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Final Report

Comparative Life Cycle Assessment of an Artificial Christmas Tree and a Natural Christmas Tree

for

American Christmas Tree Association

West Hollywood, California

by

thinkstep AG - a Sphera company (known as "PE Americas" at the time)

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ABBREVIATIONS

a	Year (365 days)
AP	Acidification Potential
C	Carbon (molar mass 12u)
CO_2	Carbon dioxide (C x 16/12)
CH_4	Methane (C x 44/12)
d	Day (24 hours)
dm	Dry matter (water free)
EoL	End-of-Life
EP	Eutrophication Potential
EPA	Environmental Protection Agency
equiv.	Equivalent
fm	Fresh matter (e.g. 40% water content)
GaBi	Ganzheitlichen Bilanzierung (German for holistic balancing)
G&S	Goal and Scope
GWP	Global Warming Potential
h	Hour (1/24th day)
H+	Hydrogen ion
ha	Hectare, 10000 m2
Hu	Lower Heating Value (MJ)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
K2O	Potassium Oxide (K x factor 1.205)
kg	Kilogram, 1000g (SI unit of mass)
kWh	Kilowatt hour (kW*h)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
m	Meter
MJ	Mega Joule, energy unit (3.6 x kWh)
mol	mole; an SI unit approximately equal to 6.022 x 1023 atoms
N	nitrogen (atomic, molar mass = 14u)
N_2O	Nitrous dioxide (N x 44/14)
NH_3	Ammonia (N x 17/14)
NO_3^-	Nitrate (N x 62/14)
NO_x	Nitrogen oxides
OPP	Oriented Polypropylene
P_2O_5	Phosphate pentoxide (P x factor 2.291)
PEA	PE Americas
PED	Primary Energy Demand
POCP	Photochemical oxidant creation potential
SI	International System of Units
SO_x	Sulfur dioxides
Tbsp.	Tablespoon (unit of volume)
TRACI	Tool for the Reduction and Assessment of Chemical and other environmental impacts
u	Unified Atomic Mass Unit (1 u = 1,660,538,782 x 10-27 kg)
US	United States of America

1 PROJECT CONTEXT AND STUDY GOALS

The American Christmas Tree Association (ACTA) is interested in understanding the "cradle-to-grave" environmental impacts of artificial and natural Christmas trees that are sold and used in the United States. To accomplish this, the American Christmas Tree Association has engaged thinkstep to conduct a Life Cycle Assessment (LCA) that compares the most common artificial tree and the most common natural tree across a range of environmental impacts. PEA is an independent consultancy with extensive experience in conducting LCA studies and facilitating critical stakeholder review processes.

The ACTA is an industry association with many members of the artificial tree industry. This comparative study is expected to be released to the public by the ACTA to refute myths and misconceptions about the relative difference in environmental impact by real and artificial trees. The findings of the study are intended to be used as a basis for educated external communication and marketing aimed at the American Christmas tree consumer. As required by the ISO 14040-series standards, for the public dissemination of comparative LCAs a third party critical review panel has been asked to verify the LCA results.

The goal of this LCA is to understand the environmental impacts of both the most common artificial Christmas tree and the most common natural Christmas tree, and to analyze how their environmental impacts compare. To enable this comparison, a cradle-to-grave LCA was conducted of the most commonly sold artificial and the most commonly sold natural Christmas tree in the United States.

Understanding that there are a wide range of Christmas tree products available (for both natural and artificial trees), the study goal does not include the comparison of every species of natural tree to every model of artificial tree available on the market. It also does not compare the average artificial tree to the average natural tree. Rather, the two products are chosen because they are the most common artificial and natural Christmas tree purchased in the United States.

Note that the two Christmas trees modeled in this study are not comparable in appearance or physical properties (weight, fullness, character). It is understood that the consumer's decision to purchase an artificial tree or a natural tree is based primarily on factors such as tradition, convenience, maintenance, and geography. Because of this, and because there is already a division between artificial and natural tree owners, it is not expected that consumers will compare a similar looking artificial and natural trees. Rather, data shows which trees are most common among the natural tree constituency and the artificial tree constituency.

2 SCOPE OF THE STUDY

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

2.1 Definition of Product Systems

This Life Cycle Assessment (LCA) evaluates the complete life cycle environmental impacts of the following two product systems, which represent the **most common** artificial and natural Christmas tree purchased in the United States.

2.1.1 Artificial Tree

The most commonly purchased artificial tree is manufactured at a large facility in China. Primary plant data for the manufacturing of this tree were collected in 2009. After manufacturing, the tree is shipped to the US and is distributed by a major big box retailer. The artificial tree including the tree stand is made of metal and plastic parts, is 6.5 ft tall, and weighs 5.1 kg (11.2 lb) out of the box.

According USA TRADE 2009, over 10 million artificial trees have been imported to the United States each year for the years 2005-2008. According the ACTA, of this 10 million, 4 million are 6.5 ft trees, and 2 million (or roughly 20%) of the trees sold in the US are the same SKU as the tree modeled in this study. Therefore, **this study models the environmental impact of the most common artificial tree, which represents approximately 20% of the US artificial tree market.**

Similar models to this artificial tree are sold at other major big box retailers making this artificial tree extremely representative.

2.1.2 Natural Tree

The most commonly purchased natural tree is a Fraser fir (NIX 2010). This tree is modeled using literature and industry data for a 6.5 ft Christmas tree cultivated on wholesale natural tree farms, and distributed to the consumer through large retailers. The natural tree has a dry mass of 6 kg, and a total mass of 15 kg with a water content of 60%. The accompanying tree stand is 10% metal and 90% plastic. Therefore, **this study models the environmental impact of an American-grown Fraser fir, the most common natural tree grown in the United States.**

2.2 System Description Overview

The environmental indicators analyzed in this study include: Primary Energy Demand, Global Warming Potential, Eutrophication, Acidification and Smog. Environmental indicators are calculated for the artificial tree and compared to the natural tree for three scenarios:

- **1-year:** Assuming the artificial tree is only used for one year, the comparative natural tree scenario is the use of one natural tree. This scenario includes the production of 1/10th of a natural tree stand, assuming the tree stand will last ten years. The artificial tree stand is assumed to have a lifetime equal to that of the artificial tree in all scenarios.

- **5-year:** Assuming the artificial tree is used for five years before disposal, the comparative natural tree scenario is the purchase of a new natural tree every year for five years or in total, five natural trees over five years. This scenario includes 5/10th of a natural tree stand, assuming the tree stand will last ten years.

- **10-year:** Assuming the artificial tree is used for ten years before disposal, the comparative scenario is the purchase of a new natural tree every year for ten years or in total, ten natural trees over ten years. This scenario includes one natural tree stand, assuming the tree stand will last ten years.

Note that for the artificial tree, the tree stand is included in the product, and is assumed to have a lifetime equal to that of the artificial tree. For comparison purposes, the natural tree model includes a Christmas tree stand that is purchased separately by the user. It is assumed that the natural tree stand will last for 10 years. Therefore the impacts of the natural tree stand are allocated based on the number of years the artificial tree is kept. For instance, in the 1-year scenario, 1/10th of the tree stand impact is included in the overall natural tree life cycle. A detailed breakdown of impacts is summarized in this report for the artificial tree and for the 1-year scenario for the natural tree. The 5-year and 10-year natural tree scenarios are scaled from the 1-year baseline, such that relative impacts will be consistent between the three natural tree scenarios. Additionally, sensitivity analyses are performed by varying key parameters to test their significance to the model.

2.3 Functional Unit

All impacts were related to the functional unit, which is displaying one unlit, undecorated Christmas tree with tree stand in the home during one holiday season.

Although the most common artificial tree sold is a pre-lit tree, the material and impacts associated with the lights have been removed from the study boundaries. It is assumed that the lighting and decorations on each tree would be equivalent, and are therefore excluded from the study.

2.4 Study Boundaries

This study includes the cradle-to-grave environmental impacts of producing and using a Christmas tree in the home during one holiday season.

For the artificial tree the system boundary includes:

- Cradle-to-gate material environmental impacts;
- The production of the artificial tree with tree stand in China;
- Transportation of the tree and stand to a US retailer, and subsequently a customer's home; and
- Disposal of the tree and all packaging.

For the natural tree, the system boundary includes:

- Cradle-to-gate material environmental impacts;
- Cultivation including initial growth of the tree in a nursery, transplant of the seedling to the field, harvesting the full size tree, and post harvest treatment of the tree;
- Transportation from the farm to retailer, and subsequently to a customer's home;
- Use phase watering;
- Disposal of the tree and all packaging; and
- Cradle-to-grave impacts of a natural tree stand.

Both tree models include all impacts associated with the upstream production of all materials and energy used.

Foreground datasets used in this assessment do not account for production and maintenance of infrastructure (streets, buildings and machinery). That means that impacts associated with building and maintaining infrastructure were excluded. In other words, mechanical processing on farms accounts for fuel use but not production or maintenance of the tractor. Odor, biodiversity aspects, noise and human activities are also excluded from the system analysis.

Additionally, overhead warehouse and retail impacts are excluded from this study. The only impact included at the retailer is the disposal of shipment packaging.

Table 1 summarizes what is included and excluded in this study.

Table 1: Tree System Boundary – Inclusions and Exclusions

Inclusions	Exclusions
Production/Cultivation of raw materials	Construction of capital equipment
Energy production	Maintenance and operation of support equipment
Processing of materials	Human Labor
Operation of primary production equipment	Manufacture and transport of packaging materials not associated with final product
Transport of raw materials and finished products	Internal transportation of materials within production facilities
Packaging of products	Overhead – heating and lighting of manufacturing facilities, warehouses, and retail stores.
End-of-Life treatment for all materials	

Additional details describing the modeled contents of each stage in the life cycle are included in Section 3: Life Cycle Inventory (LCI).

2.4.1 Technology Coverage

The most recently available data were used to model both the artificial tree and the natural tree. The artificial tree was modeled using data collected during the 2009 season production run of the most commonly purchased artificial tree in the US market, produced at one of the largest Chinese artificial tree factories. The natural tree was modeled using published literature describing the production of a Fraser fir, the most commonly sold natural tree. For upstream raw material production, fuels and power, average industry or US national or regional mix profiles from the GaBi databases 2006 for life cycle engineering database were utilized. Additional details on the datasets used to represent each of these upstream processes are provided in Chapter 3.

2.4.2 Geographic & Time Coverage

For manufacturing of the artificial tree, the electricity grid mix and fuel datasets used in the model represent Chinese boundary conditions. For the US distribution, use, and disposal of artificial trees, all background datasets chosen are based on US boundary conditions. For the natural tree, all background datasets are based on US boundary conditions with cultivation of the tree on a natural tree farm .

This study evaluates Christmas trees used in the United States in the years 2003-2009. The artificial trees are modeled using primary data collected in 2009. Data describing natural tree production in 2009 was not available at the time of this study; therefore the most recent published data available (2003-2008) were used in this model.

2.5 Selection of Impact Assessment Categories

The US EPA TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) impact assessment methodology was chosen because the geographical coverage of this study is the United States, and the TRACI methodology was developed specifically for US environmental conditions. Since TRACI does not include an index for the consumption of renewable or fossil energy sources, Primary Energy Demand is included as an additional environmental indicator. Specifically this study looks at Primary Energy from non-renewable resources, as this is more important environmentally than total Primary Energy Demand. Note that Primary Energy Demand is not an environmental impact category but is included in this section as it is also a sum value indicating the total amount of energy extracted from earth or based on renewable resources.

2.5.1 Included Impact Categories

Use of fossil energy sources and Global Warming Potential are included in the study because of their growing importance to the global environmental and political/economic realm. Acidification, Eutrophication, Photochemical Ozone Creation Potential/ Smog are included because they reflect the environmental impact of regulated and additional emissions of interest by industry and the public, e.g. SO_2, NO_X, CO, and hydrocarbons. These categories have been used as key indicators to determine the environmental performance of the different trees. A short description of each impact category is shown in Table 2.

Table 2: Life cycle impact assessment categories, indicators of contribution to environmental issues, units of measure, & brief descriptions

Impact Category (issue)	Indicator	Description	Unit	Reference
Energy Use	Primary Energy Demand, non-renewable (PED)	A measure of the total amount of non-renewable primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.).Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ	An operational guide to the ISO-standards (Guinée *et al.*) Centre for Milieukunde (CML), Leiden 2001.

Impact Category (issue)	**Indicator**	**Description**	**Unit**	**Reference**
Climate Change	Global Warming Potential (GWP)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.	kg CO_2 equivalent	Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2001: The Scientific Basis*. Cambridge, UK: Cambridge University Press, 2001.
Eutrophication	Eutrophication Potential	A measure of emissions that cause eutrophying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems	kg Nitrogen equivalent	Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002.
Acidification	Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight.	mol H+ equivalent	Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002.
Smog	Photo chemical Oxidant Potential (POCP)	A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOCs under the influence of UV light.	kg NOx equivalent	Bare et al., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts JIE, MIT Press, 2002.

2.5.2 Common Excluded Impact Categories

The following impact categories are not included in this study.

2.5.2.1 Ozone Depletion Potential (ODP)

ODP has not been selected as it is only relevant once cooling fluid is consumed in a high quantity. As this is not the case in either manufacturing process, ODP has not been included in the report.

2.5.2.2 Toxicity

In 2004 a group of environmental leaders released a report, the Apeldoorn Declaration (Ligthart et al 2004), describing the shortcomings of toxicity and hazard characterization within LCA. As per this declaration, it is the position of this study that "even though LCIA can use models and methodologies developed for Risk Assessments, LCA is designed to compare different products and systems and not to predict the maximal risks associated with single substances." Human and eco-toxicology results are best suited to case- and site-specific studies that accurately model dispersion pathways, rates, and receptor conditions. As a result of this declaration, the LCIA categories of human health toxicity (cancer and non-cancer) and ecological toxicity were not included in the study.

2.5.2.3 Fossil Fuel Depletion

This impact category will not be included as part of this study as the non-renewable Primary Energy Demand (PED) indicator will succinctly communicate the impact of fossil fuel depletion through non-renewable energy consumption. In addition, the endpoint methodology is not readily understood by a variety of audiences, technical and non-technical alike.

2.5.3 Normalization, Grouping and Weighting

Additional optional Life Cycle Impact Assessment (LCIA) steps include normalization, grouping and weighting. Due to uncertainties associated with the incongruence between the normalization boundary associated with readily available datasets and the boundary of impact[1], normalization was not included as part of this study. Further, due to the subjective nature of grouping impact categories and/or applying value-based weights, the impact results that are included are communicated in disaggregated form.

2.6 Data Collection

In modeling a product system, it helps to consider the foreground system and the background system separately. For the foreground system, primary data from the artificial tree manufacturing plant in China and published literature describing natural tree production in the United States was collected. For all background data (production of materials, energy carriers, services, etc.) the GaBi databases 2006 were used. In modeling, the product flows of the foreground system are connected to the background datasets of the respective products. In doing so, the quantities of the background datasets are scaled to the amount required by the foreground system.

2.6.1 Artificial Tree Production

Data for the production and transportation of an artificial tree were collected for a manufacturing facility in China. At this plant, Christmas trees and stands are produced in the summer and then shipped to the US for distribution and sale during the winter holiday season. This plant is one of the largest Chinese artificial tree manufacturers. Production line data was collected from equipment dedicated to tree production by an ACTA member

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[1] For example in practice the normalization boundary is typically a geographical boundary that is determined by a political boundary, such as a country. However, incongruence occurs as some impact categories express potential impacts outside the political boundary (GWP), as well as greatly exceed the boundary of impact (Acidification Potential).

during the 2009 summer production season. Data was collected for a specific artificial tree model that is the most common artificial tree sold in the United States.

