
Logs for sale	0.00E+00	0,63
Slabs (69% MC), kg	6.01E-02	0,01

Veneer sheet clipping residue (10% MC) , kg	2.86E-01	0,0869
Wood chips (15% MC) (as total wood waste residues), kg	6.74E-02	0,0848
Sheet residues (Trim)	0.00E+00	0,0259
Water vapour, kg	4.52E-01	n/a
Packaging waste (plastic), kg	9.39E-05	n/a
Steel waste, kg	3.41E-04	n/a
Waste (unspecified), kg	0.00E+00	n/a
Sludge, kg	3.62E-04	n/a
Waste water, kg	5.07E+00	n/a
Acetaldehyde, kg	6.84E-06	
Acetone, kg	1.04E-05	
Acrolein,kg	8.95E-06	
Formaldehyde,kg	6.84E-07	
Hazardous air pollutants,kg	1.81E-05	
Hydrocarbons,kg	3.32E-04	
Methanol,kg	9.69E-06	
Methyl isobutyl ketone kg	8.88E-06	

Table B: Hardwood veneer inventory for 1 m^2 rotary veneer (0,6mm) & co-product prices (for respective MC assumed in the model)

Inventory data from a 1 m^2 rotary veneer (0,6mm) in cradle-to-gate (based on species mix).

INPUTS	Amount	Price [USD/kg]
Roundwood with bark, hardwood, green, kg	1.75E+00	n/a
Wax (synthetic), kg	9.51E-04	n/a
Electricity, MJ	4.93E-01	n/a
Thermal energy, onsite boiler, MJ	4.91E+00	n/a
Diesel, combusted in industrial equipment, m^3	2.04E-06	n/a
Lubricating oil, kg	2.40E-04	n/a
Water (tap water), kg	1.89E+00	n/a
Water (well), kg	0.00E+00	n/a
Water (rain), kg	4.28E+00	n/a
Steel banding kg	0.00E+00	n/a

Knives (Steel hot rolled), kg	1.69E-04	n/a
Polyethylene-film, packaging, kg	3.46E-04	n/a
OUTPUTS	Amount	Price [USD/kg]
Hardwood veneer clipped (10% MC), kg	4.54E-01	4,25
Hardwood veneer unclipped (10% MC), kg	0.00E+00	3,17
Backing boards (69% MC), kg	0.00E+00	0,191
Bark, hardwood green (60% MC), kg	2.08E-01	0,0109
Bunch clipped waste (8,6 % MC) , kg	8.95E-02	0,0244
Cores (66,6% MC), kg	1.22E-01	0,0285
Flitch surface material (69% MC), kg	0.00E+00	0,0221
Log trimmings (81,8% MC), kg	2.01E-01	0,022
Logs for sale	2.33E-01	0,63
Slabs (69% MC), kg	0.00E+00	0,01
Veneer sheet clipping residue (10% MC) , kg	0.00E+00	0,0869
Wood chips (15% MC) (as total wood waste residues), kg	0.00E+00	0,0848
Sheet residues (Trim)	2.37E-02	0,0259
Water vapour, kg	4.09E-01	n/a
Packaging waste (plastic), kg	3.66E-05	n/a
Steel waste, kg	0.00E+00	n/a
Waste (unspecified), kg	0.00E+00	n/a
Sludge, kg	5.49E-03	n/a
Waste water, kg	6.16E+00	n/a
Acetaldehyde, kg	6.85E-06	
Acetone, kg	1.04E-05	
Acrolein,kg	8.95E-06	
Formaldehyde,kg	6.84E-07	
Hazardous air pollutants,kg	1.81E-05	
Hydrocarbons,kg	3.32E-04	
Methanol,kg	9.68E-06	
Methyl isobutyl ketone kg	8.88E-06	

Table C: Hardwood veneer inventory for 1 m^2 rotary veneer (2-2,5mm) & co-product prices (for respective MC assumed in the model)

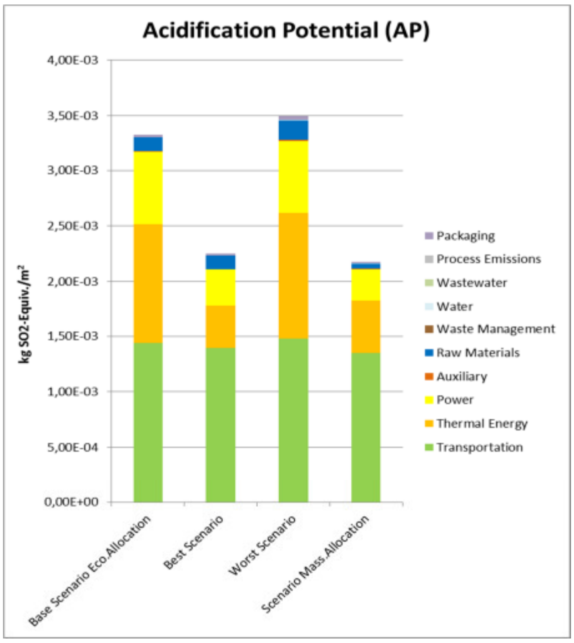
Inventory data from a 1 m^2 rotary veneer (2-2,5mm) in cradle-to-gate (based on species mix).

