PE INTERNATIONAL
EXPERTS IN SUSTAINABILITY

Final Report

Life Cycle Assessment of Rough-sawn Kiln-dried Hardwood Lumber

for

AHEC – American Hardwood Export Council

by

PE INTERNATIONAL AG

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ACRONYMS

ADEME	French Environment and Energy Management Agency (French: Agence de l'Environnement et de la Maîtrise de l'Energie)
AHEC	American Hardwood Export Council
AP	Acidification Potential
C	Carbon
CFC	Hydro chlorofluorocarbons
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
dLUC	Direct Land Use Change
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
GaBi5	GaBi 5 is a software for Life Cycle Assessment. GaBi stands for ”Holistic balance“ (German: Ganzheitliche Bilanzierung)
GWP	Global Warming Potential
H^+	Hydrogen Ion
Ha	Hectare
IBU	Construction and Environment Institute (German: Institut Bauen und Umwelt e.V.)
ILCD	International Reference Life Cycle Data System
iLUC	Indirect Land Use Change
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
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

1 EXECUTIVE SUMMARY

The goal of this study was to conduct a Life Cycle Assessment (LCA) in compliance with the ISO 14040/44 standards for U.S. hardwood lumber products. The LCA was completed to: (1) better understand the environmental performance of US hardwood lumber products on a "cradle-to-gate" basis, including transportation to representative international destinations; (2) identify areas with high potential for improvement of environmental sustainability performance; and (3) respond to customer and public requests for environmental information.

LCA is a standardised 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" LCA of U.S. hardwood lumber. Due to the broad range of products produced from the lumber, the use and end-of-life of these final products are excluded from this study. They can be added in product specific studies to reflect the complete life cycle.

The study contains the data on the environmental profile of rough-sawn, kiln-dried hardwood lumber using 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 lumber product consumers, designers and buyers, government agencies, non-governmental organisations, LCA practitioners, and the media.

The main study outcomes can be summarised as follows:

- The main source of environmental impact for U.S. hardwood lumber production at the kiln gate is the kiln drying process. For example, depending on species of 1 inch lumber, it leads to 8-32% of the Global Warming Potential (GWP), 6-26% of the Acidification Potential (AP), and 78-86% of the Photochemical Ozone Creation Potential (POCP).
- The forestry stage is not dominant in overall environmental impact due to the low intensity of U.S. hardwood forest management and reliance on natural re-generation after harvest. Due to removal of biomass in the forest, 56-73% of the total primary energy demand is defined by the forestry stage. In all other indicators the largest share of the forestry stage in the environmental profile of 1 inch lumber is 18% for Eutrophication Potential (EP).
- Transport to customer can be the most significant factor contributing to environmental impact in certain impact categories, notably EP and AP (due to sulphur emissions associated with sea freight). The impact of transport to customer on GWP is also significant, similar to and sometimes exceeding the impact of kiln drying depending on the hardwood species and thickness. The relative impact of transportation is higher for fast-drying species and thin lumber products. For 2.54 cm (1 inch) thick lumber of fast drying species the impact of transportation can be as high as or even higher than the impact of kiln drying, becoming a major source of environmental impact (up to 77% of AP, 75% of EP, and 58% of GWP). For thicker lumber and longer-drying species, the share of transportation in the overall impact is lower.

- The difference in environmental impact between hardwood lumber of different species and thicknesses is very high and environmental profiles should be communicated on a specific species and board thickness basis. For example, the GWP impact of producing lumber from a long-drying species (e.g. oak) can be twice as high as that from a fast-drying species (e.g. pecan) if all other product properties are the same. Similarly, impacts of producing and delivering 2 inch lumber (8.05 cm) can be more than twice that of 1 inch (2.54 cm) if all other product properties are the same.
- There is significant potential to improve the environmental performance of hardwood lumber through alterations to the drying process.

2 GOAL OF THE STUDY

AHEC is conducting a 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** environmental performance of hardwood lumber and provide credible scientific evidence for informed decision making in areas related to the environmental impact of American hardwood products.

Therefore AHEC is interested in:

- compiling life cycle inventory data for hardwood forestry, logging, sawing and drying of selected American hardwood species to facilitate preparation of further LCA studies;
- compiling cradle-to-gate Life Cycle Assessment of AHEC lumber of selected American hardwood species;
- understanding the environmental impact of hardwood lumber production steps, related to the supply chain and transportation;
- understanding the variability in environmental performance of the different hardwood lumber products;
- identifying areas of high importance to the hardwood products environmental performance and areas 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 lumber;
- acquiring the data could be published as inventory datasets in databases like ILCD, ADEME, US LCI;
- supporting external communication with reliable scientific information in Environmental Product Declarations.

The study is intended to be the basis for EPD of typical lumber products. The overall goal of an EPD is to provide relevant, verified and comparable information about the environmental impact from goods and services. The creation of the EPD from this study will follow the EPD system requirements. 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 panel has been engaged to meet the ISO standards for quality control. A publication of the LCA study is foreseen following a successful critical review. Based on the study an EPD will potentially be prepared and published following the ISO 14025.

The study is not intended to be used in comparative assertions intended to be disclosed to the public. EPD are not comparative assertions (ISO 14025).

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 “green washing”, 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 lumber 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 relate to the chapter 3.4.

3 SCOPE OF THE STUDY

The following section describes the general scope of the project that has been set to achieve the stated goals. This includes the identification of specific products to be assessed, the supporting product systems, the boundary of the study, the allocation procedures, and the cut-off criteria.

3.1 SYSTEM DESCRIPTION

The life cycle stages are described in more detail in this chapter and shown in Figure 1.

3.1.1 Forest

The forest aspect of the system includes:

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

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

Hardwood forest in the US in not planted but is naturally grown. No active management is required until the harvest. Hardwood forests 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 harvested by hand felling[1]. 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 (sawing logs) or to the chipping mill (pulp logs). Some biomass (limbs, tops and other unmerchantable materials also known as slash[2]) are left in woods. For the modeled 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 increased constantly over the last 50 years. The U.S. Forest Service forecasts expect an additional increase of American hardwood stock of at least 15% through 2030. Therefore planting of the seedlings has not been modeled as natural regeneration is assumed

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

[2] 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)

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 sawing logs and pulpwood logs. The ratio of pulpwood logs to sawlogs can vary, with sawlogs 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 sawing logs. The chosen allocation approach follows the requirements of PCRs for IBU[3] EPD program and is intended to align to the ECO[4] EPD platform. These requirements aim to harmonise the LCA methodology choices for European construction products. For details on allocations see chapter 3.6. The alternative allocation approaches are evaluated in chapter 4.4.4.

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

3.1.2 Sawing

This process begins with logs in the mill yard and includes:

- sorting and storage of logs; storage in either wet or dry conditions depending on weather and species
- in-yard transportation of logs from the point of unloading to the deck;
- in-yard transportation of logs from the storage deck to the mill in-feed and debarker;
- debarking of the logs (by-product is bark);
- breakdown of logs into rough-sawn lumber, slabs, edgings, sawdust, and chips;
- trimming, grading, and sorting;
- stacking, stickering, and in-yard transportation of rough-sawn lumber to kiln facilities;
- saw sharpening and maintenance of all sawmill equipment and yard transportation vehicles;
- treatment of process air, liquids, and solids.

[3] 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=l=96646193/Home.htm

[4] 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“.

In the sawing process, the hardwood logs are sawn into rough-sawn green lumber (mostly 25.4 mm or 50.8 mm (1 or 2 in) thick, random widths and mostly 2.44-3.66 m (8-12 foot) lengths. Rough sawn lumber is the lumber that was not planed.

The outputs of this process are sawn rough green lumber and wood residues from the sawing process: bark, sawdust, slabs, edgings, and chips (hog fuel is a mixture of the wood residues produced). Most wood residue is sold as a co-product such as mulch, paper chips, feedstock for particleboard plants, etc., while the other residues especially sawdust are combusted as fuel, mostly to dry lumber.

Price data for co-products was used for the economic allocation of saw mill products. The chosen allocation approach follows the requirements of the PCRs for IBU and ECO EPD programs. For details on allocation see chapter 3.6. The alternative allocation approaches are evaluated in the sensitivity assessment chapter 4.4.4.

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

3.1.3 Drying of Lumber

This unit process begins with rough-sawn green lumber and includes:

- pre-dryer (sometimes);
- air drying yards (sometimes);
- walnut steamer (for walnut only);
- drying, equalizing, and conditioning of lumber in a kiln;
- maintenance of all kiln equipment and related yard transportation vehicles;
- treatment of process air, liquids and solids;
- internal transportation.

Some lumber occasionally goes through pre-drying or air-drying, and all lumber is kiln-dried. The output of this process is rough-sawn kiln-dried lumber.

Different drying methods and schedules are used in kiln drying processes and energy consumption varies widely depending on species, lumber thickness and grade, and the adopted drying schedule. The kiln drying process was modeled to reflect these specific features. The daily energy consumption of a kiln is modeled based on the equipment efficiency and size. The number of days inside the kiln is then adjusted depending of the species, thickness of lumber product and amount of moisture needed to be removed from the wood (the moisture content of input lumber and moisture content of kiln-dried lumber). The model developed in this study can be used for assessing environmental impacts of kiln drying for 19 target species, lumber thickness ranging from 0.2 to 5 inches and different pre-drying options.

Please refer to the chapter 3.5.3 for a detailed description of the kiln drying data collection, treatment and representativeness.

3.1.4 Transport

Transportation was modeled taking into account the transportation mode and distances. Primary data, and statistical data from AHEC members and some geographical estimations were used to develop a representative transportation model for AHEC lumber. Please refer to chapter 3.5.4 for more details of the transportation data collection, treatment and representativeness.

Transport methods modeled include transportation of the logs from the forest to saw mill, transportation of green lumber from saw mill to kiln, transportation of the dried lumber to the port of export and hence overseas to the port of import in Europe. The onward transportation of lumber to customers in Europe is also included.

3.1.5 Hardwood species under consideration

The forests of the United States include a wide variety of hardwood species that can be used for lumber production. Some are less available for commercial purposes, and produced in small volumes for regional use only. The species for this study were chosen based on their commercial relevance for AHEC members (export volumes) and the availability of data.

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).

Life Cycle Inventory data for lumber from the following American hardwood species has been generated:

- Ash (*Fraxinus spp.*)
- Aspen (*Populus tremuloides*)
- Basswood (*Tilia americana*)
- Beech (*Fagus grandifolia*)
- Yellow birch (*Betula alleghaniensis*)
- Cherry (*Prunus serotina*)
- Cottonwood (*Populus deltoides*)
- Red elm (*Ulmus rubra*)
- American Gum (*Liquidambar styraciflua*)
- Hackberry (*Celtis occidentalis*)
- Hickory (*Carya*)

- Pecan (*Carya illinoinensis*)
- Hard maple (*Acer saccharum, Acer nigrum*)
- Soft maple (*Acer rubrum, Acer saccharinum*)
- Red oak (*Quercus* spp.)
- White oak (*Quercus* spp.)
- Tulipwood (*Liriodendron tulipifera*)
- Black walnut (*Juglans nigra*)
- Willow (*Salix nigra*).

3.2 System Boundaries

The system boundaries were defined following the European core rules for the product category of construction products (EN 15804, 2012)[5] and specific PCR for wood materials (IBU, 2009) to enable the study results to be used in EPD communication.

Rough-sawn, kiln-dried hardwood lumber exported by AHEC members is a raw material for construction and furniture-making and requires additional cutting and shaping. Thus, the Use and the End-of-Life life cycle stages depend highly on the final product and are out of AHEC members' control. To address the goals stated, the cradle-to-customer gate system was chosen.

AHEC members export sawn lumber to Canada (33%), to Europe and China (22.5% each), Mexico (9%), South East Asia (8%) and other regions (5%). The percentages represent the average share of export volumes in 2003-2009. As the impact of transportation is an important discussion and communication for AHEC products, the system was defined to include the overseas transport of lumber. Europe was chosen as the customer destination location for this study as it has significant transportation distance, high share of export and an increased market who are interested in environmental aspects.

The product system under study is a cradle-to-customer gate system covering process steps from the point of forestry and harvesting to the point of delivery to the importers yard in Europe:

- Hardwood forestry management and logging;
- Saw milling of hardwood;
- Manufacturing of rough-sawn kiln-dried lumber in the US;
- Cradle-to-gate production of energy and ancillary materials needed to manufacture the lumber;

[5] 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.

- Handling of production wastes generated in the cradle-to-gate system;
- Transportation of hardwood logs and ancillary materials within the cradle-to-gate system;
- Transportation of lumber to the customer yard in Europe.

Elements excluded from the system are the production of capital equipment, human labor and commuting. These elements are traditionally excluded from the product-LCAs as they are assumed to fall far below the cut-off criteria. Table 1 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 1: System boundary – inclusions and exclusions

Cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

included	examples
Production of raw materials	• Forest logging for lumber manufacturing
Production of auxiliary materials	• Production of lubricants for equipment
Energy production	• Production of electricity and thermal energy needed for lumber manufacturing
Operation of primary production	• Energy and material requirements of saws and kilns
Transport	• Transport of logs from forest to saw mill
excluded	examples
Construction of capital equipment	• Production of chain saws • Construction of sawmill and kiln buildings
Human labor and employee transport	• Production of food for employees • Employees commuting to work
Use phase and EoL phase	• Production of final product from rough-sawn kiln-dried lumber • 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 lumber at a later stage. The system boundary for the system under investigation is given in Figure 1 below. All cradle-to-gate process steps and transportation to customers in Europe are included with the customer gate-to-grave system being out of scope.

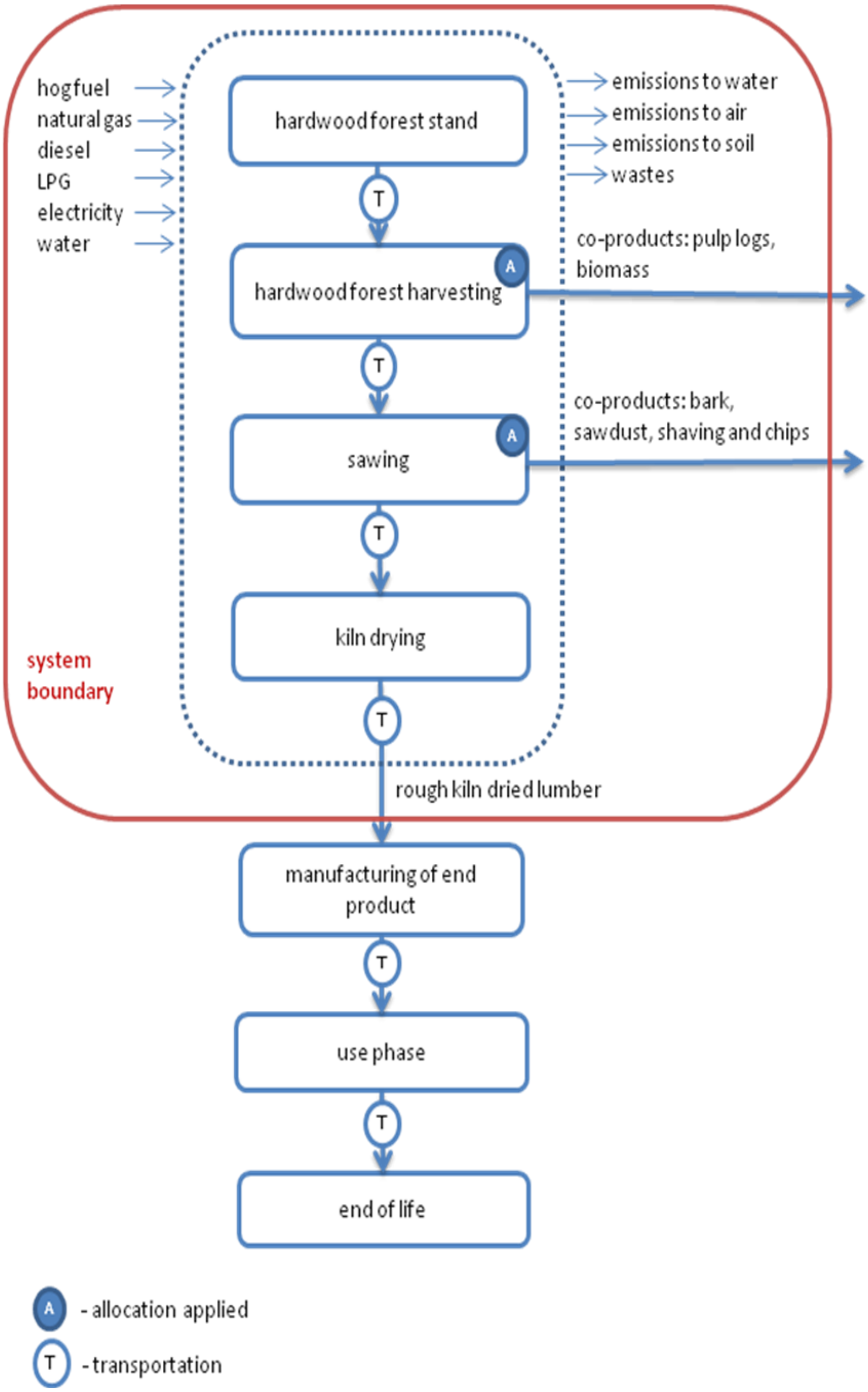

Figure 1: Life cycle flow diagram

Simplified system boundary for Cradle-to-gate plus transport LCA of rough-sawn, kiln-dried US hardwood lumber.