2.6.2 Natural Tree Cultivation

US impacts from agricultural production depend upon local conditions such as climate, soil type, fertility, indigenous pests and also on available technology (degree of mechanization, use of fertilizers and pesticides, etc.). The data used for modeling a Fraser fir, the most commonly sold natural Christmas tree, were collected from literature, international electronic databases, and personal interviews. Mean values were derived from data comparisons. An overview of the main literature used is given in Sections 3 and 3.2. Data were calculated using the Agrarian Model within the LCA software GaBi 4 of thinkstep, which calculates environmental impacts of crop products by considering all relevant inputs and outputs. For more details on the Agrarian Model refer to Section 9: Appendix - Description of Agrarian Model.

2.6.3 Transportation

The GaBi database for transportation vehicles and fuels were used to model the transportation associated with both the artificial and natural tree. US average fuels were used for all transportation within the US. Chinese fuels were used for all transportation within China and originating from China. The transport of the artificial tree from China was modeled using a global truck (factory to port) and container ship (Chinese port to US port). All truck transportation within the United States was modeled using the GaBi 4 US truck transportation datasets. In accordance with the US CENSUS BUREAU 2002, Vehicle Inventory and Use Survey results:

- Seedlings (assumed to be similar to grains) are transported in a dump truck;
- Wood and agriculture products (including cultivation intermediary steps) are transported using a US flatbed or platform truck, however the finished trees product are transported from farm to retailer using a pole, logging, pulpwood, or pine truck;
- Fertilizers are transported using a US liquid or gas tanker truck;
- Wastes are transported using a US dump truck; and
- Raw materials and artificial tree products are transported using a basic enclosed trailer.

The vehicle types, fuel usage, and emissions for each truck model were developed using a GaBi model based on the most recent US Census Bureau Vehicle Inventory and Use Survey (2002) and US EPA emissions standards for heavy trucks in 2007. The 2002 VIUS survey is the most current available data describing truck transportation fuel consumption and utilization ratios in the US, and the 2007 EPA emissions standards are considered by this study's authors to be the most appropriate data available for describing current US truck emissions.

For each modeled truck, the utilization ratio can be varied. The utilization ratio can be thought of either as the percentage of miles while carrying the maximum cargo load, or the percentage of the maximum cargo load which is being carried during an average mile. The three trucks used in this model are as follows:

Table 3: US Truck Specifications

Truck Type	Max Cargo (lbs)	Miles per Gallon	Utilization Ratio
Pole, logging, pulpwood, or pipe	50,000	5.25	57%
Basic enclosed trailer	45,000	6.06	78%
Dump Truck	52,000	5.64	54%

The combination of cargo capacity and utilization ratio determines how much cargo is carried on the truck. For example, given that each natural tree weighs 15 kg, the model therefore assumes that 861 trees are carried on each logging truck: (50,000lb x 1 kg/2.2lb) x 0.57/ 15 kg.

The transportation by consumers in a passenger car of the tree from a retail store to their home is modeled in GaBi 4 according to the US Department of Energy GREET model of US car emissions.

2.6.4 End-of-Life

Material-specific (PVC, steel, pine tree, etc) GaBi 4 US landfill, incineration and composting datasets are used throughout the model. The landfill processes are used for the disposal of all wastes on the natural tree farm, packaging wastes for both trees by both the retailer and end-user, and final disposal of both Christmas trees. The End-of-Life treatment of the natural tree includes incineration and composting in addition to the landfill process. Credits for electricity recovery from landfill methane emissions and incineration are included in this model. PVC and steel artificial tree production waste streams in China are assumed to be recycled. More details on the End-of-Life model are presented in Section 3.1.4 (for the artificial tree) and 3.2.4 (for the natural tree).

2.6.5 Fuels and Energy – Upstream Data

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi databases 2006. For activities occurring in China, the fuel and energy models were based on Chinese boundary conditions. For all activities occurring within the United States, national average electricity and fuel datasets were chosen.

2.6.6 Raw and process materials

LCI data for all upstream raw and process materials were obtained from the GaBi databases 2006.

2.6.7 Co-product and By-product Allocation

A process, sub-system or system may produce co-products in excess of the specified functional unit. Such co-products leave the system to be used in other systems yet should carry a portion of the burden of their production system. In some cases materials leaving the system are considered “free of burden.” To allocate burden in a meaningful way between co-products, several procedures are possible (e.g. allocation by mass, market value, heating value, etc.). Whenever allocation was necessary, the method was chosen based upon the original intent of the process in need of allocation. For instance, in the case of mining precious metals where the desired object (e.g. gold) is only a small fraction of the total mass of products produced (e.g. gravel), it is illogical to allocate the burdens of mining based upon mass. However, for transportation processes where the amount of cargo carried per trip is determined by weight limits, mass allocation is appropriate.

In this study, no allocation was necessary for the manufacturing processes associated with the production of the trees as the artificial tree data were collected during the tree producing season from equipment dedicated to tree production. All recycling and disposal of scrap materials associated with the artificial tree production is included in the model.

The by-products of the natural tree that were produced in the system (stem wood, cutting, root system and pruning) were also included inside the system boundaries and assumed to be disposed in a landfill. In later stages of the life cycle, some by-products occur (e.g. organic material). In these cases allocation is avoided by system expansion. An overview of the by-products and the substituted product is given in Table 4.

Table 4: By-products and their Consideration in this Study

Product and point of formation	Assumptions	Substituted Process
Natural Tree		
EoL of Natural Christmas Tree (Incineration)	Burned at Incinerator	Beneficiation of power from average power grid mix US Beneficiation of steam from US steam from natural gas
EoL of Natural Christmas Tree (Landfill)	Disposal in Landfill Methane Obtained from Landfill Body Methane Combustion	Beneficiation of power from average power grid mix US
EoL of Natural Tree Packaging (plastic film for seedlings, seedling pot, string for baling, steel and plastic tree stand)		
EoL of Natural Christmas Tree Stand		

Product and point of formation	Assumptions	Substituted Process
Artificial Tree		
EoL of Artificial Tree Packaging (paper slip and plastic shrink wrap for shipping, cardboard box for retail)	Disposal in Landfill Methane Obtained from Landfill Body Methane Combustion	Beneficiation of power from average power grid mix US
EoL of Artificial Tree		

Allocation of upstream data (energy and materials):

- For all refinery products, allocation by mass and net calorific value is applied. The manufacturing route of every refinery product is modeled and so the effort of the production of these products is calculated specifically. Two allocation rules are applied: The raw-material (crude oil) consumption of the respective stages, which is necessary for the production of a product or an intermediate product, is allocated by energy (mass of the product * calorific value of the product). The energy consumption (thermal energy, steam, electricity) of a process, e.g. atmospheric distillation, being required by a product or a intermediate product, are charged on the product according to the share of the throughput of the stage (mass allocation).

- Materials and chemicals needed during manufacturing are modeled using the allocation rule most suitable for the respective product. For further information on a specific product see http://documentation.gabi-software.com/.

Emissions associated with the truck and rail transportation of cans and upstream can parts are allocated across the vehicle's cargo by mass.

2.6.8 Emissions to Air, Water and Soil

Emissions data associated with the production of the artificial trees were determined by primary technical contacts familiar with specific plant operations, and literature for the natural trees. Data for all upstream materials and electricity and energy carriers will be obtained from the GaBi databases 2006.

Emissions associated with transportation were determined by modeling the modes of transportation and distances most likely to occur for each tree. Energy use and the associated emissions were calculated using pre-configured transportation models from the GaBi databases 2006.

No emissions are expected during the use stage of either tree.

End-of-Life emissions were determined by the percentage of trees sent to landfill vs. incineration or composting.

2.6.9 Cut-off Criteria

The cut-off criteria applied in this study for including or excluding materials, energy and emissions data is as follows:

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

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

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

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

The small quantities of chemical additives used with PVC during the artificial tree manufacturing process are excluded given these criteria.

2.6.10 Data Quality

Data quality is judged by its precision (measured, calculated or estimated), completeness (e.g. are there unreported emissions?), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, time period, technology). To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent, upstream LCA information from the GaBi databases 2006 were used. This upstream information from the GaBi databases 2006 is widely distributed and used with the GaBi 4 Software. These datasets have been used in LCA-models worldwide for several years in industrial and scientific applications for internal as well as critically reviewed studies. In the process of providing these datasets they have been cross-checked with other databases and values from industry and science.

Precision and completeness

- **Precision:** Detailed data were measured during the production of top selling artificial Christmas trees in 2009. The natural tree model is built upon the latest published literature describing Fraser fir production. The precision of each upstream dataset used is documented within the GaBi 4 software and available online at http://documentation.gabi-software.com/.

- **Completeness**: All relevant, individual flows are considered and modeled for each process.

Consistency and reproducibility

- **Consistency:** To ensure consistency only primary data of the same level of detail and upstream data from the GaBi databases 2006 are used. While building up the model cross-checks concerning the plausibility of mass and energy flows are continuously conducted. The provided primary data were checked thinkstep. No inconsistency was found.

- **Reproducibility:** The study results are reproducible by thinkstep and the Artificial Christmas Tree Association (ACTA) as the ACTA provided the details necessary to model the primary technology used in this study, and the models are stored in an internally-available database. For the external audience reproducibility is limited to the details shared in this report due to the confidential nature of the artificial tree data.

Representativeness

- **Time related coverage:** The artificial tree production is based upon 2009 data. The natural tree production and all upstream datasets are based upon data from the years 2002-2009 based upon availability.

- **Geographical** coverage: The geographical coverage is the United States, with production of artificial trees in China. The natural tree model is based upon the growth of Fraser fir trees, but may be representative of the growth of other natural Christmas trees in the United States as well.

- **Technological coverage:** The most common processes for current production of both natural and artificial trees were used in this study.

Uncertainty

- Uncertainty quantification in LCA has two dimensions: uncertainty on flow level, and uncertainty on process level, the latter of which is more relevant. The uncertainty at the process level is about appropriateness of the dataset for the intended application and representativeness of data sets in the system’s life cycle. The quantification of the overall uncertainty (number or figure) is not currently possible in a reliable, scientifically defendable, and reproducible manner. Databases that quantify uncertainty base the figures on a mixture of semi-quantitative approaches and guess work; the reliability of such uncertainty figures is very low.

2.6.11 Exceptions

There are no exceptions to the stated scope of this study.

2.7 Software and Database

The LCA model was created using the GaBi 4 software system for life cycle engineering, developed by thinkstep The GaBi databases 2006 provides the Life Cycle Inventory data for several of the raw and process materials obtained from the upstream system.

2.8 Analysis of Results

The results of the LCI and LCIA are interpreted with regards to the goal and purpose of the project. The interpretation addresses the following topics:

- Identification of significant findings, such as the primary materials and processes contributing to the overall results, and the potential contribution of emissions for main impact categories in the context of the whole life cycle.

- Evaluation of completeness, sensitivity, and consistency, to confirm the inclusion or exclusion of data from the system boundaries as well as the cut off criteria and data quality checks are described in Section 3 and 3.2.

- Conclusions, limitations and recommendations including stating the appropriateness of the definitions of the system functions, the functional unit and system boundary.

2.9 Critical Review

The applicable ISO standards require a critical review in cases where a comparative assertion is being made and communicated publicly. The primary goals of a critical review are to provide an independent evaluation of the LCA study and to provide input to the study proponents on how to improve the quality and transparency of the study. The benefits of employing a critical review are the following:

- To provide precise instructions in the numerous situations where documented approaches described in appropriate reference materials were deficient of detail;

- Identification and assurance that the most significant inputs and outputs of the system studied are identified; and

- Assure that the data collected, the models developed, and the sensitivity analyses performed are of sufficient quality, both qualitatively and quantitatively, to ensure that the system assessed is truly represented and supports the claims made.

If applicable, the peer review panel can serve to comment on suggested priorities for improvement potential.

The peer review panel committee consists of the following experts:

- H Scott Matthews, Chair (Carnegie Mellon University)
- Mike Levy (American Chemistry Council)
- Eric Hinesley (North Carolina State University)

3 LIFE CYCLE INVENTORY (LCI)

The life cycle of the artificial and the natural Christmas tree were modeled in GaBi 4. Separate models were developed for the artificial and natural tree due to the differences in production.

The life cycle of the artificial tree and natural tree are divided into four comparable phases (Figure 1):

1. Manufacturing/Cultivation;
2. Finished Tree to Home;
3. Use Phase[2]; and
4. End-of-Life.

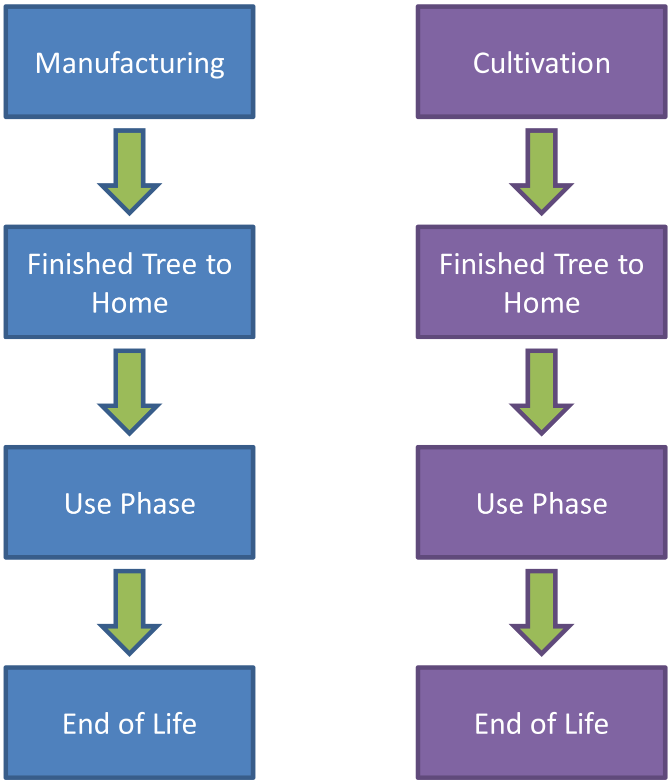

Figure 1: Process Flow for Artificial Tree (left) and Natural Tree (right)

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[2] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

3.1 Artificial Tree

The artificial tree process flow (Figure 2) is characterized below and detailed in the following sections.

1. **Manufacturing:** The manufacturing phase includes cradle-to-gate manufacturing including raw materials, production of the components, tree assembly and packaging (shelf and shipment) in China; and
2. **Finished Tree to Home:** The finished tree to home phase includes a transportation phase and disposal of packaging at the retailer:
    - ***Transportation:*** transportation includes transportation of the artificial tree to the consumer's home via a retail store. This includes truck transportation of the packaged tree from the Chinese factory to the Chinese port, shipment from the Chinese port to the US port, trucking from the US port to the US retail store, and personal car use between the retail store and the consumer's home.
    - ***Packaging disposal***: Packaging disposal includes unpacking and disposal of the shipment packaging (recycled paper slip and polypropylene shrink wrap) at the retailer.
3. **Use Phase:** The use phase for the artificial tree models disposal of the tree shelf packaging (cardboard box) in a landfill.
4. **End-of-Life (EoL):** The EoL model consists of transport and disposal of the artificial tree at a municipal landfill.

3.1.1 Manufacturing

Artificial trees are manufactured from three main components: polyvinylchloride (PVC) resin, polypropylene (PP) resin and steel sheets. The production involves a series of processes including molding and cutting of the plastic, and assembly of the parts such as the branches, and packaging. Additional steps include rolling, cutting, stamping, and pressing the steel to make the artificial tree pole and hinges. Process steps are summarized Figure 3. The bill of materials for the artificial tree, including the raw material source, is summarized in Table 5.

