CORRIM Report

Life Cycle Assessment of Softwood Lumber Production – Southern Region

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Table 3. Changed unit of Eutrophication potential from kg PO_4e to kg Ne

Table 23. Typo in A3 changed from 1,031.31 to 1,001.31 kg CO2e

Abbreviations

BF	Board Feet
CLR	Cubic Lumber Recovery
AP	Acidification Potential of Soil and Water Sources
CED	Cumulative Energy Demand
CFCs	Chlorofluorocarbons
CFC-11	Trichlorofluoromethane
EP	Eutrophication Potential
EPD	Environmental Product Declaration
FW	Consumption of Freshwater Resources
GWP	Global Warming Potential
GWP_{FOSSIL}	Global Warming Potential as an output from the TRACI impact methods. Does not include carbon dioxide released from biogenic sources
$GWP_{BIOGENIC}$	Global Warming Potential released from the combustion of biogenic materials (e.g., wood)
HLRW	High-level Radioactive Waste, Conditioned, to Final Repository
HWD	Hazardous waste Disposed
ILLRW	Intermediate- and Low-Level Radioactive Waste, Conditioned, to Final Repository
ISO	International Organization for Standardization
kg	Kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Low heat value (Net Caloric Value)
LRF	Lumber Recovery Factor, expressed in board foot of Lumber per Cubic foot of logs
m^3	Cubic Meters
MC	Moisture Content
MJ	Megajoule
NCV	Net Caloric Value
NHWD	Non-Hazardous Waste Disposed
NRPRE	Non-Renewable Primary Energy Carrier Used as Energy
NRPRM	Non-Renewable Primary Energy Carrier Used as Material
O_3	Ozone
ODP	Depletion potential of the stratospheric ozone layer
OD	Oven-dry
PCR	Product Category Rules
RPRE	Renewable Primary Energy Carrier Used as Energy
RPRM	Renewable Primary Energy Carrier Used as Material
SFP	Formation Potential of Tropospheric Ozone
tkm	Metric-Tonne – Kilometers
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

Glossary of Terms

Allocation – partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (14040:2006/Amd1:2020)

Biogenic Carbon-carbon derived from biomass ($CO_{2BIOGENIC}$) (ISO 21930:2017)

By-product- any of two or more products coming from the same unit process or product system (ISO 14040:2006/Amd1:2020)

CO_2 eq/Carbon dioxide equivalent/CO_2 equivalent. Unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide (ISO 14067)

Cradle-to-gate – Covers the mandatory production stage that includes the following information modules: extraction and upstream production (raw material supply), transport to factory and manufacturing (ISO 21930:2017)

Declared Unit - quantity of a construction product for use as a reference unit in an EPD based on LCA, for the expression of environmental information needed in information modules. When the precise function of the product or scenarios at the construction works level is not stated, or is unknown, a declared unit may be used instead of the functional unit (ISO 21930:2017)

Embodied Carbon- Carbon emissions associated with materials and construction process throughout the whole life cycle of a building or infrastructure (World Green Building Council)

Life cycle assessment (LCA) – compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle (14040:2006/Amd1:2020)

Life cycle inventory (LCI) phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (14040:2006/Amd1:2020)

Life cycle impact assessment (LCIA) – phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (14040:2006/Amd1:2020)

Product Category Rules (PCR) – Set of specific rules, requirements, and guidelines for the development of type III environmental declarations for one or more product categories (ISO 14025).

System boundary – A set of criteria that specifies which unit processes are part of a product system (ISO 14044/Amd1:2017/Amd2:2020)

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1 Background

Producing all materials, renewable and non-renewable, has environmental impacts. Over the years, assessment of environmental burdens has evolved from not just considering site-specific impacts but to now including impacts of specific products' processes and use. The increased need for product specific environmental information has progressed the use of environmental product declarations (EPDs) as one tool for product selection.

Historically, a preferred environmental building product was one that was made from renewable or recycled resources. Today, building materials are held to a higher standard of transparency that goes beyond their natural attributes. Builders, designers, politicians, and the public are asking for the full suite of a material's environmental impacts to meet "green building" standards as well as state and national emission reduction benchmarks, just to name a few. Building materials that have low embodied carbon and energy are sought out, and other functional aspects such as structural performance, ease of installation, and product durability are also desired. Users of building materials are increasingly relying on science-based quantitative life cycle assessment (LCA) studies and EPDs that offer assurance that the material has the environmental attributes they seek.

LCAs will become increasingly important as they are used by all industries to inform product and process design, as well as build system development, as they seek to minimize energy consumption and carbon release. Going forward, the need for credible, scientific, LCA-based information will be greater than ever.

This report describes the cradle-to-gate energy and materials required for producing softwood lumber from the Southern region in the United States (U.S.) and the subsequent releases into the environment. The Southern region encompasses the states in Figure 1 (orange). This region was previously called the Southeast region. Facilities included in this LCA are members of the American Wood Council (AWC) and voluntarily participated in AWCs online LCA survey which collected primary data on each participating facility's material use and energy consumption for the 2022 calendar year. Inputs included logs, fuels, energy, ancillary materials, and packaging materials used for producing dry planed softwood lumber.

Data collection followed ISO 14040/10444 standards (ISO 2006a-c), ISO 21930 (ISO 2017), and the Product Category Rules (PCR) for North American Structural and Architectural Wood Products, Part B (UL 2020) and Part A: Life Cycle Assessment Calculations Rules and Report Requirements (UL 2018).

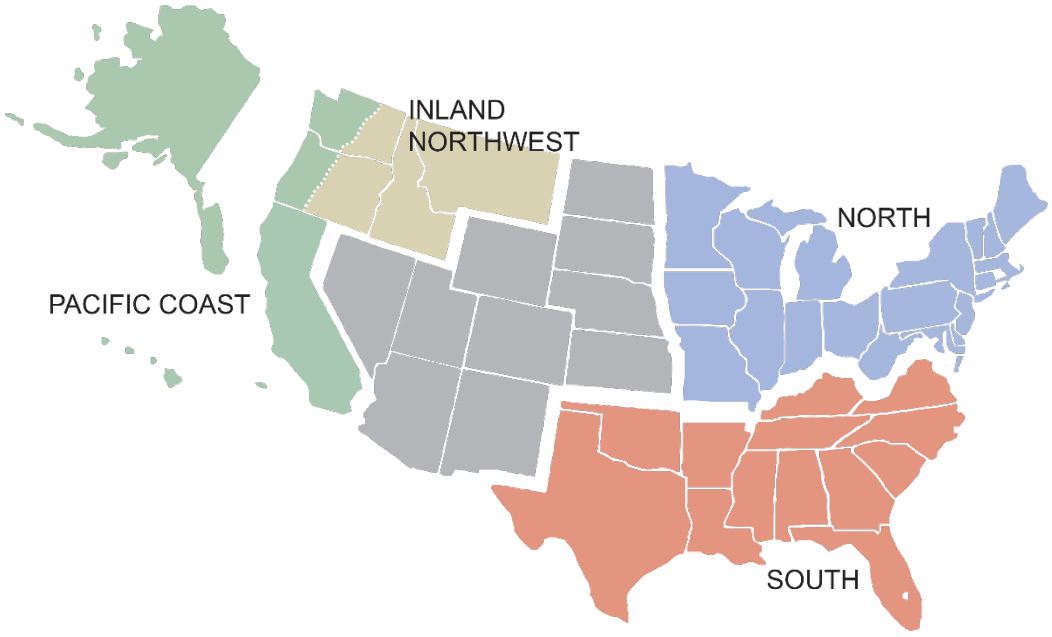


Figure 1. Geographical Distribution of Softwood Lumber Product Regions.

2 Life Cycle Assessment

Life-cycle assessment (LCA) has evolved as an internationally accepted method to analyze complex impacts and outputs of a product or process and the corresponding effects they might have on the environment. LCA is an objective process to evaluate a product's life cycle by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and materials uses and releases on the environment; and to evaluate and implement opportunities to effect environmental improvements. LCA studies can evaluate full product life cycles, often referred to as "cradle-to-grave," or incorporate only a portion of a products life cycle, referred to as "cradle-to-gate," or "gate-to-gate." This study is a cradle-to-gate LCA as it includes forestry operations through production of the product ready for shipment.

As defined by the International Organization for Standardization (ISO 2006a-b), LCA is a multiphase process consisting of a 1) Goal and Scope Definition, 2) Life Cycle Inventory (LCI), 3) Life Cycle Impact Assessment (LCIA), and 4) Interpretation (Figure 2). These steps are interconnected, and their outcomes are based on goals and purposes of a study.

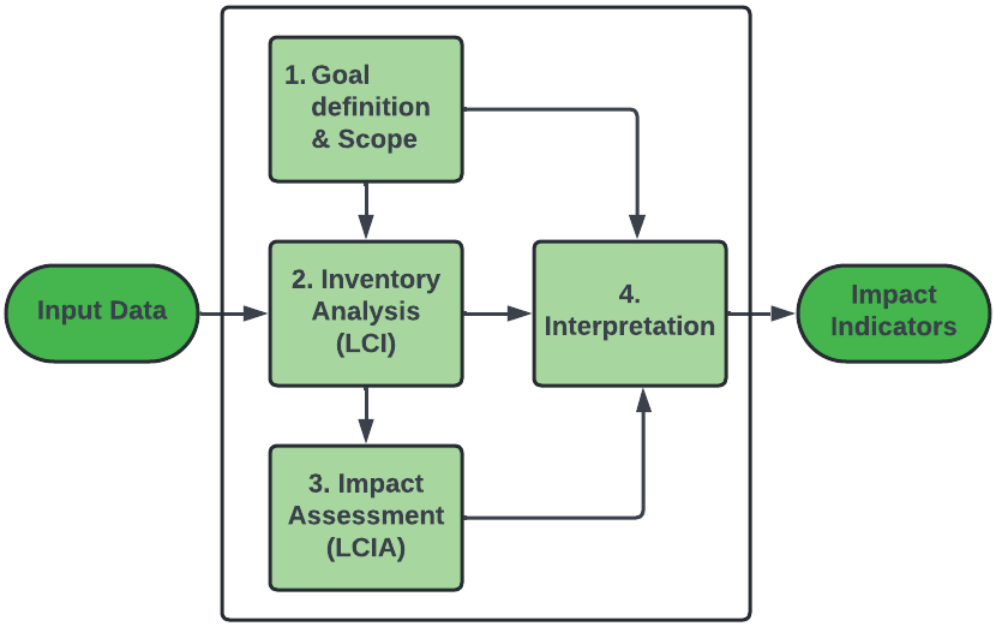


Figure 2. Steps Involved in a Life Cycle Assessment.

An LCA begins with a project goal, scope, functional unit, system boundaries, any assumptions and study limitations, method of allocation, and the impact categories that will be used.

The key component is the LCI, which is an objective, data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases occurring within the system boundaries. It is this information that provides a quantitative basis for comparing wood products, their manufacturing processes and, most importantly from the forest industry point of view, wood products performance against competitors who use other resources to create alternative products.

The LCIA process characterizes and assesses the effects of environmental releases identified in the LCI into impact categories such as global warming, acidification, eutrophication, ozone depletion, and smog.

The life cycle interpretation is a phase of LCA in which the findings of either the LCI or the LCIA, or both, are evaluated in relation to the defined goal and scope to reach conclusions and recommendations. This final step in an LCA involves an investigation of significant environmental aspects (e.g., energy use, greenhouse gases), their contributions to the indicators under consideration, and which unit processes in the system are generating the emissions. For example, if the results of a LCIA indicate a particularly high value for the global warming potential indicator, the analyst could refer to the inventory to determine which environmental flows are contributing to the high value, and which unit processes contribute to those outputs. This is also used as a form of *quality control*, and the results can be used to refine the scope definition to focus on the more important unit processes. This step also supports arriving at more certain conclusions and supportable recommendations.