3.3 FUNCTION AND FUNCTIONAL UNIT

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

3.3.1 Function

Lumber is an intermediate product further processed into final products to be used for a wide range of applications, from fine furniture and cabinets to internal joinery such as doors, stairs, floorings and paneling.

3.3.2 Functional Unit

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

For hardwood lumber the chosen functional unit and reference flow declared in this report is **1 cubic metre of rough-sawn kiln-dried lumber** of specific species, moisture content and thickness delivered to the European customer. The table below describes the range of products covered by the study.

Table 2: Products covered

Hardwood lumber product range covered in the cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

Species	19 species
Thickness	0.2 - 5 inches
Density	394 – 788 kg/m^3 (species dependent)
Moisture content of dried lumber	7% MC
Technology	Conventional kiln drying

The FU chosen for lumber products is consistent with the Product Category Rules (PCR) for solid wood products for the IBU[6] and ECO[7] EPD programs.

[6] 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

[7] 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“.

As the products covered by the study vary in several aspects, a base scenario product was defined to simplify the report and to serve as a basis for the comparison with other scenarios. White oak lumber, of 1 inch thickness was chosen as the product for the base scenario. White oak is the biggest commercial export species (more than 41% of export volume to Europe in 2006-2010 (AHEC statistic data) and 1 inch thickness is the most common lumber thickness exported (AHEC judgment). The table below describes the base scenario.

Table 3:Base scenario

Base scenario used in cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

Species	White Oak
Thickness	1 inch
Pre-drying and air-drying	None
Moisture content of dried lumber	7% MC
Technology	Conventional kiln drying

3.4 Selection of Impact Assessment Categories

3.4.1 Main indicators

A comprehensive set of environmental impact categories has been investigated. 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 inventory flows and environmental 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 if not recommended by the European EPD rules for construction products (EN 15804, 2012) and some are addressed qualitatively (see also chapter 3.4.3). 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 4. While the indicators chosen for this study are latest CML indicators (CML method from 2001, factors updated 2010), the nomenclature in TRACI[8] is included in the table and main results in TRACI units are reported in Appendix C, taking into consideration the US location of many study stakeholders.

[8] Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), EPA

Table 4: Life cycle impact assessment categories & indicators

LCIA categories and indicators used in cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

Category Indicator	Impact category	Description	Unit	Reference
Energy Use	Primary Energy Demand (PE)	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, uranium, 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, 2006, *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	Guinée et al., 2001, factors updated in 2010
	Stratospheric Ozone Depletion		CFC 11 equivalent	Bare et al., 2011

* 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 CO2.

3.4.2 Optional elements of LCIA

Optional elements of the ISO 14040/44, 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 included contribution analysis (identification of the greatest contribution to the indicator result), and scenario analysis (identification of how changes in data and methodological choices affect the results of the LCIA).

3.4.3 Impacts not considered in a quantitative way

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 (direct and indirect)
- Water related impacts
- Biodiversity

Qualitative assessment and some inventory results are used to address these impacts in this study. Chapter 4.1 contains the discussion on the potential relevance of these issues for the hardwood lumber environmental profile, estimations and relevant inventory data.

3.4.4 Biogenic carbon

During growth, carbon is stored in the wood via photosynthesis. This biogenic carbon is stored in the lumber and its subsequent products. The carbon stored in biomass will - sooner or later- be released – at the end of the product's life cycle. The end of the product's life cycle is not included in this study. The potential benefits from carbon storage, delayed emissions or substituting effect could be fully excluded or accounted differently according to different standards. To enable study stakeholders to utilise the data for different applications, and to avoid the AHEC communication being perceived as "green washing", the stored (biogenic) carbon will be clearly quantified in the inventory for transparent 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 lumber product, e.g. carbon stored in forest leftover biomass (e.g. small branches) or saw-mill co-products (e.g. chips, dust) is not assigned to the lumber. It is assumed to be eventually converted back to CO2 and emitted. Carbon in the forest floor or forest soil is not assigned to the lumber. Only the carbon that is stored in the final lumber product is accounted as stored carbon.

Not enough data is available on the carbon content in different hardwood species and a conservative value 46.27% carbon in abs dry mass was modeled as carbon storage for all hardwood species. This is a minimum value reported for hardwoods (Lamlom, Savidge, 2003).

Besides the carbon stored in the final lumber product, removals from the atmosphere from biogenic sources are not modeled in this study. Therefore, Biogenic carbon dioxide emissions are modeled as carbon neutral (no impact of the GWP) as they are offset by the uptake in biomass.

3.5 Data Collection And Treatment

Primary and secondary data collected were provided in a consistent way to GaBi 5 background data. Table 5 illustrates an overview of the main production steps and the data sources.

Table 5: Data sources overview

Sources overview for cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

data	data source
hardwood forest stand establishment and harvesting	CORRIM, adapted with prices from secondary data (industry price reports) and with species-specific densities
hardwood sawmill	CORRIM data and primary data from 20 AHEC members. Adapted with species-specific densities. The prices for the co-products were provided by Hardwood Publishing Co., Inc.
air-drying and pre-drying	AHEC members primary data
Steaming (walnut only)	AHEC members primary data
kiln drying	AHEC members primary data from 46* companies, and USDA published values
transportation	primary data on modes and distances, GaBi 5 data on emissions
background data (fuels and energy)	GaBi 5 (2011)

* 46 AHEC companies that provided primary data represent approximately 20% of AHEC members and approximately 12% of the hardwood lumber production volume. See also data representativeness chapter 3.8.

3.5.1 Forest

Forest model is “generic” for US hardwoods (not specie-specific) although certain species-specific aspects such as density, moisture content and transport needs were incorporated.

After extensive research, forestry data from The Consortium for Research on Renewable Industrial Materials (CORRIM) was found to be the only feasible data source for North American hardwood forestry inventory.

Data for forestry for the study was taken from CORRIM research (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 weighted average of three forest management scenarios developed for the region.

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 have been developed by CORRIM research and 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. The module A of the Phase II CORRIM research was taken as the basis for modeling the hardwood forest.

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.

Northeast-North Central regions cover forests from Minnesota to Maine and south as far as Missouri, West Virginia and Pensylvania. Appendix D contains the maps 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 AHEC members by regional location and where approximately 46% of total US hardwood annual removals take place.

The hardwood harvesting and lumber production volumes are split around half between SE and NE/NC regions (Pacific Northwest contributes only a few percent to the total of US hardwood lumber manufacturing). No data on hardwood forestry is available for the SE region, so the data from NE/NC region was extrapolated to represent the US hardwood forestry. It is estimated that this data assumption has very minor impact due to (1) SE region provides a different hardwood 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 lumber environmental impact is relatively small so the differences in forestry practices have small impact on the environmental performance of the hardwood lumber. For discussion on forestry data representativeness please also refer to chapter 3.8.

The forestry 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-specific densities (at 80% MC) to reflect the differences in species mass for transportation.

The allocation between saw logs and pulp logs was made based on the average saw log and pulp log prices from 2009-2010 and are not species specific: 43.6 [$/m^3] for saw logs and 32.7 [$/m^3] 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 saw logs vary substantially both across species and grades. For example, the white oak saw log may cost a third of the same grade as hard maple. Furthermore, saw log prices vary within the species with, for example, hard maple of the lowest grade of saw log three times cheaper than the highest grade.

(Northeast Timber Exchange, 2012). To further complicate the issue, the wood prices are not very stable with the price relationship of pulpwood to saw log fluctuating over the years.

The species and grade-specific allocation was not performed to avoid over-complication of the report due to too many possible products. However the interpretation of results chapter evaluates the impacts of alternative allocation of lumber LCA results (chapter 4.4.4), suggesting that even in extreme cases the results for lumber will not be affected by more than 12%, with the exception of primary energy demand (PED) that can increase by up to 71% which is related to PED from renewable sources.

The primary energy is extracted from the environment when wood is harvested. The primary energy consumption from wood harvesting (net calorific value) is the energy incorporated in wood as was assumed to be 10.33 MJ per kg of wood (for all species).

The hardwood forest model was built in the GaBi 5 LCA software, using the CORRIM data on hardwood forestry management and logging. GaBi 5 datasets on fuels and transportation were used.

3.5.2 Sawing

Data for hardwood sawing was taken from primary data from AHEC members and CORRIM research (CORRIM, Module C, 2008 and Module L, 2010). The CORRIM data on sawing reflects average hardwood log sawing inventory per kg of hardwood lumber output (abs dry) in Northeast/North Central (NE/NC) and South East (SE) regions of the US. The CORRIM inventories were developed based on the primary data from 20 mills for NE/NC and 12 mills for SE regions with secondary data being collected from peer-reviewed literature. For more information on CORRIM research and documentation please refer to the previous chapter.

The hardwood harvesting and lumber production volumes are split around 50:50 between SE and NE/NC regions (Pacific Northwest contributes only a few percent to the total US hardwood lumber manufacturing). The saw mill inventory data from CORRIM was averaged across NE/NC and SE regions and geographical coverage is 96-97% of the hardwood saw mills.

Primary data was collected from AHEC members on saw mill energy consumption. Data from 20 AHEC members confirmed the CORRIM values are in an appropriate range, on the conservative side. CORRIM values were adopted for the base scenario, and the range of value from primary data was used to check the possible variation in a scenario assessment.

Prices of saw mill co-products were provided by AHEC from the Hardwood Review data on US hardwood lumber (Hardwood publishing, 2011). According to AHEC, this data source is extremely comprehensive and representative of the industry as a whole. The prices are averages from weekly data across 1 year and across 7 key hardwood species and grades.

The total mass of the sawmill product output was adapted based on the species-specific density. Table 6 summarises the inputs and outputs of the saw mill process and prices used for economic allocation.

Table 6: Generic hardwood saw mill inventory & co-product prices

Inventory data used for modeling saw mill in cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber. Not species specific, only outputs are adjusted with specie-specific densities.

INPUTS	amount	Price [USD/kg]
Roundwood, hardwood, green, m^3	3.16E-03	n/a
Bark, hardwood, green, kg	1.07E-01	n/a
Natural gas (combusted in industrial equipment), litres	4.02E-05	n/a
Gasoline (combusted in industrial equipment), litres	1.34E-04	n/a
Electricity, onsite boiler, kWh	3.59E-03	n/a
Electricity, from grid, kWh	9.89E-02	n/a
Diesel, combusted in industrial equipment, litres	1.43E-03	n/a
Heat, onsite boiler, MJ	2.63E-01	n/a
OUTPUTS	In mass % of the output*	Price [USD/kg]
Sawn lumber, hardwood, rough, green	56 %	0.77
Sawdust, hardwood, green	4%	0.025
Hogged fuel, hardwood, green	6%	0.028
Bark, hardwood, green	6%	0.029
Woodchips, hardwood, green	18%	0.032
Wood fuel, hardwood, green	10%	0.029

* The product outputs are provided in mass % of total output as they are calculated for each species based on the species green density. Species specific average moisture content used for calculation can be found in the Appendix E.

3.5.3 Drying of lumber

Kiln-drying of lumber consumes more energy than any other lumber production processes and primary data from 46 AHEC members together with literature values was used to model the kiln drying process in a representative manner.

The energy for lumber drying originates from natural gas or from biomass burned onsite. Average energy mix is estimated as 90% biomass and 10% natural gas. This share is derived from the primary data of 35 AHEC members[9] and is consistent with CORRIM research findings (modules C and L). It is also possible to dry lumber with solar energy (solar kilns) but these were excluded from the study as this study focuses on dominant conventional kiln technologies.

[9] 46 AHEC members provided primary data. However, not all members have all production stages in their plants and not all values were reported by every member. So the amount of data points for specific value could be less than 46.

As mentioned in chapter 3.1.3, the energy consumption of lumber drying depends on multiple factors: wood species, lumber thickness, presence and type of pre-drying (air drying or drying in the pre-dryers). The final product can be dried to 6% or only to 12%, affecting the drying times required and subsequently the energy consumption. During the drying, wood shrinks and up to 14.3% of the volume can be lost depending on the species (14.3 % is the shrinkage rate when drying hickory from 80 to 6% MC). Fact is that the kiln efficiencies can vary, affecting the energy consumption.

It was essential for the goal of this study to capture these differences to be able to evaluate the environmental performance of the hardwood lumber products. The approach taken is described in the paragraphs below; it covers the differences in drying between different hardwood lumber species and products and follows a conservative approach to avoid underestimation of potential hardwood lumber impacts: where a range of values was available the option with the highest environmental impact was applied to stay conservative. For the further description of the kiln drying modeling approach please refer to chapter 3.5.3. The main data sources for developing product-specific kiln inventories are primary data from AHEC members (46 companies) and the industry standard USDA manual on drying hardwood lumber (USDA, 2000). Additionally, AHEC publications were used to reference hardwood species average densities and shrinkage rates (AHEC, 2009).

Kiln energy consumption per day

Data from USDA on kiln efficiencies and energy consumption of hardwood kilns per day were validated through AHEC member interaction. Primary data on kiln efficiencies and daily energy consumption was collected from 30 AHEC members. USDA values are slightly higher than the reported average from primary data and were adopted as a base scenario (Table 7).

Table 7: Kiln energy consumption, main parameters

Kiln energy consumption values used in cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

Kiln parameter	details	unit	default value
Kiln efficiency	% energy that ends up evaporating water. Losses are initial heating, ventilation, losses through walls etc.	[%]	53
Kiln power consumption	The electric power used by the kiln for fans, etc. The power is assumed to come from the power grid.	[kWh/MBF[10]/day]	17
Kiln thermal energy consumption	The thermal energy used in the kiln to dry the lumber, before heat loss. The thermal energy is assumed to come from an onsite boiler	[kWh/MBF/day]	24.85

[10] MBF stands for thousand board feet. One MBF is this study equals 2.36 cubic meters. It is a unit widely used in US wood industry. It was not converted into the cubic meters in the tables due to different conversion scales possible and also to enable the AHEC members to relate to the reported values.

Pre-drying & steaming

Sometimes the lumber is air-dried before entering the main kiln. Air drying can be natural or utilise energy to power fans. Sometimes the lumber is dried in pre-driers before entering the main kiln. It should be noted that practices vary between species and mills. Drying the lumber before entering the main kiln shortens the time needed in the main kiln and is expected to lower the total energy demand for kiln drying. For the base scenario it was assumed that lumber of all species goes into the main kiln without pre-drying, at the average green moisture content of the respective species (see species properties in the Appendix E). Alternative scenarios with air-drying and pre-drying are assessed in the interpretation chapter.