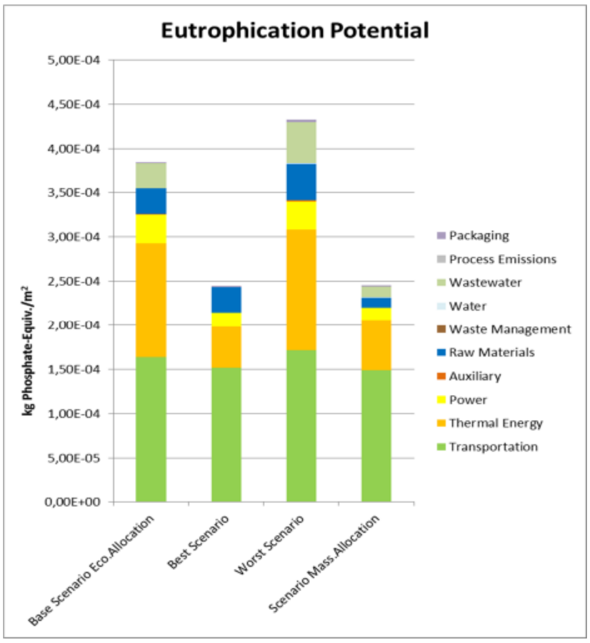
INPUTS	Amount	Price [USD/kg]
Roundwood with bark, hardwood, green, kg	5.46E+00	n/a
Wax (synthetic), kg	4.78E-05	n/a
Electricity, MJ	2.83E+00	n/a
Thermal energy, onsite boiler, MJ	9.40E+00	n/a
Diesel, combusted in industrial equipment, m^3	3.28E-04	n/a
Lubricating oil, kg	6.39E-05	n/a
Water (tap water), kg	1.32E+00	n/a
Water (well), kg	0.00E+00	n/a
Water (rain), kg	1.60E-01	n/a
Steel banding kg	0.00E+00	n/a
Knives (Steel hot rolled), kg	1.00E-04	n/a
Polyethylene-film, packaging, kg	4.47E-04	n/a
OUTPUTS	Amount	Price [USD/kg]
Hardwood veneer clipped (10% MC), kg	1.45E+00	4,25
Hardwood veneer unclipped (10% MC), kg	0.00E+00	3,17
Backing boards (69% MC), kg	0.00E+00	0,191
Bark, hardwood green (60% MC), kg	3.43E-01	0,0109
Bunch clipped waste (8,6 % MC) , kg	1.14E-02	0,0244
Cores (66,6% MC), kg	2.64E-02	0,0285
Flitch surface material (69% MC), kg	0.00E+00	0,0221
Log trimmings (81,8% MC), kg	0.00E+00	0,022
Logs for sale	0.00E+00	0,63
Slabs (69% MC), kg	0.00E+00	0,01
Veneer sheet clipping residue (10% MC) , kg	0.00E+00	0,0869

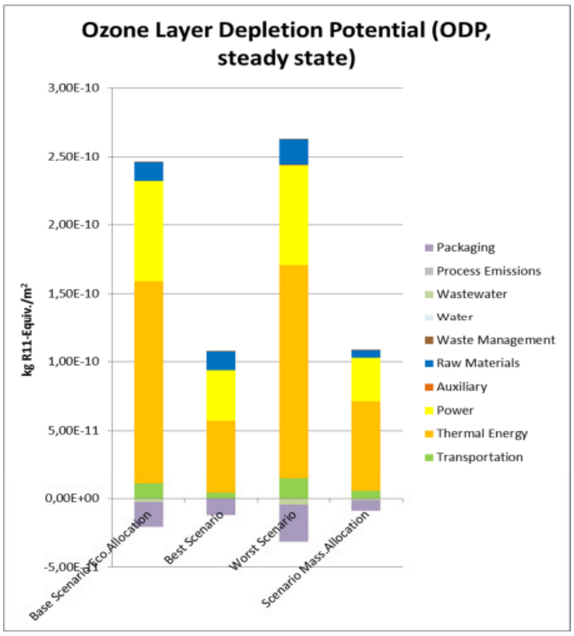
Wood chips (15% MC) (as total wood waste residues), kg	9.63E-01	0,0848
Sheet residues (Trim)	4.00E-01	0,0259
Water vapour, kg	1.82E+00	n/a
Packaging waste (plastic), kg	6.45E-06	n/a
Steel waste, kg	0.00E+00	n/a
Waste (unspecified), kg	3.09E-03	n/a
Sludge, kg	4.85E-04	n/a
Waste water, kg	1.48E+00	n/a
Acetaldehyde, kg	6.86E-06	
Acetone, kg	1.04E-05	
Acrolein,kg	8.96E-06	
Formaldehyde,kg	6.83E-07	
Hazardous air pollutants,kg	1.81E-05	
Hydrocarbons,kg	3.32E-04	
Methanol,kg	9.69E-06	
Methyl isobutyl ketone kg	8.88E-06	