Artificial tree packaging includes shipment packaging (recycled paper slip and polypropylene shrink wrap) and shelf packaging (cardboard box).

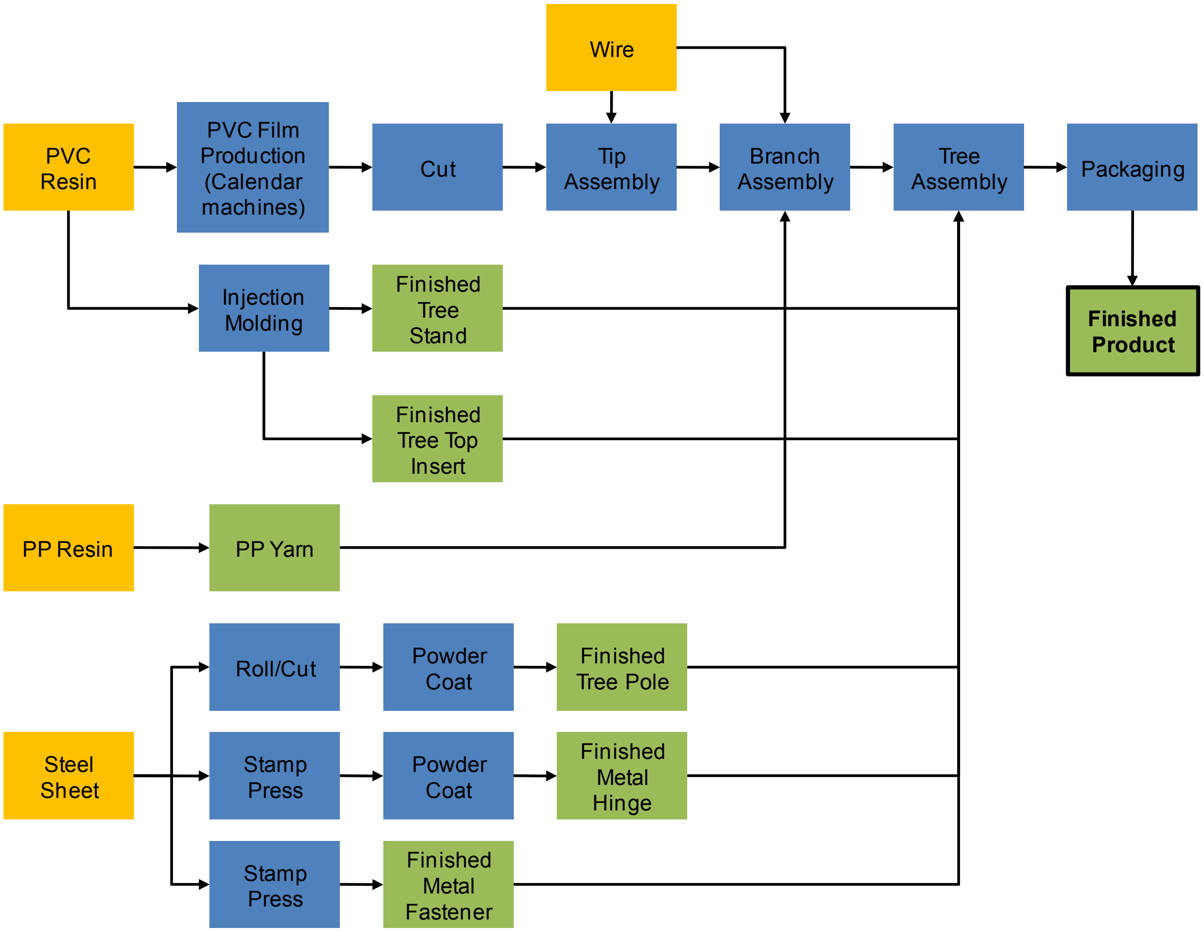

Figure 2: Artificial Tree Production

Yellow Boxes represent cradle-to-gate material inputs, blue boxes represent processes, and green boxes represent products of the blue processes.

Table 5: Raw Materials for Artificial Tree

Material	Amount (kg)	Source of Materials
PVC Resin for Tips	1.684	Japan, US, Taiwan
PVC Stabilizer WINSTAB	0.0203	Taiwan
PVC Processing Aid (P-201)	0.0318	Taiwan
PVC Impact Modifier (M-51)	0.0978	Taiwan
PVC Lubricant Winnox (G-876)	0.0094	Taiwan
PVC Lubricant Winnox (SG-16)	0.0125	China (Guandong)
SiO2 (HO5)	0.0272	China (Guandong)
Stearic Acid (SA-1801)	0.0069	China (Guandong)
PVC Resin for Tree Top Insert	0.014	Japan, US, Taiwan
PVC Resin for Stand	0.41	Japan, US, Taiwan
PP Yarn	0.277	Taiwan
Steel Tree Tip Wires	0.99	China (Tianjin, HeBei)
Steel Tree Branches	0.723	China (Tianjin, HeBei)
Steel Tree Pole	0.55	China (Guandong)
Steel Hinges	0.293	China (Guandong)
Steel Fasteners	0.046	China (Guandong)
Packaging (42"x7"x10.5")	1.2	China (Guandong)
Tape	0.03	China (Guandong)

*Japan: 46.9%, US: 28.9%, Taiwan: 24.2%

Production of five separate components are modeled and then assembled for final tree production. The five components, summarized in Figure 3, are:

- Production of branches;
- Production of tree stand and top insert;
- Production of tree pole;
- Production of metal hinge; and
- Production of metal fastener.

Schematics detailing the process steps involved in producing each of the five components are shown in Figure 4 through Figure 8.

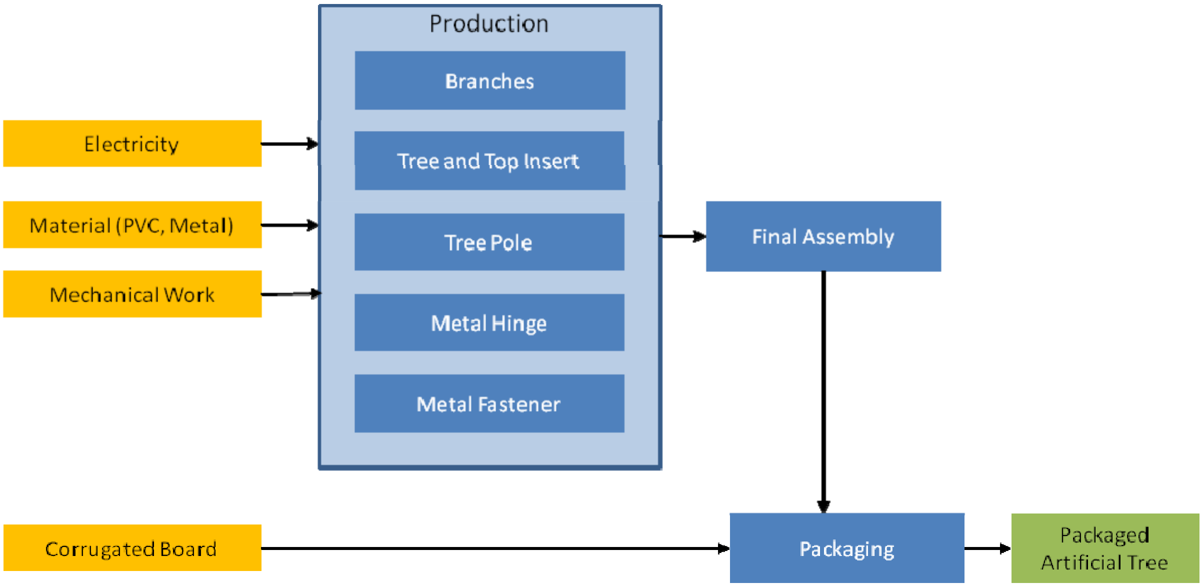

Figure 3: Production of Artificial Tree Components

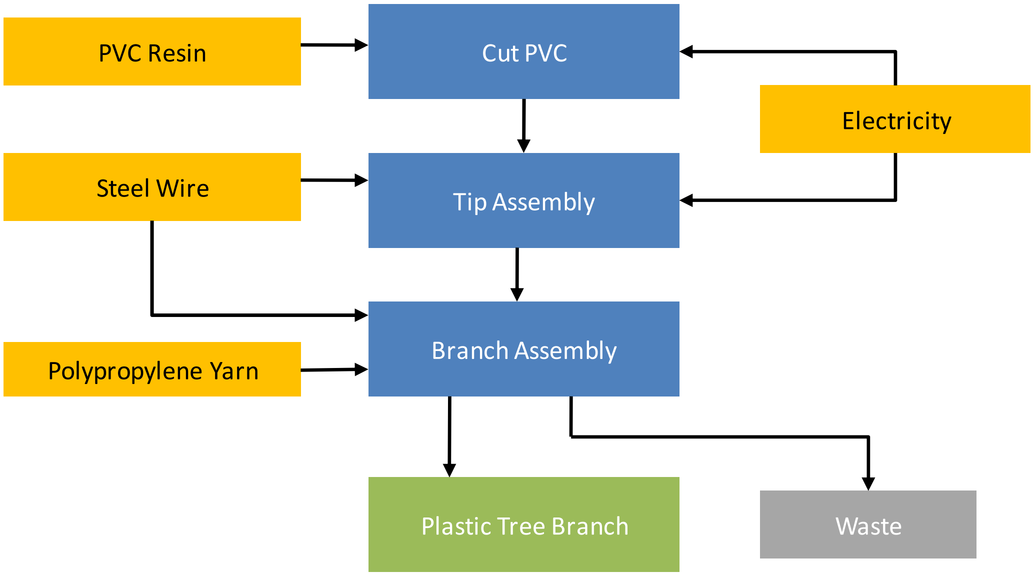

Figure 4: Production of Branches

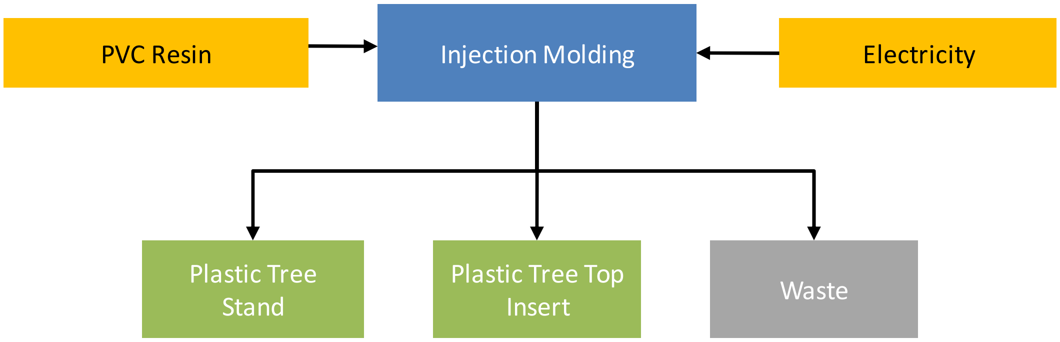

Figure 5: Production of Tree Stand and Top Insert

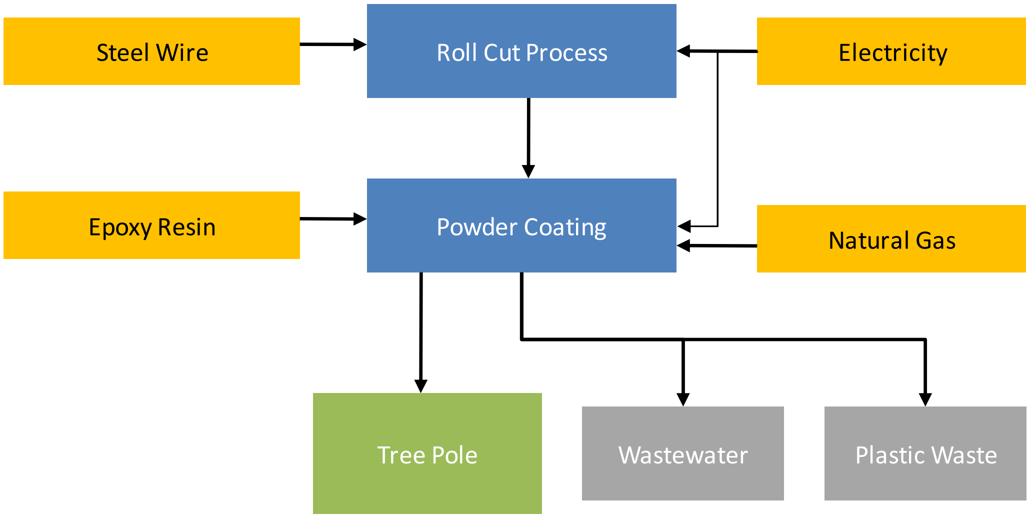

Figure 6: Production of Tree Pole

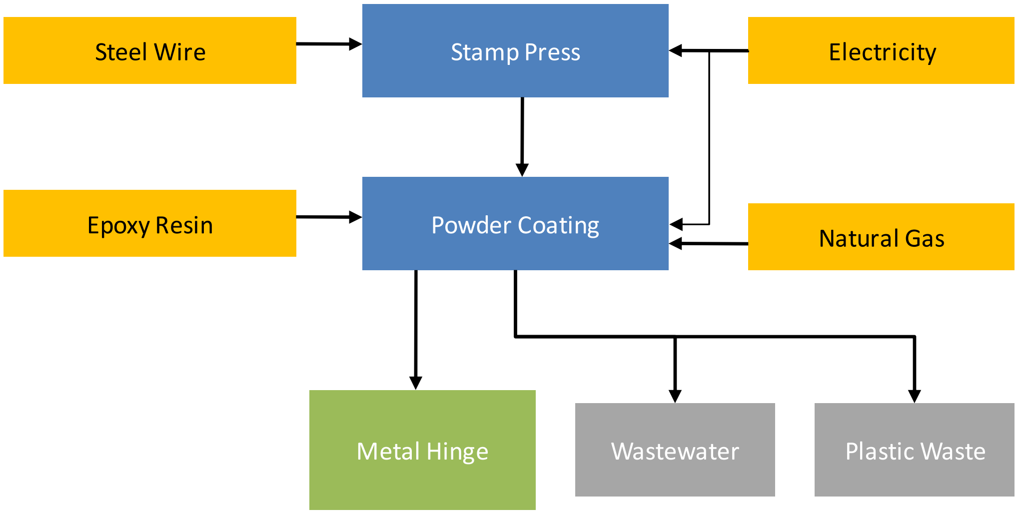

Figure 7: Production of Metal Hinge

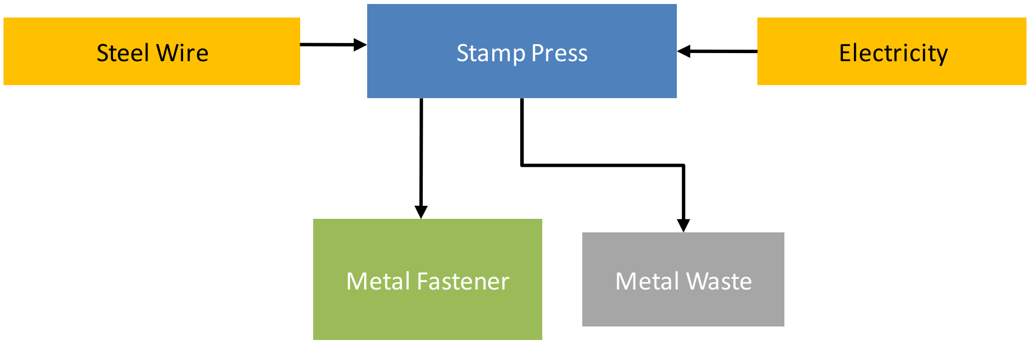

Figure 8: Production of Metal Fastener

The artificial tree is packaged in corrugate board after the production process and before the tree is shipped from China to the US. The modeled packaging is shown in Figure 9.

