Comparative LCA of Three Decking Materials

On Behalf of AZEK Building Products

Client:	**AZEK Building Products**
Title:	**Comparative Life Cycle Assessment of Three Decking Materials**
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List of Acronyms

ACQ	Alkaline Copper Quaternary (wood treatment substances)
ADP	Abiotic Depletion Potential
AP	Acidification Potential
CML	Centre of Environmental Science at Leiden
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
PSL	Product Service Life
RSL	Reference Service Life
SFP	Smog Formation Potential
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
USLCI	U.S. Life Cycle Inventory
VOC	Volatile Organic Compound

Glossary

Life cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

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" (ISO 14040:2006, section 3.3)

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" (ISO 14040:2006, section 3.4)

Life cycle interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Functional unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

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" (ISO 14040:2006, section 3.17)

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, section 4.3.4.3.3)

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study." (JRC 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, section 3.45).

Executive Summary

AZEK Building Products commissioned Sphera to conduct a life cycle assessment (LCA) of its TimberTech decking board products and compare them to a traditional wood alternative. The study was critically reviewed by a panel of three independent experts.

The product systems under study comprise the following decking-board products:

- TimberTech Capped Wood Plastic Composite (full profile and scalloped profile),
- TimberTech Capped Cellular Polyvinyl Chloride (PVC), and
- ACQ treated pine.

All product systems are assumed to be suitable as decking boards for outdoor deck areas in residential settings and are either designed to resemble wood (composite, PVC) or are made of wood. While the composite and PVC decking boards represent manufacturing averages from the two AZEK facilities, the pine decking boards represent a typical product available in the US.

The study uses a net area of 1,000 ft^2 of decking board and a Reference Service Life RSL of 25 years as a baseline scenario aiming to generate results that can be compared to LCA results published by one of AZEK's industry peers, who offers a comparative analysis of 1,000 board feet (i.e., 1 MBF) each of their own composite product and of treated pine. The cradle-to-grave system boundary of the LCA includes raw material supply and product manufacturing; distribution to market; installation; maintenance; and end of life.

The reference flows of the four product systems are a function of the ratios of their respective Product Service Life (PSL) and the Reference Service Life (RSL):

- 25 (RSL) / 27.8 (PSL) x 1,000 ft^2 = 899 ft^2 of TimberTech composite decking board (with an average manufacturer warranty of 27.8 years), which is a production-weighted average of
  - 25/30 x 1,000 ft^2 = 833 ft^2 of full-profile TimberTech composite decking board (30-year warranty);
  - 25/25 x 1,000 ft^2 = 1,000 ft^2 scalloped-profile TimberTech composite decking board (25-year warranty);
- 25/50 x 1,000 ft^2 = 500 ft^2 of TimberTech PVC decking board (with a warranty of 50 years); and
- 25/10 x 1,000 ft^2 = 2,500 ft^2 of treated-pine decking board (with an assumed lifetime of 10 years).

The above distinguishes the amounts of material necessary to deliver the functional unit, i.e., approximately one TimberTech composite or half of one TimberTech PVC deck installation or 2.5 deck installations of pine. The annual maintenance regimen in the use phase distinguishes the TimberTech decking systems only from the pine decking systems, as all decking materials are assumed be cleaned with deck cleaning solution and brush while pine is assumed to require staining every third year. At the end of the products' useful lives, landfilling is the assumed disposal method for all product systems.

The cradle-to-grave carbon footprint (Global Warming Potential – GWP100) results of the three product systems, normalized to the result of the production-weighted average for TimberTech composite decking (TimberTech CompAvg), are shown in Figure ES-1. GWP100 excluding biogenic carbon (GWP100 fossil) results show TimberTech composite decking outperforming treated pine by 16%. TimberTech PVC decking has a fossil GWP100 that is 13% higher than TimberTech composite and 5% lower than treated pine.

Sensitivity analysis shows pine decking's GWP100 excluding biogenic carbon (GWP100 fossil) result on par with TimberTech PVC's when pine is assumed to last 10.5 years and on par with TimberTech average composite (baseline) when pine is assumed to last 12.5 years. Consequently, a treated pine decking product that lasts 0.5 – 2.5 years (or 5% – 25%) longer than assumed in the baseline scenario would have a similar GWP100 fossil result as TimberTech PVC and composite decking, respectively.

Results for GWP100 including biogenic carbon (GWP100 total), which incorporates the uptake of biogenic carbon from the atmosphere, show TimberTech composite as well as the pine decking system as net carbon sinks due to the permanent sequestration (i.e., for at least 100 years from the time of disposal) of almost all of the wood's biogenic carbon content in the landfill at EoL, while TimberTech PVC decking does not net-sequester carbon.

Sensitivity analysis further shows that this net carbon benefit would decrease with an increase in assumed Product Service Life (PSL) of the wood deck as the amount of carbon that is permanently sequestered by landfilling would decrease accordingly. While the benefits in terms of permanent sequestration are deemed valid based on EPA data of average US decomposition rates in landfills, *these findings shall not be misunderstood to mean that replacing wooden decks as often as possible will automatically render the biggest overall benefit for the climate*. The answer to this question ultimately depends on the carbon management practices of the forestry operations that produce the lumber used, including changes in soil carbon, below-ground biomass, dead organic matter, and the carbon capture rates of old growth versus new growth. As there still is no international consensus on how to model forestry operations in this regard, the results in this study consider above-ground biomass only and implicitly assume that the net carbon balance of the forestry operations beyond the harvested biomass are zero. Even if the net carbon balance of the forest operations were not zero and if it were included in the wood inventories, the question would remain how an increase in demand for pine lumber due to a higher replacement rate of wooden decks may or may not alter that balance.

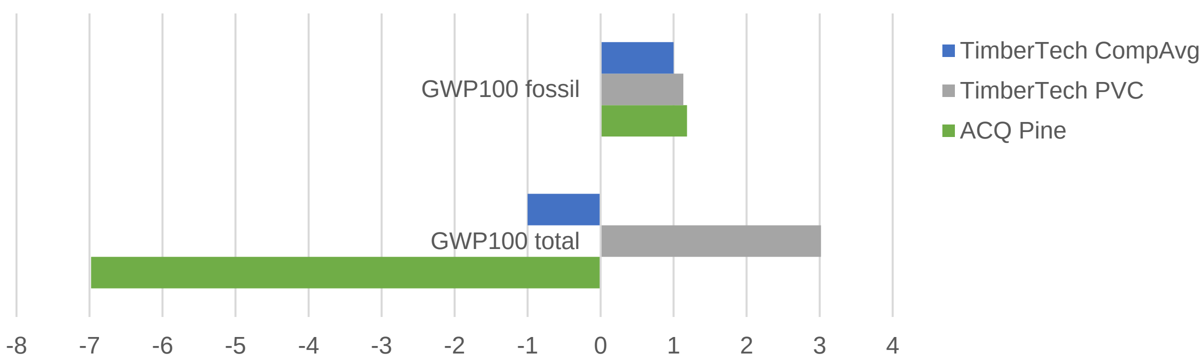

Figure ES-1: Carbon footprint overview, cradle-to-grave, normalized to average TimberTech composite

Other key environmental indicator results, i.e., Acidification Potential (AP), Eutrophication Potential (EP), Smog Formation Potential (SFP), Primary Energy Demand from non-renewable resources (PED_{nr}), and Blue Water Consumption (Water), normalized to the result of the production-weighted average for TimberTech composite decking, are shown in Figure ES-2.

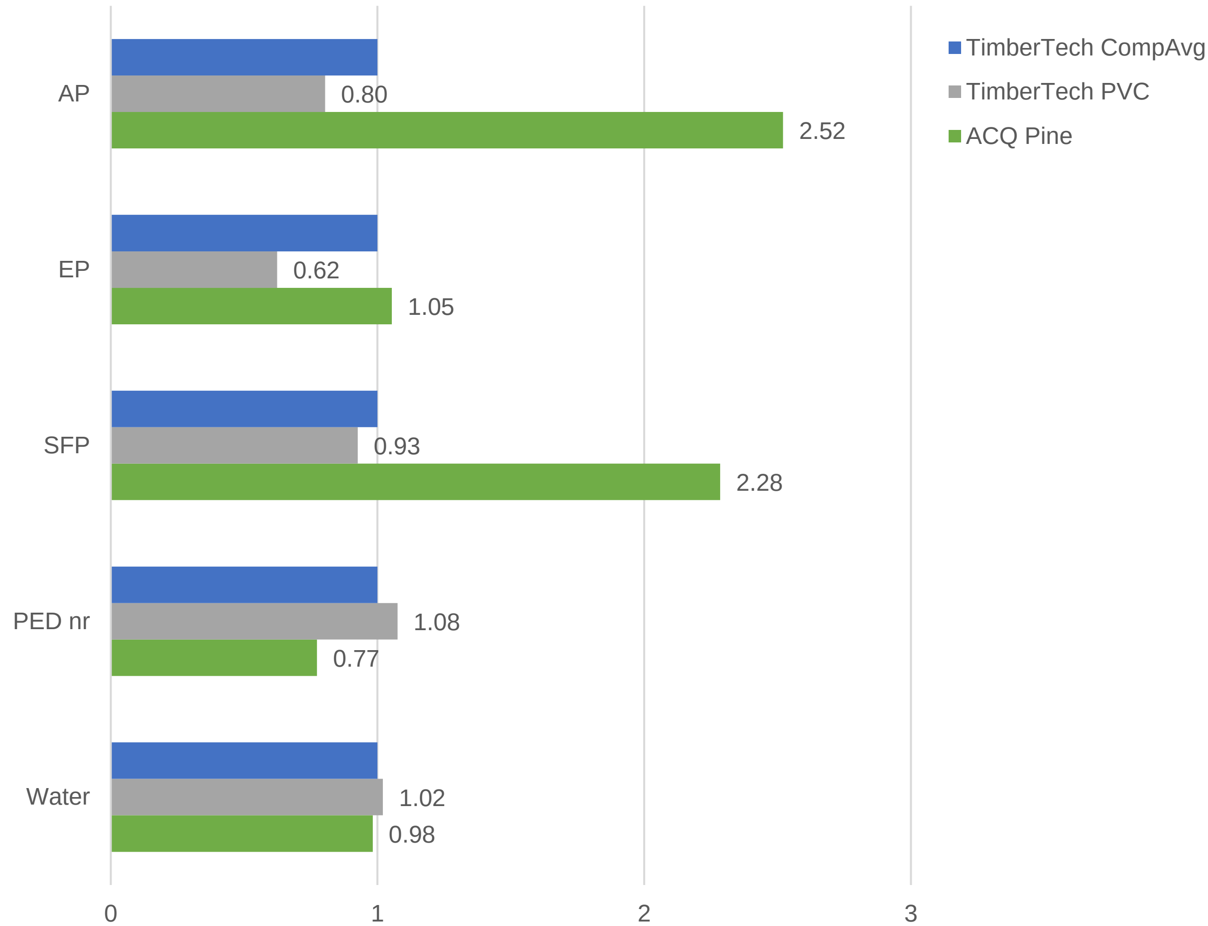

Figure ES-2: Other environmental indicator results, cradle-to-grave, normalized to TimberTech composite

Among the key environmental indicators beyond carbon footprint, TimberTech composite decking performs most strongly with pine on AP, EP, and SFP where upstream timber supply drives the results of the manufacturing phase. On PED_{nr} and Water, TimberTech composite decking results come in higher than pine. Pine is ACQ-treated for durability and represents 2.5 installations. On PED_{nr}, pine decking outperforms the TimberTech products due to their use of renewable resources for manufacturing energy (wood waste). TimberTech PVC decking outperforms pine decking on AP, EP, SFP, and Water, while showing the highest PED_{nr} due to upstream PVC granulate production.

Overall, the TimberTech decking product systems, compared to conventional pine decking, demonstrate strengths on most environmental performance indicators. TimberTech decking products compete on environmental performance due to their high longevity relative to pine decking, which likely needs to be replaced more frequently in normal outdoor conditions. Reduction potential on GWP fossil of TimberTech composite decking is greatest in the areas of virgin-polymer supply and electricity use in manufacturing, suggesting further increases in the use of recycled polymers and reduction of energy intensity or increasing the share of natural gas or electricity from renewable resources. The single greatest reduction potential on GWP fossil of TimberTech PVC decking is represented by virgin polymer supply.

1. Goal of the Study

A heightened interest in product environmental performance among its internal and external stakeholders prompted AZEK Building Products, a division of The AZEK Company, (AZEK) to commission an LCA study to quantify its TimberTech decking products' environmental profiles compared to an alternative wood decking product. Therefore, two key applications of the study outcomes are anticipated to be the identification of opportunities to improve product environmental performance and the support of marketing communications around product environmental performance. Additional applications can be the use in corporate carbon footprinting and product environmental product declarations (EPDs). The audience of this study includes AZEK's product development, marketing, and senior management, as well as external interested parties concerned with or affected by the outcomes of the study, such as customers and other stakeholders in the company's value chain.

The study has been conducted according to the requirements of ISO 14044 and critically reviewed by a three-person panel. See critical review statement for details.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product System(s)

The product systems under study comprise the following decking-board products:

- TimberTech Capped Wood Plastic Composite (full profile and scalloped profile),
- TimberTech Capped Cellular Polyvinyl Chloride (PVC), and
- ACQ treated pine.