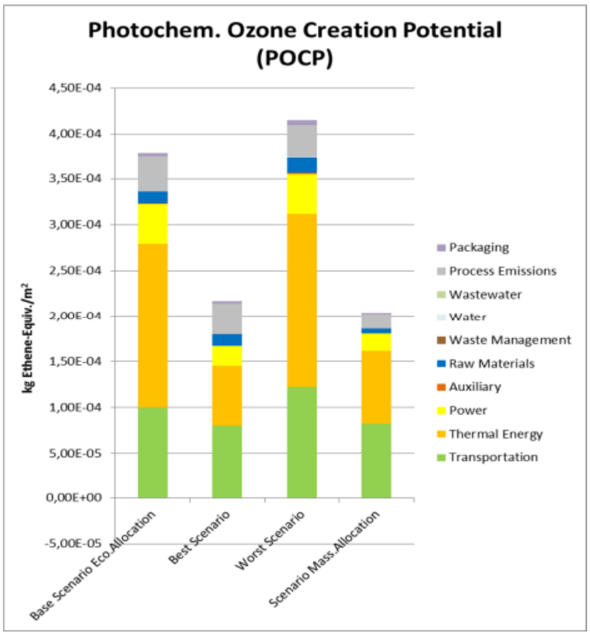
Appendix C Results for other LCIA Categories by best and worst case scenarios