Walnut lumber is in most cases steamed before the drying process. The sapwood of walnut is white while the heartwood sap is dark, which is considered unattractive for further processing. The practice of steaming was developed to turn sapwood to the colour of heartwood. The base scenario for walnut includes steaming where the walnut lumber is steamed for 72 hours and a total of 796 MJ/m^3 of medium pressure steam (627 pounds of steam per MBF) is consumed during this process (primary data from 1 AHEC walnut lumber producer). Lumber of all the other species does not require the steaming step.

Drying times

Drying times for different species were taken from the USDA hardwood drying manual (USDA, 2000). The data is the minimum drying time required to dry 1 inch lumber of a particular hardwood species from 80% to 6% moisture content; the manual also specifies that in practice the drying time is at least 25% higher than the minimum times. Following the conservative approach, the minimum drying times as reported by the USDA manual were increased by 50%. The resulting drying times vary from 6 days for pecan to 34.5 days for white oak.

To account for drying different thickness, a conversion factor of $X^{1.406}$ (where X is drying time for 1 inch lumber) was used as the relationship between the lumber thickness and drying time is not linear. USDA hardwood drying manual (USDA, 2000) provides the drying factors for different lumber thicknesses of the same species. The factors were plotted and the exponential function was defined to fit the plot (R-value of 0.998). The drying time of a target thickness is calculated as follows.

$$\textbf{Drying time of thickness X= drying time of 1 inch * } X^{1.406}$$

The function allows calculation of the drying time for custom lumber thicknesses between 0.508 and 12.7 cm (0.2 - 5 inches).

USDA drying times define the drying days when lumber is entering the kiln green (at 80% MC) and leaved the kiln at 6% MC. In practice, the lumber can enter and leave the kiln at different moisture content levels. The drying time depends on the total moisture that is removed during the kiln drying process but also on the moisture content during the drying. At high moisture contents the water evaporates fast, and the evaporation slows down as the moisture content goes down. This exponential function is slightly different for each species. The exponential function was developed based on the published plots for drying spruce wood (Ananias et al, 2009). Figure 2 below depicts the drying time factor as a function of moisture content as adopted in the LCA model. This curve is an estimation allowing accounting for the fact that it takes more time to dry the final percentages of moisture, than it does for the first percentages of moisture.

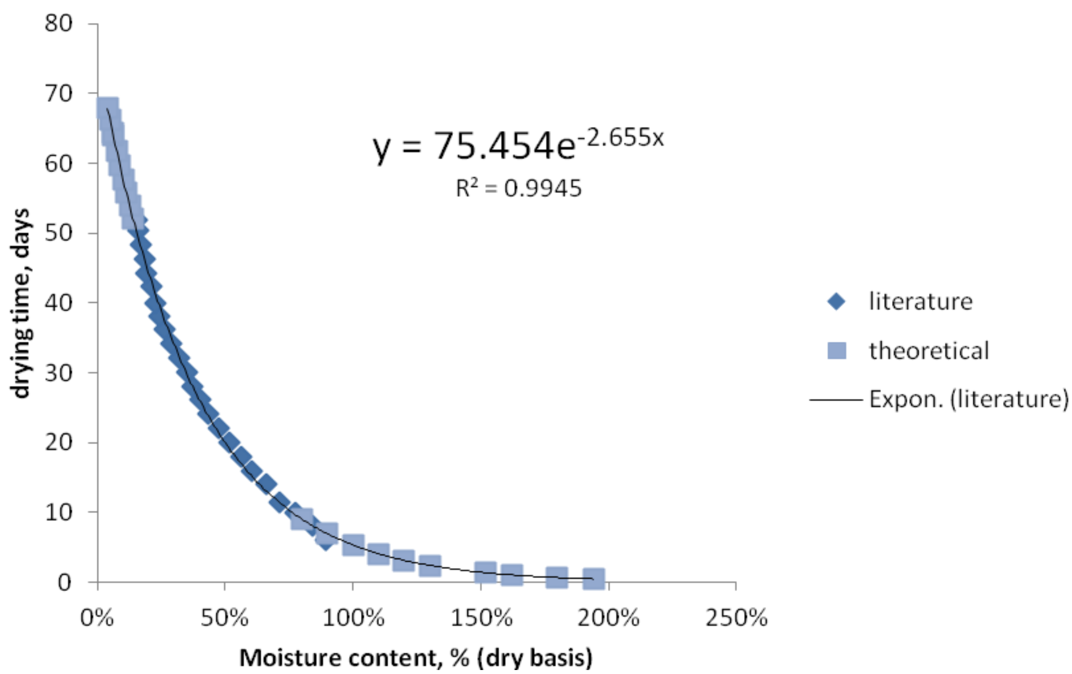

Figure 2: Drying time as function of moisture content[11]

VOC emissions

During the kiln 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 lab measurements was adopted in the model (Rice and Erich 2006). The VOC emissions from kiln drying are species, temperature, wood type (sapwood or heartwood) and moisture dependent. The estimated NMVOC release per cubic metre of lumber in this study is assumed to be 0.669 kg (3.5 lb/MBF). This amount was modeled as a non-specific volatile organic compound emission to air (VOC) contributing to the POCP and toxicity impacts. The estimated VOC release is under 3.5 lb/MBF in all cases. Some samples from red oak had produced estimates that were much higher than expected but the source of these variations is unclear. Thus the assumption taken is a very conservative assumption for all species (with the potential underestimation for red oak) and does not reflect the above-mentioned variability.

[11] Function utilized to adjust the drying time in kiln in cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

3.5.4 Transport

Average transportation distances and modes (container ship, truck, and rail) were provided by AHEC and member companies. Fuel use and the associated emissions were calculated using pre-configured transportation models from the GaBi 5 database 2011. The transportation models for truck transport were based on the GaBi 5 database using emission standards and factors for trucks in the US and EU. The fuel used for transport was modeled 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-specific density and the moisture content at the respective transportation stage.

Primary data from 35 AHEC members suggests that transportation distances from forest to saw mill range from 48 to 241 km (30 to 150 miles) and the transport mode is 100% truck. Average distance of 96.5 km was taken for all species.

Transportation of sawn green lumber from the saw mill to kiln varies greatly. AHEC members (43 members reported data) report distances from a few hundred metres by forklift up to around 1300 km. Some lumber producers have saw mills combined with kiln operations on one site while others operate them separately. All primary data points were reporting transportation by truck. An average value of 117.5 km was modeled with trucking as the transport mode.

Transportation from kiln to port of export was modeled taking into account the specific species harvesting location and its main export port. Appendix B contains the tables with calculations of distances per species. These distances (from 504 km for Beech to 1328 km for Walnut) were used in calculating the respective species inventory. Trucking was assumed as the transport mode.

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

The Us truck dataset is modeled 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. Lumber truck transport is assumed to have 57% utilization ratio (average in US for poles truck) 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 modeled based 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). 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 5 ppm. Table 8 summarizes the transport distances, modes and parameters as used in the LCA.

National averages for fuel inputs and regional US electricity grid mixes were used from the GaBi 5 database 2011. GaBi databases are updated on a yearly basis. The GaBi datasets used for this study are based on the data from 2000-2011.

Table 8: Transport distances, modes and parameters

Transport modeled in cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

Transport	Mode	Average Distance [km]	Share of biogenic carbon [%]	Sulphur content in fuel	Utilization ratio [%]
logs from forest to sawmill	US Truck, diesel driven (truck for pole, logging, pulpwood, or pipe transport), 9 t payload capacity	96.5	8	15 ppm	57
sawmill to dry kiln	US Truck, diesel driven (truck for pole, logging, pulpwood, or pipe transport), 9 t payload capacity	117.5	8	15 ppm	57
dry kiln to US overseas port	US Truck, diesel driven (truck for pole, logging, pulpwood, or pipe transport), 9 t payload capacity	504-1328 (species specific)	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 saw mill unit processes generate co-products in a way that it is not feasible to split the process into the smaller processes (each producing only one product), so the allocation is necessary. Due to the high difference in the co-product prices, the mass allocation (or any other physical mean allocation) does not capture the underlying revenue intention of the production process. Therefore the price 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 between forestry and sawmill co-products. The allocation approach follows the requirements of the core rules for EPD's surrounding construction products in Europe and complies with the 14044 ISO standard.

Prices for the forestry co-products are reported in chapter 3.5.1 with the prices for saw mill co-products being reported in chapter 3.5.2.

In both cases some primary data on prices was collected from the AHEC members. However, due to the hardwood industry specifics with hundreds of small companies and mills, the representative values were not reached and secondary data had to be utilised from statistical price reviews.

As mentioned before, the prices are subject to change due to variation within years, species and grades. The scenario assessment (chapter 4.4.4) includes the evaluation of extreme scenarios, where all the values are assigned to the lumber or where the value of the co-products is the same as the lumber price.

Stored carbon was not allocated based on the price. For the approach on stored carbon please refer to the chapter 3.4.4.

The background data utilized also has allocation applied: it includes for example energy content allocation; price allocation etc. Allocation mean is carefully chosen and documented in the GaBi 5 datasets documentation [GaBi 5].

3.7 Cut-off Criteria

The cut-off criteria for the study are described below. The flows that were excluded following these criteria are listed in Table 9. The decision on the exclusion of materials, energy and emissions data was made following the aforementioned criteria:

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 1 in chapter 3.2 contains the list of elements excluded from the system boundary (like buildings or human labor). These elements are assumed to fall far below the cut-off criteria and no estimation is provided on them. In the study, some minor flows were excluded following the cut-off criteria described above. The excluded flows are listed in Table 9 with an estimation of their relevance.

Table 9: Cut off - excluded flows

Flows excluded from cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

flow	description	Estimated amount per m^3 of lumber
Thin wood strips	Thin non-treated wooden strips are used in the drying to create space between individual lumbers for better air flow. The strips are reusable.	<0.01 kg
Water for logs sprinkling	When stored, logs in the log yard are typically protected by water sprinkling during warm weather to reduce checking, sapwood stain, and decay.	<1 l
Log ends coating	If the logs are stored for long time, a wax-based sealer can be sprayed sometimes on the logs ends to prevent drying.	<0.01 kg
Water use for boiler refill	Most of the lumber mills have a boiler onsite. Water in the boiler requires refills.	<0.01 kg
Total mass of excluded flows per product FU is estimated to be less than 0.2% of the saw mill of kiln inventories.		

3.8 Overall Data Quality and Representativeness

The study is based on the data from CORRIM research, literature values, primary data from AHEC members and data from the GaBi 5 databases.

Collected primary data went through quality and plausibility checks, and all unreliable data points were excluded from the data. Literature based values were confirmed with primary data from AHEC hardwood product producers. For all key parts of the model the range of values were assessed and the conservative values were taken for the assessment of potential environmental performance.

Based on key quality criteria discussed below, the overall quality is estimated as very good. For the potential study limitations associated with data please refer to chapter 3.9.4.

The data quality is concluded to be the best available data and is sufficient for the defined goal and scope.

3.8.1 Precision and completeness

All relevant foreground (gate-to-gate) data is either primary data, literature data confirmed by primary data or based on CORRIM data. As no additional primary data was available and the used literature data was confirmed by primary data, no better precision is reachable within this project. However for future up-dates additional data should be collected. All upstream data is consistently GaBi LCI data with the documented precision.

All relevant, specific processes for the different options are considered and modeled to represent each specific situation. Any upstream processes are taken from the GaBi databases (see GaBi 5 documentation).

3.8.2 Consistency and reproducibility

To ensure consistency only primary data of the same level of detail and upstream data from the GaBi 5 data base 2011 were used. While building up the model cross-checks concerning the plausibility of mass and energy flows were continuously conducted. The provided primary data has been cross checked and compared with internal as well as public sources. No inconsistency could be found.

The reproducibility is given for internal use since the models are stored and available in a database. For the external audience it is possible that no full reproducibility in any degree of detail will be possible.

3.8.3 Geographical Coverage and representativeness

The geographical coverage of this study should represent the cradle to gate hardwood lumber production in the US and further transportation to Europe.

CORRIM data was utilised to represent hardwood forest stand establishment and harvesting and covers Northeastern 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. No hardwood forestry data was available for the Southeast region where the other half of the lumber production is located. The NE/NC data was extrapolated to represent the US hardwood production (see also chapter 3.5.1 on forestry data).

Saw milling data from CORRIM reports covers NE/NC and SE regions where around 96.7% of the hardwood lumber is produced (see also chapter 3.5.2 on saw mill data).

Kiln drying data is based on the literature values from the industry-recognised USDA manual which is assumed to be representative for the US hardwood industry. This data was validated with the primary data from 46 AHEC members (see also chapter 3.5.3 on kiln data).

Transportation data is primarily data from AHEC members and is representative for American Hardwood products exported to the European market (see also chapter 3.5.4 on transport data).

Background GaBi 5 datasets were chosen to represent the US geography for lumber production and EU geography for inland EU transportation.

The data on hardwood forests could be improved by collecting the data from Southeast region. The achieved geographical coverage is concluded to be representative for the production of rough-sawn kiln-dried lumber in 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 lumber 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 used for hardwood forestry management, logging and sawing comes from the CORRIM reports published in 2005-2010.

Kiln drying data is based on the USDA literature values published in 2000 and validated by the primary data gathered from AHEC members in 2010 and 2011. This data is representative for the 2009/2011 timeframe and covers the hardwood processing co-product prices, transportation distances and modes, fuel mix, kiln drying inventories, and onsite energy generation inventories.

The background data on energy and fuels are obtained from the GaBi 5 database 2011 and are representative of the years 2008-2013.

The achieved time coverage is representative for the current production technology and distribution practices of AHEC members. It is estimated the study up to the kiln gate is representative for the next 1o years, while the transportation should be reviewed after 2015 as the 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 and thus represents the current technology state. Saw mill data on energy requirements reflects the average energy consumption of current saw mills which is the mix of different blade types (e.g. circular and band saws) and mill sizes.

Kiln drying data represents the conventional kiln technology (solar kiln were excluded from the study).

Energy and transportation datasets from GaBi 5 database 2011 and are representative of the years 2008-2013.

The hardwood lumber production is a relatively mature industry, and it is estimated that the study will stay representative of the US hardwood lumber 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

3.9.1 Potential Limitations Related to System Boundary

The afore-mentioned system boundaries (chapter 3.2) may have some limitations on the applicability of the study, its results, and the interpretation of its findings. It is therefore stated here that this study is only applicable to the specific conditions as 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 were 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.

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 the mass allocation be used instead.

The allocation was included into the sensitivity assessment and showed that allocation by mass would result in the decrease of environmental impacts assigned to lumber by 6-11% for all impacts except for the primary energy demand (37% decrease) and POCP (17% decrease). See chapter 4.4.4 for more details.

3.9.4 Potential Limitations Related to Data

Forest

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. No principal differences are expected in the SE hardwood harvesting.

Saw mill

The inventory of the saw mill reflects the average hardwood sawing and is not species specific. While it is estimated that species have minor impacts on the sawing processes energy requirements, this assumption should be revisited in future work.

Drying of Lumber

Hardwood drying energy requirements highly depend on the drying schedules and the presence of pre-drying (air drying or heated drying). The chosen schedules vary significantly between different hardwood lumber producers. On top of the drying schedule differences, kilns may have different efficiencies, sizes, and fuel mixes. Defining the base scenario, the conservative approach was used. The alternative scenarios are assessed in chapter 4.4 Sensitivity analysis.

Transport

The modes and distances of transportation are modeled based on average distances. The impacts of the transportation to customers could be much lower if exported to Mexico or much higher if delivered to China.

Species specific emissions and carbon uptake

VOC emissions from kilns (see chapter 3.5.3 for details), embodied energy in wood and carbon storage (based on carbon content in dry mass) in products (see chapter 3.2 for details) are modeled the same for all species and do not reflect the differences between them. These are data gaps as the values are not collected or measured. As the conservative values were taken for all species, refined data will probably improve the assessed environmental performance of hardwood lumber.

3.10 Software and Database

The LCA model is created using the GaBi 5 Software system for life cycle engineering, developed by PE International. The GaBi database provides the life cycle inventory data for fuels and energy obtained from the background system.