3 Goal and Scope

It is the goal and scope that provide the plan for conducting the LCI including data collection, compilation, and interpretation. The EPD developed from this LCA study is intended for use in Business to Business (B to B) communications.

3.1 Goals and Objectives

3.1.1 Goals

The primary goal is to generate a cradle-to-gate LCA of construction grade softwood lumber. The LCA will follow data and reporting requirements which provide guidance for preparation of a B-to-B EPD.

3.1.2 Intended Audience and Uses

The primary audience for the results of this LCA report is AWC members and the participating facilities. The intended audience for the subsequent EPD includes AWC, Southern Pine Lumber Association, Softwood Lumber Board, and Western Wood Products Association and their members, architectural and engineering professionals, government organizations, academia, policy makers, or other interested parties.

3.1.3 Comparative Assertions

The report does not include product use and end of life phases which are required for comparative assertions relative to substitute products. If comparative studies are intended and disclosed to the public, reporting will be consistent with the 14044:2006/Amd1:2017/Amd2:2020: guidelines and principles and ISO 21930:2017 core rules for EPDs (ISO 2006a-c, ISO 2017), and will follow the PCR for Building Products (Part A) and the PCR for Structural Wood Products (Part B) (UL 2018 and 2020). No comparative assertions are made in this LCA.

3.2 Scope of Considered System

This LCA follows the attributional approach as outlined in ISO 21930 Section 7.1.1.

3.2.1 System Boundary

Information modules included in the LCA are shown in Table 1. This LCA includes mandatory modules A1-A3 for a cradle-to-gate analysis. The cradle-to-gate system boundary is shown in Figure 2. The system boundary begins with regeneration of the forest in the southern region and ends with planed dry lumber packaged at the plant gate. The system boundary includes forest operations (A_1), which include growing seedlings in a nursery, planting the seedlings, managing the forest (which may include pre-commercial and commercial thinning), fertilization, and final harvesting, with the logs brought to a landing and loaded on the truck ready for transportation to the manufacturing facility; transportation of all resources and materials (A_2); and softwood lumber production (A_3) (Figure 3). The sawmill complex is divided into four processes: log yard/sawmill, kiln drying, energy generation, and planing. The recognized four processes are accounted for in module (A_3).

Both human activity and capital equipment were excluded from the system boundary. The environmental effects of manufacturing and installing capital equipment and buildings have generally been shown to be minor relative to the throughput of materials and components over

the useful lives of the buildings and equipment. Human activity involved in the manufacturing of softwood lumber products no doubt has a burden on the environment. However, the data collection required to properly quantify human involvement is particularly complicated, and allocating such flows to the production of materials as opposed to other societal activities was not feasible for a study of this nature. Typically, human activity is only considered within the system boundary of an LCA when value-added judgements or substituting capital for labour decisions are within the study scope. These types of decisions are outside the current goal and scope of this study.

Table 1. Description of System Boundary Modules.

PRODUCTION STAGE			CONSTRUCTION STAGE		USE STAGE							END-OF-LIFE STAGE				OPTIONAL BENEFITS
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Extraction and up-stream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance	Repair	Replacement	Refurbishment	Building Operational Energy Use During Product Use	Building Operational Water Use During Product Use	Deconstruction	Transport	Waste	Disposal	Reuse, Recycle, & Recovery benefits
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

MND – Module Not Declared

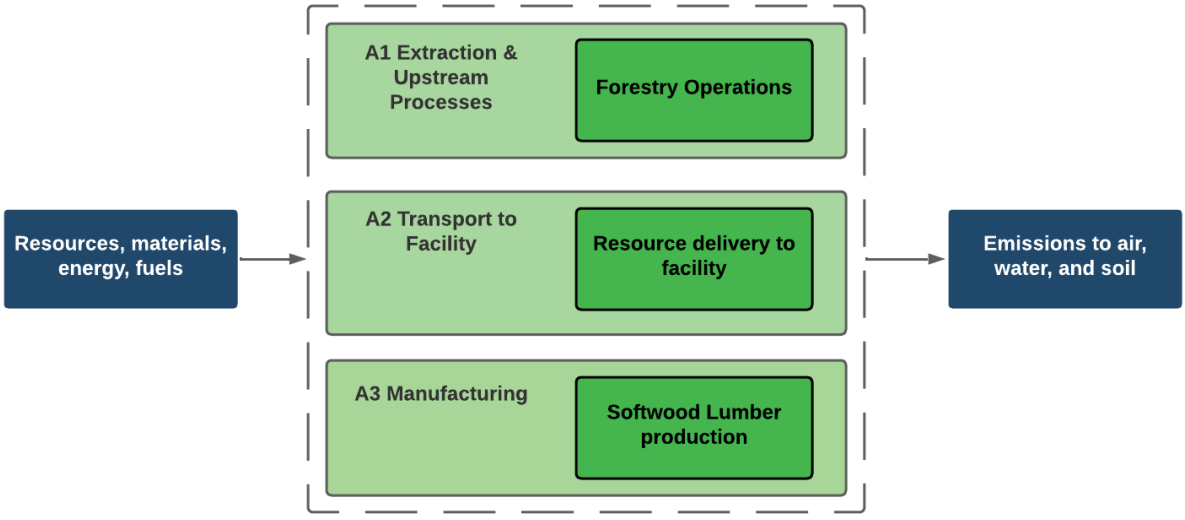


Figure 3. Cradle-to-Gate (A1-A3) System Boundary for Southern Softwood Lumber Production.

3.2.2 Cut off Rules

The cut-off criteria for all activity stage flows considered within the system boundary conform with ISO 21930: 2017 Section 7.1.8. Specifically:

- All inputs and outputs for which data are available are included in the calculated effects and no collected core process data are excluded.
- A one percent cut-off is considered for a) renewable and non-renewable primary energy consumption and b) the total mass of inputs within a unit process. The sum of the total neglected flows does not exceed 5% of all energy consumption and mass of inputs.
- All flows known to contribute a significant impact or to uncertainty are included.
- The cut-off rules are not applied to hazardous and toxic material flows, all of which are included in the life cycle inventory.

No material or energy input or output was knowingly excluded from the system boundary.

3.2.3 Data Collection

Primary data from each facility was collected via an online LCA survey portal developed and managed by AWC. These data were used to develop the LCI in accordance ISO 14044/Amd1:2017/Amd2:2020 standards. This study relied almost exclusively on 2021/2022 production and emissions data provided by each facility, with upstream secondary data on fuels and electrical grid inputs from the US database (Datasmart 2023) and European datasets (Ecoinvent 3.8) (LTS 2023, Wernet et al. 2016). Eighty five facilities from the southern region participated in the survey.

3.2.4 Calculation Rules

Log consumption was reported on a mass basis (e.g., weight log scale in short tons). The log scale quantities reported were converted to cubic volume using a factor of using a weighted average green specific gravity of 0.49 and oven-dry specific gravity of 0.56.

Lumber was reported in board feet and converted to cubic meters using a regional average of 564 BF/m^3 actual lumber dimensions (2x6, nominal).

All flow analyses of the product and co-products in the process were determined on an oven-dry weight basis. An overall wood mass balance was determined for material input to material output using the weighted average oven-dry density of 564.97 kg per m^3.

The survey results for each unit process were converted to a production basis: per m^3 of rough green lumber for the sawmill, per m^3 of rough dry lumber for drying, and per m^3 of planed-dry lumber for planing. The values reported by each mill were combined into a production-weighted average for each input (see text box below). Thus, the value from a large mill had more weight. This approach resulted in a sawmill complex that represents a composite of the mills surveyed and maintains confidentiality. SimaPro, version 9.5 (Pré Consultants 2023) was used as the accounting program to track material flows.

Averaging weighting factors for each softwood lumber facility are calculated respectively as follows:

Example y_1, 85 facilities are representative of the Southern region in this LCA

$$w_1 = y_1 / (y_1 + y_2 + y_3 \ldots y_{85}) = y_1 / Y_{total}$$

$$w_1 (\%) = (y_1 / Y_{total}) * 100$$

where:

Y_{total} Total lumber production of all 13 facilities (m^3 basis)
y_1 Lumber production of facility 1 (m^3 basis)
y_2 Lumber production of facility 2 (m^3 basis)
y_3 Lumber production of facility 3 (m^3 basis)
$\ldots y_{85}$ Lumber production of facility 85 (m^3 basis)

Missing data is defined as data not reported in surveys. Whenever missing data occurred for survey items, they were checked with plant personnel to determine whether it was an unknown value or zero. Missing data were carefully noted so they were not averaged as zeros.

3.2.5 Functional and Declared Unit

In accordance with the PCR, the declared unit for lumber is one cubic meter (1.0 m^3) of planed dry lumber packaged for shipment. A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a wood building cannot be stated (UL 2018). The inventory input data is presented as unallocated flows, all input and output flows allocated to the main product. This analysis does not take the declared unit to the use stage; therefore, no service life is assigned. Weighted average specific gravity and density for southern softwood lumber is reported in Table 2.

Table 2. Southern Lumber Weighted Average Specific Gravity and Density.

	Specific gravity			Density (kg/m3)		
Moisture content	Green	15%	0%, oven-dry	100%	15%	0%, oven-dry
	0.49	0.52	0.56	977.68	600.96	564.97

3.2.6 Allocation Rules

Allocation is the method used to partition the environmental load of a process when several products or functions share the same process. The input material for producing softwood lumber is a round log with bark. Processing the log involves multiple steps with generation of by-products (e.g., sawdust, chips, bark). Following the PCR, Parts A and B, allocation is based on physical properties (e.g., mass or volume). For this study, a mass allocation was used for the primary product and subsequent by-products. Some by-products used internally were used for on-site energy generation. Packaging inputs are not related to the by-products and are allocated 100% to the final product.

3.2.7 Impact Categories / Impact Assessment

The life cycle impact assessment (LCIA) phase establishes links between the LCI results and potential environmental impacts. The LCIA calculates impact indicators (Table 3), such as global warming potential and smog. ***These impact indicators provide general, but quantifiable, indications of potential environmental impacts.*** The target impact indicator, the impact category, and means of characterizing the impacts are summarized in Table 3. **Note:** *Six impact indicators listed in Table 3, global warming potential, ozone depletion potential, acidification potential, eutrophication potential, smog formation potential, and abiotic resource depletion potential of non-renewable (fossil) energy resources, are globally deemed mature enough to be included in a Type III environmental declaration. Other categories are being developed and defined and LCA should continue making advances in their development. However, with the results from this LCA as they appear in the subsequent EPDs, users shall not use additional measures for comparative purposes.*

US Environmental Protection Agency's (EPA) TRACI 2.1 v1.08 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare 2012) environmental impacts are determined using several methods obtained with the SimaPro software package and include the North American TRACI method (Bare 2012). Additional impact indicators were generated using the European CML Baseline, and Cumulative Energy Demand (CED, LHV, v.1.0) as well as several indicators calculated from the LCI results. This LCIA does not make value judgments about the impact indicators, meaning a comparison of indicator values is not valid. Additionally, each impact indicator value is stated in units that are not comparable to others. For the same reasons, indicators should not be combined or added. Additionally, the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Cumulative Energy Demand is based on fuels' lower heating values (LHV). Cumulative Energy Demand is calculated from data published by Ecoinvent and expanded by PRé for energy resources available in the SimaPro database. Characterization factors are given for six impact categories: 1. Non-renewable, fossil, 2. Non-renewable, nuclear, 3. Non-renewable, biomass, 4. Renewable, biomass, 5. Renewable, wind, solar, geothermal, and 6. Renewable, water. The primary fuels are categorized into non-renewable (fossil and nuclear) and renewable (biomass, geothermal, solar, wind, and hydro). Table 3 summarizes the source and scope of each impact category reported in this report, as required to be in conformance with the PCR (UL 2018, 2020) and ISO 21930.