All product systems are assumed to be suitable as decking boards for outdoor deck areas in residential settings and are either designed to resemble wood (composite, PVC) or are made of wood. While the composite and PVC decking boards represent manufacturing averages from the two AZEK facilities, the pine decking boards represent typical products available in the US.

2.2. Product Function(s) and Functional Unit

The basis of comparison described below is consistent with the study's goal (see section 1) and puts a focus on the common functionality of all products systems to achieve functional equivalency.

2.2.1. Product function

The key function of the product is as an outdoor deck surface to walk and sit on. No additional product functions are applicable for any of the product systems under study. Differences in appeal, feel, color, retail price, or other product attributes are not considered.

2.2.2. Functional unit

The functional unit under study is a deck area of 1,044 ft^2 providing the key product function over 25 years (Reference Service Life – RSL).

2.2.3. Reference flow

The functional unit is designed so it can be supplied by a reference flow of 1,000 ft^2 of decking board, making the study results comparable to a peer study. The functional unit is achieved when 1,000 ft^2 of decking board are assembled in 43 rows of 5.5-inch wide decking board at a length of 50.7 ft, installed with a 1/4-inch spacing and resulting in a width of 20.6 ft. The reference flows of the different product systems are based on the ratios of their respective Product Service Life (PSL) and the Reference Service Life (RSL):

- 25/30 of 1,000 ft^2 of full-profile TimberTech composite decking board (with a warranty of 30 years);
- 1,000 ft^2 of scalloped-profile TimberTech composite decking board (with a warranty of 25 years);
- 25/50 of 1,000 ft^2 of TimberTech PVC decking board (with a warranty of 50 years); and
- 25/10 of 1,000 ft^2 of treated-pine decking board (with an expected lifetime of 10 years).

2.2.4. A discussion of the 1,000 ft^2 of decking board and 25-year lifetime baseline scenario

This study uses a net area of 1,000 ft^2 of decking board and an RSL of 25 years as a baseline scenario aiming to generate results that can be compared to LCA results promoted by one of AZEK's industry peers, who offers a comparative analysis of 1,000 board feet (i.e., 1 MBF) each of their own composite product and of treated pine. Board foot (BF) is a unit of volume (i.e., 1/12 of a ft^3), which is commonly used to quantify wooden board products—including decking boards with a typical 1" thickness. However, TimberTech composite decking boards are manufactured with a target thickness of 0.936" +/-0.03" tolerance. Thus, the comparison per MBF of each product would have required the scaling of volume (and mass) for the TimberTech composite decking product while no longer representing the product as it is commercially available. In order to avoid forcing this type of normalization, this study compares areas of decking board products rather than volumes with the understanding that for all but the TimberTech composite decking boards, it can be assumed that the board thickness is 1" and, therefore, 1,000 ft^2 of decking board have a volume of 1 MBF.

Deck installations typically introduce spacing between decking boards to allow for easy water runoff and venting of the sub-system. Consequently, a 1,000 ft^2 deck, installed, requires less than 1,000 ft^2 of decking boards. However, this study disregarded any spacing in installation in order to generate an assessment that compares directly to the per-MBF analysis published by AZEK's industry peer.

2.3. System Boundaries

This cradle-to-grave LCA includes the following life cycle stages:

- Raw material supply and product manufacturing,
- Distribution to market,
- Installation,
- Maintenance, and
- End of life.

Warehousing and the retail environment are excluded from the study as they are assumed to be identical for all product systems under study. At installation, all decking board products under study are typically rated to span 16" on center, meaning that the outdoor deck's sub-structure is similar for product systems and can, therefore, be excluded. The product systems are also similar in their compatibility with railings and other outdoor deck features, which allows those deck parts to also be excluded from the study.

Table 2-1: System boundaries

Included	Excluded
✓ Raw material supply ✓ Energy and fuels ✓ Product manufacturing ✓ Distribution to market ✓ Installation and replacement ✓ Maintenance ✓ End of life	× Capital goods × Infrastructure × Worker commute × Warehousing and retail environment × Deck components other than decking boards

The system boundary was drawn, based on expert judgement, to exclude the items listed in the table above, as they are not expected to help discern the environmental performances of the product systems under study.

2.3.1. Time Coverage

The study is intended to represent 2019 product systems. Results for the TimberTech product systems are assumed to be valid for at least the next two years, unless significant technological changes occur.

2.3.2. Technology Coverage

The study is intended to capture the manufacturing technologies at the two AZEK facilities, which produce composite and PVC decking boards, and capture average or generic manufacturing technologies for the comparable wood decking-board product.

2.3.3. Geographical Coverage

The study is intended to represent products manufactured, sold, and installed in the U.S. market.

2.4. Allocation

2.4.1. Multi-output Allocation

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2. No multi-output allocation was necessary for any of the activities in the foreground system.

Allocation of background data (energy and materials) taken from the GaBi 2019 databases is documented online at http://documentation.gabi-software.com/.

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3.

Material recycling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary at end of life is drawn after scrap collection to account for the collection rate, which generates an open scrap output for the product system. The processing and recycling of the scrap is associated with the subsequent product system and is not considered in this study. The AZEK Company offers a jobsite recycling program which may be studied in future work.

Energy recovery & landfilling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary includes the waste incineration and landfilling processes following the polluter-pays-principle. In cases where materials are sent to waste incineration (applies only to scenario analysis, see section 4.4.1), they are linked to a life cycle inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. In cases where materials are sent to landfills, they are linked to a life cycle inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). No credits for power or heat production are assigned. See Table 3-13 for details of the datasets used in EoL modeling.

2.5. Cut-off Criteria

No cut-off criteria are defined for this study. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analyzed and is discussed in Chapter 5.

2.6. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-2 and Table 2-3. TRACI 2.1 has been selected as it is the official impact assessment framework developed and published by the Environmental Protection Agency (EPA) (Bare, 2012) (EPA, 2012). For impact categories where TRACI characterization factors are not available (e.g., water footprinting) or where they are not considered to be the most current (global warming potential), alternative methods have been used and are described in more detail below.

Global Warming Potential and Non-Renewable Primary Energy Demand were chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be one of the most pressing environmental issues of our time. The global warming potential impact category is assessed based on the current IPCC characterization factors taken from the 5th Assessment Report (IPCC, 2013) for a 100 year timeframe (GWP100) as this is currently the most commonly used metric.

The global warming potential results either include or exclude the photosynthetically bound carbon (also called *biogenic carbon*) as well as the release of that carbon during the use or end-of-life phase as CO_2 and/or CH_4. Hence, two separate metrics for GWP will be evaluated (GWP fossil and GWP total). For more information, please refer to http://www.gabi-software.com/support/gabi/gabi-modelling-principles/.

Eutrophication, Acidification, and Photochemical Ozone Creation Potentials were chosen because they are closely connected to air, soil, and water quality and capture the environmental burden associated with commonly regulated emissions such as NO_x, SO_2, VOC, and others.

The *Montreal Protocol on Substances that Deplete the Ozone Layer* was implemented in 1989 with the aim of phasing out emissions of ozone depleting gases. The protocol has been ratified by *all* members of the United Nations – an unprecedented level of international cooperation. With a few exceptions, use of CFCs, the most harmful chemicals, has been eliminated, while complete phase out of less active HCFCs will be achieved by 2030. As a result, it is expected that the ozone layer will return to 1980 levels between 2050 and 2070. In addition, no ozone-depleting substances are emitted in the foreground system under study. For these reasons, ozone depletion potential is not considered in this study.

Water consumption, i.e., the anthropogenic removal of water from its watershed through shipment, evaporation, or evapotranspiration, has also been selected due to its high political relevance.

The present study excludes the assessment of resources, as despite 20 years of research, there remains no robust, globally agreed upon method - or even problem statement - for assessing mineral resource inputs in life cycle impact assessment (Drielsmaa, et al., 2016). One may further argue that the concern regarding the depletion of scarce resources is not as much an 'environmental' one, but rather about the vulnerability of markets to supply shortages. These shortages, in return, are driven by various factors that are not captured well by current metrics. Accordingly, resource criticality has emerged as a separate tool to assess resource consumption (Nassar, et al., 2012; Graedel & Reck, 2015). As a complete criticality assessment is out of scope for this work and the environmental interventions associated with the production and consumption of these resource are captured by the other impact categories the study at hand therefore excluded the assessment of abiotic resources.

Table 2-2: Impact categories used in this study

Impact Category	Description	Unit	Reference
IPCC Global Warming Potential (GWP100), excluding and including biogenic CO_2	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, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	(IPCC, 2013)
Eutrophication Potential	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg N equivalent	(Bare, 2012) (EPA, 2012)

Impact Category	Description	Unit	Reference
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	kg SO_2 equivalent	
Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg O_3 equivalent	
Eco-toxicity	A measure of toxic emissions which are directly harmful to the health of humans and other species.	Comparative toxic units (CTUe)	(Rosenbaum, et al., 2008)

Table 2-3: Other environmental indicators

Indicator	Description	Unit	Reference
Primary Energy Demand (PED)	A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ (lower heating value)	(Guinée, et al., 2002)
Water Consumption	A measure of the net intake and release of fresh water across the life of the product system. This is not an indicator of environmental impact without the addition of information about regional water availability.	Liters of water	(thinkstep, 2014)

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the life cycle inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

As this study intends to support comparative assertions to be disclosed to third parties, no grouping or further quantitative cross-category weighting has been applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

2.7. Interpretation to Be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

Note that in situations where no product outperforms all of its alternatives in each of the impact categories, some form of cross-category evaluation is necessary to draw conclusions regarding the environmental superiority of one product over the other. Since ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, this evaluation will take place qualitatively and the defensibility of the results therefore depend on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.8. Data Quality Requirements

The data used to create the life cycle inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modeling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in section 5 of this report.

2.9. Type and format of the report

In accordance with the ISO requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Software and Database

The LCA model was created using the GaBi 9 Software system for life cycle engineering, developed by Sphera (formerly thinkstep). The GaBi 2019 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.11. Critical Review

A panel review was conducted according to ISO 14044, section 6.3.

The panel of reviewers comprises:

- Sangwon Suh, Ph.D., of VitalMetrics (Chair);
- Jim Bowyer, PhD., Professor emeritus, Department of Bioproducts and Biosystems Engineering, University of Minnesota, and Senior Contributor, Dovetail Partners, Inc.;
- Mike Levy of First Environment.

The Critical Review Statement can be found in Annex A. The Critical Review Report containing the comments and recommendations of the independent experts as well as the practitioner's responses is available upon request from the study commissioner in accordance with ISO/TS 14071.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

All primary data were collected using customized data collection templates, which were sent out by email to the respective data providers at AZEK. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

3.2. Composite Decking Board

3.2.1. Overview of Product System

TimberTech composite decking board is manufactured mainly from recycled polyethylene and wood flour (sawdust). The packaged product is distributed to market by truck. The product is installed with an electric driver power tool and deck screws. Starting one year after installation, an annual cleaning is performed with TimberTech deck cleaner and water, using a scrub brush. At the end of the product's useful life, the decking boards are deinstalled and disposed of.

Figure 3-1: Flowchart of foreground system for composite decking board

Figure 3-2: TimberTech composite decking

As introduced in section 2.2, TimberTech composite decking comes in two profile versions, i.e., full and scalloped, as shown here. The full profile is covered by a 30-year manufacturer warranty and the scalloped profile by a 25-year manufacturer warranty. With the full-profile decking representing 55% of annual production output (by mass) and the scalloped-profile decking making up the remaining 45%, a production-weighted average composite decking product would carry a theoretical warranty of 27.75 years. Therefore, the following deck fractions provide the functional unit under study:

- Production-weighted avg. composite decking board: 25 years / 27.75 years/deck = 0.901 decks;
- Full-profile composite decking board: 25 years / 30 years/deck = 0.833 decks;
- Scalloped-profile composite decking board: 25 years / 25 years/deck = 1 deck.

The table below shows the installed mass of 1,000 ft^2 of composite decking boards as well as the mass of the reference flow to deliver the functional unit, along with the ratio of Product Service Life (PSL) and Reference Service Life (RSL).

Table 3-1: Composite decking board mass per 1,000 ft^2 and per functional unit

Type	Unit	AVGERAGE PROFILE Value	FULL PROFILE Value	SCALLOPED PROFILE Value	DQI*
Installed decking boards	kg	2,367	2,640	2,041	Calculated
	m^2		92.9		-
	ft^2		1,000		-
	lb/ft^2	5.22	5.82	4.50	Calculated
Reference flow to deliver the functional unit	kg	2,135	2,198	2,041	Calculated
	PSL/RSL	0.901	0.833	1.00	Calculated

* measured / calculated / estimated / literature

3.2.2. Product Composition

TimberTech composite decking board is made from post-industrial recycled wood flour, recycled polyethylene (PE), and auxiliary input materials. Details are provided in Table AB-1 in the confidential Annex B.

3.2.3. Manufacturing

TimberTech composite decking board is produced in Wilmington, Ohio. Raw materials are delivered to silos by truck over a mass-weighted average distance of 232 km (144 miles). Wood flour is dried. Substrate raw materials are blended in a batch process and conveyed to a holding bin. Multiple production lines call for substrate material which is pneumatically conveyed as needed. A twin-screw extruder processes the substrate material. A co-extruder applied a non-wood filled polymer capstock at the die. The extrudate is embossed, cooled in a water tank, cut to length, and then unitized. A unit typically consists of 64 boards stacked 8x8. Packaging includes a base layer of wood dunnage boards, a sheet of plywood, corner boards, a unit cover, and PET banding.