3.11 Interpretation approach

Interpretation is performed by:

- 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;
- conclusions, limitations, and recommendations.

3.12 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 5 commercial database. The results will be provided to AHEC members and LCI datasets could 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 materials based on this study, e.g. a technical summary of the report, a flyer addressing the major outcomes of the study etc.

The study results will be used to prepare an EPD following the European rules (EN 15804, 2012). EPD(s) will be published on the EPD program holder website and can be shared with AHEC' members, customers and stakeholders.

3.13 Critical Review

The review panel consists of:

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

Prof. Dr. Richard Murphy. Imperial College London

Pankaj Bhatia. Director, GHG Protocol, World Resources Institute

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

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

The Critical Review Panel Statement Letter can be found in Appendix F, at the end of this document.

4 RESULTS

The following section describes, discusses and interprets the results in terms of their contributing factors (contribution analysis) and stability (scenarios). All results refer to 1 m^3 of hardwood lumber produced in the US and delivered to the customer overseas. 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 the chapter 3.4. Table 10 below summarises the main impact categories used in the life cycle impact assessment and provides abbreviations and units used in all relevant graphs and tables below. For the description of the indicators (which environmental issue they measure) please refer to Table 1 for short description and Appendix A for more details.

Table 10: Impact measured, short names and units

Impact indicator	Short name	unit
CML2001 - Nov. 2010, Acidification Potential	AP	[kg SO2-Equiv.]
CML2001 - Nov. 2010, Eutrophication Potential	EP	[kg Phosphate-Equiv.]
CML2001 - Nov. 2010, Global Warming Potential	GWP	[kg CO2-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 and non renewable resources (net calorific value)	PED	[MJ]
Primary energy from non-renewable resources (net calorific value)	PED nr	[MJ]
Potential carbon storage in product	CS	[kg CO2-Equiv.]

4.1 QUALITATIVE DISCUSSION OF NON CONSIDERED IMPACTS

This chapter provides a qualitative discussion relevant for the following impacts:

- Toxicity;
- Land use (occupation);
- Land use change (direct and indirect);
- Water related impacts;
- Biodiversity.

These impacts are classified with II and III in the ILCD handbook (II: recommended but in need of some improvements; III 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.

4.1.1 Toxicity

Toxicity aspects play an important role in the environmental and 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 there are no fertilisers 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 harmonised 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™ characterisation 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 characterisation 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 production and the current uncertainties in the toxicity evaluation models, the USEtox™ characterisation factors are only used within this study to identify key contributor substances within the product system boundary that influence the product's toxicity potential.

The Ecotoxicity impact of 1 cubic metre of dried lumber delivered to European customer is 0.104 [PAF m^3.day] (as defined by USETox2008 method). Most of this impact is associated with transportation of lumber to a customer overseas (52%), namely, emissions from container ship operations and from production of heavy fuel oil and diesel at the refinery (used for shipping lumber).

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

The Human toxicity impact of 1 cubic metre of dried lumber delivered to a 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.

4.1.2 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 [m^3/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 [m^3/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 metre 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 metre 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 metre of dried lumber are 1.66 [Ha*years][12] 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 equals 0.28 [m2*year] for a cubic metre 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.

Summarizing the abovementioned information, wood from low managed forest management requires less land than the wood from highly managed forests does. The mass allocation results in lower land occupation for hardwood lumber than economic allocation and the allocation choice has a higher impact on the results than the forestry management practices.

Depending on the intensity of forest management and the chosen allocation approach, the potential range of land required to produce of 1 cubic metre dried hardwood lumber is 0.354 - 2.37 [Ha*years].

[12] 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.

4.1.3 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 it affects 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 m^3 to 11,326 million m^3 (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 explicitly included in the scope of this study. However, as there is no land use change associated with U.S. hardwood forestry the inclusion of LUC in the study would not alter any of the results. If there is no LUC in the product system, the resulting GHG values for both direct and indirect LUC have obviously a value of zero. As direct LUC does not take place, there are no secondary effects resulting from it so no indirect land use change.

4.1.4 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 lumber production, the biodiversity was not included as a main indicator in this study.

4.1.5 Water consumption and depletion

There is no agreed standard so far on how to assess water use in a LCA framework (Berger, Finkbeiner, 2010). In this study the inventory for water flows was made by following the framework proposed by Bayart et al (Bayart et al, 2010). The complete GaBi 5 database complies with this framework, allowing for consistent water modeling. The paragraphs below discuss the main aspects of the hardwood lumber water inventory.

The biggest water balance item is evapotranspiration in the forest (rain water absorbed and evaporated by trees), i.e. green water consumption[13]. In the eastern US, the hardwood harvest region, average yearly 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 metre of dried lumber should be in the range from 1354 [m^3] (assuming 38cm evapotranspiration rate) to 21662 [m^3]. The range is big due to the different allocation choices possible, different forest management practices and different evapotranspiration rates.

One cubic metre of white oak hardwood lumber has total water inputs of the 6704 m^3. 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 kiln drying. In the most conservative estimation up to 0.64 m^3 water per m^3 of dried lumber is stored and released in the kiln, assuming hickory with a density of 833 [kg/m^3 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 [m^3 per cubic metre of hardwood lumber] from all sources and is mostly the river water associated with the hydropower production. Thus blue water[14] 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 (Berger, Finkbeiner, 2012). 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

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

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

on water resource depletion: the blue water consumption is low, and the green water consumption is excluded from the impact assessment of most available methods[15] (Bayart et al 2010).

4.2 BASE SCENARIO - 1 INCH WHITE OAK LUMBER

The base scenario was defined to look at the results in more details and to serve as a reference when comparing other scenarios.

The default product used as a base scenario in the study is 2.54 cm (1 inch) thick white oak lumber. For the justification of the base scenario choice please refer to the chapter 3.3. Table below contains the summary of main environmental impacts associated with production and transportation of 1 m^3 of white oak lumber with a thickness of 2.54 cm.

Table 11: LCIA of 1 m³ of white oak lumber

LCIA results for 1 m^3 rough-sawn, kiln-dried U.S. white oak lumber, 1 inch thick. cradle-to-gate plus transport

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr	CS
Species/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO2-Equiv.]
White oak	4.14	0.45	556	7.3E-06	1.02	26387	7820	-1114

One cubic metre of 2.54 cm thick white oak lumber at the customer yard generates the following environmental impacts: it contributes to the acidification as much as a emission of 4.19 kg sulphur dioxide would. Contribution to eutrophication equals a discharge of 0.46 kg of phosphate. The Global Warming Potential impact equals the release of 412 kg $CO_{2.}$ Discharge of 7.24E-06 kg of CFC-11 represents the potential effect on the ozone depletion. Smog creation potential (POCP) equals 0.53 kg of Ethene-equivalent.

Total demand of primary energy (PED) equals 24602 MJ. This includes the energy incorporated within the wood itself (low heating value). Around a quarter of this is comprised of the primary energy consumed from the non-renewable resources equaling (5845 MJ).

[15] 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).

One cubic metre of white oak lumber contains biogenic carbon that refers to the 1114 kg of carbon dioxide being removed from the air. This value is written in faded colour to highlight that this is an area for potential storage that would be released at the end-of-life for the final product.

<u>General comment on handling carbon</u>

The carbon storage value refers to the carbon stored in lumber only, and 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. See also chapter 3.4.4 for more detailed description on biogenic carbon and carbon storage in product.

The figure below utilises contribution analysis (identification of the greatest contribution to the indicator result). The following contributing elements were formulated: forestry, transport (forest to kiln) sawing, kiln drying, and transport to customer.

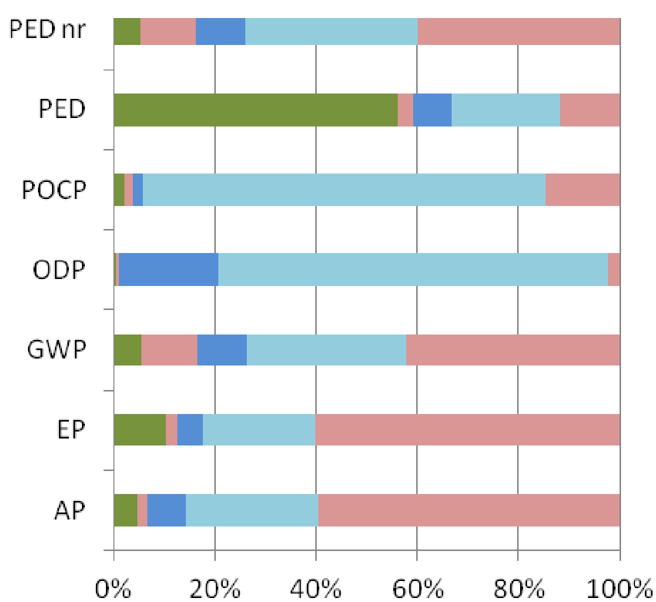

Figure 3: Contribution analysis (process stages) - base scenario

LCIA results, contribution analysis for rough-sawn, kiln-dried U.S. white oak lumber, 2.54 cm (1 inch) thick.

Figure 4 depicts the main impact indicators and their compositions in terms of major emissions.

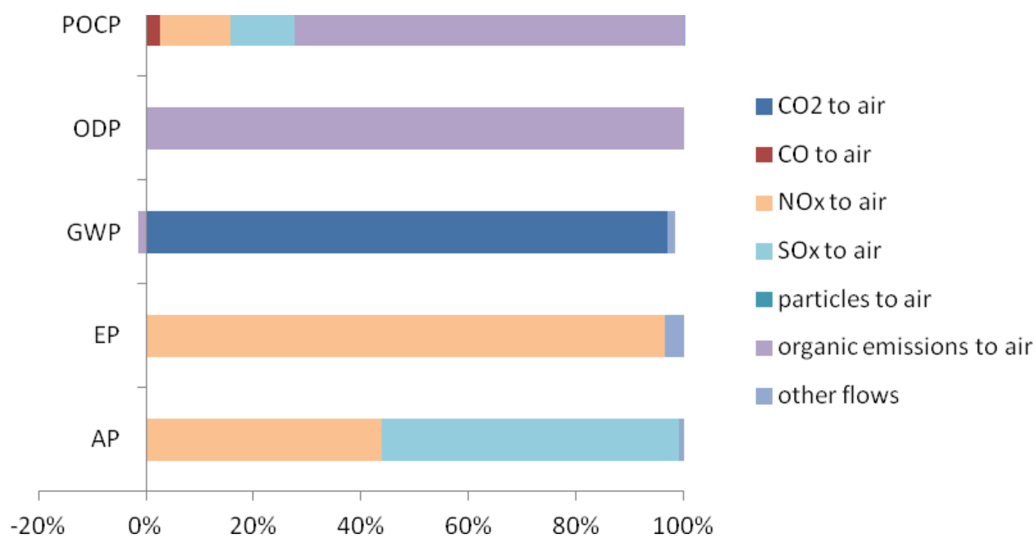

Figure 4: Contribution analysis (emissions) - base scenario

LCIA results, contribution analysis for rough-sawn, kiln-dried U.S. white oak lumber, 2.54 cm (1 inch) thick.

Contribution analysis suggests that most of the non-renewable resources are consumed for the kiln drying process and come from the electricity supply chain (coal, natural gas etc, consumed to produce electricity used by the kiln. The next big non-renewable resource is transport to customer, where crude oil is mined to produce diesel and heavy fuel oil utilised by trucks and container ships. Total primary energy demand is dominated by the energy incorporated in wood (this is included within the 'Forestry' element of the life cycle). The primary energy harvested with the wood (net calorific value) was assumed to be 10.33 MJ/kg for all hardwoods.

POCP impact is dominated by kiln emissions, namely by the VOC emissions released during wood drying (approximately 70% of kiln related POCP), and a mix of organic and inorganic emissions emerging from fuel burning in the electricity supply chain and in onsite boilers. Kiln POCP impact is followed by emissions emerging during transportation to customer, 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 in the electricity supply chain. For white oak, more electricity is consumed during kiln drying than during the sawing. Similar studies indicate that on average the saw milling process is the main electricity consuming process, but with the base conservative scenario for white oak, the kiln electricity consumption is more than threefold of that in the saw mill.

GWP is dominated by the greenhouse gases emitted during electricity production. The main contributing element is the kiln. The Kiln is followed by the greenhouse gases emitted during transportation to the customer (12% from US inland transport, 63% from the overseas shipping, 25% from inland shipping to customer in Europe).

EP and AP are heavily dominated by the emissions generated during transportation to the customer, 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 percent by weight(currently for the ocean transport a world average of 2.7percent by weight 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.

Forestry saw milling and transportation from forest to kiln contribute less to all main environmental impacts of white oak lumber than the transport to customer and kiln drying.

4.3 Scenarios

In this chapter various scenarios are presented. The scenarios on thickness and transportation have been performed on the base scenario - 1 m³ of white oak lumber with a thickness of 2.54 cm.

4.3.1 Different thickness

The thicker the lumber the longer it takes to dry, affecting the energy consumption and environmental performance of the product. Two scenarios were evaluated for thickness: 2.54 cm (1 inch and 5.08 cm (2 inch). All the other parameters were left at default as defined in the Table 3.

The table below contains the impact assessment results for 1 m^3 of white oak lumber of two different thicknesses: 2.54 cm (1 inch) and 5.08 cm (2 inches). As expected, the impact of thickness on the kiln drying energy and therefore on the overall results are quite high. The impacts in different indicators increase by 24-129% (Table 1). The carbon storage does not change as the amount of wood stored per cubic metre does not change.

Table 12: impact of different thickness

LCIA results for 1 m^3 rough-sawn, kiln-dried U.S. white oak lumber, cradle-to-gate plus transport: 2.54 cm (1 inch) and 5.08 cm (2 inch) thick.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr	CS
thickness/ unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO2-Equiv.]
2.54 cm (1 Inch)	4.14	0.45	556	7.3E-06	1.02	26387	7820	-1114
5.08 cm (2 Inch)	5.91	0.61	845	1.7E-05	1.15	35666	12225	-1114
% increase	43%	37%	52%	127%	13%	35%	56%	0%

Figure 5 below depicts the contribution analysis for the GWP of 2 lumber thicknesses illustrating that the increase in the impact is solely due to the kiln energy consumption increase. Contribution analysis of other impacts provides the same conclusion, so their graphs are not included.

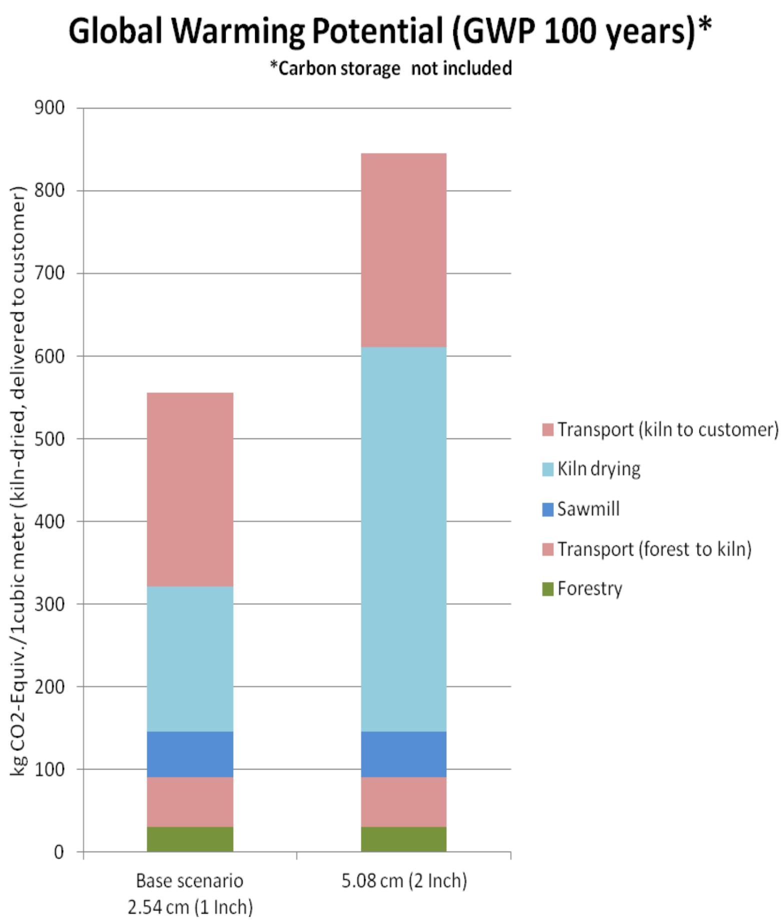

Figure 5: GWP contribution analysis for 1 m^3 for different thicknesses

GWP results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber, cradle-to-gate plus transport: 2.54 cm (1 inch) and 5.08 cm (2 inch) thick.