Table 3. Selected Impact Category Indicators and Inventory Parameters.

Impact Indicators per ISO 21930	Abbreviation	Units	Method
Core Mandatory Impact Indicator			
Global warming potential, Total	GWP_{TOTAL}	kg CO_2 eq	$GWP_{BIOGENIC}$ + GWP_{FOSSIL}
Global warming potential, Biogenic	$GWP_{BIOGENIC}$	kg CO_2 eq	TRACI 2.1 V1.08+ LCI Indicatory
Global warming potential, Fossil	GWP_{FOSSIL}	kg CO_2 eq	TRACI 2.1 V1.08
Depletion potential of the stratospheric ozone layer	ODP	kg CF-11e	TRACI 2.1 V1.08
Acidification potential of soil and water sources	AP	kg SO_2e	TRACI 2.1 V1.08
Eutrophication potential	EP	kg Ne	TRACI 2.1 V1.08
Formation potential of tropospheric ozone	SFP	kg O_3e	TRACI 2.1 V1.08
Abiotic depletion potential (ADP fossil) for fossil resources;	ADPf	MJ, LHV	CML-IA Baseline V3.08
Fossil fuel depletion	FFD	MJ Surplus	TRACI 2.1 V1.08
Use of Primary Resources			
Renewable primary energy carrier used as energy	RPRE	MJ, LHV [a/]	CED (LHV) V1.00
Renewable primary energy carrier used as material	RPRM	MJ, LHV	LCI Indicator
Non-renewable primary energy carrier used as energy	NRPRE	MJ, LHV	CED (LHV) V1.00
Renewable primary energy carrier used as material	NRPRM	MJ, LHV	LCI Indicator
Secondary material, secondary fuel and recovered energy			
Secondary material	SM	kg	LCI Indicator
Renewable secondary fuel	RSF	MJ, LHV	LCI Indicator
Non-renewable secondary fuel	NRSF	MJ, LHV	LCI Indicator
Recovered energy	RE	MJ, LHV	LCI Indicator
Mandatory Inventory Parameters			
Consumption of freshwater resources;	FW	m^3	LCI Indicator
Indicators Describing Waste			
Hazardous waste disposed	HWD	kg	LCI Indicator
Non-hazardous waste disposed	NHWD	kg	LCI Indicator
High-level radioactive waste, conditioned, to final repository	HLRW	m^3	LCI Indicator
Intermediate- and low-level radioactive waste, conditioned, to final repository	ILLRW	m^3	LCI Indicator
Components for re-use	CRU	kg	LCI Indicator
Materials for recycling	MR	kg	LCI Indicator
Materials for energy recovery	MER	kg	LCI Indicator
Recovered energy exported from the product system	EE	MJ, NCV	LCI Indicator
Additional Inventory Parameters for Transparency			
Biogenic Carbon Removal from Product	BCRP	kg CO2e	Manual
Biogenic Carbon Emission from Product	BCEP	kg CO2e	Manual
Biogenic Carbon Removal from Packaging	BCRK	kg CO2e	Manual
Biogenic Carbon Emission from Packaging	BCEK	kg CO2e	Manual
Biogenic Carbon Emission from Combustion of Waste from Renewable Sources Used in Production Processes	BCEW	kg CO2e	Manual
Biogenic Carbon Removal from Product	BCRP	kg CO2e	Manual

3.3 Biogenic Carbon

Wood is a biobased material and thus contains biogenic carbon. The accounting of biogenic carbon follows the requirements set out in ISO 21930:2017 section 7.2.7 and 7.2.12. Per ISO 21930, biogenic carbon enters the product system (removal) as primary or secondary material. Carbon removal is considered a negative emission. The biogenic carbon leaves the system (emission) as a product, co-products, and directly to the atmosphere when combusted. These mass flows of biogenic carbon from and to nature are listed in the LCI and are expressed in kg CO_2.

In the LCIA, the LCI flow of biogenic carbon removal is characterized with a factor of -1 kg CO_2e/kgCO_2 of biogenic carbon in the calculation of the GWP[1]. Likewise, the LCI flow of biogenic carbon emission is characterized with a factor of +1 kg CO_2e/kg CO_2 of biogenic carbon in the calculation of the GWP. Emissions other than CO_2 associated with biomass combustion (e.g., methane or nitrogen oxides) are characterized by their specific radiative forcing factors in the calculation of the GWP.

The UL PCR 2020 specifies TRACI as the default LCIA method for GWP (GWP_{FOSSIL}). The TRACI method does not account for the removals or emissions of biogenic CO_2. We have thus manually calculated the component of the global warming potential related to biogenic carbon separately. We have reported the GWP indicator both with and without the biogenic CO_2 component for maximum transparency.

The results for global warming potential (GWP) and biogenic CO_2 are as follows:

- GWP_{FOSSIL} includes greenhouse gases (GHG) emissions from the combustion of fossil resources, and GHG emissions other than CO_2 from the combustion of biogenic resources (TRACI method)
- $GWP_{BIOGENIC}$ adds the net emissions of biogenic carbon to the GWP (TRACI method + net biogenic carbon = GWP_{TOTAL})
- LCI flows of biogenic carbon emissions and removals (Section 7.2; Table 22)

[1] ISO 21930 requires a demonstration of forest sustainability to characterize carbon removals with a factor of -1 kg CO_2e/kg CO_2. ISO 21930 Section 7.2.1 Note 2 states the following regarding demonstrating forest sustainability: “Other evidence such as national reporting under the United Nations Framework Convention on Climate Change (UNFCCC) can be used to identify forests with stable or increasing forest carbon stocks.” Canada’s UNFCCC annual report Table 6-1 provides annual net GHG Flux Estimates for different land use categories. This reporting indicates non-decreasing forest carbon stocks and thus the source forests meet the conditions for characterization of removals with a factor of -1 kg CO_2e/kg CO_2.

4 Description of Industry

The lumber industry is a subset of the very broad forest products industry which also produces plywood, fiberboard, particleboard, paper, cabinetry, furniture, millwork, and other products derived from trees. A distinction is often made between primary and secondary forest product industries with the former including products such as lumber and panels and the latter including products derived from lumber and panels such as cabinets and furniture.

The lumber industry can be further segmented in other ways. For example, there are significant differences between processing hardwood logs and softwood logs into lumber and there are very different markets for the products. There are also regional differences. The inputs and processing of western softwood lumber and southern softwood lumber yield similar (but not identical) allocations of by-products, but the inputs come from completely different forest management regimes and the outputs go to different markets.

4.1 Location of Markets and Typical Transportation Methods

About 63 percent of the lumber produced in the southern part of the U.S. is sold in the southern states, 6 percent to the Pacific Coast, 4 percent in the Inland Northwest, and the balance to export outside the U.S (1.23%) (AWC 2024). On average southern softwood lumber is shipped by rail (65%) and truck (35%) but varies by destination region (AWC 2024).

4.2 Plant Geographical Distribution

Many sawmills have been on site for many years; however, they have been continually updated to remain competitive. Over the years, log size has changed, and facilities have had to upgrade their technology to process these smaller logs at the highest efficiency.

The southern softwood lumber production region is represented by the states from Texas in the West to Kentucky and Virginia in the North (Figure 1). This production region considers the different forest management intensities and activities within the southern region, as well as accounting for the different species of trees, and different wood properties from the different species.

4.3 Description of Product

Lumber can include a variety of products ranging from boards to beams and timbers. Dimension lumber and studs (framing lumber) are the main products produced at the sawmills used in this study.

Dimension lumber is sold as 2”x4”, 2”x6”, 2”x8”, 2”x10”, and 2”x12”. Studs are sold as 2”x4” or 2”x6”. These numbers represent the nominal size of the lumber. The actual size of the lumber can vary depending on the stage of processing. Take a 2x4 as an example. A 2x4 might be 41 mm in thickness and 94 mm in width (1.61” x 3.7”) when green. This condition is called “rough green” in this report. After drying the actual dimensions might change to 39 mm in thickness by 90 mm in width (1.55” x 3.55”). This condition is called “rough dry” in this report. The dimensions after final finishing (planing) are 38 mm in thickness by 89 mm in width, based on grading rules which specify (in inches) 1.5” x 3.5” as the final size. This condition is called “planed dry” in this report.

Figure 4. Southern Pine Lumber (photo credit www. Homedepot.com)

When converting lumber from board feet to cubic meters, the actual dimensions were used in this report. For the southern region, there are 0.00177 m^3/BF or 564.20 BF/m^3 planed dry lumber.

Construction lumber is categorized by United Nations Standard Products and Services Code (UNSPSC) 111220 00 and Construction Specifications Institute (CSI) codes for wood framing 06 11 00 (Table 4). In addition, Structural Solutions products fall into the North American Industry Classification System (NAICS) Code 321113— and the Standard Industrial Classification (SIC) Code 2421—Sawmills and Planing Mills, General.

Table 4. United Nations Standard Products and Services Code (UNSPSC) and Construction Specification Institute (CSI) MasterFormat Code for Softwood Lumber.

Classification Standard	Category	Subcategory	Product Code
UNSPSC	Structural Products	Framing Lumber	30103603
CSI	Sawn timber (Lumber)	Wood Framing	06 11 00

4.3.1 Categories of Products and By-products

The primary product from southern softwood sawmills is construction grade lumber. Other products (by-products) are also made when logs, which are round in cross section, are processed into lumber, which is rectangular in cross section. These by-products could include chips for pulp and sawdust and shavings for panels, paper, or fuel. Logs arrive at the mill with much of the tree's bark intact. The bark is removed and used for fuel or sold for landscaping. Another product of the mill is hog fuel, which can be bark or a mix of bark and wood depending on how individual mills classify it. Hog fuel goes to a boiler or is sold. Southern lumber facilities reported 74 percent of the by-products produced in the sawmill was sold and 82 percent of the by-product produced during the planing process was sold.

4.4 Annual Operating and Production Statistics of the Industry

Southern regional mills accounted for 56 percent of the 45,567 million board feet (MMBF) of U.S. softwood lumber capacity in 2022 (Forisk 2024). The southern region's capacity is 25,470 MMBF. Participating facilities for the LCA represented over 53 percent (13,597 MMBF) of the regional capacity.

There are approximately 85 softwood lumber sawmills in the southern region (Table 5). Of the reporting facilities (n=85), the annual production ranged from approximately 23 MMBF to 373 MMBF with a weighted average of 190,738 MMBF. Table 5 lists the number of participating sawmills per production class in the southern region compared with the regional production capacity.

Table 5. Production by Southern Softwood Lumber Sawmills.