<u>Slicer veneer 0.5-0.6 mm thick with 10% MC</u>

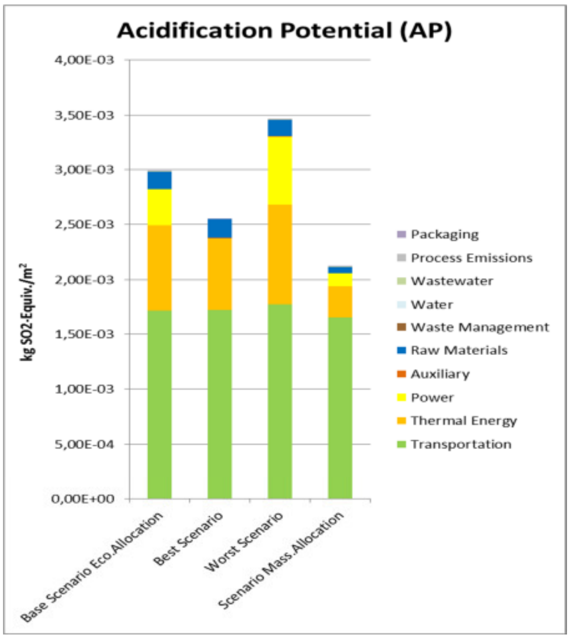


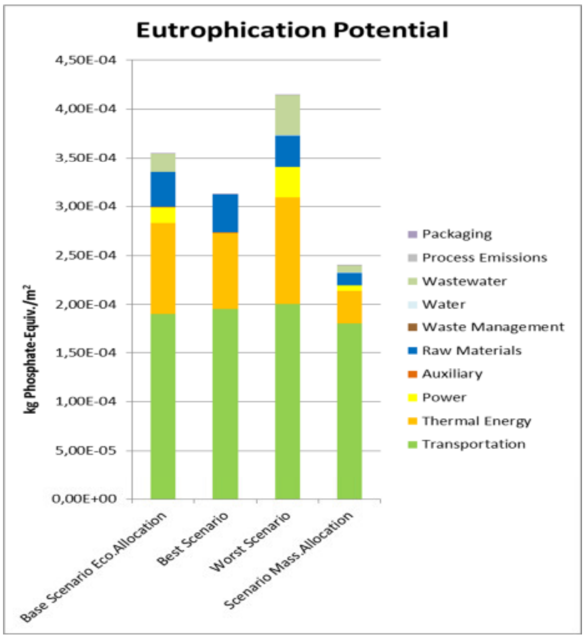


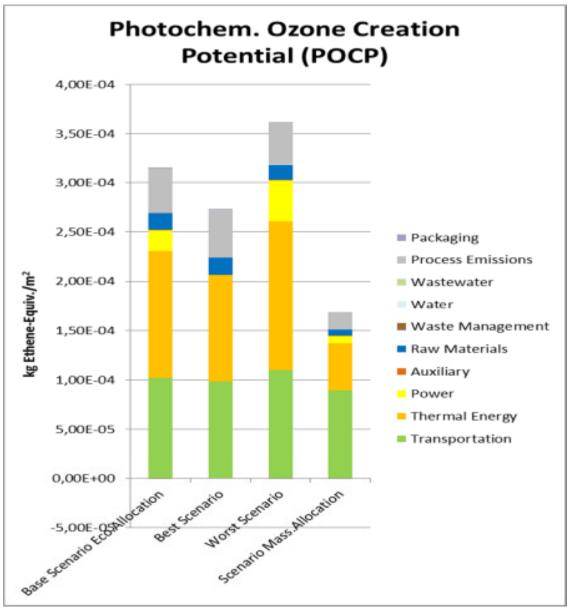


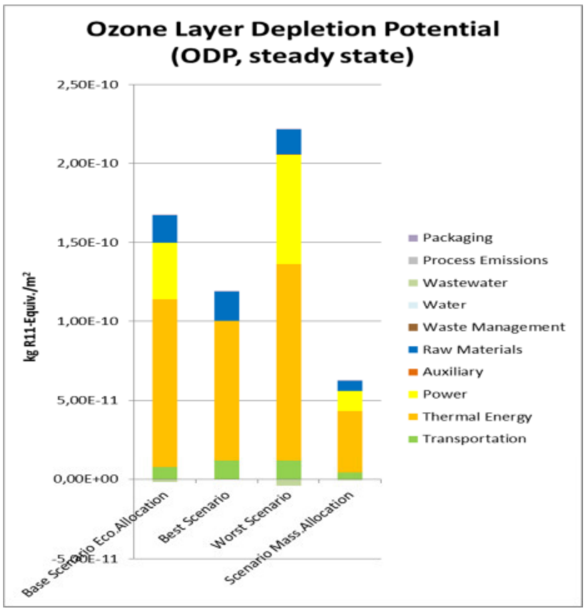


Rotary veneer 0.6 mm thick with 9% MC

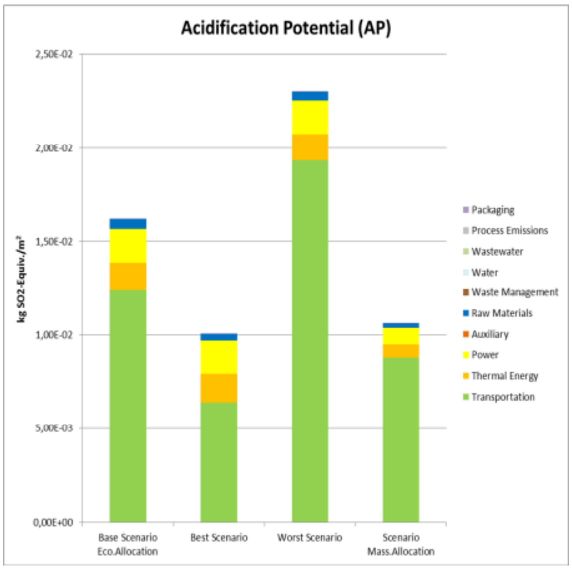


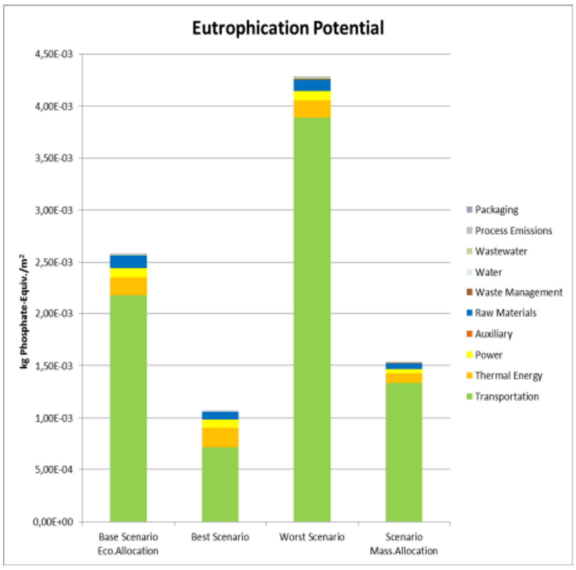


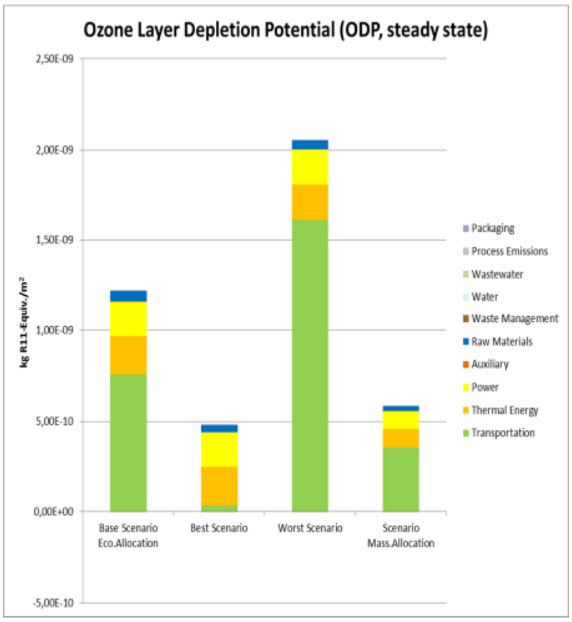


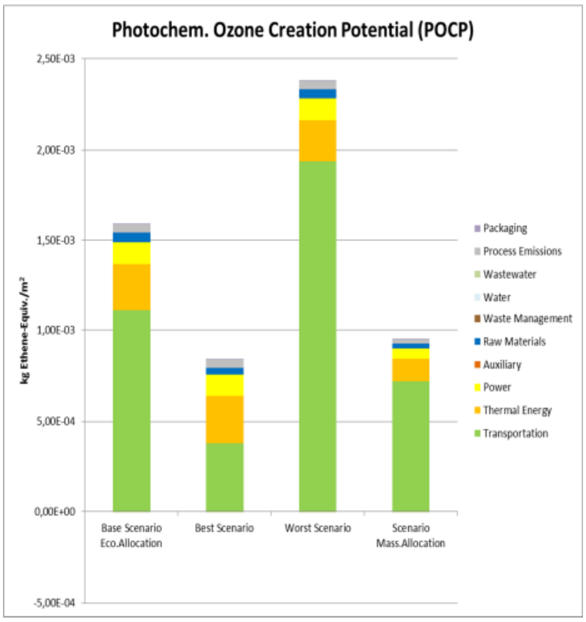


Rotary veneer 2-2.5 mm thick with 9% MC


Acidification Potential (AP)
kg SO2-Equiv./m²
Base Scenario Eco.Allocation
Best Scenario
Worst Scenario
Scenario Mass.Allocation
Packaging
Process Emissions
Wastewater
Water
Waste Management
Raw Materials
Auxiliary
Power
Thermal Energy
Transportation


Eutrophication Potential
kg Phosphate-Equiv./m²
Base Scenario Eco.Allocation
Best Scenario
Worst Scenario
Scenario Mass.Allocation
Packaging
Process Emissions
Wastewater
Water
Waste Management
Raw Materials
Auxiliary
Power
Thermal Energy
Transportation

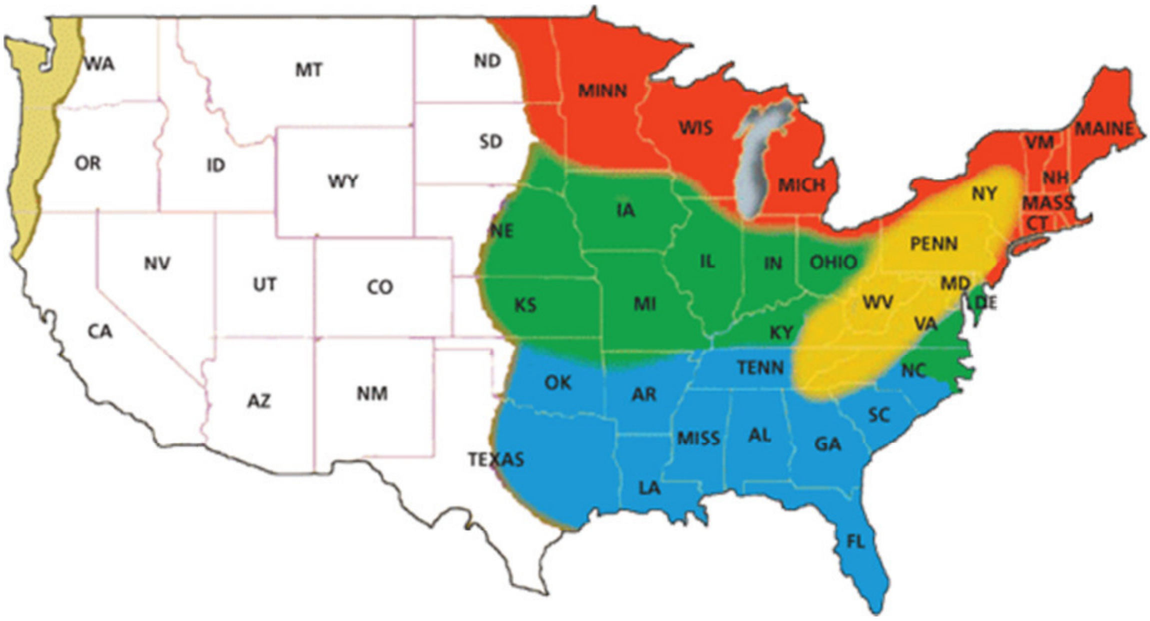

Ozone Layer Depletion Potential (ODP, steady state)
kg R11-Equiv./m²
Base Scenario Eco.Allocation
Best Scenario
Worst Scenario
Scenario Mass.Allocation
Packaging
Process Emissions
Wastewater
Water
Waste Management
Raw Materials
Auxiliary
Power
Thermal Energy
Transportation


Photochem. Ozone Creation Potential (POCP)
kg Ethene-Equiv./m²