4.3.2 Different species

Different hardwood species have different densities, shrinkage rates and drying times. Typical inland transportation distances vary for different species due to their growing geography. Walnut is the only species that goes through steaming procedures before drying. All these features affect the energy and fuel consumption along the system assessed. Appendix E contains the summary of the main properties of the 19 hardwood species considered that influence the result.

Scenarios for 19 main hardwood species are presented below. For all species it was assumed that wood enters the kiln green (80% MC). For the assessment of the pre-drying and air drying scenarios please refer to chapter 4.3.4. The graph below shows the differences in the GWP results including contribution assessment of the main US export hardwood species.

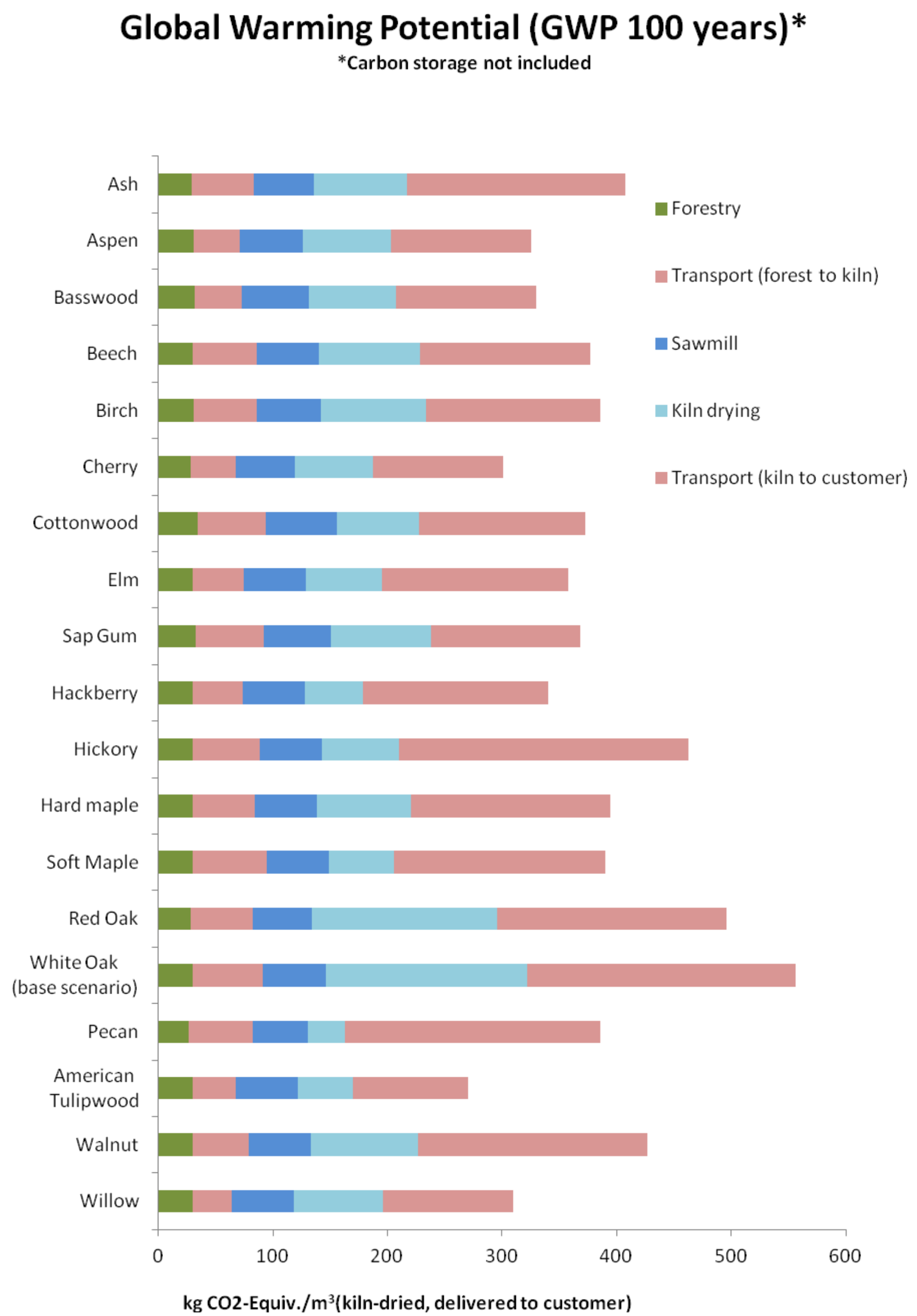

Figure 6: GWP for 1 m^3 of different species including contribution analysis.

GWP results for 1 m^3 rough-sawn, kiln-dried U.S. lumber 2.54 cm thick, cradle-to-gate plus transport for 19 different species.

Figure 6 suggests that the species differences play out in GWP mostly in the kiln drying process (drying times). Small differences in forestry and saw milling come from the different species densities and the differences in transport are driven by differences in densities and typical inland US transport distances. Same is true for the POCP, ODP and PED nr. AP and EP are more defined by transport elements so the differences in transportation distances and densities have a more prominent effect on the results (Figure 7).

Figure 7: AP for different species including contribution assessment

AP results for 1 m[3] rough-sawn, kiln-dried U.S. lumber 2.54 cm thick, cradle-to-gate plus transport for 19 different species.

The table below provides results for different impact indicators and species. The table containing assessment results in TRACI indicators is included in Appendix C.

Table 13: Impact assessment results for lumber for 19 hardwood species. CML indicators.

LCIA results for 1 m^3 rough-sawn, kiln-dried U.S. lumber 2.54 cm thick, cradle-to-gate plus transport for 19 different species.

Impact	**AP**	**EP**	**GWP**	**ODP**	**POCP**	**PED**	**PED nr**	**CS**
Species/ unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]	[kg CO2-Equiv.]
Ash	3.20	0.35	407	4.2E-06	0.95	21850	5651	-974
Aspen	2.38	0.26	325	4.1E-06	0.90	21643	4548	-603
Basswood	2.40	0.27	330	4.1E-06	0.90	22409	4611	-603
Beech	3.41	0.37	377	4.4E-06	0.95	22161	5236	-1073
Birch	3.30	0.36	385	4.6E-06	0.95	22656	5359	-997
Cherry	2.69	0.30	301	3.7E-06	0.90	20095	4175	-812
Cotton-wood	2.56	0.29	373	4.1E-06	0.92	24154	5193	-650
Elm	2.86	0.32	357	3.7E-06	0.92	21339	4954	-857
Sap Gum	2.88	0.32	368	4.5E-06	0.93	23466	5137	-789
Hackberry	2.76	0.31	340	3.2E-06	0.92	20974	4695	-857
Hickory	3.68	0.41	463	3.8E-06	0.98	22844	6371	-1206
Hard maple	3.30	0.36	394	4.3E-06	0.95	22241	5465	-1020
Soft Maple	3.37	0.37	390	3.4E-06	0.95	21747	5368	-1125
Red Oak (base scenario)	3.79	0.41	496	6.8E-06	0.99	24451	6985	-1020
White Oak	4.14	0.45	556	7.3E-06	1.02	26387	7820	-1114
Pecan	3.09	0.34	386	2.5E-06	0.94	19667	5276	-1067
American Tulipwood	2.25	0.25	270	3.1E-06	0.88	19955	3746	-650
Walnut	3.19	0.36	427	4.5E-06	0.96	23861	5987	-882
Willow	2.36	0.26	310	4.1E-06	0.89	21154	4336	-603
max difference	1.89	0.19	285	4.8E-06	0.14	6720	4075	603

Oaks and hickory have the highest impacts while cottonwood and American tulipwood have lower impacts amongst the considered species. Walnut is the only species that is steamed, but its environmental profile does not stand out, as its kiln drying time is not the highest. The impact assessment results for different species suggest that the differences between lumber products of different species can vary significantly: impacts of the same hardwood lumber products made of different species can differ from the other species results more than two times. The general trend can be identified as follows: more dense species require longer drying time and thus have higher impacts from energy consumption. At the same time, heavier species contain more carbon per unit of volume. Appendix E contains the list of 19 hardwood species with densities and other relevant properties.

General comment on handling carbon

The carbon storage value refers to the carbon stored in lumber only, and 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. See also chapter 3.4.4 for more detailed description on biogenic carbon and carbon storage in product.

4.3.3 Different transport

The impacts of lumber transportation contribute a significant part to the overall impact of delivered hardwood lumber. In particular, the transportation to customer is associated both with high variance depending on customer location and high impact. The scenarios below are assessed to evaluate the environmental impacts of the lumber delivered to a different location. The scenarios include the base reference scenario (base scenario), where the overseas shipping distance is the average weighted distance of transporting hardwood lumber from ports in the US to ports in the EU. Two EU scenarios were added: the Eastern EU scenario assumes transport from Norfolk to Gdansk, the Western EU scenario assumes transport from Norfolk to Valencia. Additionally a scenario for China (Norfolk – Shanghai) and for Canada (Charlotte (NC, US) to Edmonton, Alberta by truck) were assessed. All the other parameters were left at default as defined in Table 3. Table 14 below contains the summary of the evaluated scenarios.

Table 14: transportation scenarios, port to customer

Transportation scenarios modeled in the cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

parameter/unit	EU average (base scenario) [km]	Eastern EU [km]	Western EU [km]	China [km]	Canada [km]
Overseas transport (container ship)	7735	7263	6943	19168	0
Inland transport (truck)	500	500	500	500	4023

As transportation has the most impact on the AP and EP impacts, the AP results are shown in the Figure 9 below as well as GWP in Figure 8. All the other impacts are summarised in the Table 15.

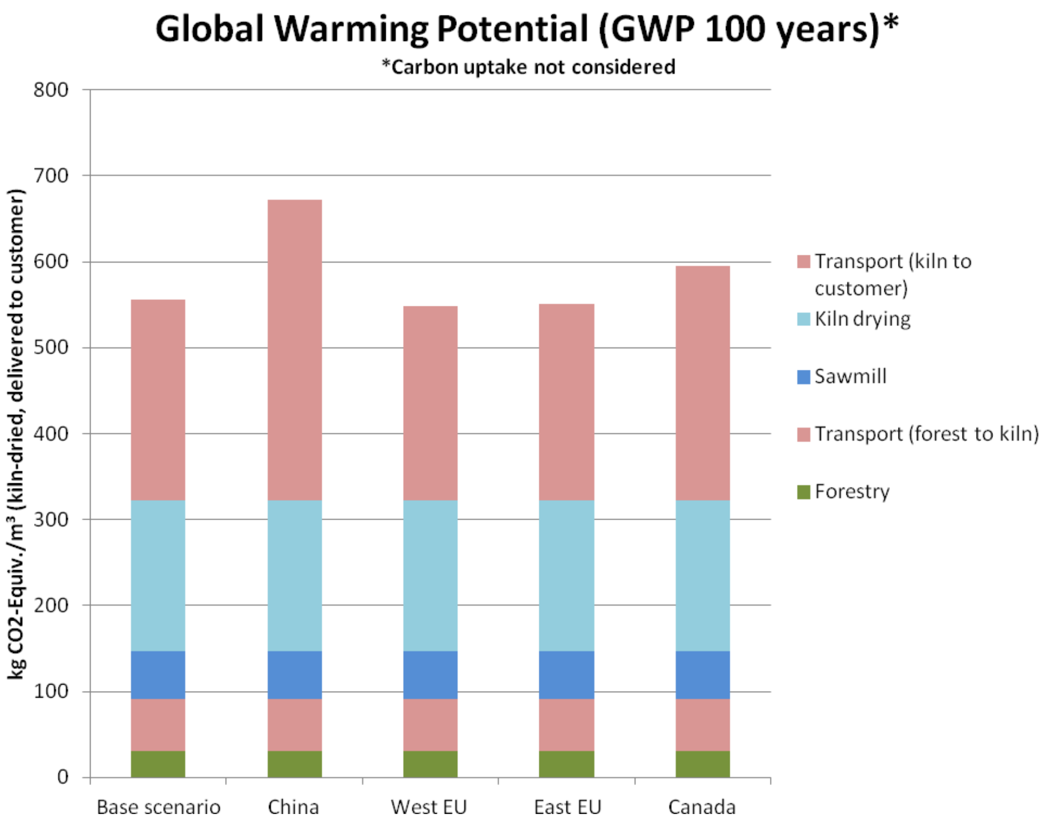

Figure 8: GWP results for transport scenarios

GWP results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 5 different transport scenarios.

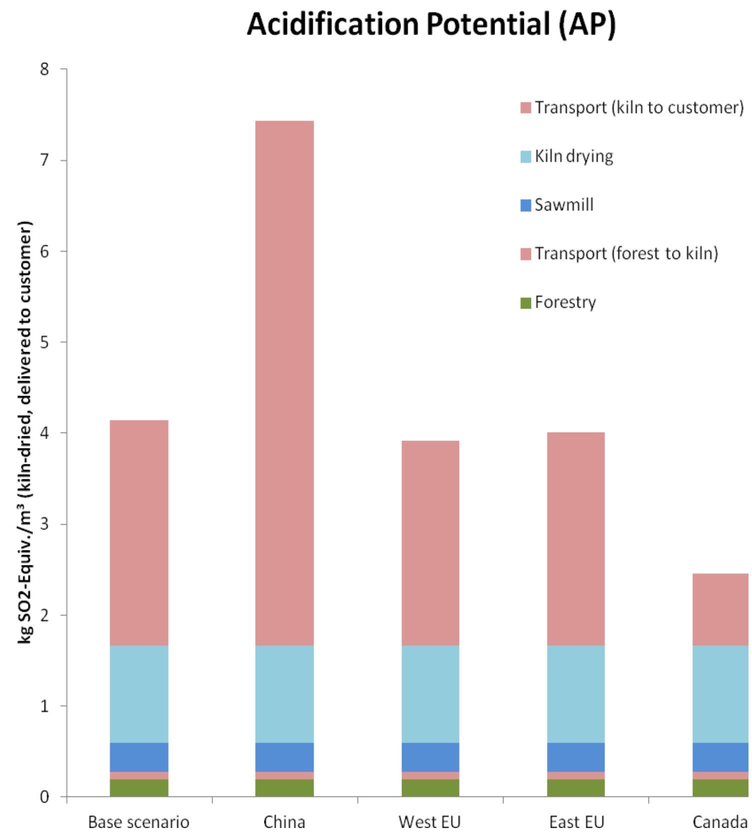

Figure 9: AP results for transport scenarios

AP results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 5 different transport scenarios.

Transportation is a significant part of the hardwood lumber life cycle. The impact of transportation depends both on the transport mode and distance.

Comparing lumber transported by container ship to Europe with one transported inland to Canada (by truck), ship transport to Europe has lower impacts in GWP, ODP, POCP and PED but results in higher AP and EP impact results. Environmental advantages of ocean transport are however reduced when transporting much longer distances compared to road transport: the scenario of transporting lumber to China results in higher environmental impacts across all indicators.

AP is directly related to the sulphur content of the fuel (and associated SO_2 emissions). Sulphur content of marine fuel is currently under discussion to be further limited up to 0.1 percent by weight (currently for the ocean transport a world average of 2.7percent by weight is assumed). It should also 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.