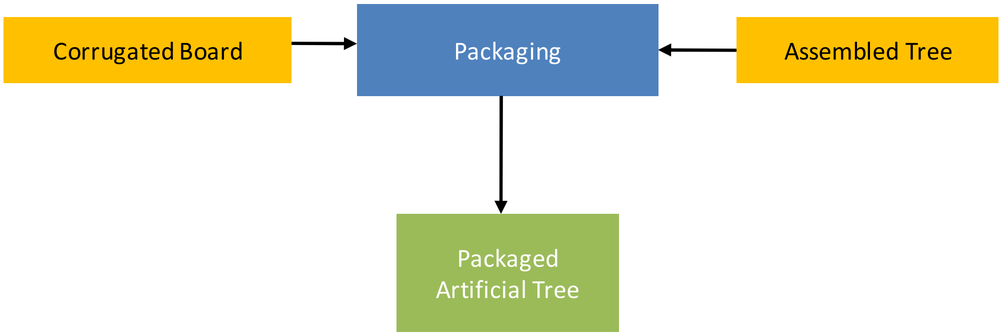

Figure 9: Packaging of Artificial Tree

3.1.2 Finished Tree to Home

The finished tree is transported by truck from Chinese factory to Chinese port, by container ship to US port, and again by truck in to the US retailer. At the retailer shipment packaging is removed and landfilled. From the retailer, the consumer drives the Christmas tree home in a personal vehicle.

Note that the operation of the retail store is out of scope of this analysis. Although some artificial trees may go unsold at the end of the year, it is assumed that excess stock will be sold at discounted rates on post season sales. If there are damaged or returned items that cannot be resold, the impact of the artificial tree increases. In other words, if 10% of artificial trees go unsold, the artificial tree impacts upstream of the retailer will also be increased by 10%. The model, however, assumes an equivalent 0% loss rate for both the artificial and natural trees.

3.1.3 Use Phase

At the final customer, the tree is assembled and shelf packaging waste (artificial tree cardboard box) is discarded. Because the tree is undecorated and does not require water, besides landfilling of packaging, there is no impact associated with the use of the artificial tree. Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

3.1.4 Disposal (End-of-Life)

Although the majority of the artificial tree materials are recyclable, given lack of customer awareness of this fact, and a lack of infrastructure that would allow artificial trees to be recycled in much of the US, a worst-case scenario is modeled in which it is assumed that 100% of the artificial trees are landfilled upon disposal.

3.1.5 Transport of Artificial Tree

The GaBi database for transportation vehicles was used to model the transportation associated of the artificial tree. For transportation modeling details refer to Section 2.6.3.

The transportation distances during production and shipping of the artificial tree are well known and provided by ACTA. However, the distances associated with transport from storage to the retailer, from the retailer to the customer, and from the customer to the landfill are undefined and case-specific. For instance, a customer in a rural mountain region may have a different transportation profile than a customer in a coastal more densely populated region of the United States. Based on 2007 transportation data for the United States Bureau of Transportation Statistics (BTS 2008), miscellaneous durable goods for merchant wholesalers travel 881 miles per shipment; this distance is used to approximate the truck transport from storage to retailer. The transport from point of waste disposal to End-of-Life treatment (landfill, composting, incineration, recycling) is assumed to be 20 miles, consistent with the default values used in EPA's WARM Model (EPA 2009B).It is assumed that the round trip distance traveled from the end customer to retailer is 5 miles. This is consistent with a survey done by the American Christmas Tree Association that found approximately 40% of consumers drive less than 5 miles round trip to purchase their trees. Additionally, the US Federal Highway Administration's National Household Travel Survey states that the average distance driven for any type of shopping is 6.7 miles (USDOE 2001). However, because this distance may vary significantly by consumer, a sensitivity analysis was completed as detailed in Section 5: Sensitivity and Break Even Analysis.

Transportation distances are summarized in Table 6.

Table 6: Artificial Tree Transportation Distances

Transportation - Artificial Tree		
From – To	**Vehicle Type**	**Distance (one-way)**
Factory - Harbor	Truck 20 - 26 t total cap./17.3 t payload	81 mi (130 km)
China – US	Shipping (water)	7471 mi (12,023 km)
Harbor - Storage	Truck-trailer, basic enclosed up to 4500 lb payload (8b)	15.5 mi (25 km)
Storage - Retailer	Truck-trailer, basic enclosed up to 4500 lb payload (8b)	881 mi (1,418 km)
Retailer - Customer	Car	2.5 mi (4 km)
End-of-Life	Truck – Dump truck	20 mi (32 km)

3.2 Natural Tree

The natural tree process flow (Figure 10) is characterized below and detailed in the following sections.

1. **Cultivation**: The Cultivation phase of the natural tree includes growth of a 6.5 ft tree on a natural tree farm, including applying polypropylene string for transport to retailer. This phase of the life cycle also includes the cradle-to-gate impacts of a natural tree stand (made of steel and ABS plastic) to be consistent with the boundaries of the artificial tree life cycle.

2. **Finished Tree to Home:** The finished tree to home phase includes a transportation phase and disposal of packaging at the retailer:

- Transportation: transportation includes truck transportation of the natural tree from the farm to the retail store, and personal car use between the retail store and the consumer’s home.

- Packaging disposal: Packaging disposal includes unpacking and disposal of the polypropylene string applied at the farm for transport and taken off at the retailer for display.

3. **Use Phase:** The use phase for the natural tree includes watering of the natural tree.

4. **End-of-Life (EoL):** The EoL consists of transport and disposal of the natural tree. Disposal scenarios are examined for trees that are 100% landfilled, 100% incinerated and 100% composted.

3.2.1 Tree Cultivation

The natural tree cultivation phase of the life cycle includes the farming activities that take place within the boundary of a natural tree farm and includes:

- Planting of the seed;
- Cultivation (0-2 years) of the seed;
- Operation of a greenhouse including peat production and thermal energy consumption (natural gas);
- On farm transport and packaging (ABS plastic for the young seed);
- Cultivation (3-4 years) of the tree;
- Transplant of the seedling to the field including on farm transport and packaging (Polyethylene film)
- Planting of the seed in the field including diesel consumption;
- Cultivation (4-11 years) of the natural tree;
- Plantation care (motor saw operation);
- Harvesting the full size tree; and
- Packaging of the natural tree in polypropylene string for shipment to the retailer.

To be consistent with the artificial tree life cycle, the natural tree cultivation phase also includes manufacturing of a natural tree Christmas stand.

Note that cultivation practices of Christmas trees in the United States can vary significantly and that impacts from agricultural production depend on local conditions such as climate, soil type, fertility, indigenous pests and also on available technology (degree of mechanization, use of fertilizers and pesticides, etc.). Climactic conditions for North Carolina were modeled and data used for modeling were collected from literature, international electronic databases, and personal interviews.

3.2.1.1 Cultivation Boundary Conditions

The cultivation phase (agrarian system) is the main component of the natural Christmas tree life cycle. In this study relevant input materials for the cultivation process itself (commercial fertilizer including lime, organic fertilizer, pesticides, seeds including their production, and transport) are integrated in the model as cradle-to-gate datasets. This LCA includes fuel consumption and air emissions that are related to the use of farming equipment during cultivation. The provision of cultivated products including harvests (output) is integrated up to the edge of field or plantation. All relevant processes taking place on the area under cultivation with emissions into air and ground water (lower limit of rooted soil zone) are considered. Heavy metals remaining in the soil are modeled as emissions to soil and integration of erosive loss of N_{org} and C_{org} as well as other nutrients are included in the model.

From seed to harvest, the life span of a typical Christmas tree was assumed to be 11 years (4 years in a nursery followed by 7 years in the field). The growing life span was modeled using the information from Peregrim 2009. There, the growing time in a nursery is given to be 2 + 2 years. System boundaries for natural tree cultivation are shown in Figure 10.

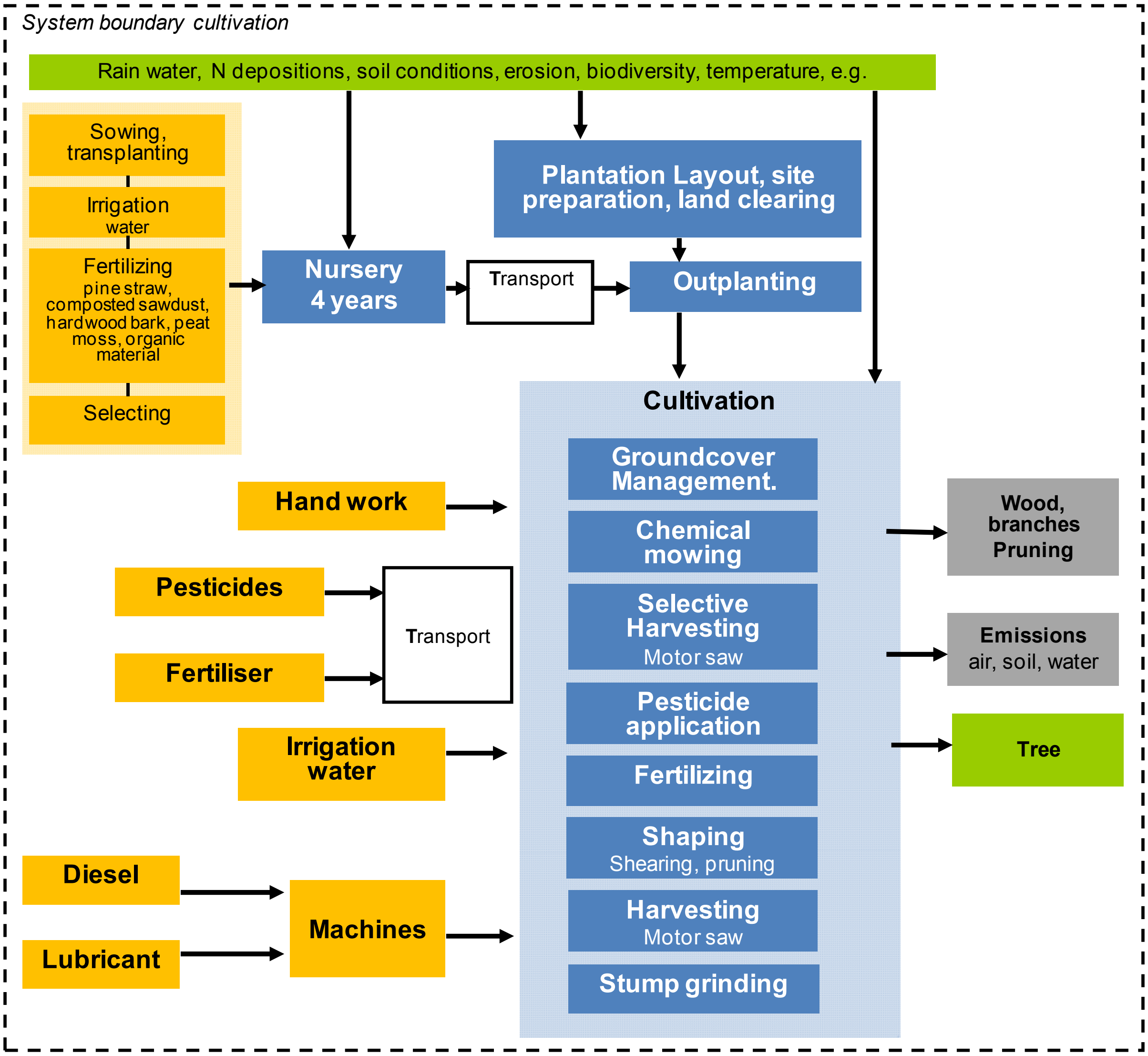

Figure 10: System Boundaries of Natural Tree Cultivation

3.2.1.2 *Seeds to Young Trees*

Seeds are initially sown, at a sowing rate of 100 seeds per square meter, in a seedbed where seedlings develop and grow for two years. It was assumed that the seedlings are grown in so called “cold green houses”. Energy demand of the houses and the amount of pot soil used for the seedlings are presented in Figure 3. After the seeding bed the seedlings, anywhere from 15 - 30 cm tall, are transplanted into larger transplant beds (density 200,000 plants per hectare and average weight 0.0066 kg per small tree). The transplants are kept in the transplant beds again for two years, where they reach a height of 40 - 50 cm and an average weight of 0.06 kg per tree. From here, the young trees are planted in fields (plantation), where they remain for seven additional years up to a height of 200 cm until harvest (density 4,000 trees per hectare) (NCDA 1996). The basic data used in this study are presented in Figure 11.

According to NCDA 1996 it was assumed that out of the 4,000 transplanted trees 3,500 finished trees could be harvested after seven years of cultivation in the plantation per hectare. The average weight of the trees after 11 years was assumed to be 15 kg per tree (Konsumo 2008, Wahmhoff 2008,HINESLEY AND WRIGHT 1989).

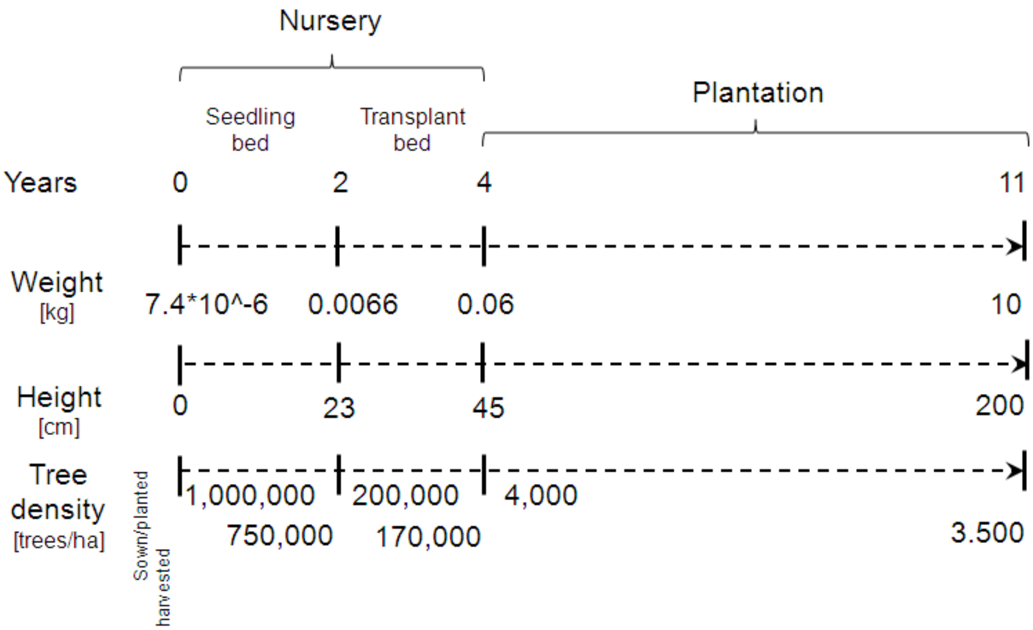

Figure 11: Time Boundaries and Specification of Natural Tree Cultivation

Christmas tree plantations need yearly care; annual care consists of tree shaping with hand pruners, shearing knives, and gas powered rotary knives. The impact of yearly care was considered according to KUHNS 2004. At the end of the cultivation period, the trees are harvested manually with motor saws. fuel consumption for care and harvest are calculated by considering the specific tree density. This data was obtained by personal communication (STIHL 2008). The motor saw is modeled using a Stihl professional chain saw (3.9 kW, MS441 type) and operates at 85% load resulting in a diesel consumption of 0.002 gallons of gasoline and 3.8 x10^{-5} gallons of lubricating oil per tree.