The inputs and outputs of the manufacturing process are shown in Table AB-2 in the confidential Annex B.

3.2.4. Distribution

Distribution to the market was estimated to be by truck over 161 km (100 miles) for all product systems.

3.2.5. Installation

As described in section 3.2.1, three composite decking board variations are considered, i.e., average, full profile, and scalloped profile, each with a specific lifetime based on warranty. With lifetimes exceeding the study's reference service life, this results in scaled installations <1,000 ft^2 for the average and full profile product to deliver the functional unit, while the installation of the scalloped profile product represents exactly 1,000 ft^2. Installation is assumed to require stainless steel deck screws, i.e., 17.2 kg (38 lbs), and electricity to operate a driver power tool, i.e., 6.48 MJ (1.8 kWh), per 1,000 ft^2 of decking board. The study disregards installation scrap. Details are provided in the table below.

Table 3-2: Unit process data for composite decking board installation, per functional unit

Type	Flow	Unit	AVGERAGE PROFILE Value	FULL PROFILE Value	SCALLOPED PROFILE Value	DQI*
Inputs						
Product	Composite decking board	kg	2.13E+03	2.20E+03	2.04E+03	Measured
		m^2	83.7	77.4	92.9	Calculated
		ft^2	901	833	1,000	Calculated
Material	Deck screws	kg	1.55E+01	1.44E+01	1.72E+01	Estimated
Energy	Electricity	MJ	5.84E+00	5.40E+00	6.48E+00	Estimated
Outputs						
Assembly	Installed deck	kg	2.15E+03	2.21E+03	2.06E+03	Calculated

* measured / calculated / estimated / literature

3.2.6. Maintenance During Use

Composite decking requires annual cleaning, assumed to begin one year after installation, resulting in 24 cleaning events over the study's reference service life of 25 years. For a 92.9 m^2 (1,000 ft^2) deck, a single cleaning involves the use of 3.785 liters (1 gallon) of TimberTech DeckCleaner concentrate mixed 1:1 with water, and a scrub brush. The deck surface is then rinsed using a normal-pressure hose flowing at 22.7 liters (6 gallons) per minute for 10 minutes. AZEK does not recommend pressure washing of composite decking. The table below specifies key use phase aspects.

Table 3-3: Unit process data for composite decking board maintenance, per functional unit

Type	Flow	Unit	AVGERAGE PROFILE Value	FULL PROFILE Value	SCALLOPED PROFILE Value	DQI*
Inputs						
Assembly	Deck	kg	2.15E+03	2.21E+03	2.06E+03	Calculated
Material	Water	kg		5.54E+03		Estimated
	Cleaning concentrate	kg		9.08E+01		Estimated
Outputs						
Assembly	Cleaned deck	kg	2.15E+03	2.21E+03	2.06E+03	Calculated
Emission	Soapy water emitted to soil below deck	kg		5.63E+03		Calculated

* measured / calculated / estimated / literature

3.2.7. End-of-Life

Decking boards and fasteners of all product systems under study are assumed to be landfilled. Transportation to landfill is excluded from the study due to expected short distance and various transport mode options to local landfill as well as the low relevance to the study's goals. Composite decking boards are recyclable at the AZEK facility, but collection and return shipment currently are not practicable.

3.3. PVC Decking Board

3.3.1. Overview of Product System

TimberTech PVC decking board is manufactured mainly from recycled and virgin polyvinylchloride (PVC) in combination with minor ingredients like talc. The packaged product is distributed to market by truck and is installed with an electric driver and deck screws. Starting one year after installation, an annual cleaning is performed with TimberTech deck cleaner and water, using a brush. At the end of the product's useful life, the decking boards are deinstalled and disposed of.

Figure 3-3: Flowchart of foreground system for PVC decking board

As introduced in section 2.2, TimberTech PVC decking is covered by a 50-year manufacturer warranty. Therefore, the following deck fraction provide the functional unit under study:

- PVC decking board: 25 years (RSL) / 50 years (PSL)/deck = 0.5 decks.

The table below shows the installed mass of 1,000 ft^2 of PVC decking boards as well as the mass of the reference flow to deliver the functional unit.

Table 3-4: PVC decking board mass per 1,000 ft^2 and per functional unit

Type	Unit	Value	DQI*
Installed decking boards	kg	1,465	Calculated
	m^2	92.9	-
	ft^2	1,000	-
	lb/ft^2	3.23	Calculated
Reference flow to deliver the functional unit	kg	732	Calculated
	PSL/RSL	0.5	Calculated

* measured / calculated / estimated / literature

3.3.2. Product Composition

TimberTech PVC decking board is made from recycled and virgin polyvinylchloride (PVC), talc and other material additives. Details are provided in Table AB-3 in the confidential Annex B.

3.3.3. Manufacturing

TimberTech PVC decking board is produced in both Wilmington, Ohio, and Scranton, Pennsylvania. Raw materials are delivered to silos by rail (virgin PVC resin) or truck (all other materials) over a mass-weighted average distances of 691 km (429 miles) or 405 km (251 miles), respectively. PVC substrate raw materials are blended, and additives are fused to PVC molecules in a high intensity mixing batch process. The batch is transferred to a cooled mixer, and then conveyed to a silo.

Multiple production lines call for substrate material which is pneumatically conveyed as needed. A twin-screw extruder processes the substrate material and a foaming agent is used to create a cellular foamed substrate. Single screw co-extruders apply a PVC alloy capstock at the die. The extrudate is cooled through calibration plates and then passes through a submerged water bath followed by water spray. The decking is cut to length, and then reheated through infrared heaters just before embossing with an electrically heated metal embossing roll. A unit typically consists of 64 boards stacked 8x8. Packaging includes a base layer of wood dunnage boards, a sheet of plywood, corner boards, a unit cover, and PET banding. The inputs and outputs of the manufacturing process are shown in Table AB-4 in the confidential Annex B.

3.3.4. Distribution

Distribution to the market was estimated to be by truck over 161 km (100 miles) for all product systems.

3.3.5. Installation

As described in section 3.3.1, PVC decking board is assumed to have a 50-year lifetime based on warranty, double the functional unit's reference service life. This results in a reference flow of 500 ft^2 PVC decking installed per functional unit. Installation is assumed to require stainless steel deck screws, i.e., 17.2 kg (38 lbs), and electricity to operate a driver power tool, i.e., 6.48 MJ (1.8 kWh), per 1,000 ft^2 of decking board. The study disregards installation scrap. Furthermore, the study disregards that decking boards are installed with spacing between boards. Details are provided in the table below.

Table 3-5: Unit process data for PVC decking board installation, per functional unit

Type	Flow	Unit	Value	DQI*
Inputs				
Product	PVC decking boards	kg	7.32E+02	Measured
		m^2	46.5	Calculated
		ft^2	500	Calculated
Material	Deck screws	kg	8.62E+00	Estimated
Energy	Electricity	MJ	3.24E+00	Estimated
Outputs				
Assembly	Installed deck	kg	7.41E+02	Calculated

* measured / calculated / estimated / literature

3.3.6. Maintenance During Use

PVC decking requires annual cleaning, assumed to begin one year after installation, resulting in 24 cleaning events over the study's reference service life of 25 years. For a 92.9 m^2 (1,000 ft^2) deck, a single cleaning involves the use of 3.785 liters (1 gallon) of TimberTech DeckCleaner concentrate mixed 1:1 with water, and a scrub brush. The deck surface is then rinsed using a normal-pressure hose flowing at 22.7 liters (6 gallons) per minute for 10 minutes. AZEK does not recommend pressure washing of PVC decking. The table below specifies key use phase aspects.

Table 3-6: Unit process data for PVC decking board maintenance, per functional unit

Type	Flow	Unit	Value	DQI*
Inputs				
Assembly	Deck	kg	7.41E+02	Calculated

Type	Flow	Unit	Value	DQI*
Material	Water	kg	5.54E+03	Estimated
	Cleaning concentrate	kg	9.08E+01	Estimated
Outputs				
Assembly	Cleaned deck	kg	7.41E+02	Calculated
Emission	Soapy water emitted to soil below deck	kg	5.63E+03	Calculated

* measured / calculated / estimated / literature

3.3.7. End-of-Life

Decking boards and fasteners of all product systems under study are assumed to be landfilled. Transportation to landfill is excluded from the study due to expected short distance and various transport mode options to local landfill as well as the low relevance to the study's goals. Composite decking boards are recyclable at the AZEK facility, but collection and return shipment currently are not practicable.

3.4. Treated Pine Decking Board

3.4.1. Overview of Product System

The life cycle stages of treated pine comprise the supply of pine from managed forestry operations as well as the supply of treatment substances to manufacturing, i.e., ACQ treatment. Alkaline copper quaternary (ACQ) treated pine decking board is represented by the product system which provided the foundation for the dataset published by the U.S. Life Cycle Inventory Database (National Renewable Energy Database, 2012) and, subsequently, included in GaBi. Documentation can be found in a supporting journal article (Bolin & Smith, 2011) and via the dataset's online listing: USLCI dataset "Lumber, softwood, ACQ treated, SE."

Figure 3-4: Flowchart of foreground system for treated pine decking board

Distribution to market is followed by installation, i.e., as many installations as needed to deliver the functional unit. Starting one year after installation, an annual cleaning is performed with deck cleaner and water, using a brush. Every third cleaning includes staining. At the end of the product's useful life, the decking boards are deinstalled and disposed of.

As introduced in section 2.2, treated pine decking installations are expected to last ten years. Therefore, the following provides the functional unit under study:

- Treated pine decking board: 25 years (RSL) / 10 years (PSL)/deck = 2.5 decks.

The table below shows the installed mass of 1,000 ft^2 of treated pine decking boards as well as the mass of the reference flow to deliver the functional unit, along with the area-equivalent of that mass.

Table 3-7: Treated pine decking board mass per 1,000 ft^2 and per functional unit

Type	Unit	Value	DQI*
Installed treated pine decking boards	kg	1,247	Measured

Type	Unit	Value	DQI*
	m^2	92.9	-
	ft^2	1,000	-
	lb/ft^2	2.75	Calculated
Reference flow to deliver the functional unit	kg	3,120	Calculated
	RSL/PSL	2.5	Calculated

* measured / calculated / estimated / literature

3.4.2. Product Composition

Treated pine decking board, in this study, is pine softwood which contains <0.5% by mass of ACQ additives. Product density is 529 kg/m^3. Details are provided in the table below.

Table 3-8: Material composition of treated pine decking board, per functional unit

Material	Mass [kg]	Mass [%]	DQI*
Pine timber, 10.7% water content	3,106	99.5	Literature
Mono ethanol amine (MEA)	9.12	0.292	Literature
Copper oxide	3.32	0.106	Literature
Quaternary (didecyl dimethyl ammonium chloride DDAC)	1.66	0.0531	Literature
TOTAL	**3,120**	**100%**	

* measured / calculated / estimated / literature

3.4.3. Manufacturing

ACQ treatment of pine is modeled with pine timber and the three treatment substances as material inputs, process water, and energy inputs. Details are provided in the table below.

Table 3-9: Unit process data for treated pine decking board manufacturing, per functional unit

Type	Flow	Unit	Value	DQI*
Inputs				
Materials	Pine timber, 10.7% water content	kg	3.12E+03	Literature
	Mono ethanol amine (MEA)	kg	26.0E+01	Literature
	Copper oxide	kg	9.44E+00	Literature
	Quaternary (DDAC)	kg	4.72E+00	Literature
Water	Water	kg	5.33E+02	Literature
Energy	Electricity grid mix	MJ	2.57E+02	Literature
	Diesel, combusted in industrial boiler	m^3	7.13E-03	Literature
	Gasoline, combusted in equipment	m^3	1.78E-04	Literature
	Liquefied petroleum gas, combusted in industrial boiler	m^3	1.97E-03	Literature
	Natural gas, combusted in industrial boiler	m^3	9.66E+00	Literature
	Natural gas, processed, at plant	m^3	3.05E+01	Literature

Type	Flow	Unit	Value	DQI*
Outputs				
Product	Treated pine decking board	m^3	5.90E+00	Literature
		kg	3.12E+03	Literature

* measured / calculated / estimated / literature

3.4.4. Distribution

Distribution to the market was estimated to be by truck over 161 km (100 miles) for all product systems.

3.4.5. Installation

As described in section 3.4.1, treated pine decking board installations are assumed to last ten years, requiring 2.5 installations to cover the study's service life, resulting in a reference flow of 2,500 ft^2 installed per functional unit. Installation is assumed to require stainless steel deck screws, i.e., 17.2 kg (38 lbs), and electricity to operate a driver power tool, i.e., 6.48 MJ (1.8 kWh), each per 92.9 m^2 (1,000 ft^2) of decking board. The study disregards installation scrap. Furthermore, the study disregards that decking boards are installed with spacing between boards. Details are provided in the table below.