Survey Sawmills		Survey Sawmills Representation		Region production Capacity		
Million BF / year	Number of Mills by Capacity in Survey	% of Production by Capacity in Survey	Million BF in Survey	Number of Mills by Capacity in Region	% of Production by Capacity in Region	Million BF in Region
< 100	16	8%	1,154	88	12%	3,113
100-150	28	26%	3,519	44	22%	5,513
150-200	18	22%	3,050	35	25%	6,287
200 and >	23	23%	5,875	40	41%	10,557
Totals	**85**	**100%**	**13,597**	**207**	**100%**	**25,470**

4.5 Conversion Efficiencies

The fraction of log cubic volume recovered as lumber is call the cubic recover ratio (CRR). It is an accurate and consistent measure of the conversion efficiency used in scanners in sawmills to measure the log and lumber dimensions. As log diameter increases, the fraction of the log recovered as rough green lumber increases, and the fraction of by-products such as chips decreases while sawdust decreases. The weighted average CRR for southern sawmills was 0.505 m^3_{lumber}/ m^3_{log} for rough green lumber. When the overall process is considered (to produce planed-dry lumber), the CRR was 0.445 m^3_{lumber}/m^3_{log}. Another measure of mill efficiency is the lumber recovery factor (LRF) which measures the amount of recovered lumber, in board feet divided by the cubic volume of log. LRF is more sensitive to product mix than the CRR. As mills have adapted to cutting smaller diameter logs, it is possible to produce more board feet of dimension lumber out of a log than larger timbers, increasing the LRF while lowering the CRR. The weighted average LRF for southern softwood lumber is 7.692 (BF_{lumber}/ft3 $_{log}$).

4.6 Typical Emission Control Measures

Facilities reported processing steps (such as debarking, sawmilling, chipping, pneumatic transfer equipment and kiln), material moving through each process, and associated emission control devices (ECD) at each processing stage. Sawmill activities including debarking reported baghouse and cyclone ECD. Dry and green pneumatic transfer also used either baghouse or cyclone or both ECD. Kilns used for drying lumber used multicyclones and electrostatic precipitators (ESP).

4.7 General Types of Wastes and Emissions

The air emissions collected include dust, particulate matter (PM), volatile organic compounds (VOCs), and hazardous air pollutants (HAPs). Mills classed as major sources under EPA rules are required to report methanol, formaldehyde, phenol, acetaldehyde, propionaldehyde, and acrolein which are on the EPA's HAPs list. If boilers are included, then there are some sulfur dioxide and oxides of nitrogen emitted. Emissions to air for each facility were provided by the National Council for Air and Stream Improvement (NCASI) and reported for each unit process (see Tables 9-11). Water emission reported include ammonia, phosphorus and nitrogen.

Most mills reported mill waste going to landfills, recycling, compost, and/or incineration with and without energy recovery. Most common waste types reported were ash, oils and greases, metals, and wood waste.

4.8 Wood Species

Dimension lumber and studs in the southern region are sold as southern pine. This is a mixture of several species with similar characteristics. The species are primarily longleaf (*Pinus palustris*), loblolly (*P. taeda*), short leaf (*P. echinata*), and slash (*P. elliottii*) pines. Southern pine *spp.* dominates the species mix in southern sawmill responses, representing 84 percent (Table 6). Some facilities reported specifically using loblolly pine (4%), and some facilities reported input wood as peeler cores from plywood production (12%). Southern pine is defined as those species whose major range is in the United States, south of the Mason-Dixon line and east of the Great Plains (Figure 1).

Table 6. Species and Representation for the Southern Region.

Species Grouping	Scientific Name	Survey Composition
Southern pine mix	*Pinus spp.*	84%
Loblolly pine	*Pinus taeda*	4%
Southern pine mix, peeler cores	*Pinus spp.*	12%
		100%

4.9 Moisture Content

The average moisture content of the lumber leaving the sawmill was 100 percent dry basis. After drying, the grading rules specify that the lumber moisture content is 19 percent or less. Mills reported dry moisture contents between 12 and 19 percent. For all dry lumber,15 percent was assumed as an average.

5 Life Cycle Inventory Analysis

The life cycle inventory in this section presents the unit process flows for 1 m^3 of planed dry lumber. The LCI was calculated based on 2022 production and the corresponding flows of materials during that period. No data gaps were recorded.

5.1 A1- Resource Extraction

Logs used in the production of softwood lumber in the southern region include in their life cycle the upstream activities associated with establishment, growth, and harvest of trees (Figure 3). This group of activities is collectively referred to as forest resource extraction. The forest

resource extraction life cycle stage includes the efforts required to establish a forest stand, to treat that stand through to maturity, and to harvest the merchantable logs from the stand (Oneil 2021).

Forest resource extraction includes growing seedlings, site preparation, planting, fertilization (where applicable), and final harvest. These activities have been divided into two processes: Silvicultural operations and Harvesting. Seedling production involves greenhouse operations and planting. Stand management includes precommercial thinning (where applicable) and fertilization. Harvesting includes felling, skidding, processing, and loading for both commercial thinning and final harvest operations. The primary output product for this analysis is a log at a landing destined for the lumber mill. Non-merchantable slash is generally left at a landing to decay in-situ (Oneil 2021).

Resource extraction and the associated impacts will change based on both past and prospective technologies, evolving forest management procedures, and market demands. Given that productivity gains are not confirmed or well developed, this assessment was based on data representing the current state of the art. It does not discount future operations or estimate potential productivity gains from future technologies. Product output, consumed resources, and emissions associated with resource extraction were developed as a weighted average across the hectares managed for timber production. Weighted averages consider inherent differences in site productivity, management practices, and energy usage.

Softwood forests in the southern pine region are dominated by loblolly pine (*Pinus taeda*) / shortleaf pine (*Pinus echinate*) (82%) and longleaf pine (*Pinus palustris*) / Slash pine (*Pinus elliottii*) (18%) (Oneil 2021). Eight-five percent of the total forested acres in the south are considered timberland[2], with 13% classified as other than timberland and 2% reserved from harvest (Ibid.). Southern pine forests are both planted (57%), and naturally regenerated (43%), with large differences in management inputs, rotation age, and yield (Table 7).

Table 7. Southern Pine Forest Characteristics (Oneil 2021).

Softwood timberland		Management type (% of area)		Avg. growth (CF/ac)		Avg. harvested (CF/ac)		Avg mortality (CF/ac)	
	Total acres	Planted	Natural	Planted	Natural	Planted		Natural	Planted
Longleaf / slash pine	12,984,000	45%	55%	47.8	106.6	13.0	57.5	15.1	8.3
Loblolly / shortleaf pine	58,978,500	42%	58%	101.2	152.3	25.3	82.3	19.8	7.7

Forest landownership is divided among large industrial, real estate investment trusts, and small private, tribal landowners, with lesser amounts of public land ownership by county and local governments, and federal interests (Figure 5). The thirteen states that make up the southern pine forest region (Table 8) are identified as the southeast or southcentral in the USDA FIA (Oswalt et al. 2019) reporting.

[2] Forest land that is producing or capable of producing 20 cubic feet per acre or more per year of wood at culmination of mean annual increment. Timberland excludes reserved forest lands (Oswalt et al. 2019)

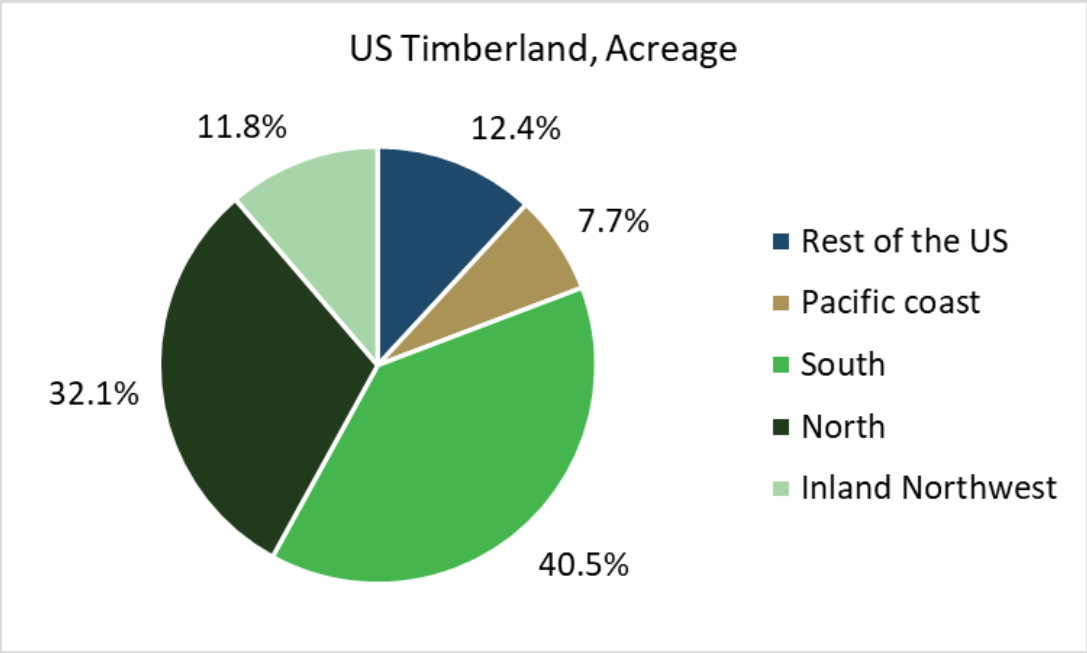


Figure 5. Regional Timberlands as a Percent of US Total Timberlands by Acreage (Oneil 2021).

Table 8. The US South Softwood Timberlands Ranked by Area in Each State (Oneil 2021).

State	Timberlands	
	1,000 hectares	
Georgia	24,061	9,737
Alabama	23,029	9,320
Mississippi	19,179	7,761
Arkansas	18,492	7,483
North Carolina	18,139	7,341
Florida	15,409	6,236
Virginia	15,389	6,228
Louisiana	14,707	5,952
Texas	14,137	5,721
Tennessee	13,407	5,426
South Carolina	12,756	5,162
Kentucky	12,246	4,956
Oklahoma	7,141	2,890

Seventy eight percent of all southern pine removals come from Georgia, Alabama, Mississippi, Louisiana, South Carolina, North Carolina, and Florida, which covers the lower and upper coastal plain and the Piedmont physiographic regions.

When trees are harvested, the tops, limbs, damaged and undersized trees are left behind as forest residues. These residues will either decay in-situ or can be yarded to the landing where they are piled and left to decay, piled and burned, or removed as a source of bioenergy or other

feedstocks. If the material is removed from the site as a source of pulp fiber or for bioenergy, it becomes a co-product (economic value) and can be assigned the upstream forestry burdens and subsequent associated impacts. Burdens associated with these non-sawlog uses were allocated to the non-sawlog and thus leave the system boundary. This is most apparent where thinning produced only pulp quality material.

5.2 A2 – Transport

The A2 module includes the transportation of resources and materials used in the production of softwood lumber. The distances are weighted averages based on lumber production volume. Incoming roundwood resources (logs) are transported by road within 179.4 kilometers (111.5 miles) of the landing. Other transportation for ancillary materials and purchased wood fuel are also part of this module (Table 9).

5.3 A3 – Lumber Manufacturing

5.3.1 Equipment: Type and Fuel Consumption

The equipment used in the manufacturing process falls into two broad categories: stationary machines and rolling stock (wheeled machinery, such as forklifts, for moving materials within a production facility). Stationary machinery in the sawing unit process includes debarkers, merchandisers, headrigs, resaws, edgers, sorters, scanners, stackers, and conveyors and other handling equipment. Stationary equipment in the planing unit process includes unstackers, moisture meters, planers, trim saws, sorters, scanners, stackers, conveyors, and other handling equipment. Stationary equipment is powered electrically.