Table 15: LCIA results - Impact of different transportation

LCIA results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 5 different transport scenarios.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
Base scenario - EU average	4.14	0.45	556	7.3E-06	1.02	26387	7820
Eastern EU	4.01	0.43	551	7.3E-06	1.01	26327	7761
Western EU	3.91	0.42	548	7.3E-06	1.01	26287	7720
China	7.44	0.78	672	7.4E-06	1.22	27832	9261
Canada	2.46	0.34	595	7.3E-06	0.71	27115	8488
max difference:	4.97	0.44	77	1.0E-07	0.51	716	773
max difference in % of the minimum value:	202%	127%	13%	1%	72%	3%	9%

AP, EP and POCP indicators are the most sensitive to transportation. The impact of different transport to customer is small on PED and negligible on ODP. GWP and PED nr can vary by 40 and 47 % respectively when comparing transport to Canada with transport to China.

4.3.4 Pre-drying and air-drying

Some lumber goes into the kiln green, some is pre-dried in a pre-drier (with energy consumed), and some is air-dried (no energy or small amounts for fans). Oaks are pre-dried more often than other species in order to decrease the long oak drying times in the kiln. The scenarios formulated below explore what difference on the environmental profile of lumber the different pre-drying approaches have.

In the reference scenario the white oak goes into the kiln green (at 80 % MC). In the pre-drying scenario white oak spends some days in the pre-drier till it reaches a MC of 30%. The energy consumption during this process is derived from primary data from 1 AHEC member. For the air drying scenario, the lumber is left in the yard without fans till it reaches the MC of 30% (no energy consumption was assumed). All the other parameters were left as default and defined in Table 3. Table 16 summarises the scenarios.

Table 16: pre-drying scenarios

Pre-drying scenarios modeled in the cradle-to-gate plus transport LCA of rough-sawn, kiln-dried U.S. hardwood lumber

parameter	Electric power required by the pre-drier	Thermal energy required by the pre-drier	Moisture content of Oak lumber put into the kilns
scenario/unit	[kWh/MBF]	[kWh/MBF]	[% MC], dry basis
no pre-drying (base scenario)	0	0	80
pre-drying to 30%	354	623	30
air drying to 30%	0	0	30

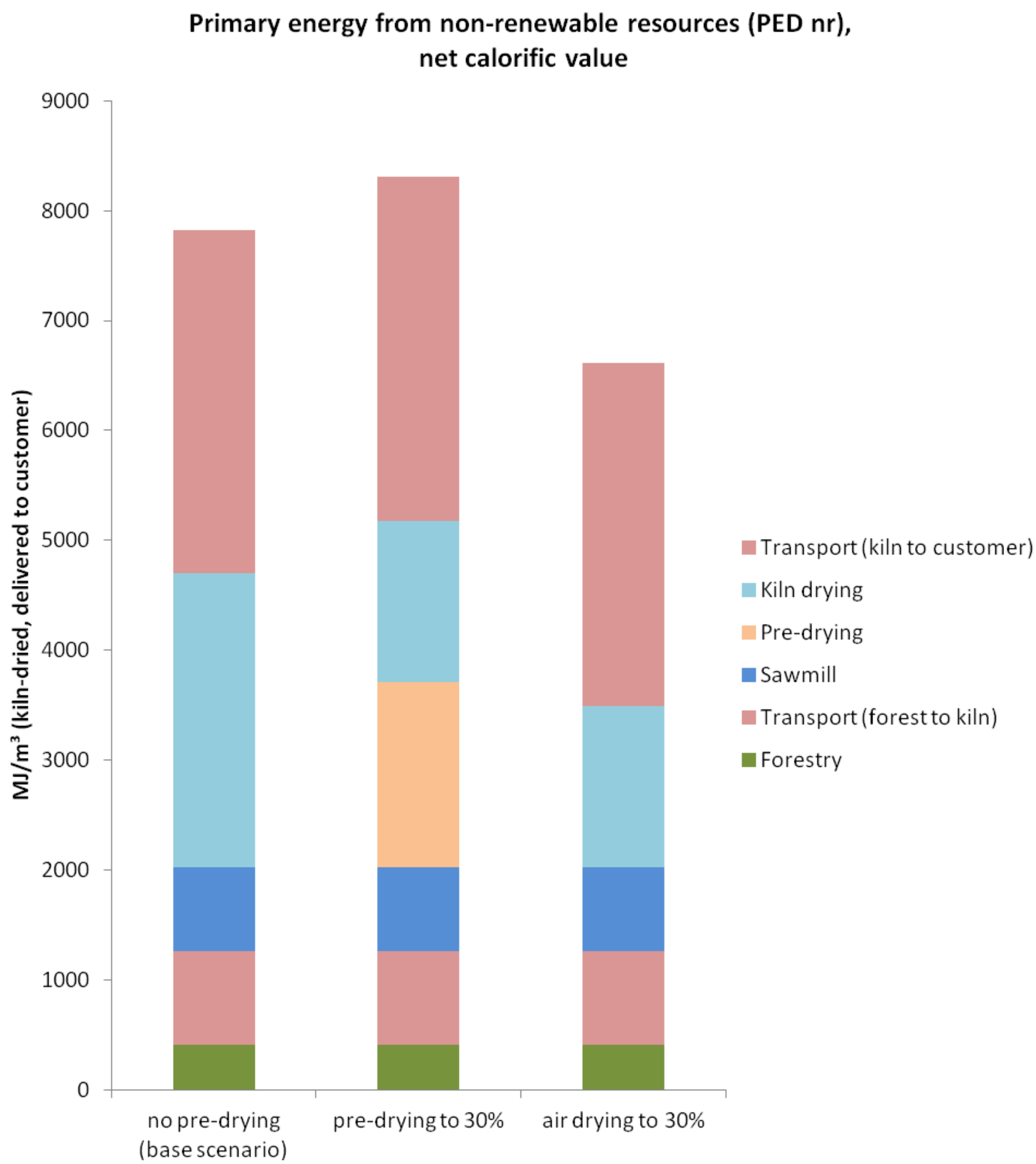

Figure 10: impact of pre-drying scenarios on PED nr

PED nr results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different pre-drying scenarios.

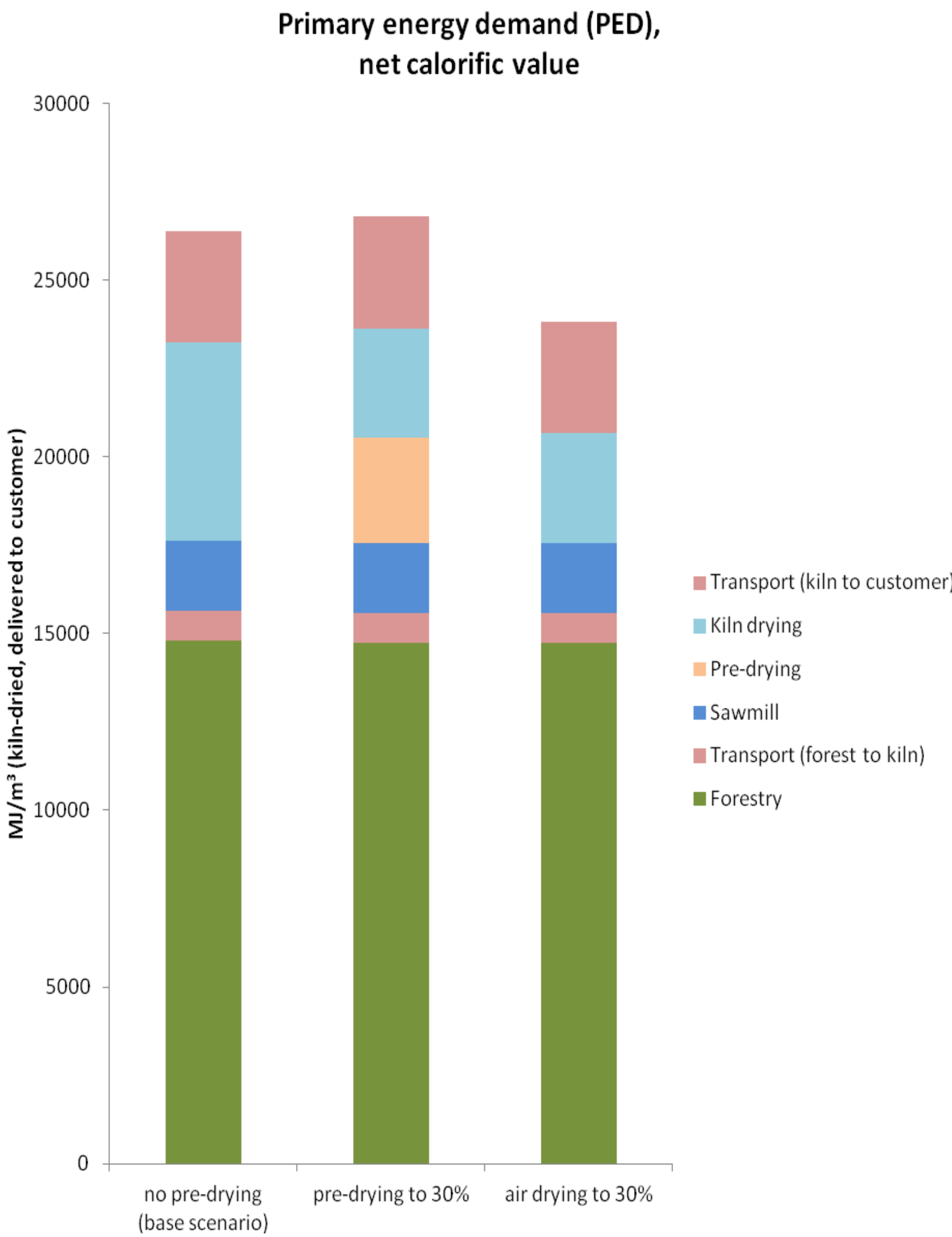

Figure 11: impact of pre-drying scenarios on PED

PED results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different pre-drying scenarios.

Figure 10 above illustrates the effect the different pre-drying scenarios have on the PEDnr. The GWP results look very similar. Pre-drying decreases the energy consumed in the kiln drying process. However, as the relationship between moisture content and kiln drying time is not linear (the last percents of moisture are harder to dry that the first ones), the effect is not as big as it would be with a linear function. The energy consumption in the pre-dryer at the same time has a higher share of electricity and the values for energy consumption represent a conservative scenario. The results suggest that according to the scenarios defined the total primary energy consumption from non-renewable resources grows if lumber is pre-dried to 30% MC.

The results for total primary energy demand (Figure 11) are also slightly higher for the pre-drying scenario. It seems unlikely that the kiln operator would apply pre-drying if this would bring the total energy consumption up. Together with the fact that pre-drying data came from only one source, the assumptions made for the scenario should be reviewed with more primary data before any conclusions of the benefits or draw backs of pre-drying practice can be made.

The air drying practice, in contrast, presents environmental advantage over the other two scenarios. Air drying in the scenario does not require electrical energy or fuels and also lowers the energy consumption of the following kiln process, thus presenting an environmentally-preferable option. The air drying practice, however, can significantly increase the wood loss (e.g. wood decay or wood stains). This was not incorporated into the current assessment and has to be further investigated to define the optimal drying option.

The most sensitive indicator for these scenarios is ODP. ODP is defined mostly by electricity consumption and as pre-dryers consume a higher share of electricity than the kiln the results of ODP when switching from air-drying to the pre-drying scenario grow by 75% (Table 17).

Table 17: LCIA results - Impact of pre-drying

LCAI results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different pre-drying scenarios.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
no pre-drying (base scenario)	4.14	0.45	556	7.3E-06	1.02	26387	7820
pre-drying to 30%	4.30	0.45	589	8.5E-06	1.03	26791	8304
air drying to 30%	3.66	0.40	477	4.8E-06	0.98	23810	6617
max difference:	0.64	0.05	113	3.7E-06	0.04	2981	1686
max difference in % of the minimum value:	18%	13%	24%	78%	5%	13%	25%

4.3.5 Different final moisture content

The average and most common moisture content of the final lumber product is 7%. The maximum range of this value from primary data is 6-12% MC. As the final percent of moisture are harder to dry, the scenario with 6% MC and scenario with 12% MC of final product were run to test for the relevance of this parameter. All the other parameters were left at default as defined in Table 3.

Table 18 summarises the impact the final product moisture content has on the results. The differences are not big in absolute numbers (up to 27%) but taking into account that these are only a few percent differences in moisture content the results are worth further investigation. The impacts of the lumber dried to 6% MC are 27% higher for ODP, 12% higher for GWP and 14% higher for PED nr. AP, EP, POCP and PED total are less sensitive to the change in final lumber moisture content.

Table 18: Impact of final MC

LCAI results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different final moisture content scenarios.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
final MC 6%	4.16	0.45	560	7.5E-06	1.02	26574	7882
final MC 7% (base scenario)	4.14	0.45	556	7.3E-06	1.02	26387	7820
final MC 12%	4.09	0.44	539	6.5E-06	1.01	25522	7546
difference:	0.06	0.00	21	1.0E-06	0.01	1051	336
difference in % of the 12% MC value:	2%	1%	4%	16%	1%	4%	4%

4.4 Sensitivity analysis

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 - 1 m³ of white oak lumber with a thickness of 2.54 cm.

4.4.1 Kiln energy consumption

Kiln energy consumption is the main driver of the lumber environmental profile. The reported kiln energy consumption in primary data from AHEC members ranges for electrical energy from 6 to 22 [kWh/MBF/day] and thermal energy from 17 to 38 [kWh/MBF/day]; most of the reported values were well grouped around the average of 14 [kWh/MBF/day] for power and 25 [kWh/MBF/day] for the thermal energy. This is consistent with the values published in the USDA hardwood drying manual (USDA, 2000) of 17 [kWh/MBF/day] for power and 25 [kWh/MBF/day] for thermal energy (1 MBF is 2.36 cubic metres in this study).

While it is unclear whether the reported values which are “off” the average are due to the issues in data quality or refer to actual energy efficiency improvements, the scenario assessment for the reported range was done. The High energy consumption scenario for kiln has 22 [kWh/MBF/day] of electricity and 38 [kWh/MBF/day] of thermal energy. The Low energy consumption scenario for the kiln has an energy consumption of 6 [kWh/MBF/day] of electricity and 38 [kWh/MBF/day] of thermal energy (1 MBF is 2.36 cubic metres in this study).

The scenario analysis suggests that the impact assessment results for lumber are sensitive to the assumption of kiln energy consumption (Table 19, Figure 12). The lowest reported kiln energy demand results in an environmental profile with 49% less impact for ODP and 26-27% less impact for GWP and PED nr. With the High energy consumption scenario the impacts of lumber would increase by 24% for ODP, 14-15% for GWP and PED nr and 6-10% for all other impacts.