Base Scenario Eco.Allocation
Best Scenario
Worst Scenario
Scenario Mass.Allocation
Packaging
Process Emissions
Wastewater
Water
Waste Management
Raw Materials
Auxiliary
Power
Thermal Energy
Transportation

Appendix D : MAIN RESULTS IN TRACI

	Acidifi-cation Air [kg H+ moles-Equiv.]	Eutro-phication [kg N-Equiv.]	Global Warming Air [kg CO_2-Equiv.]	Ozone Depletion Air [kg CFC 11-Equiv.]	Smog Air [kg O3-Equiv.]
Slicer veneer panel (0.5-0.6mm)	3.50E-03	1.15E-04	4.81E-01	2.38E-10	5.09E-02
Rotary veneer panel (0.6 mm)	3.17E-03	1.08E-04	3.32E-01	1.76E-10	5.14E-02
Rotary veneer panel (2-2.5 mm)	1.88E-02	8.23E-04	2.49E+00	1.30E-09	4.44E-01

Appendix E : US HARDWOOD HARVESTING REGIONS



Northern region	Long winters, short summers. Particularly suited to slow grown, tight grained hardwoods such as maple and birch.
Central region	Hot summers, cold winters. Particularly suited to species such as walnut and hickory.
Appalachian region	Variable climate, due to differences in both elevation and latitude. Most hardwood species thrive here.
Southern region	Short winters. Long hot summers. Producing fast grown large dimension species such as tulipwood and sapgum.
Pacific Northwest region	Maritime climate. Separated geographically from the main hardwood growing regions in the East. Red alder and Pacific Coast/Big leaf maple grow exclusively here.