Rolling stock, such as loaders, are used to move logs in the log yard and to move packages of lumber from one -unit process to another and to load the final product for transport. Rolling stock is mainly powered by diesel but also by a smaller amount of gasoline and propane.

5.3.2 Onsite Energy Production

Heat energy is used in the drying process and is generated on site from a wood-fired or natural gas boiler. Gas boilers produce less than 10 percent of the energy for the dryers and wood boilers supply the remaining 90 percent for the industry.

Of the wood fuel burned, 94 percent is produced on site. The fuel supplied to the boiler is a mix of bark, hog fuel, planer shavings, and dry wood waste. Thermal energy is created when the wood is combusted and makes steam in a boiler (indirect-heated kilns). Other kilns are direct-fired by burning wood. The combustion of wood and its emissions at the kiln is factored into this LCA (Puettmann and Milota 2017). Wood boilers produce ash in addition to steam. Boiler ash is sent to composting, recycling (fertilizer use), or incineration.

Lumber manufacturing was divided into three-unit processes: log yard/sawing, drying, and planing. The wood boiler represents a fourth process that provides heat for drying. Figure 6 shows the relationship between the processes and the woody inputs to and from each process.

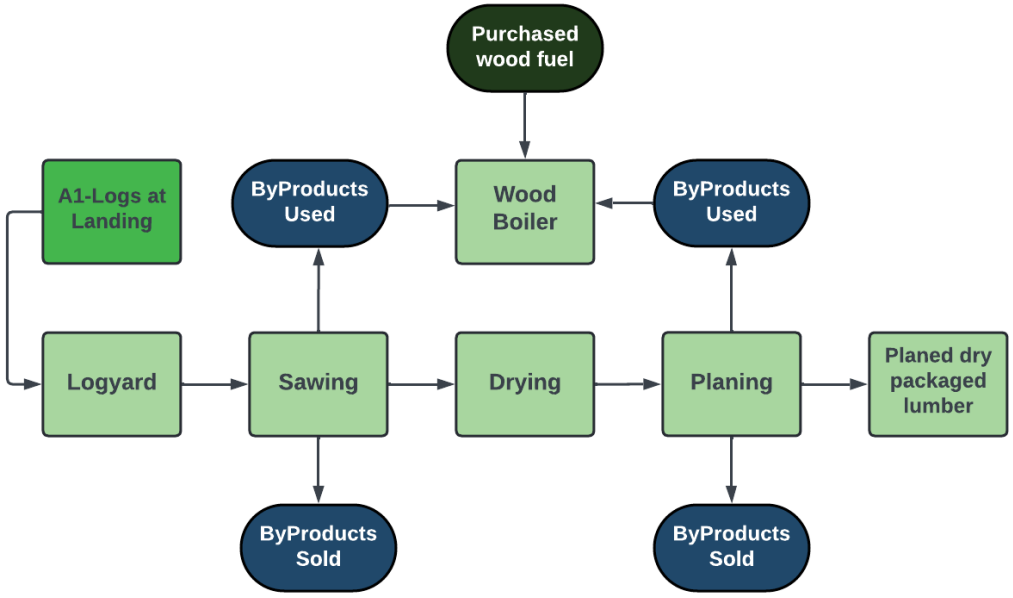


Figure 6. Sawmill Unit Processes from Roundwood to Planed Dry Lumber from Logs.

5.3.2.1 Log yard and Sawmill

The log yard unit process begins with logs plus the attached bark on a truck at the harvest site and ends with debarked and merchandised logs delivered to the infeed sawing process. Transportation of the logs from the forest road is included. Log trucks arrive at the log yard and are unloaded by diesel-powered wheeled loaders with log grapples (also referred to as on-site loaders and haulers or rolling stock). The unloading machines are a part of the log yard unit process. The log truck might be weighed in and out; however, all mills reported log input on a volume basis, either board feet or cubic feet. When the log trucks are unloaded the logs are either stacked in a storage deck or they are spread out, graded visually, then transferred to the deck. The logs are stored in the decks for anywhere from immediate use to months later. Having an inventory in the decks allows the mill to keep running even when log deliveries are temporarily interrupted due to weather, fire season, or supply issues. The logs are then removed from the deck and taken to the debarker and merchandiser at the infeed of the sawmill and cut into bolts.

Logs were reported on a volume basis, measured in westside Scribner. The log scale method of measuring logs is based on log diameter and length and used to predict the board feet of lumber to be recovered from the log. Due to technology changes and changes in average log diameter, log scale greatly underestimates the board feet currently recovered as lumber. The log scale quantities reported were converted to cubic volume using a factor of 164.19 BF/m^3 (4.65 BF/ft^3).

Water is used in the log yard for sprinkling log decks to prevent stain, insect infestations and log dryout. Diesel, gasoline, and liquefied petroleum gas are used as fuel for rolling stock (wheeled machinery, such as loaders, forklifts, and lumber carriers) for log unloading and moving logs through the process. Lube oil, hydraulic oil, grease, and antifreeze are also used in rolling stock.

Lubricants are also used in stationary equipment and solvents for cleaning. A small amount of electricity is used in the log yard.

The sawing process begins when bolts are received from the debarker and merchandiser and ends when rough sawn green lumber is stacked on stickers and transported to the dryer. Additionally, chips, sawdust, bark, and hog fuel are created in the sawing process, all in the green condition. Table 9 shows the products from and inputs to this process. By-product masses are given on an oven-dry basis. The allocation was based on oven-dry mass.

After sawing, the flow from all machine centers typically goes to a single sorting line. Here the pieces are scanned and trimmed to length. The pieces are then sorted by thickness, width, and length for drying. Finally, the lumber is stacked on stickers (spacers) in units that are removed from the sawmill by mobile equipment that typically uses diesel fuel or propane. Lumber was reported as board feet and converted to cubic meters as described in section 3.2.4

One m^3 southern lumber was produced from 1.90 m^3 of logs. Products are more accurately measured than logs, and the lumber is 53 percent of the wood leaving the sawmill. The balance of the wood leaving consists of chips, sawdust, bark, wood fuel, and hog fuel (Table 9). Chips are sold for paper making or other panel products such as particleboard and medium density fiberboard (Puettmann 2024) and are the most valuable by-product leaving the sawing process (29%).

All water use was allocated to the log yard/sawmill process. Diesel, gasoline, and liquefied petroleum gas are used as fuel for rolling stock for moving lumber from the process. Lube oil, hydraulic oil, grease, and antifreeze are also used in rolling stock. Lubricants are also used in stationary equipment and solvents for cleaning. Electricity is used in the log yard/sawmill to operate motors, instrumentation, and lighting, 38.5 kWh/m^3 (Table 9).

Table 9. Unit Process Inputs/Outputs for Log Yard and Sawmill Activities to Produce 1 m^3 of Rough Green Lumber, Southern, Unallocated.

A3 Production – Log yard & Sawing Process	Value	Unit	Allocation
Sawn lumber, softwood, rough, green	1.00	m3	52.6%
Bark, sold, softwood, green	56.18	kg	4.0%
Chips, sold, softwood, green	370.66	kg	28.8%
Sawdust, sold, softwood, green	19.76	kg	1.5%
Wood fuel, softwood, green	156.45	kg	12.1%
Hogged fuel, sold, softwood, green	4.58	kg	0.4%
Wood waste, sold, softwood, green	2.83	kg	0.2%
Resources			
Water	117.77	L	
Materials/fuels			
Sawlog with bark, softwood	1.90	m3	
Lubricating oil	4.48E-02	kg	
Oils and greases	8.68E-05	kg	
Antifreeze	3.87E-04	kg	
Solvent	6.06E-05	kg	
Diesel	0.45	l	
Gasoline	0.01	l	
LPG	3.11E-03	l	
Light Fuel Oil	4.03E-03	kg	
A2 Truck Transport, Log	179.39	tkm	
A2 Truck Transport, Ancillary Materials	2.46E-06	tkm	
Electricity/heat			
Electricity	37.50	kWh	
Emissions to air			
Particulates, unspecified	5.29E-03	kg	
VOC, volatile organic compounds	6.25E-02	kg	
Emissions to water			
COD (Chemical Oxygen Demand)	3.02E-03	kg	
BOD5, Biological Oxygen Demand	6.96E-05	kg	
Oils, unspecified	1.55E-04	kg	
Zinc	2.27E-06	kg	
Suspended solids, inorganic	2.89E-03	kg	
Lead	7.05E-08	kg	
Methanol	6.37E-08	kg	

5.3.2.2 Drying

The drying process begins with rough sawn green lumber placed at the kiln dryer and ends with rough sawn dry lumber delivered to the planer. The water loss during drying results in approximately 4-5 percent volume loss due to shrinkage with a corresponding increase in specific gravity.

Kilns are chambers that are 16 to 40 m in length, typically with two independent tracks running parallel to the chamber so lumber can be rolled through the kiln on carts on either track. Fans circulate air around and through the lumber stacks. Steam heat exchangers (heating coils) provide the energy to heat the air to the prescribed drying schedule temperature. The humidity is controlled by ventilators which open to release moist warm air and intake ambient air. The maximum drying temperature typically ranges from 80 to 100°C.

Diesel, gasoline, and liquefied petroleum gas are used as fuel for forklifts and modified front end loaders that move lumber into the kiln, out of the kiln, and to the planer. Lube oil, hydraulic oil, grease, and antifreeze are used in rolling stock. Lubricants are also used in stationary equipment and solvents for cleaning. Electricity, 10.15 kWh/m^3 (Table 10), is used in the dryer to operate motors, instrumentation, and lighting. Kiln emissions result when wood is heated, and volatile compounds are released.

Table 10. Unit Process Inputs/Outputs for Drying Activities to Produce 1 m^3 of Rough Dry Lumber, Southern, Unallocated.

A3 Production – Kiln Process	Value	Unit	Allocation
Sawn lumber, softwood, rough, green	1.00	m3	100%
Resources			
Water	43.70	L	
Materials/fuels			
Sawn lumber, softwood, rough, green	1.00	m3	
Lubricating oil	1.04E-02	kg	
Antifreeze	2.24E-04	kg	
Solvent	2.80E-05	kg	
Oil and greases	2.93E-05		
Diesel	4.57E-03	l	
Gasoline	2.72E-01	l	
LPG	9.99E-04	l	
Electricity/heat			
Electricity	10.15	kWh	
Natural gas	6.67	m3	
Wood fuel	162.88	kg	
Emissions to air			
Particulates, unspecified	1.69E-01	kg	
Particulates, < 2.5 um	1.12E-01	kg	
Particulates, < 10 um	1.60E-01	kg	
Particulates, unspecified	4.89E-02	kg	
VOC, volatile organic compounds, unspecified origin	1.68E+00	kg	
Carbon monoxide, biogenic	1.95E-01	kg	
Sulfur oxides	7.73E-02	kg	
Nitrogen oxides	1.59E-01	kg	
Methanol	8.11E-02	kg	
Formaldehyde	2.79E-02	kg	
Acetaldehyde	1.48E-02	kg	
Acrolein	3.54E-03	kg	
Propanal	5.90E-04	kg	
Phenol	3.58E-03	kg	

5.3.2.3 Planing

The planing process begins with rough dry lumber placed at the infeed to the planer and ends with packaged planed dry lumber loaded for shipment (Table 11). Sawdust, planer shavings, and other wood waste are generated in the planing process, all in dry condition (average 15% MC). By-products are expressed as oven-dry masses. The planed lumber is graded, trimmed, sorted, and stacked before packaging.

The product is packaged in units that are composed of lumber of a single thickness, width, and sometimes variable length. The units are typically covered with waterproof coated lumber wrap and banded with plastic or steel banding. Runners may be banded under the units to allow access for the forklift tines. The packaged units are then placed on the transport vehicle.