3.2.1.3 Mowing

Natural tree farms differ in their plantation management practices. Some farmers mechanically mow the grass between their trees many times per year. Other farmers use chemical round-up to “chemically mow” as an alternative to mechanical mowing. And some do not manage the growth between their trees at all. The natural tree model used in this study assumes chemical mowing. This includes the manual application (using backpack sprayers) of 26 ounces per acre of 41% glyphosphate (HUNDLEY AND OWEN 2005).

3.2.1.4 Fertilization

Nitrogen emissions in agricultural systems often play an important role in the overall balance of products. In LCA studies there are ambitious efforts to generate most accurate nitrogen emissions data. KUHNS 2004 mentioned that "[t]here is nothing that can be considered a standard fertilization practice in the Christmas tree industry in Pennsylvania." For this study, the nitrogen demand was calculated for average soil and weather conditions of this region. The sources and values used for this study are depicted in Table 7 and Table 8. The nutrient demand was calculated according to Baumgarten et al 2000 and Spectrum Analytic 2009.

3.2.1.5 Pesticide Treatment

In the GaBi database, datasets of specific pesticides are available and used for this study. Based on KUHNS 2004, application rates of herbicides were used (2.81 kg/ha of glyphosphate per year). However, Kuhns notes that there is "no standard fertilization practice in the Christmas tree industry." Regarding the fungicides, an application rate of 5.53 kg/ha Mancozeb (fungicide) every two years was assumed (KUHNS 2004). For application of pesticides and fertilizer the use of small tractors was assumed in the model. All input parameters used in the modeling of nursery, farm, and treatment of Christmas tree production are listed in Table 7 and Table 8.

Table 7: Input Parameters for Modeling of Seedling Production in the Nursery (Year 0 to Year 4)

Nursery: 2 years in seed bed (greenhouse), 2 years in transplant bed (field)			
Parameter	**Unit**	**Value**	**Source and remarks**
Nitrogen content seedlings 0-2 years	[% of dm]	1.5	Baumgarten et al 2000
Nitrogen content seedlings 2-4 years	[% of dm]	1.2	Baumgarten et al 2000
Seeds sawn in seed bed (grown over a period of two years)	[quantity/ha*2a-1]	1,000,000	Calculated based on Matschke 2005Matschke 2005
Germination capacity	[%]	75	Based on Matschke 2005
Weight of one seedling after two years	[kg fm/piece]	0.0066	Brang 2008
Seedlings planted in transplant bed (grown over a period of two years)	[quantity/ha *2a-1]	200,000	Based on Matschke 2005
Growth ratio transplant bed	[%]	85	Assumption
Weight of one transplant after seedling and transplant phase	[kg fm/piece]	0.06	Assumption
Potting soil	[t/a-1]	45	Assumption: 0.1l soil/seed*0,6 kg/l(soil density)*1,000,000 (seeds)*0.75 (recycling rate; 25% recycled)
Irrigation (water) seed bed	[m³/ha*a-1]	200	Assumption: 0.2l/tree*a-1

Nursery: 2 years in seed bed (greenhouse), 2 years in transplant bed (field)			
Parameter	**Unit**	**Value**	**Source and remarks**
Irrigation (water) transplant bed	[m^3/ha*a-1]	35	Assumption: 5l/tree*a-1
Green house during seedling phase	[kWh/ha*a-1]	5,000	Calculated based on Energieagentur NRW 2009Energieagentur NRW 2009
Heat demand green house during seedling phase (provided by natural gas)	[kWh/ha*a-1]	5,000	Calculated based on Energieagentur NRW 2009 Energieagentur NRW 2009
Fertilizer application			
Ammonia sulfate fertilizer (N content 21%) (seed bed/transplant bed)	[kg/ha*a-1]	119/210	Calculated based on Baumgarten et al 2000, Matschke 2005
Rock phosphate fertilizer (P2O5 content 32%) (K2O content 60%)	[kg/ha*a-1]	31/31	Calculated based on Baumgarten et al 2000 Matschke 2005
Potassium fertilizer (K2O content 60%) (seed bed/transplant bed)	[kg/ha*a-1]	25/25	Calculated based on Baumgarten et al 2000, Matschke 2005
Calcium carbonate (CaCO3 content 50%) (seed bed/transplant bed)	[kg /ha*a-1]	30/30	Calculated based on Baumgarten et al 2000
Magnesia sulfate fertilizer (MgO content 28%) (seed bed/transplant bed)	[kg/ha*a-1]	9/9	Calculated based on Baumgarten et al 2000
Pesticide application			
Herbicide (active ingredient) (seed bed/transplant bed)	[kg/ha*a-1]	1.36/1.59	Neal 1999
Fungicide (active ingredient) (seed bed/transplant bed)	[kg/ha*a-1]	2.68/3.31	MHCREC 2008Neal 1999
Insecticide (active ingredient) (seed bed/transplant bed)	[kg/ha*a-1]	-	Neal 1999
Working operations			
Working steps in total (seed bed/transplant bed) thereof:	[amount/a]	4.5/ 8	Calculated based on KTBL 2006, MHCREC 2008KTBL 2006MHCREC 2008
Seed, transplant bed preparation	[amount/a]	0/½	Matschke 2005
Sowing/transplanting	[amount/a]	½ manual/ ½	Matschke 2005
Fertilizer application	[amount/a]	2 manual/ 2	Matschke 2005
Lime application	[amount/a]	0 / 1	Matschke 2005
Chemical Mowing Glyphosphate Application (41%) - (manual application)	[ounces/acre/a]	26	Hundley and Owen 2005
Diesel consumption for all working steps			
Diesel consumption (nursery/plantation)	[liter/ha*a-1]	0 / 20.5	Calculated based on KTBL 2006

Nursery: 2 years in seed bed (greenhouse), 2 years in transplant bed (field)			
Parameter	**Unit**	**Value**	**Source and remarks**
Foils and pots			
Packaging foil for one seedling for transport from seed bed to transplant bed (after 2 years)	[kg/piece]	0.002	Assumption
Plant pot for one transplant for transport from transplant bed to plantation (after 4 years)	[kg/piece]	0.125	Assumption

Table 8: Input Parameter for Modeling of Natural Tree Production in Plantation (Year 5 to Year 11)[3]

Plantation: 7 years			
Parameter	**Unit**	**Value**	**Source and remarks**
Trees per hectare planted	[amount]	4,000	Calculated based on Matschke 2005
Trees per hectare harvested from the plantation in total	[amount]	3,500	Calculated based on NCDA 1996
Water content of trees	[%]	40	FNR 2000
Energy content (Hu)	[MJ/kg dm]	18.8	FNR 2000
Energy content (Hu)	[MJ/kg fm]	10.3	Calculated based on FNR 2000
Carbon content biomass	[% dm]	49.7	FNR 2000
Nitrogen content biomass	[% dm]	1.0	FNR 2000
Fertilizer application			
Ammonia sulfate fertilizer (N content 21%) (seed bed/transplant bed)	[kg/ha*a-1]	191	Calculated based on Baumgarten et al 2000, Spectrum Analytic 2009
Rock phosphate fertilizer (P2O5 content 32%) (seed bed/transplant bed)	[kg/ha*a-1]	278	Calculated based on Baumgarten et al 2000, Spectrum Analytic 2009
Potassium fertilizer (potassium chloride, potassium sulfate, or potassium magnesium sulfate) (K2O content 60%) (seed bed/transplant bed)	[kg/ha*a-1]	150	Calculated based on Baumgarten et al 2000, Spectrum Analytic 2009
Calcium carbonate (CaCO3 content 50%) (seed bed/transplant bed)	[kg MgO/ha*a-1]	90	Calculated based on Baumgarten et al 2000
Magnesia sulfate fertilizer (MgO content 28%) (seed bed/transplant bed)	[Kg/tree*a-1]	27	Calculated based on Baumgarten et al 2000

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[3] It takes 7 years for a tree to grow in the field. The first four years seedlings are grown in a nursery. Therefore the growth of the tree in the field occurs during years 5 through 11 for a total of 7 years.

Plantation: 7 years			
Parameter	**Unit**	**Value**	**Source and remarks**
Pesticide application			
Herbicide (active ingredient (AI)) Glyphosphate	[kg/ha*a-1]	2.81	Calculated based on KUHNS 2004
Fungicide (active ingredient (AI)) Mancozeb	[kg/ha*a-1]	5.53	Calculated based on KUHNS 2004
Insecticide (active ingredient (AI))	[kg/ha*a-1]	-	Calculated based on KUHNS 2004
Working operations			
Working steps	[amount/a]	6.3	Calculated based on KTBL 2006, MHCREC 2008
Chemical Mowing Glyphosphate Application (41%) - (manual application)	[ounces/acre/a]	26	Hundley and Owen 2005
Fertilizing	[amount/a]	2	Calculated based on Matschke 2005
Pesticide application	[amount/a]	2	Calculated based on Matschke 2005
Plowing before cultivation period (once every seven years)	[amount/a]	0.14	Calculated based on Matschke 2005
Pre-plant site preparation (grubbing) before cultivation period (once every seven years)	[amount/a]	0.14	Calculated based on Matschke 2005
Diesel consumption for all working steps			
Diesel consumption	[liter/ha*a-1]	8.74	Calculated
Packaging			
Packaging string for one tree for transport from farm to retail location	[kg/piece]	0.0025	Assumption of the weight. Dataset: Polyethylene foil (PE-LD) Plastics Europe

3.2.1.6 Post harvest treatment at farm

The natural Christmas tree is further treated in post harvest processing. Pruning, reject, roots and other organic residues are assumed to be left on or nearby the field. A carbon neutral degradation is assumed for these components.

3.2.1.7 Baling

If desired by the wholesale buyer, trees are next packaged using a baling machine or by using a simple cone that trees are pulled through to constrict them for tying. Many large retail stores purchase their trees individually baled and therefore the process of baling trees with polypropylene string was included in the model. The impact of the polypropylene string (compatible with baling machines) is included in this study. For a natural tree, approximately 0.0086 kg of polypropylene string is used per tree (BTF WHOLESALE). The baled tree is now ready for transport to the retailer (as detailed in Section 3.2.2: Finished Tree to Home). A schematic of the system boundaries for the pre- and post- harvest treatment is shown in Figure 12.

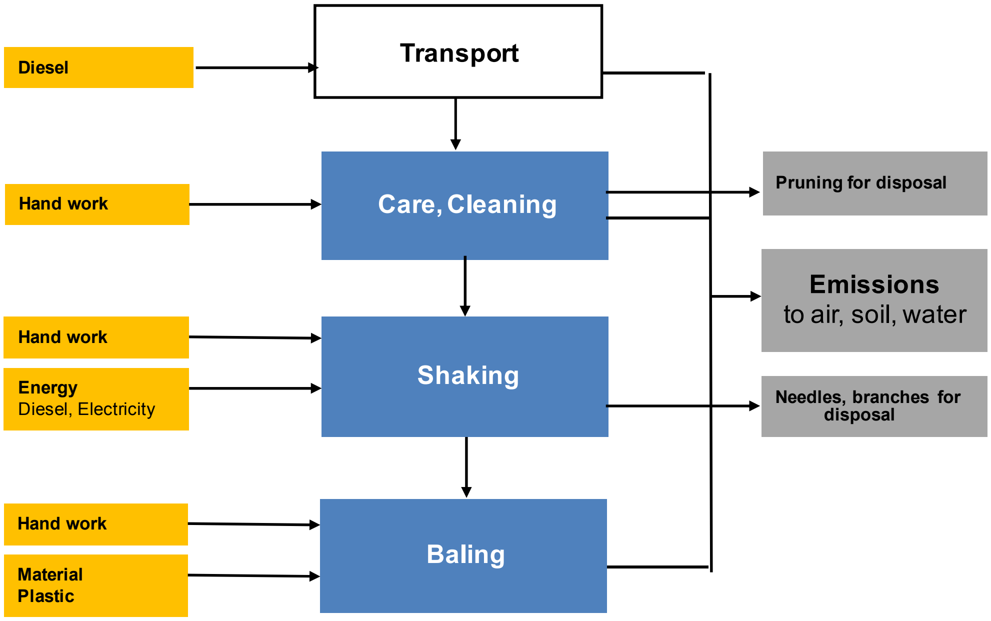

Figure 12: Pre and Post Harvest Treatment at Farm and Retailer during Production Phase

3.2.1.8 Carbon Uptake and Emissions During Cultivation

Field emissions of NH_3, NO_x, N_2, NO_3^-, CH_4, and N_2O gases from organic and mineral fertilizer degradation can be significant and have been assessed based on the methodology developed by BOUWMANN ET AL.1996, BRENTRUP ET AL. 2000, and IPCC 2006.

Carbon uptake by the crop (removing CO_2 from the atmosphere) is assessed to understand the carbon losses during post harvest and further processing. The carbon uptake is calculated by assuming a dry matter content of the whole tree of 40%, and the carbon content of dry matter is 49.7%. After multiplying the dry mass by the carbon content, it is multiplied by the molecular weight of carbon dioxide to obtain the total amount of carbon taken away from the field. The carbon losses associated with land use changes (e.g. forest clearance to produce agricultural land) have not been accounted for in this study, nor have the carbon which is stored in soil and litter been accounted for.

It was assumed that nitrate and phosphate levels in the soil are able to store the nutrients applied to field, so after accounting for nutrient uptake by crop and gaseous losses to atmosphere some parts of the remaining inputs are stored in the soil for the next cultivation phases.

Impacts associated with atmospheric deposition of nutrients plays an important role in eco systems and were considered in this assessment.

3.2.2 Finished Tree to Home

Trees are transported by truck to retailers, where they are unpacked, and sorted according to species, height, and quality. In all cases, shipment packaging materials that are removed at the retailer are assumed to be disposed of at a landfill. From the retailer, the tree is assumed to be purchased by a consumer utilizing a car to bring the tree to his/her home.

Note that operation of the retail store is out of the scope of this analysis. Although it is likely that some natural trees will go unsold at the end of the year, there is no documentation referring to the quantity of natural trees that go unsold. Therefore, as with the artificial tree model, it is assumed that there is a 0% loss rate of natural trees. This conservative assumption implies that retailers either perfectly predict consumer demand or else run out of trees before Christmas, given that shoppers do not buy natural trees after Christmas. If there is a loss rate, the amount of trees needed for each tree sold increases, and consequently the natural tree environmental impacts will increase. In other words, with a 10% loss rate of natural trees, the impacts upstream of the retailer will be increased by 10%.

Additionally, some retailers offer to bale trees for transport to the consumer's home. If the trees are re-bailed at the retailer for transport home, assuming the same polypropylene bailer string used at the farm, the same impacts associated with this step during cultivation (refer to Section 4.9.2), should be added to this phase as well. Some natural trees are never baled, some are baled either en route to the retailer or to the consumer, but not both, and some are baled for both transportation phases. As such, the natural tree model used here assumes a single baling step, and accounts for this in the cultivation phase only.

3.2.3 Use Phase

During the use phase, the customer fixes the tree in a tree stand. The tree stand is modeled to have a lifetime of 10 years, an average weight of 2.04 kg (FKF 2008, type Cynco C-144) consisting of 90% plastic and 10% metal (mainly screws). During the use phase (18 days assumed), it was estimated that the tree will take up 1.5 gallons of water in the first 24 hours, and 3.5 quarts a day after that (HINESLEY AND CHASTAGNER 2002). Over the entire use phase, based on this estimate, a total of 62 liters of water is consumed; the water is assumed to evaporate to air. A summary of input parameters during the use phase is found in Table 9.

Note that the use of lights and ornaments are excluded from this study.