Appendix F : HARDWOOD PROPERTIES

Specie	Density at 12% MC * [kg/m³]
Ash	449
Aspen	673
Basswood	417
Beech	417
Birch	741
Cherry	689
Cottonwood	561
Elm	449
Sap Gum	593
Hackberry	593
Hickory	705
Hard maple	833
Soft Maple	737
Red Oak	705
White Oak	545
Pecan	777
American Tulipwood	609
Walnut	769
Willow	417

* from AHEC species guide (AHEC, 2009)
** from USDA kiln drying manual (USDA, 2000)
*** from AHEC members primary data and statistic

Appendix G : Qualitative Discussion of non-considered impacts

The following impacts are classified with II and III in the ILCD handbook (recommended, but to be applied with caution). Qualitative assessment and some inventory results are used to address these impacts in this study. The discussion on Primary energy demand and particular emissions contributing to the main environmental impacts is included in the next chapter.

6.1.1 Toxicity

Toxicity aspects play an important role in the overall sustainability assessment of products and processes. Toxicity assessment is particularly relevant for chemical products, e.g. pesticides, detergents, household cleaning products, and other chemical products which eventually reach the environment by release of wastewater, waste and off-gas. In the production of hardwood lumber or veneer there are no fertilizers or wood treatment chemicals or any other known substances of particular toxicity concern. Thus, the toxicity assessment is not of high relevance for this study.

Another important aspect of evaluating potential toxicity impacts is the uncertainty of the evaluation models. Currently the most accepted and supportable methodology for the assessment of toxic impacts in Life Cycle Assessment is USEtox™ (Hauschild, 2008).

It is a harmonized consensus model which includes knowledge and data from all other prominent toxicity assessment methods. Its development has been supported by the UNEP-SETAC Life Cycle Initiative, and it is currently named the most supportable methodology in the ILCD Recommendations on Impact Assessment (JRC, 2011). It has also been adopted in the current TRACI 2.0 release, where it is recommended to be used for North America (Bare, 2011).

The precision of the current USEtox™ characterization factors is within a factor of 100–1,000 for human toxicity and 10–100 for freshwater ecotoxicity (Rosenbaum et al., 2008). This is a substantial improvement over previously available toxicity characterization models, but the uncertainty is still significantly higher than for the impacts noted above.

Taking into consideration the low relevance of toxicity aspects for lumber/veneer production and the current uncertainties in the toxicity evaluation models, the USEtox™ characterization factors were not used within this study.

The Ecotoxicity impact of 1 cubic meter of dried lumber delivered to European customer is 0.104 [PAF m3.day] (as defined by USETox2008 method). Most of this impact is associated transportation of lumber to a customer overseas (52%), namely, emissions from container ship operations and from production of heavy fuel oil and diesel at refinery (used for shipping lumber).

Substances of high concern include nitrogen oxides emitted to air (~76% of total impact), and emissions to fresh and see water with the biggest ones being Phenol (~6%), Anthracene (~6%).

The Human toxicity impact of 1 cubic meter of dried lumber delivered to European customer is 0.0000252104 [cases] (as defined by USETox2008 method). This impact is mostly associated with kiln drying (65% of total) and saw mills (30%) processes and is 99.3% defined by emissions to air, mostly by non-methane volatile organic compounds. Air emissions of concern are formaldehyde (69% of total impact), Ethyl benzene (~8% of total), Acrolein (~3%), benzene (~2.2%) and polychlorinated dibenzo-p-dioxins (2.2%). These are emitted mostly during the biomass burning for energy generation.

These results indicate those materials and/or processes which involve ‘substances of high concern’, but shall not be used to make any comparative assertions or be used as a main driver for product development decisions.

6.1.2 Land use (occupation)

In the analysed system land occupation is highly dominated by the forest stage.

Forest can be managed with different intensity. At the low management intensity there are no harvestings in between and the forest is harvested after around 120 years with the total harvest estimated at 339 [m3/Ha] and the share of saw logs comprising 44.8% of the total harvest volume (CORRIM, 2010, Module A). The high intensity management involves thinning cuts and final harvest after approximately 82 years with total harvest of 218 [m3/Ha]. In the high intensity management scenario, saw logs comprise around 33.5% of the total harvest volume (CORRIM, 2010, Module A). Converting this data into area and years of land occupation, 1 cubic meter of hardwood requires from 0.354 [Ha*years] (low intensity management scenario) to 0.376 [Ha*years] (high intensity management scenario). These values also represent the best-case scenario for the cubic meter of lumber (if mass allocation is applied or if the value of pulp logs and saw mill co-products is the same as the value of the saw logs).