Table 3-10: Unit process data for treated pine decking board installation, per functional unit

Type	Flow	Unit	Value	DQI*
Inputs				
Product	Treated pine decking boards	kg	3.12E+03	Calculated
		m^2	232	Calculated
		ft^2	2,500	Calculated
Material	Deck screws	kg	4.31E+01	Estimated
Energy	Electricity	MJ	1.62E+01	Estimated
Outputs				
Assembly	Installed deck	kg	3.16E+03	Calculated

* measured / calculated / estimated / literature

3.4.6. Maintenance During Use

Pine decking is assumed to require annual cleaning, beginning one year after each installation and excluding after the 25th year, resulting in 22 cleaning events over the study's reference service life of 25 years. For a 92.9 m^2 (1,000 ft^2) deck, a single cleaning involves the use of 3.785 liters (1 gallon) of deck cleaning concentrate (same as TimberTech DeckCleaner) mixed 1:1 with water, and a scrub brush. The deck surface is then rinsed using a normal-pressure hose flowing at 22.7 liters (6 gallons) per minute for 10 minutes. Every three years, 3.79 kg (1 gallon) of stain is applied to protect the wood surface. The table below specifies key use phase aspects.

Table 3-11: Unit process data for treated pine decking board maintenance, per functional unit

Type	Flow	Unit	Value	DQI*
Inputs				
Assembly	Deck	kg	3.16E+03	Calculated
Material	Water	kg	5.08E+03	Estimated
	Cleaning concentrate	kg	8.33E+01	Estimated
	Stain (4.5% organic solvents)	kg	2.52E+01	Estimated
Outputs				
Assembly	Cleaned deck	kg	3.16E+03	Calculated
Emission	Soapy water emitted to soil below deck	kg	5.16E+03	Calculated
	NMVOC (unspecified) emitted to air	kg	1.14E+00	Calculated

* measured / calculated / estimated / literature

3.4.7. End-of-Life

Decking boards and fasteners of all product systems under study are assumed to be landfilled.

3.5. Background Data

3.5.1. Fuels and Energy

National/regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2019 databases. Table 3-12 shows the most relevant LCI datasets used in modeling the product systems. Electricity consumption was modeled using national/regional grid mixes that account for imports from neighboring countries/regions.

Documentation for all GaBi datasets can be found at http://www.gabi-software.com/databases/gabi-databases/.

Table 3-12: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Reference Year	Proxy?
Electricity	Scranton, PA	US: Electricity grid mix - RFCE	Sphera	2016	-
	Wilmington, OH	US: Electricity grid mix - RFCW	Sphera	2016	-
	United States	US: Electricity grid mix (eGrid)	Sphera	2016	-
Technical heat	United States	US: Thermal energy from diesel	Sphera	2016	-
	United States	US: Thermal energy from natural gas	Sphera	2016	-
	United States	US: Thermal energy from propane	Sphera	2016	-

3.5.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi 2019 database. Table 3-13 shows the most relevant LCI datasets used in modeling the product systems. Documentation for all GaBi datasets can be found at http://www.gabi-software.com/databases/gabi-databases/.

Table 3-13: Key material and process datasets used in inventory analysis

Material / Process	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
TimberTech composite decking					
Wood flour	US	Sawdust, at sawmill, US SE	Sphera	2018	-
HDPE/LDPE, recycled	-	*N/A (cut-off approach)*	-	-	-
Talc	EU-28	Talcum powder (filler)	Sphera	2018	Geo.
HDPE, virgin	US	Polyethylene High Density Granulate (HDPE/PE-HD)	Sphera	2018	-
Lubricant	US	US: Lubricants at refinery	Sphera	2018	-
TimberTech PVC decking					
PVC, recycled	-	*N/A (cut-off approach)*	-	-	-
PVC, virgin	US	Polyvinyl chloride granulate (Suspension, S-PVC)	Sphera	2018	-
Talc	EU-28	Talcum powder (filler)	Sphera	2018	Geo.
Calcium carbonate	EU-28	Calcium carbonate > 63 microns	Sphera	2018	Geo.
Blowing agent	US	Hydrogen peroxide (100%)	Sphera	2018	Tech.
	US	Urea (stamicarbon process)	Sphera	2018	Tech.
	US	Chlorine mix	Sphera	2018	Tech.
Color concentrate (EVA carrier)	US	Ethylene Vinylacetate Copolymer (E/VA) (72% Ethylene, 28% Vinylacetate)	Sphera	2018	Tech.
Thermal stabilizer	GLO	Stabilising agent (on basis of triethanolamine)	Sphera	2018	Geo.
Lubricant	US	Lubricants at refinery	Sphera	2018	-
Wood decking					
Treated pine	US	ACQ treated pine lumber (USLCI, with EU-28 pine input)	USLCI	2015	Some geo.
Deck installation, maintenance					
Fasteners	DE	Stainless steel screw - EJOT (A1-A3)	Sphera	2018	Geo.
Water	US	Tap water from surface water	Sphera	2018	-

Material / Process	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
DeckCleaner concentrate	GLO	Detergent (fatty acid sulphonate derivate)	Sphera	2018	Tech., geo.
Stain	DE	Water based paint white (EN15804 A1-A3)	Sphera	2018	Tech., geo.
End-of-life					
Landfilling of TimberTech decking	US	Plastic waste on landfill, post-consumer	Sphera	2018	-
Landfilling of wood decking	US	Wood products (OSB, particle board) on landfill, post-consumer (according to the WARM model)	Sphera	2018	-
Landfilling of fasteners	US	Ferro metals on landfill, post-consumer	Sphera	2018	-
Incineration of wood decking *(scenario only)*	US	US: Wood product (OSB, particle board) waste in waste incineration plant	Sphera	2018	-

3.5.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities. The GaBi 2019 database was used to model transportation. Fuels were modeled using the geographically appropriate datasets. No empty backhauls were modelled, due to lack of data and low level of relevance to the study.

Table 3-14: Transportation and transport fuel datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Reference Year	Proxy?
Truck	US	Truck heavy/bulk (EPA SmartWay)	Sphera	2018	-
Freight train	US	Rail transport cargo - Diesel, average train, gross tonne weight 1,000t / 726t payload capacity	Sphera	2018	-
Diesel	US	Diesel mix at filling station	Sphera	2018	-

3.6. Life Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory (LCI) analysis result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment." As the complete inventory comprises hundreds of flows, the below tables only display a selection of flows based on their relevance to the subsequent impact assessment in order to provide a transparent link between the life cycle inventory and impact assessment results.

Table 3-15: LCI results for average-profile TimberTech composite decking (in kg), per functional unit

Type	Flow	Total	Manufac-turing	Distribution, Installation, Maintenance	EoL
Resources	Water use	**6.69E+05**	5.12E+05	1.15E+05	4.26E+04
	CO_2	**1.88E+03**	1.86E+03	1.22E+01	6.24E+00
	Crude oil	**2.86E+02**	2.23E+02	4.00E+01	2.36E+01
	Hard coal	**1.75E+02**	1.48E+02	2.30E+01	3.92E+00
	Natural gas	**2.99E+02**	2.68E+02	1.92E+01	1.15E+01
	Uranium	**4.65E-03**	3.98E-03	6.02E-04	6.80E-05
Emissions to air	CO_2	**1.20E+03**	9.38E+02	1.75E+02	9.05E+01
	CH_4	**4.13E+00**	3.49E+00	4.29E-01	2.04E-01
	N_2O	**3.05E-02**	2.25E-02	6.79E-03	1.22E-03
	NO_x	**2.50E+00**	1.82E+00	3.40E-01	3.42E-01
	SO_2	**2.96E-04**	1.48E-04	1.48E-04	5.27E-26
	NMVOC	**1.31E+00**	3.95E-01	8.70E-02	8.25E-01
	CO	**1.44E+00**	8.05E-01	3.93E-01	2.38E-01
	PM10	**9.04E-01**	8.40E-01	6.16E-02	2.85E-03
	PM2.5	**7.71E-02**	4.77E-02	1.77E-02	1.17E-02
	Heavy metals	**4.71E-03**	7.95E-04	3.81E-03	1.00E-04
Emissions to water	NH_3	**2.35E-03**	2.03E-03	3.01E-04	2.10E-05
	NO^{3-}	**1.38E-01**	1.15E-01	1.80E-02	5.02E-03
	PO_4^{3-}	**1.79E-02**	1.68E-02	5.97E-04	5.70E-04
	Heavy metals	**1.57E-01**	1.12E-01	3.46E-02	1.00E-02
Emissions to soil	PAH	**0.00E+00**	0.00E+00	0.00E+00	0.00E+00
	Heavy metals	**9.64E-04**	9.83E-06	2.48E-05	9.29E-04

Table 3-16: LCI results for TimberTech PVC decking (in kg), per functional unit

Type	Flow	Total	Manufac-turing	Distribution, Installation, Maintenance	EoL
Resources	Water use	**5.68E+05**	4.70E+05	8.39E+04	1.47E+04
	CO_2	**4.55E+01**	3.57E+01	7.66E+00	2.15E+00
	Crude oil	**2.16E+02**	1.76E+02	3.23E+01	8.13E+00
	Hard coal	**1.48E+02**	1.32E+02	1.50E+01	1.35E+00
	Natural gas	**4.11E+02**	3.92E+02	1.57E+01	3.95E+00
	Uranium	**4.45E-03**	4.04E-03	3.88E-04	2.34E-05
Emissions to air	CO_2	**1.35E+03**	1.20E+03	1.20E+02	3.12E+01
	CH_4	**4.95E+00**	4.55E+00	3.26E-01	7.03E-02
	N_2O	**6.48E-02**	5.99E-02	4.49E-03	4.19E-04
	NO_x	**2.38E+00**	2.03E+00	2.35E-01	1.18E-01
	SO_2	**8.05E-04**	7.54E-04	5.07E-05	1.82E-26
	NMVOC	**1.55E+00**	1.19E+00	7.36E-02	2.83E-01
	CO	**1.13E+00**	8.16E-01	2.34E-01	8.19E-02
	PM10	**3.67E-02**	1.54E-03	3.42E-02	9.81E-04
	PM2.5	**7.76E-02**	6.30E-02	1.06E-02	4.02E-03
	Heavy metals	**2.83E-03**	6.46E-04	2.15E-03	3.45E-05
Emissions to water	NH_3	**1.56E-03**	1.36E-03	1.90E-04	7.22E-06
	NO^{3-}	**2.43E-01**	2.29E-01	1.17E-02	1.73E-03
	PO_4^{3-}	**6.71E-03**	6.14E-03	3.75E-04	1.96E-04
	Heavy metals	**2.78E-01**	2.52E-01	2.25E-02	3.45E-03
Emissions to soil	PAH	**3.79E-24**	3.79E-24	0.00E+00	0.00E+00
	Heavy metals	**3.58E-04**	1.81E-05	1.38E-05	3.26E-04

Table 3-17: LCI results for treated pine decking (in kg), per functional unit

Type	Flow	Total	Manufac-turing	Distribution, Installation, Maintenance	EoL
Resources	Water use	**1.46E+06**	1.12E+06	2.80E+05	6.27E+04
	CO_2	**5.24E+03**	5.19E+03	3.25E+01	9.18E+00
	Crude oil	**2.34E+02**	1.43E+02	5.60E+01	3.48E+01
	Hard coal	**1.18E+02**	5.44E+01	5.82E+01	5.77E+00
	Natural gas	**1.58E+02**	1.01E+02	3.97E+01	1.69E+01
	Uranium	**5.13E-03**	3.49E-03	1.54E-03	1.00E-04
Emissions to air	CO_2	**1.38E+03**	8.57E+02	3.95E+02	1.33E+02
	CH_4	**3.08E+00**	1.89E+00	8.91E-01	3.00E-01
	N_2O	**6.47E-02**	4.56E-02	1.71E-02	2.08E-03
	NO_x	**5.47E+00**	4.11E+00	8.26E-01	5.27E-01
	SO_2	**6.93E-04**	4.77E-04	2.16E-04	7.76E-26
	NMVOC	**2.19E+00**	7.49E-01	1.28E+00	1.55E-01
	CO	**4.55E+00**	3.06E+00	1.13E+00	3.63E-01
	PM10	**8.55E-01**	6.80E-01	1.71E-01	4.19E-03
	PM2.5	**2.88E+00**	2.81E+00	4.47E-02	1.78E-02
	Heavy metals	**1.75E-02**	5.89E-03	1.15E-02	1.47E-04
Emissions to water	NH_3	**5.57E-03**	4.77E-03	7.68E-04	3.09E-05
	NO^{3-}	**1.62E-01**	1.10E-01	4.50E-02	7.39E-03
	PO_4^{3-}	**8.95E-03**	7.00E-03	1.11E-03	8.39E-04
	Heavy metals	**4.82E-01**	1.94E-01	2.74E-01	1.37E-02
Emissions to soil	PAH	**9.39E-27**	8.44E-27	9.49E-28	0.00E+00
	Heavy metals	**8.99E-04**	7.17E-04	6.88E-05	1.14E-04

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the life cycle inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Overall Results

4.1.1. Global warming potential (100 years)

Global warming potential (GWP100) results (a.k.a. the carbon footprint) excluding biogenic carbon show the weighted-average TimberTech composite decking product (CompAvg) coming in 12% below TimberTech PVC decking and 15% below treated pine decking. The manufacturing phase is the key contributor across all product systems under study. The effects of product lifetimes which are significantly higher than the study's reference service life (i.e., TimberTech PVC) or lower (i.e., treated pine) are expressed clearly in the respective product system's results. Thus, treated pine board installations show the effect of multiple installations necessary to deliver the functional unit (see sections 3.4.5). See Figure 4-1, Table 4-1, and Table 4-2 for details.