Diesel, gasoline, and liquefied petroleum gas are used as fuel for rolling stock for moving lumber from the process to truck, rail, or ships. Lube oil, hydraulic oil, grease, and antifreeze are used in rolling stock. Lubricants are also used in stationary equipment and solvents for cleaning. Wrapping material, strapping, and cardboard are used to package the product. Electricity, 19 kWh/m^3, is used in the planer to operate motors, instrumentation, and lighting.

Table 11. Unit Process Inputs/Outputs for Drying Activities to Produce 1 m^3 Rough Dry Lumber, Southern, Unallocated.

A3 Production – Planing Process	Value	Unit	Allocation
Sawn lumber, softwood, planed, dry	1.00	m3	83.3%
Chips, sold, softwood, dry	10.86	kg	1.7%
Planer shavings, sold, dry	68.84	kg	11.0%
Sawdust, sold, dry	3.13	kg	0.5%
Other wood, sold, dry	2.61	kg	0.4%
Wood fuel, dry	12.86	kg	3.1%
Resources			
Water	32.43	L	
Materials/fuels			
Sawn lumber, softwood, rough, dry	1.20	m3	
Lubricating oil	2.13E-02	kg	
Antifreeze	5.31E-04	kg	
Solvent	9.84E-05	kg	
Oil and greases	7.10E-05	kg	
Light Fuel Oil	1.92E-03	kg	
Diesel	0.12	l	
Gasoline	0.45	l	
LPG	0.05	l	
Packaging	1.125	kg	
Waste to Landfill	2.76	kg	
Waste to Recycling	16.15	kg	
Waste to Compost	7.36	kg	
Waste to Incineration	6.04	kg	
Electricity/heat			
Electricity	26.27	kWh	
Emissions to air			
Particulates, unspecified	1.34E-01	kg	
Particulates, < 2.5 um	2.74E-06	kg	
Particulates, < 10 um	7.55E-04	kg	
Particulates, unspecified	8.30E-04	kg	
VOC, volatile organic compounds, unspecified origin	6.39E-03	kg	

5.3.3 Packaging

Packing materials represent only 0.20 percent of the mass of the main product. The wood stickers and runners make up the bulk of the mass, representing 65 percent of the total packaging (Table 12). The wrapping materials represent 34 percent, followed by the strapping and cardboard at 12 percent of the total packaging mass.

Table 12. Materials Used in Packaging and Shipping per m^3 Southern Softwood Lumber.

Material	Unit	Value	Percent of Total Packaging

Wrapping Material	kg	0.380	33.78%
Steel strapping	kg	0.006	0.51%
Plastic strapping	kg	0.124	11.02%
Cardboard protectors	kg	0.009	0.76%
Runners & Lathe (wood)	kg	0.726	64.53%
TOTAL	kg	1.125	100.00%

5.4 Secondary Data Sources

Secondary data is necessary for creating the full cradle-to-gate. Tables 13, 14, and 15 list the secondary LCI data sources, geographical origin, age, and quality of the data used in this LCA study.

Table 13. Raw Material Supply Processes.

A1: Raw Material Inputs				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Logs	Database: CORRIM	US Southeast	2021	-Technology: Good Process models product specific technology. -Time: Good updated in the last 5 years -Geography: Good, Data specific to product

Table 14. Transportation Processes.

A2: Raw Material Transportation				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Trucking	Database: Datasmart v. 2023 Process: Transport, combination truck, Diesel powered NREL/US U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: good

Table 15. Manufacturing Processes

A3 Manufacturing				
Inputs	LCI Data Source	Geography	Year	Data Quality Assessment
Electricity	Database: Ecoinvent 3.9 Processes: Electricity, low voltage {SERC, US only} | market for electricity, low voltage | Cut-off, U; Electricity, low voltage {TRE, US only}| market for electricity, low voltage | Cut-off, U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: Good
Natural gas	Database: Datasmart v. 2023 Process: Natural gas, combusted in industrial boiler NREL/US U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: Good
Gasoline	Database: Datasmart v. 2023 Process: Gasoline, combusted in equipment NREL/US U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: Good
Diesel	Database: Datasmart v. 2023 Process:	North America	2023	-Technology: Good, process models average North American technology

A3 Manufacturing				
	Diesel, combusted in industrial equipment NREL/US U			-Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: Good
Hydraulic Fluid and Lubricants	Database: Datasmart v. 2023 Process: Lubricating oil, at plant/US- US-EI U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 5 years old -Geography: Good
Antifreeze	Database: Datasmart v. 2023 Process: ethylene glycol, at plant/US - US-EI U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: Good
Wrapping Materials	Database: Datasmart v. 2023 Processes: High density polyethylene resin, at plant NREL/RNA U Low density polyethylene resin, at plant NREL/RNA U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 2 years old -Geography: Good
Carboard protectors	Database: Datasmart v. 2023 and CORRIM Databases Cardboard	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 5 years old -Geography: Good
Strapping	Database: Datasmart v. 2023 Processes: Polyethylene, HDPE, granulate, at plant/US- US-EI U. Chromium steel 18/8, at plant/US- US-EI U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 5 years old -Geography: Good
Waste	Database: Ecoinvent 3.9 Processes: Process-specific burdens, sanitary landfill {RoW} | market for process-specific burdens, sanitary landfill | Cut-off, U; Process-specific burdens, municipal waste incineration {RoW} | market for process-specific burdens, municipal waste incineration | Cut-off, U; Compost {GLO} | market for compost | Cut-off, U	North America	2023	-Technology: Good, process models average North American technology -Time: Good, Data is less than 2 years old Data is less than 5 years old -Geography: Good

6 Life Cycle Impact Assessment Results

6.1 A1-A3 - Cradle-to-Gate

This section discusses the cradle-to-gate results for the declared unit, one cubic meter of southern softwood lumber. The TRACI, CML, and CED LCIA methods were used to characterize the flows to and from the environment. Allocation of environmental burdens to siding and its co-products is done according to mass allocation principles (ISO 2006 a, b). The cradle-to-gate (A1-A3) LCIA results for lumber are presented for one cubic meter (Tables 16-22).

The contribution impact of transportation of resource materials (A2) accounts for 12 percent or less of the impact in all impact categories (Tables 19-21, Figure 7).

Table 16. Cradle-to-Gate LCIA Results for 1 m^3 of Southern Softwood Lumber – Absolute Basis.

Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{TOTAL} [kg CO_2 eq]	90.39	(2,309.71)	10.90	2,389.20
$GWP_{BIOGENIC}$ [kg CO_2 eq]		(2,330.37)	-	2,330.37
GWP_{FOSSIL} [kg CO_2 eq]	90.39	20.66	10.90	58.83
ODP [kg CF-11eq]	7.77E-07	0.00	0.00	0.00
AP [kg SO_2 eq]	0.74	0.18	0.06	0.50
EP [kg N eq]	0.21	0.04	0.00	0.17
SFP [kg O_3 eq]	25.96	5.25	1.74	18.97

FFD [MJ, surplus]	162.40	37.92	20.47	104.01
ADP_{FOSSIL} [MJ, LHV]	1,194.25	267.26	136.34	790.66

Table 17. Cradle-to-Gate Resource use Results for 1 m^3 of Southern Softwood Lumber – Absolute Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	3,720.22	62.46	0.31	3,657.45
RPRM [MJ, LHV]	15,114.08	15,114.08		
NRPRE [MJ, LHV]	1,423.39	297.57	138.34	987.49
NRPRM [MJ, LHV]	0.00	0.00	0.00	0.00
SM [kg]	0.00	0.00	0.00	0.00
RSF [MJ, LHV]	0.00	0.00	0.00	0.00
NRSF [MJ, LHV]	0.00	0.00	0.00	0.00
RE [MJ, LHV]	0.00	0.00	0.00	0.00
FW [m^3]	0.73	0.10	0.00	0.62

Table 18. Cradle-to-Gate Output Flows for 1 m^3 of Southern Softwood Lumber – Absolute Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	1.48E-02	5.70E-04	8.71E-05	1.42E-02
NHWD [kg]	3.83E+01	1.46E+00	9.83E-01	3.58E+01
HLRW [m^3]	2.18E-07	3.63E-10	0.00E+00	2.18E-07
ILLRW [m^3]	2.95E-06	5.04E-08	4.28E-09	2.90E-06
CRU [kg]	0.00	0.00	0.00	0.00
MR [kg]	0.00	0.00	0.00	0.00
MER [kg]	0.00	0.00	0.00	0.00
EE [MJ, LHV]	0.00	0.00	0.00	0.00

Table 19. Cradle-to-Gate LCIA Results for 1 m^3 of Southern Softwood Lumber – Relative Basis.

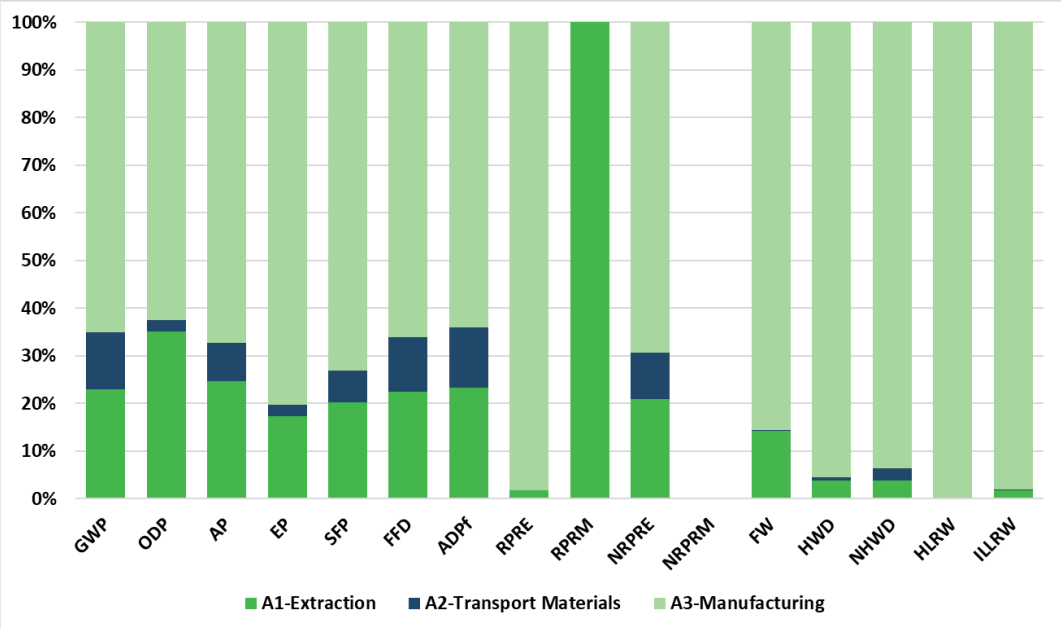
Core Mandatory Impact Indicator	Total	A1	A2	A3
GWP_{FOSSIL} [kg CO_2 eq]	100%	23%	12%	65%
ODP [kg CF-11eq]	100%	35%	2%	62%
AP [kg SO_2 eq]	100%	25%	8%	67%
EP [kg N eq]	100%	17%	2%	80%
SFP [kg O_3 eq]	100%	20%	7%	73%
FFD [MJ, surplus]	100%	22%	11%	66%
ADP_{FOSSIL} [MJ, LHV]	100%	23%	13%	64%

Table 20. Cradle-to-Gate LCIA Results for 1 m^3 of Southern Softwood Lumber – Relative Basis.