Table 9: Input Parameter for Modeling of Use Phase of Natural Christmas Tree

Parameter	Unit	Value	Source
Lifespan tree stand	[a]	10	Assumption
Weight tree stand	[kg]	2.04	Based on FKF 2008
Ratio plastic of total tree stand	[% weight]	90	Acrylnitril-Butadien-Styrol granulate mix (ABS) PE Gabi database
Ratio metal of total tree stand	[% weight]	10	Sheet steel 0,75mm BVZ (0,03mm; 1s) PE GaBi database

3.2.4 End-of-Life

All intermediate wastes at the farm (organics), packaging wastes (string), and product waste (tree stand) are assumed to be transported to a municipal landfill by a dump truck and disposed of. All landfill processes in the model are material specific and include energy recovery from methane production.

The End-of-Life treatment (landfill, incineration, compost, etc.) of the average American natural tree is not well documented. Although it is suspected that most trees are collected through municipal programs, at the time of this study there was no definitive literature available on this topic. The choice of End-of-Life treatment for each natural tree affects how much of the carbon is sequestered during the tree's cultivation is re-released to the environment. As a result, the choice of End-of-Life treatment for the natural tree has a significant impact on the comparison between artificial and natural trees. For instance, incineration releases most of the stored carbon during the burning process. Conversely, US landfills release only 33% of the carbon input (EPA 2006); the rest remains sequestered in the landfill for more than 100 years (the time horizon of GWP for this study). Municipal composting releases approximately 50% of the carbon input as CO_2 and CH_4 while the other 50% remains sequestered in the biomass.

Because of the wide range of impacts, three End-of-Life scenarios are considered:

A. 100% Landfilling of Natural Tree

B. 100% Incineration of Natural Tree

C. 100% Composting of the Natural Tree

The End-of-Life model for natural tree disposal is based on the chemical composition of a natural tree. It was assumed that the tree itself loses ten percent of its wet mass during the end-of-life phase; this reduction in mass is due to loss of water through evaporation, particularly when the tree dehydrates after it is taken outside for disposal. The water content of the naturally dehydrated tree when disposed is 54%. The US landfill, US incineration, and US municipal composting process models were adjusted to match this tree composition. The composition of the natural tree is based on the Phyllis database (ECN 2009) data for the average composition of untreated wood of fir/pine/spruce trees including the trees' wood, bark and needles. All End-of-Life models reflect this composition summarized in Table 10.

Table 10: Natural Tree Composition

Variable Description	Value Used	
Density of Waste	830	[kg/m3] range: 800-1200, default 1050
Water Content	0.54	[frac] water content of waste
Dry Fraction	0.46	[frac] dry matter of waste
Carbon Content of the Dry Waste	0.526	[kg/kg] C content of waste
Oxygen Content of the Dry Waste	0.406	[kg/kg] O content of waste
Hydrogen Content of the Dry Waste	0.0611	[kg/kg] H content of waste
Nitrogen Content of the Dry Waste	0.0094	[kg/kg] N content of waste
Potassium Content of the Dry Waste	0.001991	[kg/kg] K content of waste
Sodium Content of the Dry Waste	0.000357	[kg/kg] Na content of waste
Sulfur Content of the Dry Waste	0.0003	[kg/kg] S content of waste
Chlorine Content of the Dry Waste	0.00006	[kg/kg] Cl content of waste

It was estimated that transportation by dump truck to the municipal landfill, incinerator, and composting facility is 20 miles (EPA 2009B). End-of-Life system boundaries are illustrated in Figure 13. Energy credits from End-of-Life disposal processes were considered and are described in Table 11.

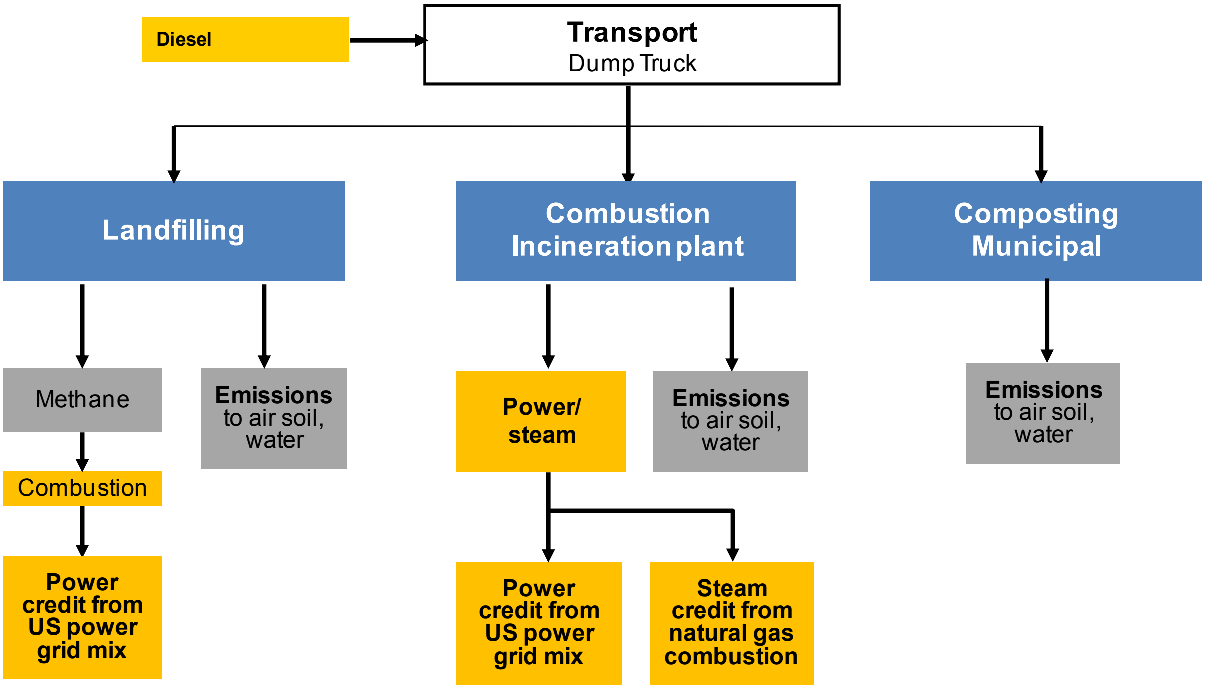

Figure 13: System Boundaries for End-of-Life Phase

Table 11: Assumptions for End-of-Life Phase

Scenario	Parameter	Value
A	Trees deposited in landfill - Electricity production by methane combustion in a combustion plant treated as a replacement of electricity supplied by US power mix.	100%
B	Trees deposited in municipal waste incineration plant - Electricity and steam production by waste combustion treated as a replacement of electricity supplied by US power mix and steam produced by natural gas combustion.	100%
C	Trees deposited in municipal compost - no energy credits are received.	100%

3.2.4.1 US Landfill Boundary Conditions

For the 100% landfill scenario, the US landfill model was adjusted to reflect the disposal of a natural Christmas tree. Adjustments are made based on the EPA 2006 document; the key landfill parameters are summarized in Table 12.

Table 12: US Landfill Boundary Conditions

Variable Description	Value Used	
Period of Landfill Operation	100	[years]
Fraction of Carbon Sequestered in 100-year period	0.77	[fraction]
Optimization factor, considering real conditions to optimal conditions (default=0,7, ideal=1)	0.7	[fraction]
System-related gas intake ratio, default=0,8 (range 0-1)	0.9	[fraction]
Share of landfill gas to flare	0.28	[fraction]
Share of landfill gas to usage	0.31	[fraction]

3.2.4.2 US Incineration Boundary Conditions

For the 100% incineration scenario, the US Incineration model was adjusted to reflect the natural Christmas tree.

The incineration model calculates waste energy capture through generation of electricity and steam with 15% losses in the generator. When produced, electricity and steam are first used to meet internal needs at the incinerator, and the remaining energy is returned to the market (2.875 MJ steam/kg waste; 0.227 MJ electricity/kg waste). In the United States, 62.7% of waste incineration is waste to energy (WTE), 19.6% is WTE with cogeneration, and 17.7% produces only steam (EIA 1997). Therefore energy credit is received at 82.3% of the plants, and steam credit is received at 37.3% of the plants. Or in other words, 82.3% of the electricity produced at incineration receives energy credit, and 37.3% of the steam produced by incineration receives energy credit. The key incineration parameters are summarized in Table 12.

Table 13: US Incineration Boundary Conditions

Variable Description	Value Used	
Generator Efficiency	0.85	[fraction, 0.8 to 1]
Steam Energy Produced	2.875	[MJ/kg waste]
Electric Energy Produced	0.227	[MJ/kg waste]
Steam Energy Credit (%)	37.3	[%]
Electric Energy Credit (%)	82.3	[%]
Steam Energy Credit	1.072	[MJ/kg waste]
Electric Energy Credit	0.187	[MJ/kg waste]

3.2.4.3 US Composting Boundary Conditions

For the 100% composting scenario, the US composting model was adjusted to reflect the natural Christmas tree. The key composting parameters are summarized in Table 14.

Table 14: US Composting Boundary Conditions

Variable Description	Value Used	
Fraction of C Sequestered During Composting	0.5	[fraction]
Nitrogen Loss	0.005	[kg/kg] nitrogen losses per kg N input
Methane - Carbon Dioxide Ratio	0.1	[fraction] ratio of CH4 to CO2

3.2.5 Transport of Natural Tree

All truck transportation within the United States was modeled using the GaBi 4 US truck transportation datasets. For transport modeling details refer to Section 2.6.3.

The transportation distances during the natural tree life cycle are not well known but are based on educated assumptions and default values. Based on 2007 transportation data for the United States Bureau of Transportation Statistics (BTS 2008), farm product raw material for merchant wholesalers travel 130 miles per shipment; this distance is used to approximate the truck transport from farm to retailer. The transport from point of waste disposal to End-of-Life treatment (landfill) is assumed to be 20 miles, consistent with the default values used in EPA's WARM Model (EPA 2009b).

It is assumed that the round trip distance traveled from the end customer to retailer is 5 miles. This is consistent with a survey done by the American Christmas Tree Association that found approximately 40% of consumers drive less than 5 miles round trip to purchase their trees. Additionally, the US Federal Highway Administration's National Household Travel Survey states that the average distance driven for any type of shopping is 6.7 miles (USDOE 2001). However, because this distance may vary significantly by consumer, a sensitivity analysis was completed as detailed in Section 5: Sensitivity and Break Even Analysis.

The transportation distances used in the natural tree model are summarized in Table 15.

Table 15: Assumptions for Natural Tree Transport Distances

From - To	Unit	Value
Seed production area to nursery	[mi]	60
Seed bed to transplant bed	[mi]	15
Nursery to plantation	[mi]	15
Plantation to farm	[mi]	2
Farm to retailer	[mi]	130
End customer to retailer and back home	[mi]	5
Waste products to landfill	[mi]	20
Natural Tree to Landfill	[mi]	20
Natural Tree to Municipal Incinerator	[mi]	20
Natural Tree to Municipal Compost	[mi]	20

4 RESULT ANALYSIS

Environmental indicators are calculated for the artificial tree and compared to the natural tree for three scenarios:

- **1-year:** Assuming the artificial tree is only used for one year, the comparative natural tree scenario is the use of one natural tree for one year.
- **5-year:** Assuming the artificial tree is used for five years before disposal, the comparative natural tree scenario is the purchase of a new natural tree every year for five years, or in total, five natural trees over five years.
- **10-year:** Assuming the artificial tree is used for ten years before disposal, the comparative scenario is the purchase of a new natural tree every year for ten years, or in total, ten natural trees over ten years.

The environmental metrics analyzed in this study include: Primary Energy Demand from Non-Renewable Resources, and the US EPA TRACI indicators: Global Warming Potential, Eutrophication Potential, Acidification Potential and Smog Potential.

A breakdown of results by life cycle stage for each impact category is summarized in this report for the artificial tree and for the 1-year scenario of the natural tree. The 5-year and 10-year natural tree scenarios are scaled from the 1-year baseline, such that relative impacts will be consistent between the three natural tree scenarios This is because in the case of the natural tree a full tree life cycle is required each year, whereas for the artificial tree, only the use phase is repeated, and the use phase of this tree has no environmental impacts. Results are presented in Sections 4.4 through 4.8.

Additionally, the impacts of the artificial and natural tree are described in detail in Sections 0 and 4.10. In particular, to better understand their significant contributions to the overall product environmental burden, the impacts for the tree manufacturing/cultivation and the transportation of both the artificial tree and the natural tree are detailed.

4.1 General Considerations

When comparing the artificial tree to the natural tree during the “Finished Tree to Home” phase, it should be remembered that this phase includes the disposal of secondary packaging at the retail location, and not simply transportation. The use phase also contains the disposal of packaging by the user for both trees, as well as water consumption and disposal of the tree stand for the natural tree. End-of-Life represents the associated landfill, incineration and compositing of each tree upon its disposal.

4.2 End-Of-Life Considerations

In the absence of data regarding the natural Christmas tree’s typical End-of-Life pathway in the United States, the LCI results are presented for three Natural Tree End-of-Life scenarios:

A. 100% Landfill;

B. 100% Incineration; and

C. 100% Compost.

In the case of biomass products such as fir trees, the choice of End-of-Life is important. The natural tree End-of-Life scenario chosen impacts the overall life cycle results significantly. The magnitude of the impact varies across environmental impact categories. Further, the significance of End-of-Life to the overall LCA results varies. This is because the degradation of the biomass and resulting release or sequestration of stored carbon and nitrogen vary significantly between a landfill, incineration plant and composting facility. Additionally, energy credits are given for burning of landfill gasses and generation of electricity and steam at the incineration plant, further complicating the results. In each of the following sections, discussion is provided explaining the results for all three End-of-Life scenarios for each particular environmental impact category.

4.3 Summary of Results

A summary of results is found in Table 16; the tables shows that the overall impact of one artificial tree used for only one year is always greater than the overall impact of one natural tree used for one year, irrespective of the End-of-Life scenario. In some cases, the natural tree life cycle overall is a global warming or eutrophication sink (highlighted in grey within Table 16). In this table “Full LCA” refers to the fact that the impacts associated with cultivation/manufacturing, transportation, use and end of life treatment are included. In the following sections, the breakdown of results by impact category and life cycle stage are detailed.[4]

Table 16: Life cycle impact of artificial and natural trees used for one year prior to disposal

Impact Category	Units	Artificial Tree Full LCA	Natural Tree - Full LCA		
			Landfill	Incineration	Composting
Primary Energy Demand (PED) - Non Renewable	MJ	305.21	93.35	50.61	67.70
Acidification Potential (AP)	mol H+ Equiv.	6.15	0.94	1.09	0.75
Eutrophication Potential (EP)	kg N-Equiv.	4.62E-03	3.97E-03	-1.68E-03	-2.18E-03
Global Warming Potential (GWP)	kg CO2-Equiv.	18.58	-3.13	5.12	4.68
Smog Potential	kg NOx-Equiv.	6.16E-05	1.15E-05	1.86E-05	8.48E-06

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[4] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

4.4 Primary Energy Demand from Non-Renewable Resources

Primary energy demand (PED) is a measure of the total amount of primary energy associated with the product. This is a measure of both the "feedstock energy" within the product (energy which would be released upon combustion) plus all other energy used during the product lifecycle. PED can be 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. From an environmental standpoint, the energy demand for non-renewable resources is more important than the total primary energy demand which includes renewable resources. Therefore the following graphs are provided to show the details of the primary energy demand specifically associated with non-renewable resources. The values presented represent the net caloric value.

The main difference between the PED (renewable and non-renewable) and PED (non-renewable only) is that the cultivation of the natural tree uses a lot of renewable energy from the sun, whereas the artificial tree manufacturing only uses the renewable energy that is part of the Chinese grid mix. Because the renewable energy from the sun is not a limited source, here we only consider the non-renewable energy demand for both the artificial and the natural tree products.