The worst case scenario for lumber is if pulp logs and saw mill co-products do not have any value and the whole burden is allocated to lumber. Assuming the worst allocation case (everything allocated to lumber) and the highest volumetric shrinkage rate during kiln drying (14.3% for hickory, AHEC, 2009), the land requirements associated with production of 1 cubic meter of dried lumber are 1.66 [Ha*years]47 for low intensity management and 2.37 [Ha*years] for high intensity management.

Land occupation associated with supply chain comes from mining activities (fuel production chains) and equal 0.28 [m2*year] for cubic meter of hardwood forest and can be neglected (GaBi 5, 2011). The land occupation associated with roads or capital equipment like saw mills can be neglected as it is orders of magnitude smaller than land occupation associated with mining or the growing of biomass.

[47] This unit is used in land occupation terms, It quantifies the amount of land and the time during which the land is occupied and calculated as area occupied multiplied by the years needed.

Summarizing the abovementioned information, wood from low managed forest management requires less land than the wood from highly managed forests does.

6.1.3 Direct and Indirect Land Use Change

Besides the land occupation, the important parameters of land use are how the quality of the land is changed and how does it affect the environment (direct land use change) or how the other land use categories are affected because of the land used for the product.

- direct LUC (dLUC) = effects of direct conversion of land (e.g. forest to bioenergy crop land)
- Indirect LUC (iLUC) = LUC that occurs when the demand for a specific land use change on other land (e.g. change of crop land from food to bioenergy crops & conversion of natural land to food crops land at other locations).

Direct land use change is only of relevance once the production is associated with a change in the land use type and associated ecosystem services. In the system under investigation the main material – wood – comes from naturally re-grown forests. The harvested areas had undergone several iterations of harvesting and re-growth. After harvesting, the land is returned to forest so there is no direct land use change to account for in the timeline of few hundred years.

Regular U.S. Forest Service inventories demonstrate that between 1953 and 2007, the volume of U.S. hardwood growing stock more than doubled from 5,210 million m3 to 11,326 million m3 (USDA, 2008). The same study indicates that U.S. hardwood forests keep growing in size and timber volume, but also that existing forest management practices are contributing to enhanced forest health and diversity. The natural mixed hardwood forest is one of the most environmentally friendly industrial land uses; it offers a greater diversity of tree species than any other temperate hardwood forest resource. Unlike the European and Asian forests, which are heavily dominated by beech and oak, American hardwood forests can supply commercial volumes of over 20 hardwood species, providing ecosystem services close to those of the natural environment.

Conversion of any other commercial land into the hardwood forest would most probably be a positive impact on the land quality including biodiversity and associated ecosystem services.

Land use change was not included in the scope of this study, as based on the qualitative assessment no negative environmental impacts are associated with it.

6.1.4 Biodiversity

No mature methodology is available to evaluate the impacts of industrial activity on biodiversity.

The hardwood forest in US is naturally growing forest; it provides the ecosystem services close to those of the natural ecosystem. All forest owners in the United States are subject to Federal legislation to protect habitats for threatened species. Independent studies indicate that there is a very low risk of any American hardwood being derived from illegal sources or from forests where management practices lead to deforestation or to otherwise threaten biodiversity (Goetzl et al, 2008).

Due to the lack of methodology and the low relevance of biodiversity loss to the hardwood veneer production, the biodiversity was not included as a main indicator in this study.

6.1.5 Water consumption and depletion

There is no agreed standard so far on how to assess water use in a LCA framework. In this study the inventory for water flows was made in following the framework proposed by Bayerat et al (Bayerat et al, 2010). The complete GaBi 6 database complies with this framework, allowing for consistent water modeling. The paragraphs below discuss the main aspects of the hardwood veneer water inventory.

The biggest water balance item is evapotranspiration in the forest (rain water absorbed and evaporated by trees), i.e. green water consumption48. In the eastern US, the hardwood harvest region, average year evapotranspiration rates range from less than 60 [cm] to around 90 [cm]. Combined with the range of the area and time requirements (see paragraph on the land use (occupation) above), the evapotranspiration per 1 cubic meter of dried lumber should be in the range from 1354 [m3] (assuming 38cm evapotranspiration rate) to 21662 [m3]. The range is big due to the different allocation choices possible, different forest management practices and different evapotranspiration rates.

One cubic meter of white oak hardwood lumber has total water inputs of the 6704 m3. This is almost solely comprised by the rain water taken and later evaporated by the forest biomass.

Some of the rain water is stored in the wood and is released during drying. In the most conservative estimation up to 0.64 m3 water per m3 of dried lumber is stored and released in the kiln, assuming hickory with a density of 833 [kg/m3 at 12% MC] and shrinkage rate of 14.3 [%, volumetric shrinkage from 80 to 6% MC). The water released during the kiln drying process is also considered to be green water.

The water use in the background system (fuels, electricity etc.) is less than 30 [m3 per cubic meter of hardwood lumber] from all sources and is mostly the river water associated with the hydropower production. Thus blue water49 consumption is not a high relevance issue in the provision of American hardwood.