Table 19: Impact of kiln energy consumption

LCAI results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different kiln energy consumption scenarios.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
Base scenario	4.14	0.45	556	7.3E-06	1.02	26387	7820
high energy consumption	4.53	0.49	612	9.0E-06	1.05	28766	8700
low energy consumption	3.55	0.40	449	3.7E-06	0.98	23799	6230
increase of impact from reference	9%	10%	10%	23%	3%	9%	11%
decrease of impact from reference	14%	10%	19%	49%	4%	10%	20%

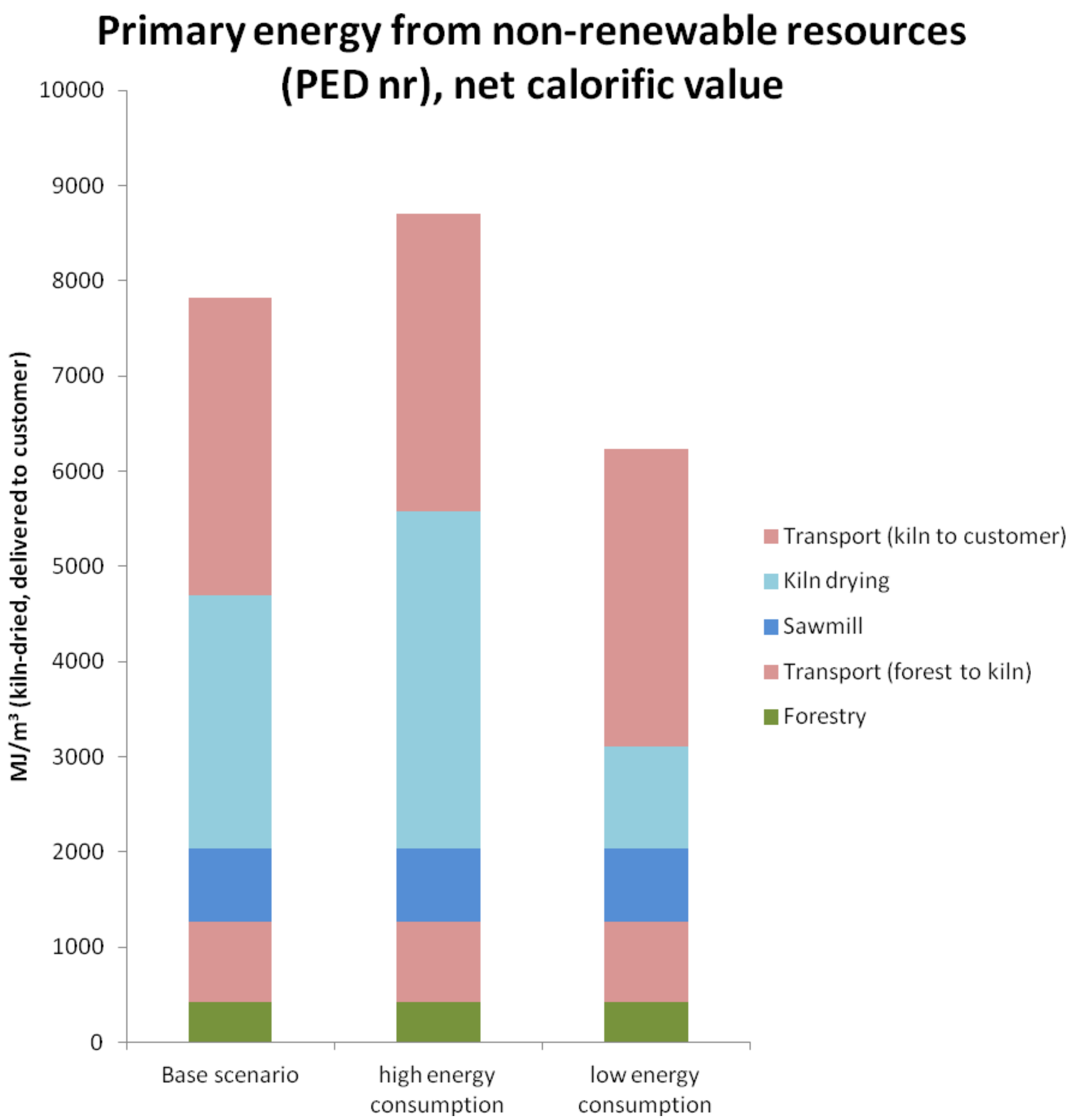

Figure 12: Impact of kiln energy consumption on PED nr

4.4.2 Kiln energy mix

The average mix of fuels used by kilns and saw mills for onsite energy production is comprised on average, of 90% biomass (wood residues). The alternative fuel used is natural gas. Some mills run almost solely on biomass and some almost solely on natural gas. The table and figure below illustrate the impact of lumber produced by the onsite boilers running on 100% natural gas and on 100% biomass fuel mix.

The biomass-based boiler for kiln drying results in slightly improved GWP, ODP and PEDnr performance and slightly increased impacts in AP, EP and POCP relative to the reference scenario.

Changes are relatively small as the base scenario already has 90% biomass and the difference with 100% biomass scenario is not so big. Switching the energy source to 100% natural gas provides benefits for the AP, EP and POCP impacts while increasing the GWP, ODP and PED nr. This tradeoff is typical when analyzing the biomass as an energy source: its renewable nature and biogenic carbon dioxide are beneficial for climate change and resource depletion but the biomass burning emissions to air have higher impacts on acidification and eutrophication.

Table 20: Impact of fuel mix on base scenario

LCAI results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different saw mill and kiln fuel mix scenarios.

Impact	AP	EP	GWP*	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
Base scenario (90% biomass)	4.14	0.45	556	7.3E-06	1.02	26387	7820
100% biomass	4.16	0.45	536	7.3E-06	1.02	26379	7504
100% natural gas	4.02	0.41	733	7.6E-06	1.00	26455	10664
change of impact from reference to 100% natural gas	-3%	-9%	32%	4%	-1%	0.26%	36%
change of impact from reference to 100% biomass	0.32%	1%	-4%	-0.45%	0.16%	-0.03%	-4%

*Biogenic carbon dioxide emissions are modeled as carbon neutral (no impact on the GWP) as they are offset by the uptake in biomass.

4.4.3 Kiln efficiency

The kiln efficiency is the share of energy that ends up evaporating water from the wood. Losses are combined through initial heating, ventilation, etc. Primary data from AHEC members provided a range from 42% to 85%. The scenarios with these two efficiencies were run for the white oak hardwood lumber. The results turned out not to be very sensitive to the kiln efficiency, with the difference between scenarios no exceeding 5.5% across all indicators (Table 21).

Table 21: Impact of kiln efficiency

LCAI results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different kiln efficiency scenarios.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
Base scenario - 53% efficiency	4.14	0.45	556	7.3E-06	1.02	26387	7820
efficiency 42%	4.22	0.46	561	7.4E-06	1.03	27228	7930
efficiency 85%	4.03	0.42	548	7.2E-06	1.00	25177	7662
change of impact - base scenario to 42% efficiency	2%	4%	1%	1%	1%	3%	1%
change of impact - base scenario to 85% efficiency	-3%	-5%	-1%	-1%	-1%	-5%	-2%

4.4.4 Allocation

The economic allocation was performed in the forest and saw mill. As discussed in chapters 3.5 & 3.9 the prices of the co-products can vary and species- specific and grade-specific price variations were not taken into account creating uncertainty.

To address this uncertainty the scenario analysis for allocation was done. The table and graph below depict the environmental impacts of hardwood lumber for two extreme allocation scenarios: mass allocation and “all-to-lumber” allocation.

In the mass allocation scenario 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 lumber, as it distributes the environmental burden evenly through the outputs, with a kg of bark taking the same burden as a kg of lumber.

Another extreme scenario assigns all the forestry and saw mill burdens to the lumber production: - the “all-to-lumber” allocation scenario. It has the same effect as if all co-products were of no value and lumber production was the only reason for the forest and sawing activities. Consistently, all non-lumber forest and saw-mill co-product becomes “free” of any burden. Thus, the biomass burned in the kiln in this scenario for example is also a burden-free fuel.

Table 22: Impact of allocation

LCAI results for 1 m3 rough-sawn, kiln-dried U.S. white oak lumber 2.54 cm thick, cradle-to-gate plus transport for 3 different allocation scenarios.

Impact	AP	EP	GWP	ODP	POCP	PED	PED nr
scenario/unit	[kg SO2-Equiv.]	[kg Phosphate-Equiv.]	[kg CO2-Equiv.]	[kg CFC-11-Equiv.]	[kg Ethene-Equiv.]	[MJ]	[MJ]
all-to-lumber allocation	4.38	0.51	441	7.1E-06	1.04	41307	6235
price allocation (base scenario)	4.14	0.45	556	7.3E-06	1.02	26387	7820
mass allocation	3.88	0.42	359	6.4E-06	1.00	15278	5109
change of impact from reference to all-to-lumber	6%	14%	-21%	-3%	2%	57%	-20%
change of impact from reference to mass allocation	-6%	-7%	-35%	-13%	-2%	-42%	-35%

Results of the allocation scenario assessment in Table 22 suggest that mass allocation would lower the impact result for lumber by 37% in total primary energy demand and in 6-17% in all the other impacts. The All-to-lumber allocation scenario would result in a lumber environmental profile that is 71% higher for total primary energy demand and 1-12% higher for the other indicators.

PED is most sensitive to the allocation applied as this is the only indicator where the forestry part dominates the impact (due to biomass harvesting). The allocation in forest and saw mill that allocate all the impacts to lumber (all-to-lumber scenario) allocates all the wood harvested in forests together with its embodied energy to lumber.

5 LIFE CYCLE INTERPRETATION

When utilizing the study results in assessing the complete life cycles, the production of final product may have impacts associated with wood processing and finishing and with the production of additional materials (e.g. textile used in furniture of lacquer used in wood panels finishing). Transportation of final product also may have a significant impact depending on the customer location. After reaching its end-of-life the final product can be disposed, incinerated or recycled. When modeling the final product's End of Life, the information on carbon storage can be utilized. The carbon stored in lumber would most probably be released through disposal or incineration as emission to air. Depending on the methodology approach chosen, the carbon storage can be claimed to have a positive impact if not released back to the environment.

The following chapter summarises the study and presents the key findings for the "cradle-to-gate plus transport to customer" assessment of rough-sawn, kiln-dried hardwood lumber.

5.1 IDENTIFICATION OF SIGNIFICANT ISSUES

The Life Cycle Impact Assessment showed that the environmental impacts are dominated by drying and transportation to customer. For the base scenario, these two phases contributed between 45% and 90% for all analysed categories with the exception of total primary energy demand which was dominated by primary energy from biomass (about 99% of the renewable share which is approximately 85% of the total PED).

The absolute contribution of transportation to final customer is directly related to target market and the sulphur content of the used fuel for container ships. The sulphur content of marine fuels is currently under discussion to be further limited to 0.1 percent by weight (currently for the ocean transport a world average of 2.7 percent by weight 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 at gate-to-gate level for all reported processes checking the completeness of the process steps considered and the coverage of energy inputs needed for the individual processes.

The cut-off criteria defined in the chapter 3.7 were met. The overall mass of excluded flows is estimated to be less than 0.2% of the respective unit process inventory input (see also Table 9 for excluded flows).

A sensitivity analysis was carried out for kiln drying based on the range of provided data as well as for allocation. The findings are presented in chapter 4.4.

Consistency checks of data provided by member companies were carried out. To check the plausibility the provided primary data has been cross checked with other data sources (publically available and proprietary data).

5.3 CONCLUSIONS AND RECOMMENDATIONS

Life cycle assessment evaluated the environmental performance of the hardwood lumber products including 19 hardwood species, and the range of lumber thicknesses and moisture contents. The results are representative for average American Hardwood lumber of the respective species. Company specific profiles could differ significantly due to specific practices, especially during drying as well as the transportation situation.

The results turn out to be highly variable between hardwood species and lumber thicknesses due to the different drying times requirements. The impacts of producing lumber from a long-drying species (e.g. oak) can be twice as high as those produced from a fast-drying species (e.g. pecan) if all the other product properties are the same. Similarly, impacts of producing and delivering a cubic metre of 2 inch-thick lumber (5.08 cm) can be more than twice of that of the 1 inch (2.54 cm) if all the other product properties are the same. Chapters 6.4 and 6.5 discuss this variation in more detail. It is highly recommended that the environmental profile of the hardwood lumber is developed and communicated on the base of hardwood species and lumber thickness.

The study has revealed that across all products the main sources of the environmental impacts are resource consumption and air emissions associated with:

- kiln drying
- transportation to customer.

Forestry process is of smaller relevance to the overall results compared to other processes involved. The only exception is 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 (56-73%) defined by the forestry process. Excluding PED, forestry contributes from 0% (ODP) to around 18% (EP) to the total lumber environmental impacts of 1 inch lumber.

Sawing process contributes less than 20% to all impacts of hardwood lumber, with the exception of ODP (up to 51%). This is true for all the species and thicknesses assessed.

Kiln drying is a dominant source of environmental impact for most of the lumber products thicker than 2 inches (5.08 cm). For the thinner lumber products of fast drying species transportation may become a more relevant source of impact, first of all in the Acidification and Eutrophication impact categories.

Transport to customer can be the most significant factor contributing to environmental impact in certain impact categories, notably eutrophication and acidification potential (due to sulfur emissions associated with sea freight). The impact of transport to customer on GWP is also significant, similar to and sometimes exceeding the impact of kiln drying depending on the hardwood species and thickness. T he impacts related to forest and sawing activities are stable and do not change much for different lumber products. The impact of lumber transportation and the potential carbon storage vary slightly per cubic metre due to the different densities. The variation between hardwood lumber products is almost fully due to the different drying requirements in the kiln.

In the kiln drying process, however, the environmental profile of lumber can be improved. Primary data indicated a range of energy consumption rates by kilns suggesting that there is a space for improvement for most of the kilns (e.g. GWP and non-renewable resource consumption are 26-27% lower for the lumber produced by the low energy demand kiln). The use of air-drying before the kiln and a careful selection of the final moisture content could be recommended as an approach to improve the hardwood lumber environmental profile. The air drying practice, however, can significantly increase the wood loss. This was not incorporated into the current assessment and has to be further investigated to define the optimal drying option.

The biomass widely used in saw and kiln mills as an energy source results in improved global warming potential impact and resource consumption (primary energy demand from non-renewable resources) 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 increase other emissions.

Some general data gaps were identified in the area of environmental performance of hardwood products. Data on species specific carbon content, low heating value and green moisture content is directly related to the hardwood species environmental performance and thus should be trucked on species basis. Volatile organic compounds emitted during kiln drying are not measured on kiln-basis and it is recommended that AHEC keeps a record of data available in this area.

Based on the study findings it is recommended that AHEC and its members:

- Communicate the environmental information for hardwood lumber per hardwood species and thickness to enable the customers to make informed decisions;
- Prepare and publish the EPDs on key hardwood lumber products;
- Focus the effort on lumber production improvement on:
    - the energy efficiency measures in the kiln drying process to reduce energy consumption,
    - increasing the use of air drying where possible, supporting a further research of air drying methods which should include the wood loss to define the drying practice optimal from environmental point of view,
    - investigate if higher final moisture content of lumber is feasible for customers,
    - Extend the AHEC species guide to include species specific green moisture content, carbon content and heating value.
- Initiate additional data collection on pre-drying practice to better understand the environmental implications;

- Keep track of the hardwood prices for forest and saw mill co-products as these data are relevant for calculation of the hardwood lumber environmental impacts;
- Utilise the developed LCA model within the hardwood lumber industry to educate hardwood lumber producers on environmental implications of their decisions. The hardwood lumber industry in the US consists mostly of small mills and thus small-scale, user-friendly solutions are necessary to involve AHEC members into sustainability activities;
- Investigate the options of sustainable shipping (e.g. MAL ships) to support long-term marketing and logistic strategy development.

6 References

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Appendix A : Description of Impact Categories

Primary energy consumption

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 consumption non renewable"**, given in MJ, essentially characterises the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.

The total **"Primary energy consumption renewable"**, given in MJ, is generally accounted seperately and comprises hydropower, wind power, solar energy and biomass.

It is important that the end energy (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end 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 (CO_2-Eq.). This means that the greenhouse potential of an emission is given in relation to CO_2 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.

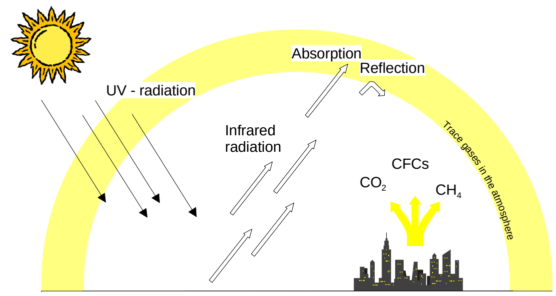


Figure A 1: Greenhouse effect

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 (SO_2-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.

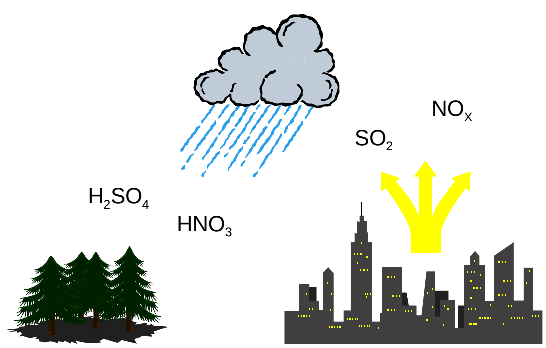


Figure A 2: Acidification Potential

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 (PO_4-Eq). As with acidification potential, it's important to remember that the effects of eutrophication potential differ regionally.