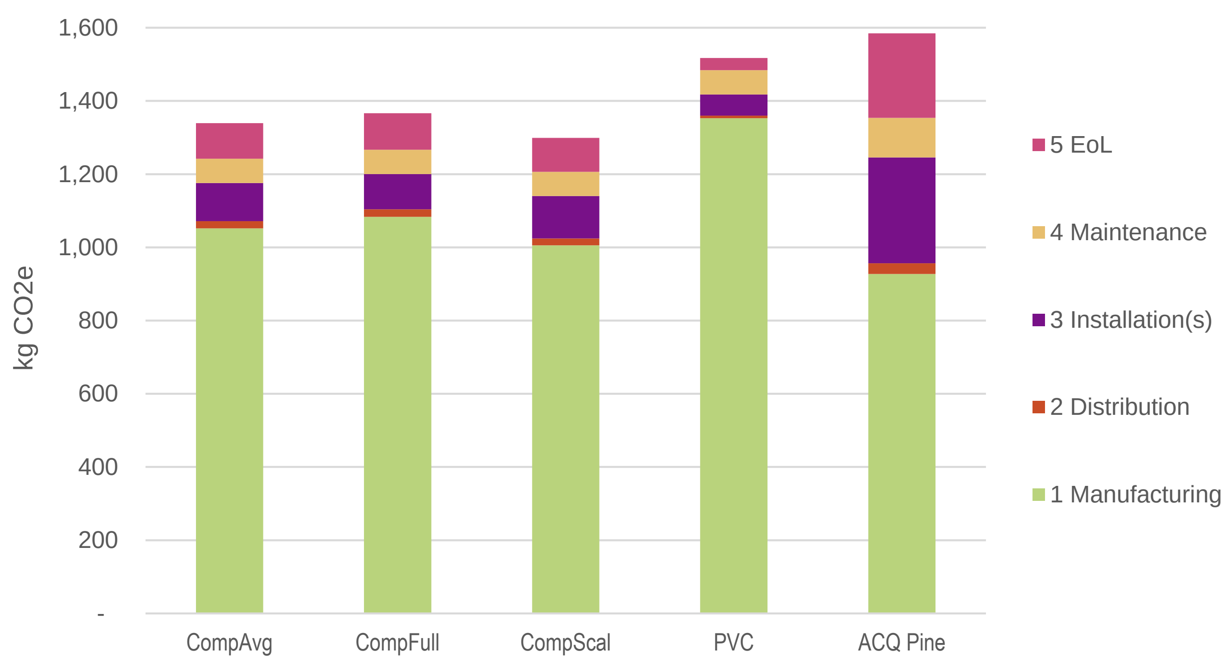

Figure 4-1: Global warming potential, excl. biogenic carbon, per functional unit

Table 4-1: Global warming potential, excl. biogenic carbon [kg CO_2e], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Instal-lation(s)	4 Mainte-nance	5 EoL
TimberTech CompAvg	**1,339**	1,052	20	104	66	97
TimberTech CompFull	**1,367**	1,084	20	96	66	100
TimberTech CompScal	**1,299**	1,006	19	116	66	93
TimberTech PVC	**1,517**	1,353	7	58	66	33
ACQ Pine	**1,585**	927	29	289	108	231

Table 4-2: Global warming potential (% contribution), excl. biogenic carbon, per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Instal-lation(s)	4 Mainte-nance	5 EoL
TimberTech CompAvg	**100%**	79%	1%	8%	5%	7%
TimberTech CompFull	**100%**	79%	1%	7%	5%	7%
TimberTech CompScal	**100%**	77%	1%	9%	5%	7%
TimberTech PVC	**100%**	89%	0%	4%	4%	2%
ACQ Pine	**100%**	59%	2%	18%	7%	15%

The results for GWP *including* biogenic carbon (i.e., “total GWP”), presented in Figure 4-2 and Table 4-3, demonstrate the effects of carbon sequestration in the product systems. While the TimberTech composite product’s wood-flour content, preserved in the decking material through to landfilling at end of life, leads to a net-negative GWP incl. biogenic carbon for that product system, TimberTech PVC decking’s GWP is not noticeably impacted by the inclusion of biogenic carbon. The wood decking product shows strong sequestration of biogenic carbon from multiple installations of treated pine decking (2.5 decks) necessary to supply the functional unit (see 2.2.3).

In summary, total GWP is net-negative for all decking products under study, except for PVC. Wood decking product made from pine sequesters approx. 7 times as much biogenic carbon dioxide per functional unit as the weighted-average TimberTech composite decking product. See below figure and table for details.

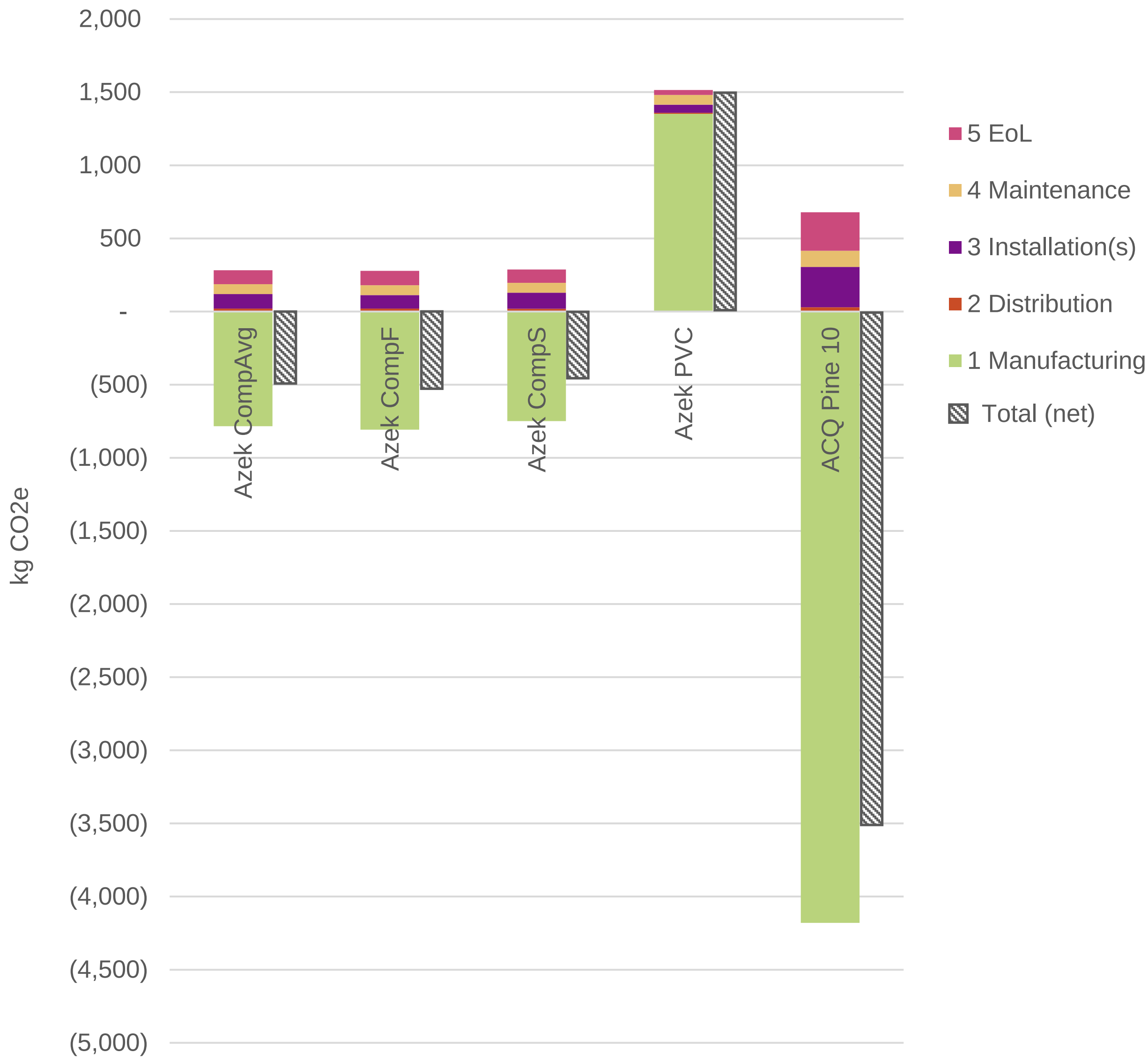

Figure 4-2: Global warming potential, incl. biogenic carbon, per functional unit

Table 4-3: Global warming potential, incl. biogenic carbon [kg CO_2e], per functional unit

	Total (net)	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
TimberTech CompAvg	**(502)**	(784)	20	99	68	95
TimberTech CompFull	**(529)**	(807)	20	92	68	98
TimberTech CompScal	**(461)**	(749)	19	110	68	91
TimberTech PVC	**1,514**	1,352	7	55	68	33
ACQ Pine	**(3,501)**	(4,179)	29	275	111	263

4.1.2. Acidification potential

Acidification potential (AP) shows the manufacturing phase as the main driver across all product systems under study. TimberTech decking products indicate favorable results compared to the pine decking, where upstream timber supply drives the manufacturing profile. Pine decking's multiple installations lead to increased impact from that life cycle phase. See below figure and table for details.

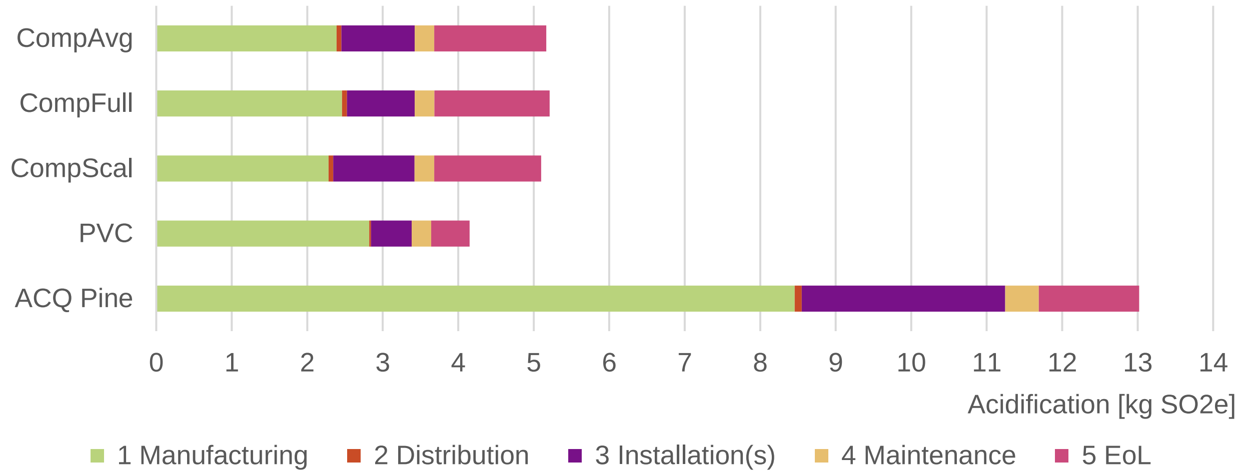

Figure 4-3: Acidification potential, per functional unit

Table 4-4: Acidification potential [kg SO_2e], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**1.30E+01**	8.46E+00	9.26E-02	2.70E+00	4.46E-01	1.33E+00
PVC	**4.15E+00**	2.82E+00	2.17E-02	5.39E-01	2.59E-01	5.09E-01
TimberTech CompScal	**5.10E+00**	2.28E+00	6.05E-02	1.08E+00	2.59E-01	1.42E+00
TimberTech CompFull	**5.21E+00**	2.46E+00	6.52E-02	8.98E-01	2.59E-01	1.53E+00
TimberTech CompAvg	**5.17E+00**	2.39E+00	6.33E-02	9.71E-01	2.59E-01	1.48E+00

4.1.3. Eutrophication potential

Eutrophication potential (EP) results show emissions from landfilling at end of life as the largest driver for TimberTech composite decking. Manufacturing is a major contributor across all product systems under study. For TimberTech composite decking, manufacturing EP is driven by various contributors, with municipal wastewater treatment being among the more significant contributors. Treated pine decking's manufacturing EP is dominated by wood cultivation. Stainless-steel screw manufacturing (NOx emissions to air from power production for operation electric arc furnaces) shows contribution to EP most strongly where multiple installations are needed to provide the functional unit (i.e., in treated pine life cycle). See below figure and table for details.