Summarizing the water inventory overview, the main element of the water inventory of hardwood lumber is green water consumption. The blue water consumption is negligible.

There is even less consistency available in the LCA community on how to perform a holistic impact assessment of water use in a LCA framework, despite some published suggestions.

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[48] The green water consumption is the amount of water evaporated from the global green water resources (rainwater stored in the soil as soil moisture).

[49] Blue water consumption is the amount of surface or ground water evaporated during a production process (e.g., cooling or irrigation water)

The assessment of impacts that water consumption has on water resource depletion is out of scope of this project and could be the subject for a follow up investigation. Based on the inventory discussed above, however, hardwood lumber is expected to have very low impacts on water resource depletion: the blue water consumption is low, and the green water consumption is excluded from the impact assessment of most available methods50 (Bayaret et al 2010).

[50] The rationale behind this is the assumption that there is no environmental impact associated with green water (i.e. rain water) consumption. Such an effect would only exist if crop cultivation results in alterations in water evapotranspiration, runoff and infiltration compared to natural vegetation. If these alterations do not occur, the use of rainwater would not change the environmental effects that would take place if the studied system was not established).

Appendix H Critical review statement

Critical Review of the study

LIFE CYCLE ASSESSMENT OF US HARDWOOD VENEER

Commissioned by:	American Hardwood Export Council - AHEC
Review Panel:	Prof. Dr. Matthias Finkbeiner, Germany (Chair) Mr. Pankaj Bhatia, USA Prof. Dr. Richard Murphy, United Kingdom
Reference	ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines

The Scope of the Critical Review

The review panel had the task to assess whether

- the methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review was performed according to paragraph 6.2 of ISO 14044, because the study is not intended to be used for comparative assertions intended to be disclosed to the public. However, in view of the desire of AHEC to place the LCA findings in the public domain and to ensure the highest levels of adherence to ISO 14044, most aspects of paragraph 6.3 of ISO 14044 were also implemented.
This review statement is only valid for this specific report dated 29th October 2014.
The analysis of individual datasets and the review of the LCA software models used to calculate the results are outside the scope of this review.

The review process

The review process was coordinated between PE INTERNATIONAL (PE) as the LCA practitioners appointed by AHEC and the review panel. The same parties completed a previous critical review process for AHEC´s LCA study on rough-sawn, kiln-dried hardwood lumber. It was agreed to follow a similar review procedure, but to start the process with the provision of the draft final report.

The first draft of final report was delivered on 29th April 2013. This document was evaluated by the review panel and discussed in a full day meeting on 2nd May 2013 at PE´s offices in Stuttgart. The second draft final report included the decisions taken at this meeting and was delivered to the review team on 12th December 2013 following some further data collection and assimilation. The critical review panel evaluated the draft and provided 145 comments of general, technical and editorial nature by 23rd February 2014.

The comments were discussed between PE and the individual reviewers to establish a common understanding on several comments. PE and AHEC revised the report accordingly and provided the third draft report on 23rd July 2014. This version of the report already addressed the major share of the comments. A few editorial issues remained, which were corrected on a bilateral feedback basis. The edited final report was received on 29th October 2014.

Overall, the feedback provided by the critical review team was adopted in the finalisation of the study. All critical issues and the great majority of recommendations of the critical review panel were addressed in a competent and comprehensive manner. The review panel has checked the implementation of the comments and has agreed that they have been satisfactorily implemented in the final report.

The critical review panel acknowledges the unrestricted access to all requested information as well as the open and constructive dialogue during the critical review process.

General evaluation

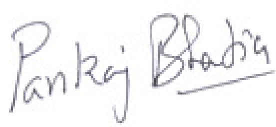
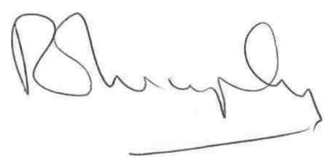
The report is the joint result of a study performed by PE, commissioned and supported by AHEC. A positive feature of the study is the substantial share of primary data collected to reach representative results for American hardwood veneer. The four companies selected for slicer technology, including five facility locations, represent about 40% of total production volume of the Hardwood Plywood Veneer Association (HPVA) members; whereas the four companies with rotary technology and five production sites represent more than 60% of HPVA members. HPVA member companies produce 90% of the hardwood plywood stock panels and hardwood veneer manufactured in North America.

Another commendable aspect of the study is the conservative approach taken with regard to modeling biogenic carbon removals from the atmosphere. The study quantifies the biogenic carbon uptake in forestry, and reports this separately from the cradle-to-gate result. This transparent and unbiased treatment of the biogenic carbon issue supports onward use of the data for future assessments of the complete life cycle of American hardwood veneer.

The scope defined for this LCA study was found to be appropriate to achieve the stated goals. Various assumptions were addressed and tested by sensitivity analyses of critical data and methodological choices. As a result, the report is deemed to be consistent with the scope of the study.

Conclusion

The study has been carried out in conformity with ISO 14040 and ISO 14044. The critical review panel found the overall quality of the methodology and its execution to be of a high standard for the purposes of the study. The study is reported in a comprehensive manner and includes appropriate and transparent documentation of its limitations and interpretation.

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