A comparison of the total primary energy demand (non-renewable) of the natural vs. artificial Christmas tree is shown in Table 17 and Figure 14. Details specific to choice of natural tree End-of-Life scenarios are detailed in the following subsections.

The non-renewable PED for the artificial tree is primarily associated with the manufacturing phase (77%), with noticeable contributions during the life cycle phase: Finished Tree to Home (18%). The Use and End-of-Life (disposal in a landfill) contribute 0.5% and 4.5% of the PED impact, respectively. The impacts are detailed further in Sections 4.9.1 and 4.10.1.

The non-renewable PED for the natural tree is primarily associated with the manufacturing/cultivation phase. Cultivation accounts for between 30% and 60% of the PED impact and Finished Tree to Home impacts range from 49% to 72% of the PED impact, depending on the End-of-Life scenario. The impacts are detailed further in Sections 4.9.2 and 4.10.2.

Table 17: PED (Non-Renewable) of Artificial vs. Natural Christmas Tree by Life Cycle Stage

		Primary Energy Demand, Non-Renewable (MJ)				
		Total	Manufacturing / Cultivation	Finished Tree to Home	Use[5]	End of Life
	Artificial Tree	305	234	56	2	14
Natural Tree 1-year	Landfill	93	30	36	1	26
	Incineration	51	30	36	1	-16
	Composting	68	30	36	1	1
Natural Tree 5-year	Landfill	467	149	181	4	132
	Incineration	253	149	181	4	-81
	Composting	338	149	181	4	4
Natural Tree 10-year	Landfill	934	297	363	9	265
	Incineration	506	297	363	9	-163
	Composting	677	297	363	9	8

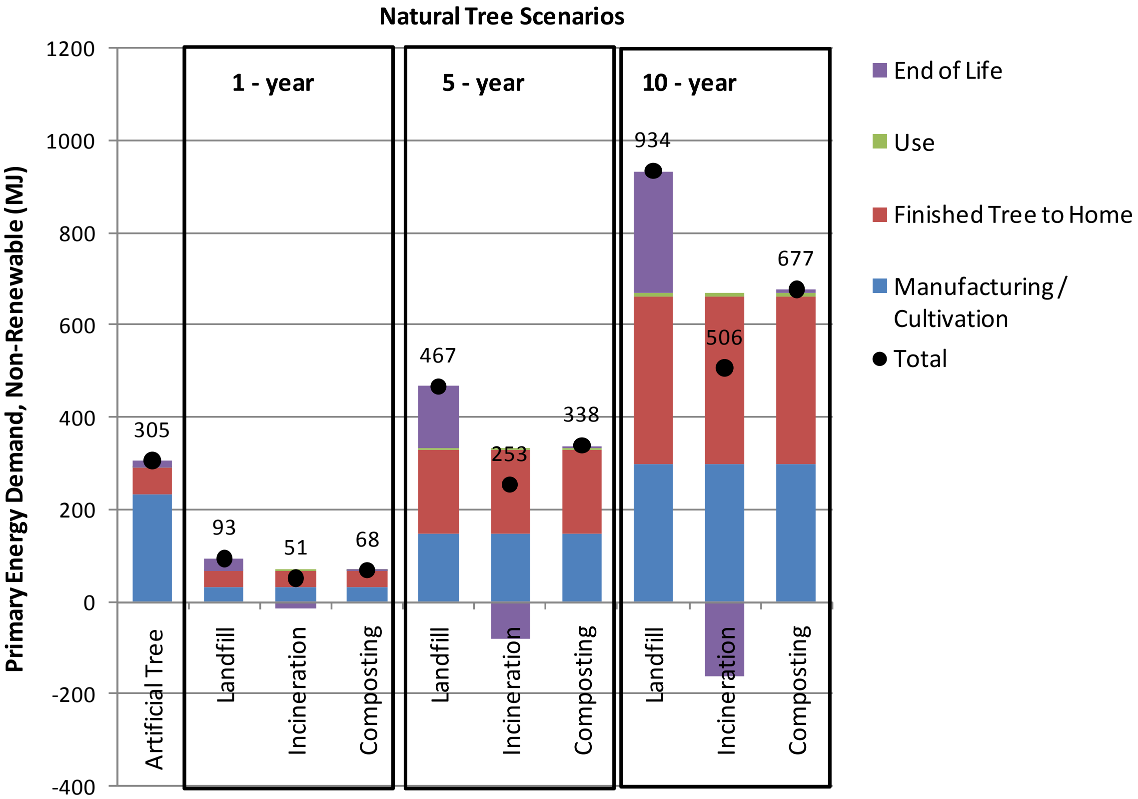

Figure 14: PED (Non-Renewable) of Artificial vs. Natural Christmas Tree by Life Cycle Stage

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[5] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

4.4.1 End-of-Life Scenario A. 100% Landfill

The artificial tree, used for only one year, when compared to a natural tree that is landfilled, requires roughly 3 times the non-renewable PED (Table 17). However, when an artificial tree is kept for five years, the non-renewable PED impact of a natural tree purchased every year is approximately 1.5 times greater (Figure 14). In 10 years, the non-renewable PED of a natural tree is 3 times greater than that of a single reused artificial tree.

The PED impact of landfilling the natural tree is associated with the energy (thermal and electric, 56%) required to operate the landfill and the surface sealing process (26%). The PED credit received for producing electricity from landfill gas offsets approximately 19% of the landfill PED. The overall PED for landfill at End-of-Life is positive and contributes roughly 28% of the overall life cycle of the natural tree; although there is energy credit received for the capture and burning of landfill gas, this energy credit does not exceed the PED associated with landfilling the natural tree.

4.4.2 End-of-Life Scenario B. 100% Incineration

The artificial tree, used for only one year, when compared to a natural tree that is incinerated, requires roughly 6 times the non-renewable PED (Table 17). When an artificial tree is kept for ten years, the non-renewable PED impact of the natural tree purchased every year is roughly 3 times the impact of a single reused artificial tree (Figure 14).

The PED for incineration is negative because the amount of energy credit received (in the form of electricity and steam) for the combustion of the Christmas tree is greater than the energy required to run the municipal incinerator. The PED required to operate the incinerator is attributed to energy (71%) and ammonia (19%). The PED credit from steam and electricity generation is 3.6 times greater than the PED required to operate the facility. In other words, the energy credit outweighs the impacts from incineration of the natural tree at End-of-Life. However, the energy credit is not large enough to offset the natural tree’s PED impacts across its life cycle.

4.4.3 End-of-Life Scenario C. 100% Compost

The artificial tree, used for only one year, when compared to a natural tree that is composted, requires roughly 4.5 times the non-renewable PED (Table 17). However, in 10 years, the non-renewable PED of a natural tree is more than double that of a single reused artificial tree (Figure 14).

There is no PED credit given for composting; the composting process is primarily passive and therefore the magnitude of End-of-Life impact is small. The overall PED impact from the End-of-Life phase is attributed primarily to transport to the composting facility (78%) and diesel used during composting (22%).

4.5 Global Warming Potential (GWP)/ Carbon Footprint

GWP is a measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.

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

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically include carbon dioxide, methane and CFCs. A weighted sum of these greenhouse gas emissions is used to calculate global warming potential, also referred to as a carbon footprint.

A comparison of the total Global Warming Potential (GWP) or "Carbon Footprint" of the natural vs. artificial Christmas tree is shown in Table 18 and Figure 15. Details specific to choice of natural tree End-of-Life scenarios are detailed in the following subsections.

Table 18: GWP of Artificial vs. Natural Christmas Tree by Life Cycle Stages

		Global Warming Potential, GWP (kg CO2 equiv.)				
		Total	Manufacturing / Cultivation	Finished Tree to Home	Use[6]	End of Life
	Artificial Tree	18.58	12.51	4.22	0.88	0.98
Natural Tree 1- year	Landfill	-3.13	-9.13	2.68	0.06	3.26
	Incineration	5.12	-9.13	2.68	0.06	11.51
	Composting	4.68	-9.13	2.68	0.06	11.07
Natural Tree 5-year	Landfill	-15.64	-45.65	13.39	0.32	16.31
	Incineration	25.59	-45.65	13.39	0.32	57.53
	Composting	23.41	-45.65	13.39	0.32	55.35
Natural Tree 10-year	Landfill	-31.27	-91.30	26.79	0.63	32.61
	Incineration	51.18	-91.30	26.79	0.63	115.06
	Composting	46.82	-91.30	26.79	0.63	110.70

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[6] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

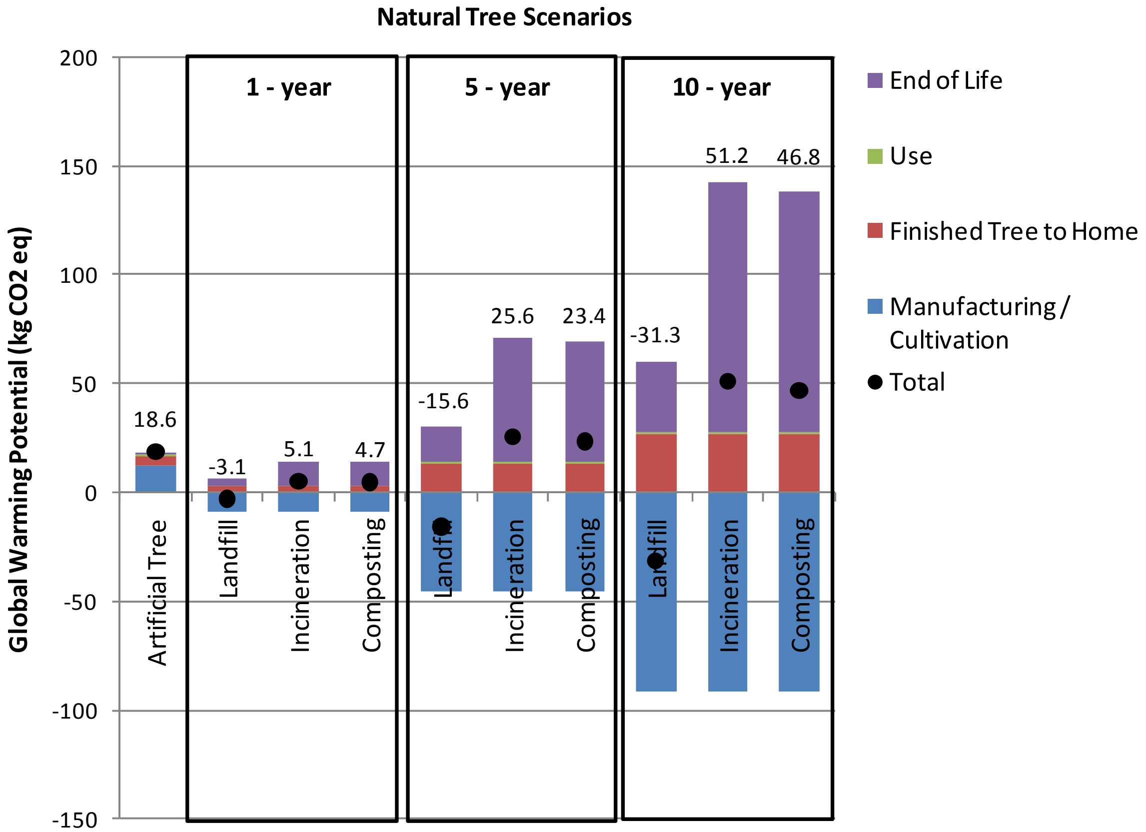

Figure 15: GWP of Artificial vs. Natural Tree by Life Cycle Stage

As discussed in Section 4.2, the various End-of-Life options release varying amounts of stored carbon in the natural tree. What is not released remains sequestered. Intuitively, the more carbon that remains sequestered at the End-of-Life, the lesser the overall global warming potential of the natural tree.

As seen in Figure 15, because 77% of carbon input into a US landfill remains sequestered in the landfill for more than 100 years (EPA 2006) the 100% landfill option has the lowest GWP burden for the natural tree. Additionally, the landfill option gets an energy credit from energy produced from the captured landfill gases (59% of total landfill gases). The incineration process releases most of the stored carbon in the biomass during burning; however, the energy credit from produced steam and electricity is significant offsetting some of the GWP burden. The 100% composting option releases 50% of the stored carbon as CO_2 (96% by mass) and CH_4 (4% by mass). The rest of the carbon is stored in the compost and will be decomposed during the following years in the soil. Composting has similar impacts to the incineration End-of-Life option.

4.5.1 End-of-Life Scenario A. 100% Landfill

The GWP impact of a natural tree that is landfilled is always negative; therefore from a GWP perspective, a natural tree that is landfilled is always environmentally preferable to an artificial tree (Table 18).

During cultivation, the natural tree sequesters carbon and stores it in the tree's biomass. When the tree is landfilled, only 23% of the stored carbon is released; the remaining 77% is sequestered in the landfill for more than 100 years (EPA 2006). In addition to the release of stored carbon, there is some positive GWP impact of landfilling the natural tree associated with the energy (thermal and electric, 31%) required to operate the landfill, and various landfill processes: surface sealing (15%), waste disposal (14%), landfill body (14%), landfill gas flare (12%), and landfill gas CHP (10%). A GWP credit is received for producing electricity from landfill gas, which offsets approximately 11% of the GWP emissions. In this case, the GWP impact from End-of-Life, Use, and Finished Tree to Home life cycle phases are not greater than the GWP benefit of growing the natural tree. Therefore, the overall life cycle of the landfilled natural tree has a net negative GWP impact.

4.5.2 End-of-Life Scenario B. 100% Incineration

The artificial tree, used for only one year, when compared to a natural tree that is incinerated, results in roughly 3.6 times more GWP (Table 18). However, when an artificial tree is kept for five years, the GWP impact of a natural tree purchased every year is approximately 1.4 times greater (Figure 15). In 10 years, the GWP of a natural tree is 2.8 times that of a single reused artificial tree.

The GWP impact of incinerating the natural tree is significant to the overall GWP impact of the incinerated natural tree. The GWP for incineration is attributed to the emissions from the boiler (95%). The GWP credit received for producing electricity and steam offsets roughly 14% of the GWP emissions.

Although there is a GWP credit received for offsetting steam and electricity generated using fossil fuels, the credit is not greater than the GWP impact of burning the tree at the incinerator. Therefore the incineration End-of-Life contributes to the overall GWP of the tree. In this case, the GWP impact from End-of-Life, Use, and Finished Tree to Home life cycle phases are greater than the GWP benefit of growing the natural tree. Therefore the overall life cycle of the incinerated natural tree contributes to GWP.

4.5.3 End-of-Life Scenario C. 100% Compost

The artificial tree, used for only one year, when compared to a natural tree that is composted, results in roughly 4 times more GWP (Table 18). However, when an artificial tree is kept for five years, the non-renewable PED impact of a natural tree purchased every year is approximately 1.3 times greater (Figure 15). In 10 years, the non-renewable PED of a natural tree is 2.5 times that of a single reused artificial tree.

The GWP associated with End-of-Life is a result of the degradation of the biomass during composting. There is no energy credit for composting. In this case, the GWP impact from End-of-Life, Use, and Finished Tree to Home life cycle phases are greater than the GWP benefit of growing the natural tree. Therefore the overall life cycle of the composted natural tree contributes to GWP.

4.6 Air Acidification Potential (Acid Rain Potential)

Air acidification potential is a measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight.

The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulfur dioxide and nitrogen oxide and their respective acids (H_2SO_4 and HNO_3) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact. Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). Buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate. When analyzing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary.

A comparison of the total acidification potential (AP) of the natural vs. artificial Christmas tree is shown in Table 19 and Figure 16. Details specific to choice of natural tree End-of-Life scenarios are detailed in the following subsections.