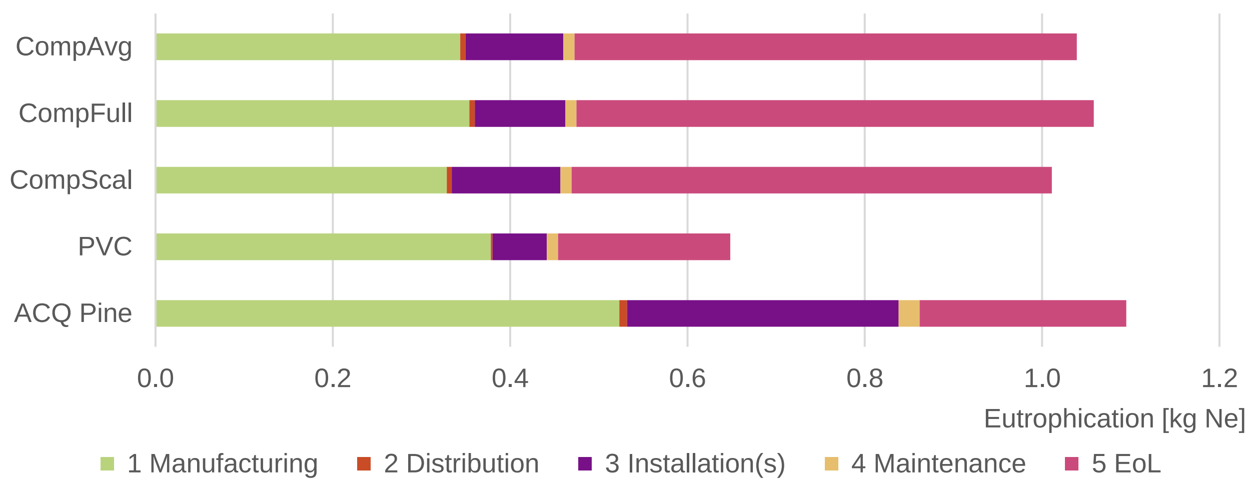

Figure 4-4: Eutrophication potential, per functional unit

Table 4-5: Eutrophication potential [kg Ne], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**1.09E+00**	5.23E-01	8.71E-03	3.06E-01	2.36E-02	2.33E-01
PVC	**6.48E-01**	3.78E-01	2.04E-03	6.13E-02	1.26E-02	1.94E-01
TimberTech CompScal	**1.01E+00**	3.29E-01	5.69E-03	1.23E-01	1.26E-02	5.42E-01
TimberTech CompFull	**1.06E+00**	3.54E-01	6.13E-03	1.02E-01	1.26E-02	5.83E-01
TimberTech CompAvg	**1.04E+00**	3.44E-01	5.95E-03	1.10E-01	1.26E-02	5.67E-01

4.1.4. Smog formation potential (smog air)

Smog formation potential (SFP) results for TimberTech composite decking is dominated by manufacturing, driven by upstream production of sawdust, HDPE and PP granulate, as well as electricity consumption in manufacturing. TimberTech PVC decking's SFP is dominated by upstream production of PVC granulate. Treated pine manufacturing's SFP is dominated by forestry operations. See below figure and table for details.

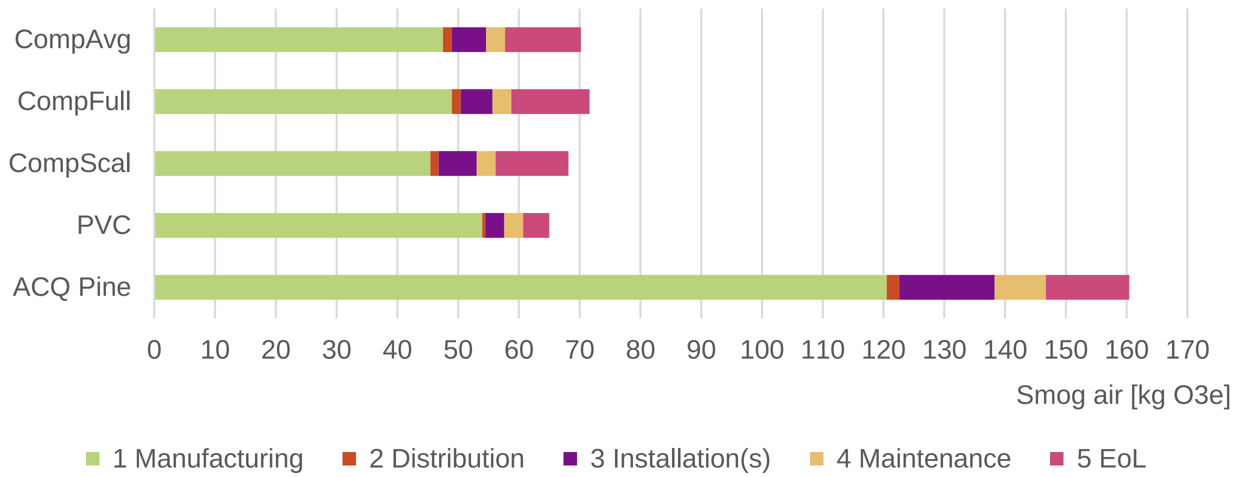

Figure 4-5: Smog formation potential, per functional unit

Table 4-6: Smog formation potential [kg O_3e], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**1.60E+02**	1.21E+02	2.09E+00	1.57E+01	8.42E+00	1.37E+01
PVC	**6.50E+01**	5.40E+01	4.91E-01	3.13E+00	3.11E+00	4.30E+00
TimberTech CompScal	**6.81E+01**	4.54E+01	1.37E+00	6.27E+00	3.11E+00	1.20E+01
TimberTech CompFull	**7.16E+01**	4.89E+01	1.47E+00	5.22E+00	3.11E+00	1.29E+01
TimberTech CompAvg	**7.02E+01**	4.75E+01	1.43E+00	5.65E+00	3.11E+00	1.25E+01

4.1.5. Primary energy demand (PED)

PED from renewable resources (PEDr) and PED from non-renewable resources (PEDnr) results for TimberTech composite decking are driven by upstream production of wood flour and virgin polymers, respectively. TimberTech PVC decking's manufacturing PED is driven by PEDnr of upstream PVC granulate production. Treated pine manufacturing PEDr is dominated by upstream lumber operations. See below figure and table for details.

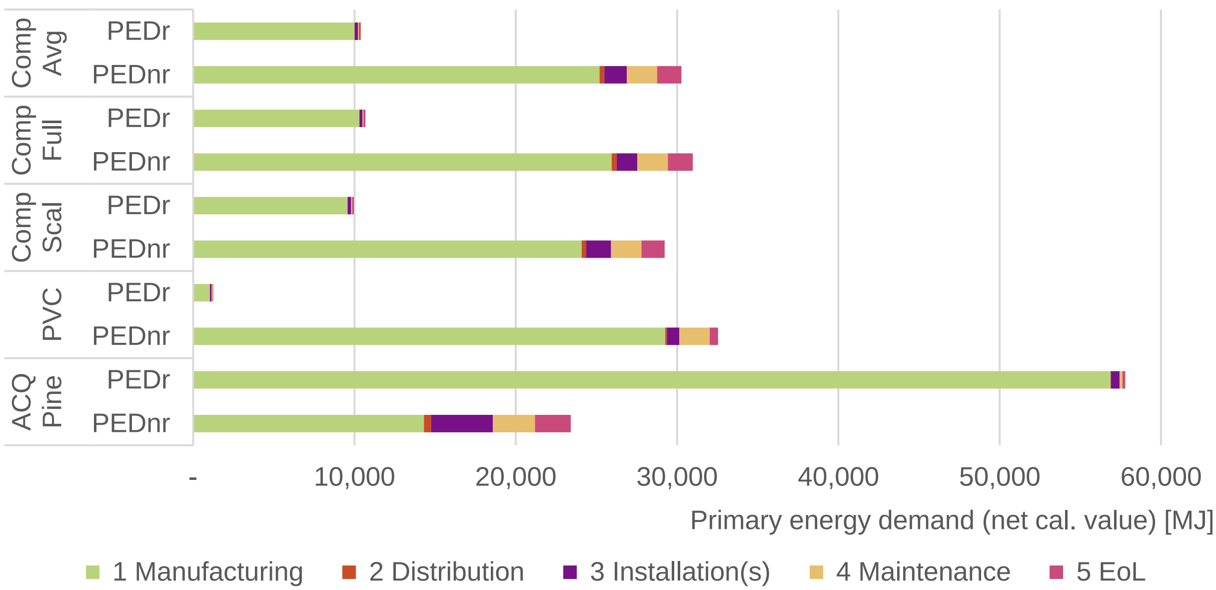

Figure 4-6: Primary energy demand (net cal. value), per functional unit

Table 4-7: Primary energy demand from ren. and non-ren. resources, combined (net cal. value) [MJ], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**81,191**	71,181	452	4,384	2,787	2,388
PVC	**33,799**	30,310	106	877	1,948	559
TimberTech CompScal	**39,197**	33,648	295	1,754	1,948	1,552
TimberTech CompFull	**41,655**	36,258	318	1,461	1,948	1,670
TimberTech CompAvg	**40,658**	35,200	309	1,580	1,948	1,622

4.1.6. Blue water consumption

Water consumption results for TimberTech composite decking are driven by evaporate from production process, while TimberTech PVC decking's manufacturing water consumption is largely due to upstream PVC granulate production. All product systems under study show cleaning water in maintenance phase as a strong contributor to overall water consumption. See below figure and table for details.

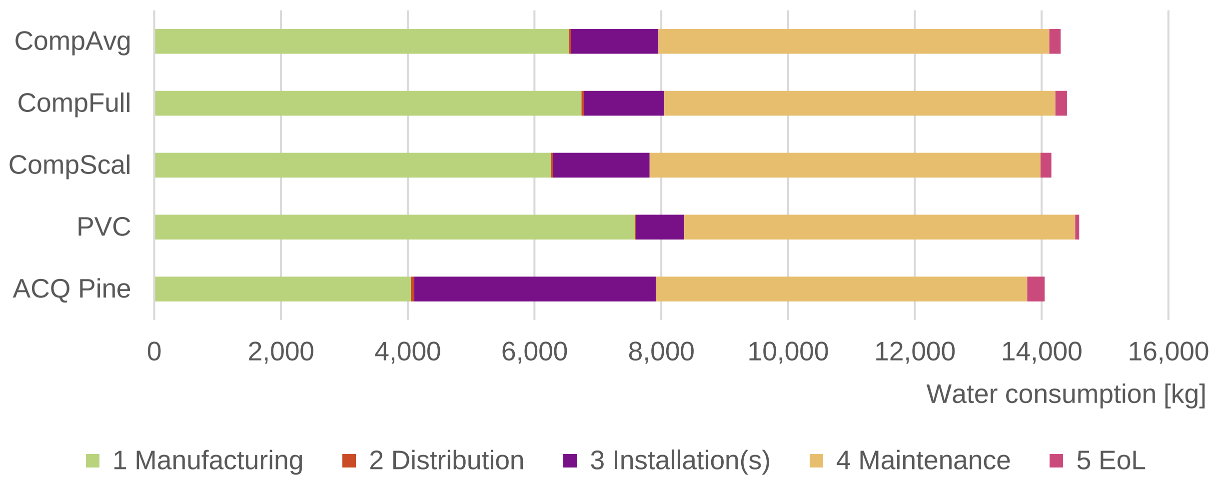

Figure 4-7: Water consumption, per functional unit

Table 4-8: Water consumption [kg], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**1.40E+04**	4.05E+03	5.25E+01	3.81E+03	5.86E+03	2.76E+02
PVC	**1.46E+04**	7.59E+03	1.23E+01	7.62E+02	6.17E+03	6.16E+01
TimberTech CompScal	**1.42E+04**	6.26E+03	3.43E+01	1.52E+03	6.17E+03	1.71E+02
TimberTech CompFull	**1.44E+04**	6.74E+03	3.70E+01	1.27E+03	6.17E+03	1.84E+02
TimberTech CompAvg	**1.43E+04**	6.54E+03	3.59E+01	1.37E+03	6.17E+03	1.79E+02

4.1.7. Ecotoxicity

Ecotoxicity potential of TimberTech composite decking is dominated by the upstream production of sawdust, while TimberTech PVC decking ecotoxicity potential is mostly due to upstream production of PVC granulate and stearic acid. Treated pine decking, modeled with a USLCI dataset, shows the largest ecotoxicity result of all product systems under study, due to dominant contribution from manufacturing (driven by transportation and energy inputs) but also by upstream production of the copper (16%), an input to ACQ treatment. See below figure and table for details.

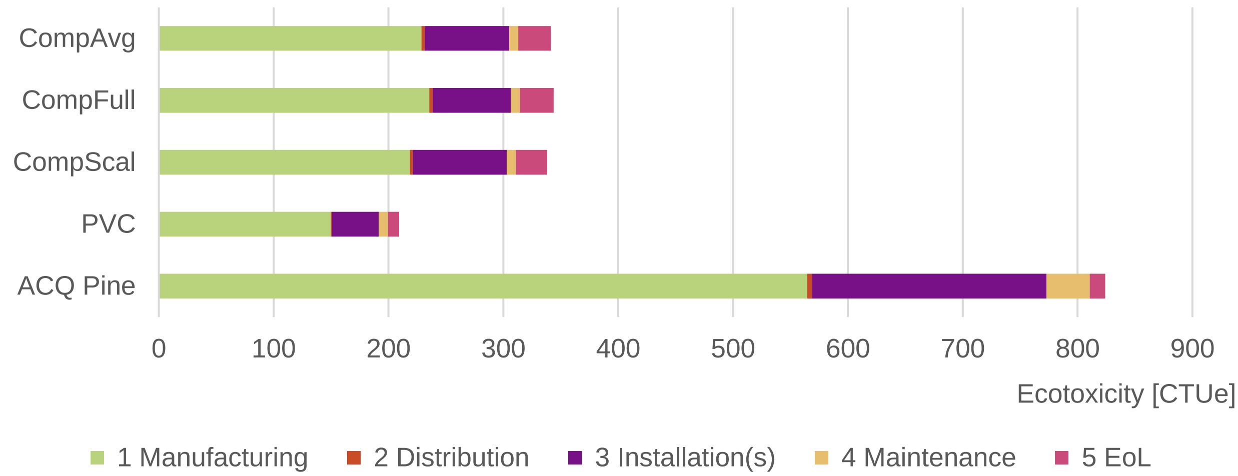

Figure 4-8: Ecotoxicity potential, per functional unit

Table 4-9: Ecotoxicity potential [CTUe], per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**8.24E+02**	5.65E+02	4.19E+00	2.04E+02	3.76E+01	1.36E+01
PVC	**2.09E+02**	1.50E+02	9.81E-01	4.08E+01	7.87E+00	9.83E+00
TimberTech CompScal	**3.38E+02**	2.19E+02	2.74E+00	8.17E+01	7.87E+00	2.73E+01
TimberTech CompFull	**3.44E+02**	2.36E+02	2.95E+00	6.81E+01	7.87E+00	2.93E+01
TimberTech CompAvg	**3.41E+02**	2.29E+02	2.86E+00	7.36E+01	7.87E+00	2.85E+01

4.2. Detailed Results for TimberTech products

4.2.1. Carbon footprint breakdown of TimberTech composite (weighted average)

Content moved to confidential annex B.