Use of Primary Resources	Total	A1	A2	A3
RPRE [MJ, LHV]	100%	2%	0%	98%
RPRM [MJ, LHV]	100%	100%	0%	0%
NRPRE [MJ, LHV]	100%	21%	10%	69%
NRPRM [MJ, LHV]	0%	0%	0%	0%
FW [m^3]	100%	14%	0%	86%

Table 21. Cradle-to-Gate LCIA Results for 1 m^3 of Southern Softwood Lumber – Relative Basis.

Indicators Describing Waste	Total	A1	A2	A3
HWD [kg]	100%	4%	1%	96%
NHWD [kg]	100%	4%	3%	94%
HLRW [m^3]	100%	0%	0%	100%
ILLRW [m^3]	100%	2%	0%	98%



GWP	Global warming potential	RPRM	Renewable primary energy carrier used as material
ODP	Depletion potential of the stratospheric ozone layer	NRPE	Non-renewable primary energy carrier used as energy
AP	Acidification potential of soil and water sources	NRPRM	Renewable primary energy carrier used as material
EP	Eutrophication potential	FW	Consumption of freshwater resources
SFP	Formation potential of tropospheric ozone	HWD	Hazardous waste disposed
ADPf	Abiotic depletion potential (ADP fossil) for fossil resource	NHWD	Non-hazardous waste disposed
FFD	Fossil fuel depletion	HLRW	High-level radioactive waste, conditioned, to final repository
RPRM	Renewable primary energy carrier used as energy	ILLRW	Intermediate- and low-level radioactive waste, conditioned,to final repository

Figure 7. Cradle-to-Gate LCIA Results for 1 m^3 of Southern Softwood Lumber – Relative Basis.

Table 22. Cradle-to-Gate Cumulative Energy Demand (CED) Results for 1 m^3 of Southern Softwood Lumber – Absolute Basis.

Impact category	A1-A3	A1	A2	A3
Nonrenewable, fossil	1,194.57	267.30	136.34	790.93
Non-renewable, nuclear	228.81	30.27	1.9929	196.55
Non-renewable, biomass	0.0084	0.0029	0.0000	0.0055
Renewable, biomass	3,663.41	59.4205	0.0638	3,603.92
Renewable, wind, solar, geothermal	28.87	1.2241	0.0687	27.57
Renewable, water	27.95	1.8186	0.1800	25.95
Total	360.03	138.65	4,644.93	5,143.61

6.2 Biogenic carbon

Table 23 shows additional inventory parameters related to biogenic carbon removal and emissions. All carbon dioxide flows (kg CO_2e) presented in Table 23 are unallocated to include by-products leaving the system boundary in module A3. Even though the system boundary for this LCA only includes modules A1-A3, in accordance with ISO 21930, emission from packaging (BCEK) is reported in A5-Construction and emission from the main product (BCEP) is reported in C3/C4-End-of-Life[3]. The net carbon emission across the cradle-to-gate life cycle is zero. It is assumed that all carbon removed from the atmosphere is eventually emitted to the atmosphere as CO_2.

Total $GWP_{BIOGENIC}$ includes biogenic carbon emissions and removals from the information modules A1-A3, A5, and C3/C4, leading to a net zero contribution of biogenic carbon to $GWP_{BIOGENIC}$. Therefore, in Table 16, results from Total GWP_{FOSSIL} and Total GWP_{TOTAL} are equal.

Using the method described earlier in this report, -2,331 kg CO_2 (reported in A1-Extraction) were removed in the production of 1 m^3 of PC softwood lumber. One cubic meter of southern softwood lumber stores 282 kg of carbon or +1,036 kg CO_2 eq (reported in C3/C4-End-of-Life). The by-products produced during lumber production account for an additional +546 kg CO_2 (reported in A3-Manufacturing) for a total “emission” in wood product leaving the system boundary of +2,037 kg CO_2. The combustion of wood fuel emitted 293 kg CO_2. Packaging resulting in removal of -1.72 kg CO_2 and an emission of +1.72 kg CO_2. In summary, total removals was -2,331 kg CO_2 and total “emissions” was +2,331 kg CO_2 from cradle-to-gate (A1-A3 of the LCA system boundary).

[3] These products are reported in modules outside the scope of this LCA system boundary to provide reference for EoL waste and emissions if a full cradle-to-grave LCA were to be performed.

Table 23. Biogenic Carbon Inventory Parameters for 1 m^3 of Southern Softwood Lumber, Unallocated.

	A1	A2	A3	A5	C3/C4	Total
BCRP [kg CO_2]	(2,330.37)	0.00	0.00	0.00	0.00	(2,330.37)
BCEP [kg CO_2]	0.00	0.00	1,001.31	0.00	1,035.78	2,037.09
BCRK [kg CO_2]	0.00	0.00	(1.72)	0.00	0.00	(1.72)
BCEK [kg CO_2]	0.00	0.00	0.00	1.72	0.00	1.72
BCEW [kg CO_2]	0.00	0.00	293.28	0.00	0.00	293.28

Southern lumber production facilities obtain their wood fiber from sources that are legally and sustainably sourced. The carbon that is part of the molecular composition of wood is derived from the carbon dioxide removed from the atmosphere by the growing of trees that produce wood. The carbon content of wood, in general, is 50 percent. The GWP_{FOSSIL} accounts for the green house gas emissions released through manufacturing (embodied carbon). In this LCA, southern softwood lumber stores more carbon than is released during manufacturing (A1-A3) by containing 1,036 kg CO_2e in the final product while emitting 90 kg CO_2e from cradle-to-gate (A1-A3). In summary the carbon balance of southern lumber is -742 kg CO_2e/m^3.

6.3 A3 – Gate-to-Gate Southern Softwood Lumber Manufacturing

The surveys did not collect fuel and energy inputs by unit process, so this softwood lumber LCAs allocations were based on the previous LCA by Milota (2020) (Table 24). Results shown in Tables 25, 26, and Figure 8 are for the A3 manufacturing module by unit process. The kiln drying unit process carried the higher allocation of the impacts in all impact categories.

Table 24. Unit Processes Allocations Used for Selected Input Fuels and Energy Inputs.

	Log yard/Sawmill	Kiln	Planer	Total
Diesel	38.46%	23.08%	38.46%	100%
Gasoline	9.06%	3.23%	87.71%	100%
Liquefied petroleum gas	5.92%	1.90%	92.18%	100%
Lubricating oils	58.56%	13.61%	27.83%	100%
Antifreeze	33.89%	19.61%	46.50%	100%
Electricity	50.73%	13.73%	35.54%	100%
Water	60.74%	22.54%	16.73%	100%

Table 25. Gate-to-Gate LCIA Results for Selected Impact Categories (TRACI) for 1 m^3 of Southern Softwood Lumber – Absolute Basis.

		A3 Total	Sawmill	Kiln	Planer
Ozone depletion potential	kg CFC-11 eq	4.85E-07	1.38E-07	1.79E-07	1.69E-07
Global warming potential	kg CO2 eq	58.83	10.88	34.30	13.65
Smog potential	kg O3 eq	18.97	0.68	17.30	0.99
Acidification potential	kg SO2 eq	0.50	0.03	0.42	0.05
Eutrophication potential	kg N eq	0.17	0.04	0.09	0.04

Wood fuel (renewable biomass) is used almost exclusively in the A3 Manufacturing module (100%) and represents 78 percent of all energy used in the A3 (Table 27)

Table 26. Gate-to-Gate Cumulative Energy Demand (CED) Results for 1 m^3 of Southern Softwood Lumber – Relative Basis.

	Sawmill	Kiln	Planer	
Nonrenewable, fossil	18%	58%	24%	100.00%
Non-renewable, nuclear	34%	28%	38%	100.00%
Non-renewable, biomass	13%	16%	71%	100.00%
Renewable, biomass	0%	99%	0%	100.00%
Renewable, wind, solar, geothermal	16%	66%	18%	100.00%
Renewable, water	13%	72%	15%	100.00%

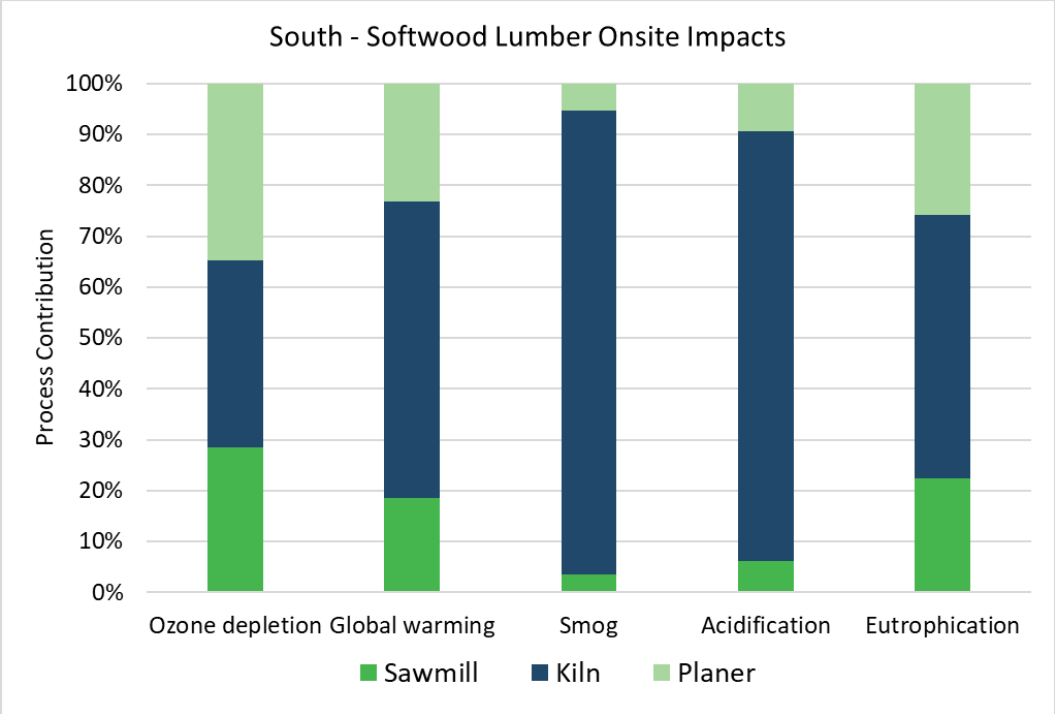


Figure 8. Contribution Analysis for A3-Manufacturing: Gate-to-Gate LCIA Results for 1 m^3 of Lumber through Each Unit Process – Relative Basis.

Table 27. Contribution Analysis for A3-Manufacturing: Gate-to-Gate Renewable and Energy Use Results for 1 m^3 of Southern Lumber, Relative Basis.

Energy Type	A3- Manufacturing	
	MJ	
Renewable	3,657.45	78.74%
Non-Renewable	987.49	21.26%
TOTAL	4,616.61	100%

7 Interpretation

As defined by ISO (2006a), the term life cycle interpretation is the phase of the LCA in which the findings of either the LCI or the LCIA, or both, are combined consistent with the defined goal and scope to reach conclusions and recommendations. This phase in the LCA reports the significant issues based on the results presented in the LCI and LCIA of this report. Additional components report an evaluation that considers completeness, sensitivity, and consistency checks of the LCI and LCIA results, and conclusions, limitations, and recommendations.