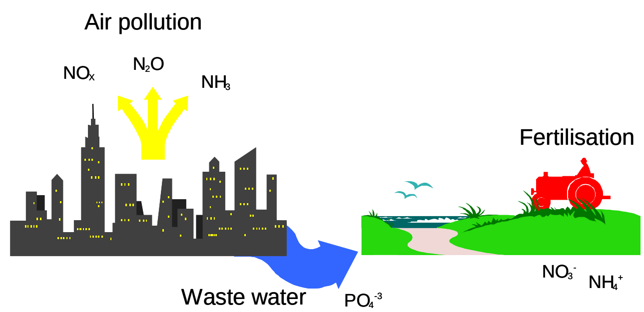


Figure A 3: Eutrophication Potential

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 (C_2H_4-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.

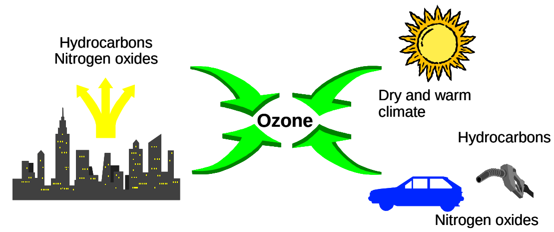


Figure A 4: **Photochemical Ozone Creation Potential**

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.

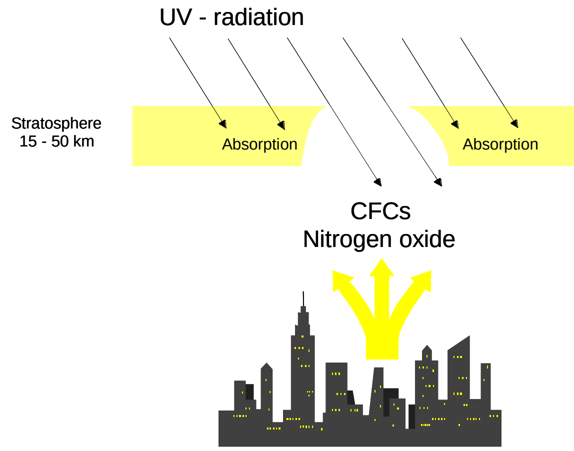


Figure A 5: **Ozone Depletion Potential**

Appendix B : TRANSPORTATION DISTANCES CALCULATION

Assumptions on typical kilning location		
Species	Location	Rationale
American Tulipwood	VA 24340	Geographic mid-point of U.S. tulipwood log harvesting
Ash	OH 43128	Geographic mid-point of U.S. ash log harvesting
Aspen	Northern Maine	USDA provides combined production data for Aspen and Cottonwood. Analysis of this data combined with other information on species distribution indicates that production of aspen in the US is concentrated in two separate areas, one in Wisconsin/Minnesota and the other in Northern Maine. Exports to Europe are assumed to come from the latter.
Basswood	MI 48152	Geographic mid-point of U.S. basswood log harvesting
Beech	PA 16915	Geographic mid-point of U.S. beech log harvesting
Birch	NY 13625	Geographic mid-point of U.S. yellow birch log harvesting
Cherry	Allegheny National Forest	No data on cherry production is available, therefore location where production of high quality cherry is known to be concentrated is assumed
Cottonwood	Greenville Mississippi	USDA provides combined production data for Aspen and Cottonwood. Analysis of this data combined with other information on species distribution indicates that production of cottonwood in the US is heavily concentrated in the vicinity of the southern Mississippi
Elm	KY 40374	No species-specific data on production is available. Elm is widely is distributed in the Eastern US therefore geographic midpoint of all US hardwood log production is used.
Hackberry	KY 40374	Hackberry and the closely related species of sugarberry (which isn't separated once converted into lumber) is widely is distributed in the Eastern US therefore geographic midpoint of all US hardwood log production is used.
HardMaple	ON L0R 1B1	Geographic mid-point of U.S. hard maple log harvesting. Due to uneven shape of the US-Canada border, the mid-point of US production is in Canada
Hickory	TN 37095	Geographic mid-point of U.S. hickory log harvesting
Pecan	TN 37095	USDA FIA provides no specific data on pecan harvesting. Therefore data for the closely related species of hickory is used.
RedOak	TN 38506	Geographic mid-point of U.S. red oak log harvesting
SapGum	AL 36279	Geographic mid-point of U.S. sweet gum log harvesting
SoftMaple	PA 16124	Geographic mid-point of U.S. "other maple" log harvesting
Walnut	IN 47838	Geographic mid-point of U.S. walnut log harvesting
WhiteOak	KY 42717	Geographic mid-point of U.S. white oak log harvesting
Willow	KY 40374	No species-specific data on production is available. Willow is widely is distributed in the Eastern US therefore geographic midpoint of all US hardwood log production is used.

Assumptions on typical port of export to Europe		
Species	Location	Rationale
American Tulipwood	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)
Ash	New York City	Main port of export for ash to Europe according to US export data (accounting for 33% of value 2007-2009)
Aspen	New York City	In absence of species-specific port export data, northern species are assumed to be exported from the largest port of export for US hardwood lumber in the north-eastern region
Basswood	New York City	In absence of species-specific port export data, northern species are assumed to be exported from the largest port of export for US hardwood lumber in the north-eastern region
Beech	New York City	Beech is widely ditributed in the Eastern US but production is heavily concentrated in the North East. In absence of species-specific port export data, northern species are assumed to be exported from the largest port of export for US hardwood lumber in the north-eastern region
Birch	New York City	In absence of species-specific port export data, northern species are assumed to be exported from the largest port of export for US hardwood lumber in the north-eastern region
Cherry	Baltimore	Main port of export for cherry to Europe according to US export data (accounting for 33% of value 2007-2009)
Cottonwood	Charleston	Significant port of export for US hardwood lumber in Southern region
Elm	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)
Hackberry	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)
HardMaple	New York City	Main port of export for maple to Europe according to US export data (accounting for 37% of value 2007-2009)
Hickory	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)
Pecan	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)
RedOak	Norfolk	Main port of export for oak species to Europe according to US export data (37% of value 2003-2009)
SapGum	Charleston	Significant port of export for US hardwood lumber in Southern region
SoftMaple	New York City	Main port of export for maple to Europe according to US export data (accounting for 37% of value 2007-2009)
Walnut	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)
WhiteOak	Norfolk	Main port of export for oak species to Europe according to US export data (37% of value 2003-2009)
Willow	Norfolk	Main port of export for "other" species to Europe according to US export data (35% of value 2003-2009)

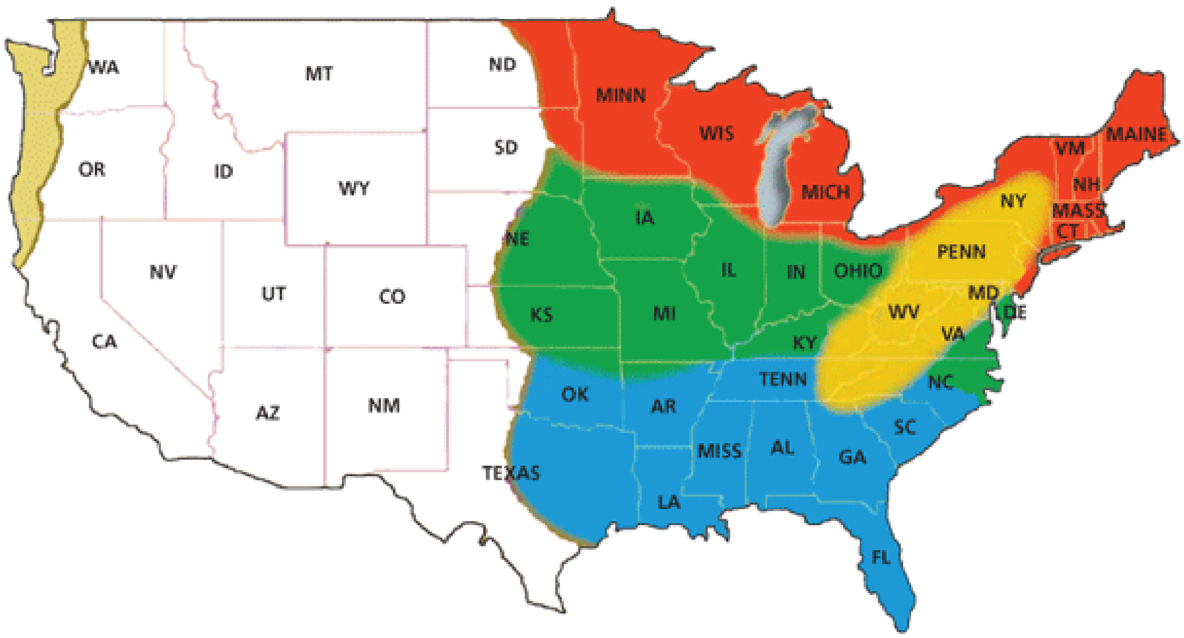
	Assumed transport distances for kilning location to port of export 100% truck transport assumed in all cases		
	Distance	Allowance for detours	calculated distance (sum of distance and allowance for detour)
Species	[km]	[km]	[km]
American Tulipwood	555	100	**655**
Ash	937	100	**1037**
Aspen	997	100	**1097**
Basswood	1007	100	**1107**
Beech	404	100	**504**
Birch	529	100	**629**
Cherry	406	100	**506**
Cottonwood	1192	100	**1292**
Elm	874	100	**974**
Hackberry	874	100	**974**
HardMaple	700	100	**800**
Hickory	1064	100	**1164**
Pecan	1064	100	**1164**
RedOak	945	100	**1045**
SapGum	644	100	**744**
SoftMaple	644	100	**744**
Walnut	1228	100	**1328**
WhiteOak	1073	100	**1173**
Willow	874	100	**974**

Appendix C : MAIN RESULTS IN TRACI INDICATORS

Impact assessment results for 1 m^3 of dried hardwood lumber delivered to customer for 19 hardwood species. TRACI indicators.

	Acidification Air	Eutrophication	Global Warming Air	Ozone Depletion Air	Smog Air	PED	PED nr	CS
	[kg H+ moles-Equiv.]	[kg N-Equiv.]	[kg CO2-Equiv.]	[kg CFC 11-Equiv.]	[kg O3-Equiv.]	[MJ]	[MJ]	[kg CO2-Equiv.]
Ash	184.18	0.13	407	4.8E-08	69.55	16199	6032	-974
Aspen	137.10	0.10	325	4.5E-08	53.90	17095	4847	-603
Basswood	138.37	0.10	330	4.5E-08	54.40	17798	4914	-603
Beech	196.18	0.14	377	5.2E-08	73.74	16925	5583	-1073
Birch	189.73	0.13	385	5.4E-08	71.52	17296	5714	-997
Cherry	155.07	0.11	300	4.0E-08	60.06	15920	4449	-812
Cottonwood	147.45	0.11	372	4.2E-08	57.54	18961	5538	-650
Elm	164.49	0.12	357	4.0E-08	63.16	16385	5286	-857
Sap Gum	165.62	0.12	368	5.1E-08	63.51	18330	5475	-789
Hackberry	159.02	0.11	340	3.0E-08	61.51	16279	5012	-857
Hickory	211.33	0.15	462	4.0E-08	78.81	16473	6808	-1206
Hard maple	189.65	0.13	394	4.8E-08	71.51	16776	5831	-1020
Soft Maple	194.31	0.14	390	3.3E-08	73.34	16379	5733	-1125
Red Oak	217.19	0.15	496	9.5E-08	79.82	17466	7443	-1020
White Oak	237.02	0.17	555	1.0E-07	86.37	18567	8335	-1114
Pecan	178.23	0.13	385	1.9E-08	67.90	14391	5642	-1067
American Tulipwood	130.17	0.09	270	2.8E-08	51.91	16209	3993	-650
Walnut	185.37	0.14	426	9.0E-08	71.70	17874	6394	-882
Willow	135.74	0.10	310	4.6E-08	53.45	16818	4619	-603

Appendix D : 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.

Source: http://www.americanhardwood.org/de/laubholzarten/region-map/

Appendix E : HARDWOOD SPECIES - AVERAGE PROPERTIES

Main hardwood export species. Average properties					
property	Density at 12% MC *	Shrinkage rate from 80% MC to 6% MC*	Kiln drying time 1 inch, from 80% MC to 6% MC**	Kilning location to port of export, km by truck***	steam used for steaming***
unit	[kg/m³]	[%]	Days	[km]	[MJ/m³]
Ash	449	9.8	9	655	n/a
Aspen	673	6.2	15	1037	n/a
Basswood	417	9.2	13.5	1097	n/a
Beech	417	12.6	13.5	1107	n/a
Birch	741	13	18	504	n/a
Cherry	689	13.4	18	629	n/a
Cottonwood	561	9.2	15	506	n/a
Elm	449	11.3	12	1292	n/a
Sap Gum	593	11	13.5	974	n/a
Hackberry	593	13.5	10.5	974	n/a
Hickory	705	11.9	16.5	800	n/a
Hard maple	833	14.3	15	1164	n/a
Soft Maple	737	0	6	1164	n/a
Red Oak	705	6.6	31.5	1045	n/a
White Oak	545	12	15	744	n/a
Pecan	777	9.9	10.5	744	n/a
American Tulipwood	609	10.2	16.5	1328	796
Walnut	769	12.6	34.5	1173	n/a
Willow	417	11.5	15	974	n/a

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

Appendix F : CRITICAL REVIEW

Critical Review of the study

LIFE CYCLE ASSESSMENT OF ROUGH-SAWN, KILN-DRIED HARDWOOD LUMBER

Commissioned by:	American Hardwood Export Council - AHEC
Review Panel:	Prof. Dr. Matthias Finkbeiner, Germany (Chair) Mr. Pankaj Bhatia, USA 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 18th June 2012.
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 chair of the review panel. Initially, the review process was discussed and agreed in a meeting at AHEC´s offices in London on 14th June 2011. The panel members were proposed by the chair and approved by AHEC.

The review process was started with the provision of the first draft of the Goal and Scope Document on 01st February 2012. This document was evaluated by the review panel and discussed in a full day meeting on 07th February 2012 at PE´s offices in Stuttgart. The draft final report included the decisions taken at this meeting and was delivered to the review team on 07th May 2012. The critical review panel evaluated the draft and provided 125 comments of general, technical and editorial nature on 14th May 2012. A full day review panel meeting was held at AHEC´s offices in London on 16th May 2012 to present the changes already made by PE and AHEC and to establish a common understanding on several comments. PE and AHEC revised the report accordingly and provided the second draft report on 04th June 2012. 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 18th June 2012.

Overall, the feedback provided by the critical review team was adopted in the finalisation of the study. All critical issues and the vast majority of recommendations of the critical review panel were addressed in a competent and comprehensive manner. The review panel 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 a dedicated team at PE commissioned and supported by AHEC. One of the outstanding features of the study is the broad coverage of American hardwood species. The 19 different species addressed represent more than 95% of the hardwood species harvested in US by volume and more than 95% of the wood volume exported by AHEC members. Another positive feature of the study is the substantial share of primary data collected to reach representative results for American hardwood lumber. Primary data were collected from 46 AHEC companies, representing approximately 20% of AHEC members and approximately 12% of the hardwood lumber production volume. Due to the substantial share and relevance of the primary data, the data quality is considered to be high.

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 proper use of the data for future assessments of the complete life cycle of American hardwood based products. The qualitative discussion on some of the potential impacts which were not covered by the quantitative impact assessment is also acknowledged as a thorough and informative aspect of the study as well.

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 adequate for the scope of the study.

Conclusion

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

Matthias Finkbeiner

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Richard Murphy

19th June 2012