4.2.2. Carbon footprint breakdown of TimberTech PVC

Content moved to confidential annex B.

4.2.3. Comparing the environmental impact profiles of TimberTech scalloped-profile composite decking and treated pine decking

TimberTech scalloped-profile composite decking compares favorably to treated pine decking across most of the environmental indicators considered (Figure 4-11). The treated pine product system sequesters 7.7x as much biogenic carbon as the composite product. See below figure for details.

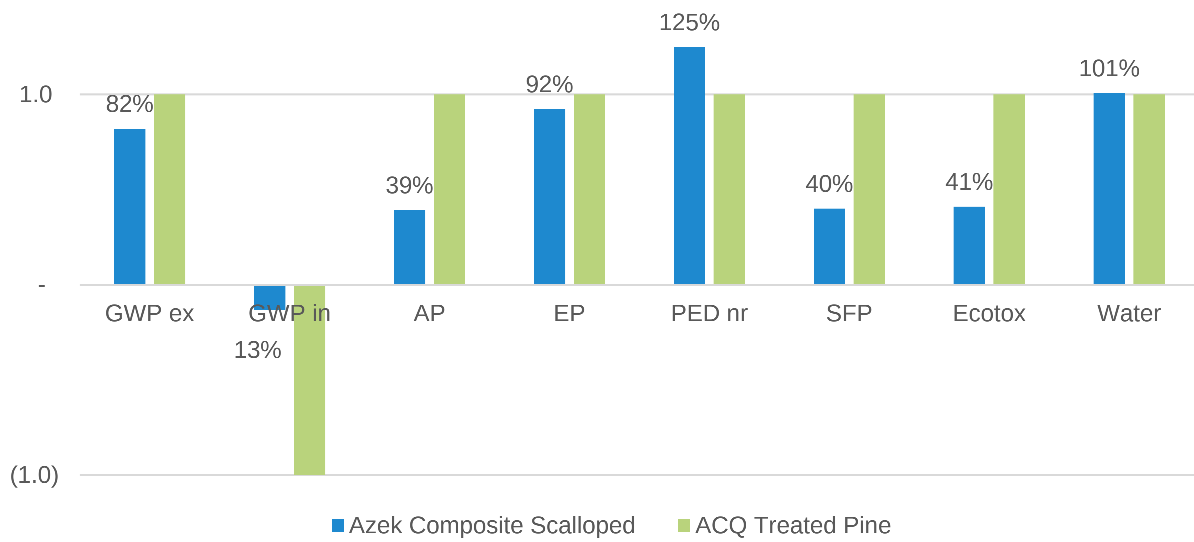

Figure 4-11: Comparing TimberTech scalloped-profile composite decking and treated pine decking, normalized to treated pine, per functional unit

4.3. Sensitivity Analysis

4.3.1. Carbon footprint of pine under alternative lifetime assumptions

The baseline scenario uses the reference flows shown in section 2.2.3, based on product service lives that match AZEK's manufacturer warranties for the composite and PVC decking products or that represent estimates for the lifetime of average ACQ treated pine decking. The sensitivity analysis in this section explores the effects of shortened and/or extended lifetimes for all decking systems on carbon footprint (GWP). The analysis considers expected years of decking product's lifetime ranging from 10 years, pine's baseline lifetime, to 25 years, the reference service life established by the functional unit (see 2.2.2).

Carbon footprint excl. biogenic carbon

As Figure 4-12 illustrates, the result for GWP excl. biogenic carbon at the ten-year mark shows the baseline comparative result for pine given in Figure 4-1, representing 2.5 pine deck installations to deliver the functional unit. At the ten-year mark, pine decking (baseline) has a slightly higher GWP than AZEK's decking products (baseline). As the assumed lifetime of the pine decking product increases, the GWP of the systems decreases, due to lessening need for wood material supply and installation efforts. The graph shows pine decking's carbon footprint on par with TimberTech PVC's (baseline) when pine is assumed to last 10.5 years and on par with TimberTech average composite (baseline) when pine is assumed to last 12.5 years. Consequently, a treated pine decking product that lasts 0.5 – 2.5 years (or

5% – 25%) longer than assumed in the baseline assumption would have a similar GWP excl. biogenic carbon as TimberTech PVC and composite decking, respectively. As the pine decking's longevity increases, theoretically, the product's GWP leads toward approx. half of TimberTech's GWP at the 25-year mark.

TimberTech average composite has a baseline lifetime of 27.8 years. Therefore, average composite's result at the 25-year mark is close to its baseline result. TimberTech PVC decking has a baseline lifetime of 50 years. At 25 years, PVC shows a GWP result that is twice as high as its baseline result.

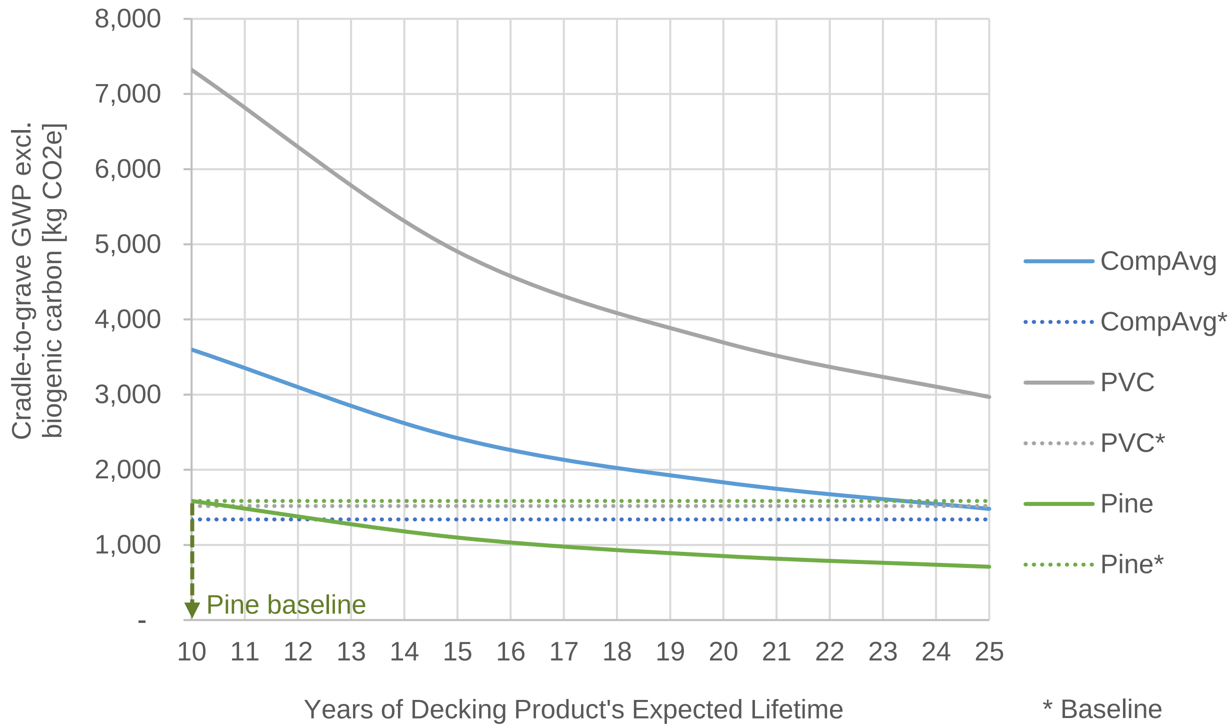

Figure 4-12: Parameter sensitivity – product service life (GWP excl. bio C)

Carbon footprint incl. biogenic carbon

While the GWP excl. biogenic carbon improves with extended lifetimes for pine, the GWP performance *including* biogenic carbon, i.e., the net sequestration of atmospheric carbon by the pine decking system, worsens with the extension of product lifetimes. As Figure 4-13 shows, at the ten-year mark, pine decking sequesters roughly 9 times as much carbon (net) as TimberTech composite decking. TimberTech PVC decking does not entail a net uptake of biogenic carbon. As pine lifetime assumptions increase, the reduction in wood material supply leads to roughly 3 times the net carbon sequestration of TimberTech composite decking.

Thus, from a total carbon footprint perspective (including biogenic carbon) perspective, pine decking boards with shorter lifetime assumptions outperform AZEK's decking products more strongly than the wood decking when it lasts longer. The TimberTech composite decking system and the wood decking system represent net carbon sinks, but at different performance levels based on the systems' wood content.

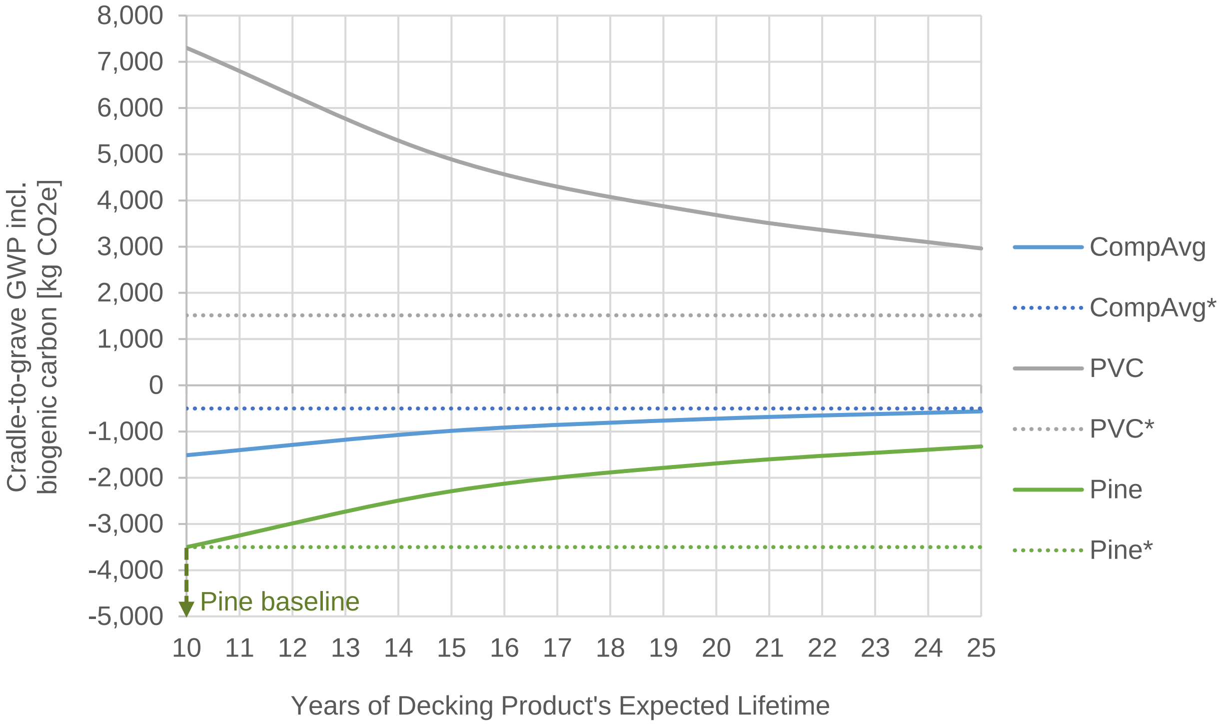

Figure 4-13: Parameter sensitivity – product service life (GWP incl. bio C)

While these benefits in terms of permanent sequestration are deemed valid based on EPA data of average US decomposition rates in landfills, *these findings shall not be misunderstood to mean that replacing wooden decks as often as possible will automatically render the biggest overall benefit for the climate*.

The answer to this question ultimately depends on the carbon management practices of the forestry operations that produce the lumber used, including changes in soil carbon, below-ground biomass, dead organic matter, and the carbon capture rates of old growth versus new growth. As there still is no international consensus on how to model forestry operations in this regard, the results in this study consider above-ground biomass only and implicitly assume that the net carbon balance of the forestry operations beyond the harvested biomass are zero, i.e., that the harvesting and replanting of pine trees is managed in a way that would not subtract from or add to the demonstrated benefits of permanently sequestering the biogenic carbon contained in the deck lumber in a landfill.

Finally, even if the net carbon balance of the forest operations were not zero and if it were included in the wood inventories, that would still not answer the question of how an increase in demand for pine lumber due to an increase in replacement rate of wooden decks may or may not alter that balance. Answering this latter question would require consequential modeling approach, which was outside the scope of this study.