7.1 Uncertainty and Sensitivity Analysis

The uncertainty and sensitivity analysis aims to assess the reliability of the final results. The uncertainty analysis investigates input data variations within the sample of production facilities. Some degree of uncertainty is present in the results due to the variation amongst different data providers. Table 28 provides statistics for lumber recovery and cubic recovery ratio. Since this LCA is based on a mass allocation, the CRR is the allocation of the primary product and therefore a main driver in the percent impact the main product has over the entire manufacturing process.

Table 28. Survey Data Statistics for Southern Lumber Recovery Factor (LRF) and Cubic Lumber Recovery (CLR).

Parameter		Weighted Average	Min	Max.	Std. Dev.	Median
LRF	BF lumber/ft^3 of logs	7.692	1.30	12.44	1.51	7.86
CRR	Rough green Lumber m^3/ m^3 logs	0.505	0.09	0.82	0.10	0.52

In the sensitivity analysis, significant inventory parameters are altered to investigate the effect on the LCIA results. Wood fuel was substituted 100 percent for natural gas. In module A3, in the kiln drying process, the LCA model was run with no wood fuel and the equivalent energy content was substituted for natural gas. Natural gas used increased from 6.7 m^3 to 99.7 m^3 to supply the same amount of energy the wood fuel generated. The increase resulted in a 243 percent increase in the embodied carbon (GWP_{FOSSIL}) and a 258 percent increase in nonrenewable fossil fuels (Table 29).

Table 29. Sensitivity Analysis – Substituting Wood Fuel for Natural Gas.

Indicator Name	Units	Base	Substitution	Percent change
Ozone depletion	kg CFC-11 eq	7.77E-07	7.10E-07	-8.60%
Global warming (GWP_{FOSSIL})	kg CO_2 eq	90.39	310.30	243.29%
Smog	kg O_3 eq	25.96	23.49	-9.52%
Acidification	kg SO_2 eq	0.74	0.70	-5.26%
Eutrophication	kg N eq	0.21	0.17	-22.53%
Nonrenewable, fossil	MJ, LHV	1,194.57	4,277.22	258.05%
Non-renewable, nuclear	MJ, LHV	228.81	211.51	-7.56%
Non-renewable, biomass	MJ, LHV	0.0084	0.01	-18.72%
Renewable, biomass	MJ, LHV	3,663.41	83.16	-97.73%
Renewable, wind, solar, geothermal	MJ, LHV	28.87	13.22	-54.19%
Renewable, water	MJ, LHV	27.95	12.02	-57.01%

7.2 Completeness and Consistency Checks

Life cycle assessment reports must be reviewed for completeness, consistency, and data sensitivity. Evaluation helps to establish and enhance confidence in, and the reliability of, the results of the LCA study, including the significant issues identified in the interpretation. The energy use (MJ/m^3) of southern softwood lumber in this LCA was compared to the previous LCA on southeastern softwood lumber (Milota 2020), and the North American softwood lumber EPD (2020) (Table 30).

Table 30. Energy Consumption of Lumber Products – Comparison of this LCA to Other Times/Regions.

Product	Total	A1-Extraction	A2-Raw Material Transport	A3-Manufacturing	Reference
	MJ/m^3				
Southern Lumber, this LCA	5,143.61	360.03	138.65	4,644.93	This LCA
Southeastern Lumber, 2020	5,107.04	193.05	154.99	4,759.00	Milota 2020
North American EPD	3,380.67	148.81	137.40	3,094.45	Softwood Lumber EPD, North American, 2020

The objective of the consistency check is to determine whether the assumptions, methods, models, and data are consistent with the goal and scope of the study. Through a rigorous process, consistency is ensured to fulfil the goal of the study in terms of assumptions, methods, models, and data quality including data source, accuracy, data age, time-related coverage, technology, and geographical coverage.

The completeness check is performed to ensure that all relevant information and data needed for the interpretation are available and complete. The data were checked for completeness including all elements such as raw and ancillary material input, energy input, transportation, water consumption, product and co-products outputs, emissions to air, water and land and waste disposal. All the input and output data were found to be complete, and no data gaps were identified.

8 Discussion

This study provides a comprehensive cradle-to-gate LCA of the production of southern softwood lumber. The primary goal of this LCA was to develop life cycle inventory data and impact assessment softwood lumber that would be used to develop a Type III Environmental Product Declaration (EPD). In addition to the impact assessment results, the life cycle inventory elements are also provided. Including the LCI elements enables the resource use inventory elements and waste flows as required by the PCR to be included in the EPDs. This cradle-to-gate LCA does incorporate the necessary scope to develop a "business-to-business" EPD for softwood lumber in accordance with the Product Category Rule Guidance for Building-Related Products and Services, Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL 2018) and Part B: Structural and Architectural Wood Products EPD Requirements (UL 2020).

As noted earlier, total energy for producing 1 cubic meter of softwood lumber from the South was 5,144 MJ, which differs from the 2020 report by less than 1 percent (5,107 MJ, Milota 2020) (Table 31). Renewable fuels use differences between the two studies is around 1 percent (1.34%) (Table 31).

Table 31. LCIA Comparison Between this LCA and the 2020 LCA on Softwood Lumber Production in the Southern Region.

Impact category	Unit	This LCA[1/]	Milota 2020[2/]	Percent change
Global warming potential, fossil	kg CO_2 eq	90.39	85.03	6.30%
Eutrophication Potential	kg N eq	0.2145	0.4942	-56.60%
Smog Potential	kg O_3 eq	25.96	17.2556	50.44%
Non-renewable fuels	MJ, LHV	1,423.39	1,336.13	6.53%
Renewable fuels	MJ, LHV	3,720.22	3,770.90	-1.34%
Fresh water	L	729.7	369.16	97.66%
Solid waste (hazardous & non-hazardous)	kg	38.29	5.5621	588.41%

[1/] Based on 2022 production data
[2/] Based on 2017 production data

9 Additional Information

Lumber production facilities in the U.S. South obtain their wood fiber from sources that are legally and sustainably sourced. Participating facilities reported Fiber Sourcing data for the three sourcing categories established in ASTM-D7612: Standard Practice for Categorizing Wood and Wood-Based Products According to Their Fiber Sources (ASTM 2021). The standard provides criteria for differentiating wood products into three categories:

1. Non-controversial Sources of Forest Products,
2. Responsible Sources of Forest Products, and
3. Certified Sources of Forest Products.

Fiber from non-controversial, or legal, sources are from geographic areas with a low risk of illegal activity and are compliant with legal or other proprietary standards. Products from responsible sources are produced with wood fiber acquired according to an independently certified procurement standard or are from jurisdictions with regulatory or quasi-regulatory programs to implement best management practices. Independently certified procurement standards include FSC Controlled Wood and SFI Fiber Sourcing. To qualify for either standard, a lumber mill must have a system in place that verifies their logs are coming from areas in compliance with forestry best management practices to protect air and water quality and ensure all fiber comes from known and legal sources. Products from certified sources are independently certified to an internationally recognized forest management certification standard, such as those from the Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), American Tree Farm System (ATFS), or the Canadian Standards Association (CSA).

The eighty-five facilities represented in this regional LCA reported on average,100% of the fiber entering their mills to be non-controversial (legal), 90.2% to be responsible (following a certified procurement standard), and 41.2% from independently certified forests.

10 Conclusions

This study provides a comprehensive cradle-to-gate LCA of the production softwood lumber produced and sourced in the Southern region of the United States. The primary goal of this LCA was to develop life cycle inventory data and impact assessment results for southern lumber that could be used to develop a product Environmental Product Declaration (EPD). In addition to the impact assessment results, the life cycle inventory elements are also provided. Including the LCI elements enables the resource use inventory elements and waste flows as required by the Product Category Rule (PCR) to be included in the EPD. This cradle-to-gate LCA does incorporate the necessary scope to develop a “business-to-business” EPD in accordance with the PCR Guidance for Building-Related Products and Services, Part A: Life Cycle Assessment Calculation Rules and Report Requirements (UL 2018) and Part B: Structural and Architectural Wood Products EPD Requirements (UL 2020).

11 Critical Review

11.1 Internal Review

The purpose of the LCA Report internal review is to check for errors and conformance with the PCR prior to submittal for external review. The technical and editorial comments of the reviewers were carefully considered and, in most instances, incorporated into the final document. CORRIM and the American Wood Council addressed the internal review comments, as appropriate, and maintains a record of all comments and responses for future reference.

- Anna Ostrander, LCA Data Specialist, American Wood Council
- Tyler Congleton, Boise Cascade Company

11.2 External Review

The external review process is intended to ensure consistency between the completed LCA and the principals and requirements of the International Standards on LCA (ISO 2006a) and ISO 21930 -Sustainability in Buildings and Civil Engineering Works - Core Rules for Environmental Product Declarations of Construction Products and Services (ISO 2017), the Product Category Rules for North American Structural and Architectural Wood Products Part B (UL 2020) and Part A: Life Cycle Assessment Calculations Rules and Report Requirements (UL 2018).

Following the internal review evaluation, documents were submitted to ASTM International for an independent external review. The independent external review performed by ASTM was conducted by:

12 References

ASTM Standard D7612-21. 2021. “Standard Practice for Categorizing Wood and Wood-Based Products According to Their Fiber Sources.” ASTM International, West Conshohocken, PA, 2021. DOI: 10.1520/D7612-21.

AWC – American Wood Council. 2024. Personal communication regarding product transport.

Bare, J. 2012. Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) - Software Name and Version Number: TRACI version 2.1 - User’s Manual. Washington, D.C.: U.S. EPA.

International Organization for Standardization ISO. 2006a. Environmental management—Life-cycle assessment—Requirements and guidelines. ISO 14044:2006/Amd1:2017/Amd:2:2020. International Organization for Standardization, Geneva, Switzerland. 46 pp/8 pp/12 pp/.

International Organization for Standardization ISO. 2006b. Environmental management—Life-cycle assessment—Principles and framework. ISO 14040. International Organization for Standardization, Geneva, Switzerland. 14040:2006/Amd1:2020. 20 pp/8 pp.

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

International Organization for Standardization ISO. 2017. Sustainability in buildings and civil engineering works – Core rules for environmental product declarations of construction products and services. International Organization for Standardization. Second edition (ISO 21930:2017-07) 80pp.

LTS. 2023 Datasmart LCI Package http://ltsexperts.com/services/software/datasmart-life-cycleinventory/

Milota, M. 2020. Life cycle assessment for the production of southeastern softwood lumber. 134 pp. https://corrim.org/wp-content/uploads/2020/06/CORIRM-AWC-SE-Lumber.pdf (Accessed June 23, 2024).

Oneil, E. 2021. Cradle to ate life cycle assessment of US regional forest resources – US Southern Pine Forests. 41pp. https://corrim.org/wp-content/uploads/2021/12/CORRIM_SE_Forest_Resources_LCA_Report.pdf. (Accessed June 23, 2024)

Puettmann, M. and M. Milota. 2017. Life cycle assessment for wood fired boilers used in the wood products industry. For. Prod. J. 67(5/6):381-389.

Puettmann, M.E. 2024. Cradle to Grave Life Cycle Assessment of Medium Density Fiberboard. March 2024. 57 pp.

Pré Consultants, B.V. 2023. SimaPro 9.5.0 Life-Cycle Assessment Software Package. Plotter 12, 3821 BB Amersfoort, The Netherlands. Http://www.pre.nl/.

UL. 2018. Product Category Rules for Building-Related Products and Services - Part A: Life Cycle Assessment Calculation Rules and Report Requirements, UL 10010, v.3.2.

UL. 2020. Product Category Rule Guidance for Building-Related Products and Services, Part B: Structural and Architectural Wood Products, EPD Requirements UL 10010-9 v.1.0.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016) The Ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, 21, 1218–1230.