4.3.2. Transport distance to installation

Outbound transportation from decking manufacturing was modeled with 100 miles via truck across all product systems. As TimberTech composite is produced exclusively in Wilmington, Ohio, a 100-mile distribution radius would service only Ohio and its adjacent states. At the same time, wood decking products are assumed to be sourced from clustered growing regions in the United States, warranting a similar exploration. Therefore, a long-haul distance of 2,400 miles was chosen to approximately represents distribution from Wilmington, OH, to San Francisco, CA. To explore the impact of the longer distribution distance, this sensitivity analysis shows changes in select impact results for TimberTech composite (scalloped profile - CompScal) and treated pine, each per functional unit.

The increase in transportation distance from 100 to 2,400 miles show an increase of total life-cycle carbon footprint (GWP excl. biogenic carbon) of 34% for TimberTech composite (from 1,280 to 1,715 kg CO_2e) and 43% for treated pine (from 1,553 to 2,219 kg CO_2e). See below figure for details.

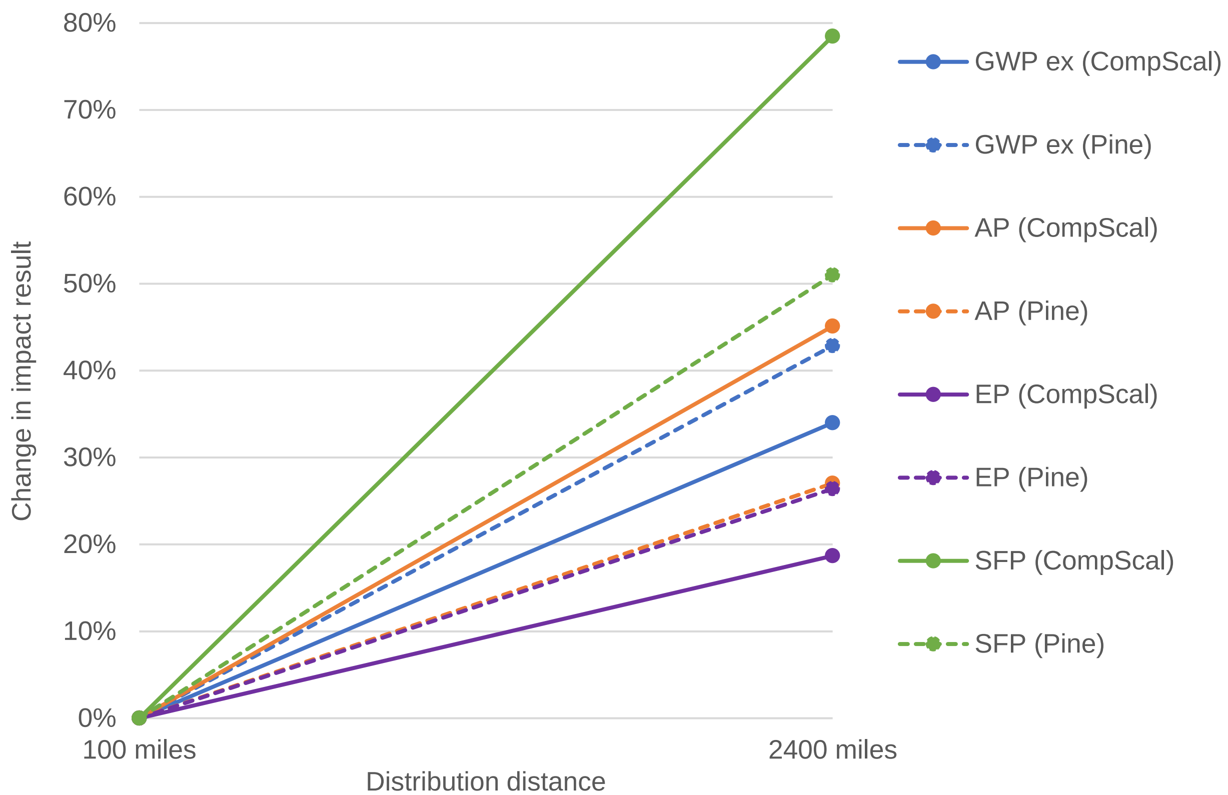

Figure 4-14: Parameter sensitivity – transportation distance

4.4. Scenario Analysis

4.4.1. EoL treatment split landfill/incineration for wood decking

The EoL baseline assumption of the study is that all decking demolition waste is landfilled. As wood decking could also be incinerated, this scenario analysis explores the impacts on GWP from partial incineration of wood decking. As such, the below figure contrasts the baseline carbon footprint including biogenic carbon to a scenario with 80% landfill and 20% incineration. The results show that the effect from partial wood incineration leads to an increase of carbon emissions at EoL, the net effect of which is a reduction of the carbon sequestered by each product system. See below figure and table for details.

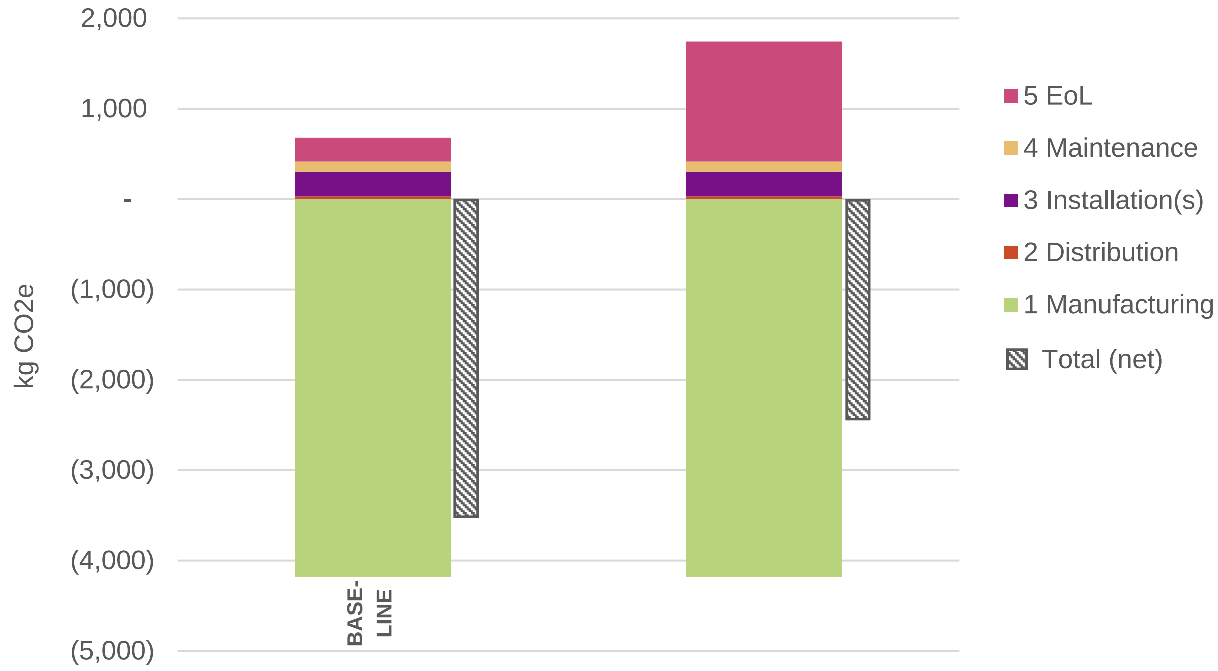

Figure 4-15: GWP incl. biogenic carbon [kg CO_2e] of wood decking, baseline and scenario with partial incineration at EoL, per functional unit

Table 4-10: GWP incl. biogenic carbon [kg CO_2e] of wood decking, baseline and scenario with partial incineration at EoL, per functional unit

	Total	1 Manu-facturing	2 Distri-bution	3 Install-ation(s)	4 Mainte-nance	5 EoL
ACQ Pine	**(3,501)**	(4,179)	29	275	111	263
ACQ Pine*	**(2,435)**	(4,179)	29	275	111	1,329

* EoL split 80% landfill, 20% incineration

5. Interpretation

5.1. Identification of Relevant Findings

From a carbon footprint perspective, excluding biogenic carbon (Figure 4-1), both TimberTech composite and PVC decking products outperform treated pine. TimberTech composite's carbon footprint comes in 12% lower than PVC's and 15% lower than pine's carbon footprint. With biogenic carbon included (Figure 4-2), pine shows a high amount of carbon sequestered and, therefore, a net-negative carbon footprint which outperforms the TimberTech decking products. TimberTech composite, based on its wood-flour ingredient, also shows a net-negative carbon footprint, while less pronounced than that of the wood decking product. The results show that wood decking sequesters roughly 7 times as much biogenic carbon (net) as TimberTech composite decking. TimberTech PVC decking shows no carbon uptake, which is why that product system's carbon footprint including and excluding biogenic carbon are practically identical.

In direct comparison, across the majority of impact categories considered (Figure 4-11), TimberTech scalloped-profile composite decking outperforms the treated-pine alternative, which represents its most direct wood-based competition in the decking market. While treated-pine decking can compete on carbon footprint (incl. biogenic carbon) there are tradeoffs, especially in acidification (Figure 4-3), smog formation (Figure 4-5), and ecotoxicity (Figure 4-8). Forest and harvesting operations, as well as ACQ treatment, lead to pronounced footprints for pine in those impact categories. Other impact categories show generally comparable impact results for most product systems.

5.2. Assumptions and Limitations

The warranty-based lifetime of TimberTech decking products is long when compared to the wood-based decking product which is assumed to require replacement at a faster rate. This allows these product systems to compete on environmental profile. Desktop research findings were limited with regard to producing robust lifetime information for pine decking that would suggest a longer service life than the 10-year baseline scenario assumption.

The study explores the effect of varied lifetimes on wood decking carbon footprints in section 4.3.1. While this sensitivity analysis shows that the net carbon benefit increases with a reduction in assumed Product Service Life (PSL) of the wood deck as the amount of carbon that is permanently sequestered by landfilling would increase accordingly. In other words, the more often a deck is replaced, the more wood—and therefore biogenic carbon—will go to landfill. While the benefits in terms of permanent sequestration are deemed valid based on EPA data of average US decomposition rates in landfills, *these findings shall not be misunderstood to mean that replacing wooden decks as often as possible will automatically render the biggest overall benefit for the climate*.

The answer to this question ultimately depends on the carbon management practices of the forestry operations that produce the lumber in question, including changes in soil carbon, below-ground biomass, dead organic matter, and the carbon capture rates of old growth versus new growth. As there still is no international consensus on how to model forestry operations in this regard, the results in this study consider above-ground biomass only and implicitly assume that the net carbon balance of the forestry operations beyond the harvested biomass are zero, i.e., that the harvesting and replanting of pine trees is managed in a way that would not subtract from or add to the demonstrated benefits of permanently sequestering the biogenic carbon contained in the deck lumber in a landfill.

Finally, even if the net carbon balance of the forest operations would not be zero and would be included in the wood inventories, it would still not answer the question of how an increase in demand for pine lumber due to an increase in replacement rate of wooden decks may or may not alter that balance. Answering this latter question would require consequential modeling approach, which was outside the scope of this study.

No key data were deliberately omitted from the study.

5.3. Results of Sensitivity, Scenario, and Uncertainty Analysis

5.3.1. Sensitivity Analysis

Sensitivity analyses were performed to test the sensitivity of the results towards changes in parameter values that are based on assumptions or otherwise uncertain. The analyses showed that the lifetime assumption made for pine decking would need to be raised by 5% or 25% for that product system to outperform TimberTech PVC or composite decking products, respectively.

Sensitivity analysis also showed that transportation distance is a consideration that potentially applies to all product systems. For the systems analyzed, the impact from transportation-distance increases was significant, but varied greatly on impact category.

5.3.2. Scenario Analysis

Scenario analysis was performed to compare results between different sets of assumptions or modeling choices. The analyses showed that partially incinerating wood decking at end-of-life does not essentially change the study results.

5.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2019 database were used. The LCI datasets from the GaBi 2019 database are widely distributed and used with the GaBi 6 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.4.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Seasonal variations/variations across different manufacturing locations were balanced out by using yearly averages/weighted averages. All background data are sourced from GaBi databases with the documented precision.

- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

5.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2019. All secondary data come from the GaBi 2019 databases and are representative of the years 2012-2018. As the study intended to compare the product systems for the reference year 2019, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.5. Model Completeness and Consistency

5.5.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regard to the goal and scope of this study.

5.5.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimized by predominantly using LCI data from the GaBi 2019 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6. Conclusions, Limitations, and Recommendations

5.6.1. Conclusions

The results provide AZEK with an extensive overview of its products' environmental performance to compare to the products in the study and those products for which company-specific data is published elsewhere.

5.6.2. Limitations

While the TimberTech decking products, i.e., composite and PVC, are represented by primary data from the manufacturing facilities, the wood decking products were represented by best-available data. Product lifetime for treated pine decking ranges widely on the climate conditions of the individual installation site and are, therefore, based on estimates.

5.6.3. Recommendations

Overall, the TimberTech decking product systems, compared to conventional treated-pine decking, demonstrate strengths on some environmental performance indicators, while showing challenges on others. TimberTech decking products can compete on environmental performance due to their high longevity relative to pine decking, which is assumed to require replacement more frequently under average outdoor climate conditions. Reduction potential on GWP fossil of TimberTech composite decking is greatest in the areas of virgin-polymer supply and electricity use in manufacturing, suggesting further increases in the use of recycled polymers and reduction of energy intensity or increasing the share of natural gas or electricity from renewable resources. The single greatest reduction potential on GWP fossil of TimberTech PVC decking is represented by virgin-polymer supply.

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