The AP for the artificial tree is primarily associated with the manufacturing phase (62%), with noticeable contributions during the life cycle phase: Finished Tree to Home (36%). The Use phase has a negligible AP impact and End-of-Life (disposal in a landfill) contributes 2% of the PED impact. The impacts are detailed further in Sections 4.9.1 and 4.10.1.

The AP for the natural tree is primarily associated with the manufacturing/cultivation phase. Cultivation accounts for between 32% and 59% of the PED impact. Finished Tree to Home PED impacts range from 18% to 26%, depending on the End-of-Life scenario chosen. The impacts are detailed further in Sections 4.9.2 and 4.10.2.

Table 19: AP of Artificial vs. Natural Christmas Tree by Life Cycle Stage

		Total	Manufacturing / Cultivation	Finished Tree to Home	Use[7]	End of Life
	Artificial Tree	6.15	3.82	2.19	0.01	0.14
Natural Tree 1- year	Landfill	0.94	0.51	0.19	0.01	0.23
	Incineration	1.09	0.51	0.19	0.01	0.38
	Composting	0.75	0.51	0.19	0.01	0.04
Natural Tree 5-year	Landfill	4.70	2.53	0.95	0.04	1.17
	Incineration	5.43	2.53	0.95	0.04	1.90
	Composting	3.73	2.53	0.95	0.04	0.20
Natural Tree 10-year	Landfill	9.39	5.05	1.91	0.09	2.35
	Incineration	10.86	5.05	1.91	0.09	3.81
	Composting	7.46	5.05	1.91	0.09	0.41

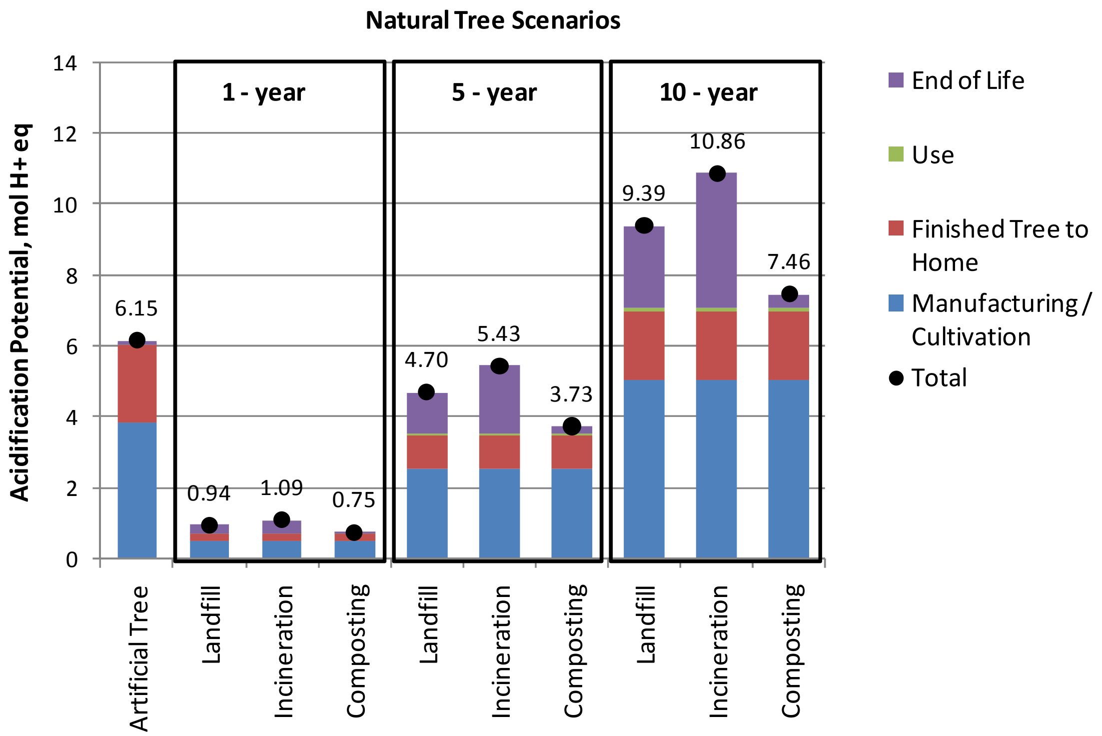

Figure 16: AP of Artificial vs. Natural Christmas Tree by Life Cycle Stage

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[7] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

4.6.1 End-of-Life Scenario A. 100% Landfill

The artificial tree, used for only one year, when compared to a natural tree that is landfilled, results in roughly 6.5 times more AP (Table 19). However, when an artificial tree is kept for ten years, the AP impact of a natural tree purchased every year is approximately 1.5 times greater (Figure 16).

The acidification impact of landfilling the natural tree is 25% of the overall AP impact of the landfilled natural tree. The AP for landfilling is associated with the surface sealing process (37%) and the energy (thermal and electric, 37%) required to operate the landfill. The AP credit received for producing electricity from landfill gas offsets approximately 36% of the AP emissions.

4.6.2 End-of-Life Scenario B. 100% Incineration

The artificial tree, used for only one year, when compared to a natural tree that is incinerated, results in roughly 5.6 times more AP (Table 19). In 10 years, the AP of a natural tree is 1.8 times that of a single reused artificial tree (Figure 16).

The acidification impact of incinerating the natural tree is 35% of the overall AP impact of the incinerated natural tree. 89% of the AC impact is attributed to emissions from the boiler. The AP credit received for producing electricity and steam offsets roughly 40% of the AP emissions.

4.6.3 End-of-Life Scenario C. 100% Compost

The artificial tree, used for only one year, when compared to a natural tree that is composted, results in roughly 8 times more AP (Table 19). In 10 years, the AP of a natural tree is 1.2 times that of a single reused artificial tree (Figure 16).

The acidification impact of composting the natural tree is small, and only contributes 5.5% of the overall AP impact of the composted natural tree.

4.7 Eutrophication Potential

Excessive nutrient input into water and land from substances such as phosphorus and nitrogen from agriculture, combustion processes and effluents.

Eutrophication is caused by excessive nutrient inputs, and can be aquatic or terrestrial. Air pollutants, waste water and fertilization in agriculture all contribute to eutrophication. The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition in the absence of oxygen). Hydrogen sulfide and methane are thereby produced. This can lead to the destruction of the eco-system. On eutrophied soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the eutrophication level exceeds the *amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water and can cause methemoglobinemia or "blue baby syndrome".*

A comparison of the total Eutrophication Potential (EP) of the natural vs. artificial Christmas tree is shown in Table 20 and Figure 17. Details specific to choice of natural tree End-of-Life scenarios are detailed in the following subsections.

The EP for the artificial tree is primarily associated with the manufacturing phase (61%), with noticeable contributions during the life cycle phase: Finished Tree to Home (28%). The Use phase and End-of-Life (disposal in a landfill) contribute 9% and 2% of the ED impact, respectively. The impacts are detailed further in Sections 4.9.1 and 4.10.1.

The cultivation phase of the natural Christmas tree has a negative eutrophication potential. This is because during cultivation, the tree absorbs nitrogen and acts as a nitrogen sink (similar to how the growth of the tree is a carbon sink). The impacts associated with the other three life cycle stages contribute to eutrophication potential; however, the contributions from Finished Tree to Home and Use phases are relatively small. As is discussed below, the overall EP of the natural tree depends heavily on whether the end of life has a small or large EP potential. The impacts are detailed further in Sections 4.9.2 and 4.10.2.

Table 20: EP of Artificial vs. Natural Christmas Tree by Life Cycle Stage

		Eutrophication Potential, EP (kg N equiv.)				
		Total	**Manufacturing / Cultivation**	**Finished Tree to Home**	**Use[8]**	**End of Life**
	Artificial Tree	4.62E-03	2.84E-03	1.30E-03	4.10E-04	7.88E-05
Natural Tree 1- year	Landfill	3.97E-03	-2.37E-03	1.38E-04	5.19E-06	6.19E-03
	Incineration	-1.68E-03	-2.37E-03	1.38E-04	5.19E-06	5.47E-04
	Composting	-2.18E-03	-2.37E-03	1.38E-04	5.19E-06	4.82E-05
Natural Tree 5-year	Landfill	1.99E-02	-1.18E-02	6.89E-04	2.60E-05	3.10E-02
	Incineration	-8.38E-03	-1.18E-02	6.89E-04	2.60E-05	2.74E-03
	Composting	-1.09E-02	-1.18E-02	6.89E-04	2.60E-05	2.41E-04
Natural Tree 10-year	Landfill	3.97E-02	-2.37E-02	1.38E-03	5.19E-05	6.19E-02
	Incineration	-1.68E-02	-2.37E-02	1.38E-03	5.19E-05	5.47E-03
	Composting	-2.18E-02	-2.37E-02	1.38E-03	5.19E-05	4.82E-04

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[8] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

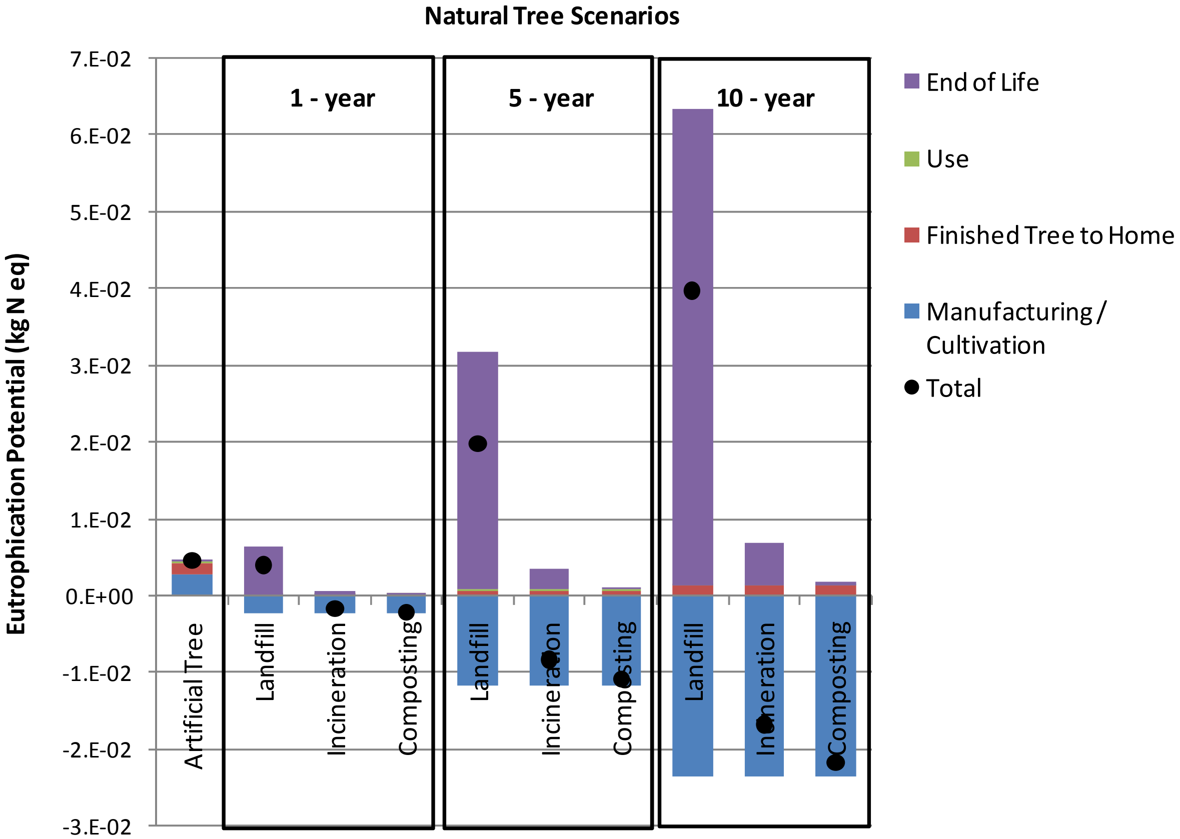

Figure 17: EP of Artificial vs. Natural Tree by Life Cycle Stage

4.7.1 End-of-Life Scenario A. 100% Landfill

The artificial tree, used for only one year, when compared to a natural tree that is landfilled, results in roughly 1.6 times more EP (Table 20). However, when an artificial tree is kept for five or ten years, the EP impact of a natural tree purchased every year is approximately 4.3 and 8.6 times greater, respectively (Figure 17).

The high eutrophication from the landfill is primarily due to high ammonia flows into fresh water from the leachate treatment at the landfill. The EP credit received for producing electricity from landfill gas is small, <1% of the EP that results from the landfill process. The eutrophication at end of life is greater than the EP credit (from nitrogen uptake) during cultivation. Therefore the landfilled natural tree has an impact associated with EP.

4.7.2 End-of-Life Scenario B. 100% Incineration

The EP from incineration is associated with the boiler stack emissions (89%). The EP credit received for producing electricity and steam offsets roughly 12% of the EP emissions.

When the natural tree is incinerated, the contributions to EP from the Finished Tree to Home, Use and End-of-Life phases is less than the EP absorbed from cultivating the natural tree. In other words, the overall EP life cycle is negative, and for a natural tree that is incinerated under the stated conditions, there is a point where the artificial tree will have a smaller EP impact.

4.7.3 End-of-Life Scenario C. 100% Compost

When the natural tree is composted, the contributions to EP from the Finished Tree to Home, Use and End-of-Life phases is less than the EP absorbed from cultivating the natural tree. In other words, the overall EP life cycle is negative, and for a natural tree that is composted under the stated conditions, there is point where the artificial tree will have a smaller EP impact.

4.8 Smog Potential

A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and volatile organic compounds (VOCs) under the influence of UV light.

Despite playing a protective role in the stratosphere, at ground-level, ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans. Radiation from the sun and the presence of nitrogen oxides and hydrocarbons incur complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides (NO_x) alone do not cause high ozone concentration levels.

Hydrocarbon emissions occur from incomplete combustion, in conjunction with gasoline (storage, turnover, refueling etc.) or from solvents. High concentrations of ozone arise when the temperature is high, humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons. Today it is assumed that the existence of NOx and CO reduces the accumulated ozone to NO_2, CO_2 and O_2. This means that high concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less NOx and CO. When analyzing, it's important to remember that the actual ozone concentration is strongly influenced by the weather and other local conditions.

A comparison of the total smog potential of the natural vs. artificial Christmas tree is shown in Table 21 and Figure 18. Details specific to choice of natural tree End-of-Life scenarios are detailed in the following subsections.

The smog potential for the artificial tree is primarily associated with the manufacturing phase (51%) and during Finished Tree to Home (45.5%). The Use phase and End-of-Life (disposal in a landfill) contributes 1% and 2.5% of the smog potential, respectively. The impacts are detailed further in Sections 4.9.1 and 4.10.1.

The smog potential for the natural tree is primarily associated with the manufacturing/cultivation phase and with the End-of-Life. Cultivation accounts for between 30% and 62% of the smog potential, whereas Finished Tree to Home smog potential ranges from 11% to 25%, depending on the End-of-Life scenario chosen. The impacts are detailed further in Sections 4.9.2 and 4.10.2.

Table 21: Smog Air of Artificial vs. Natural Christmas Tree by Life Cycle Stage

		Smog Potential (kg NOx equiv.)				
		Total	**Manufacturing / Cultivation**	**Finished Tree to Home**	**Use[9]**	**End of Life**
	Artificial Tree	6.16E-05	3.15E-05	2.80E-05	5.53E-07	1.54E-06
Natural Tree 1- year	Landfill	1.15E-05	5.35E-06	2.12E-06	9.74E-08	3.96E-06
	Incineration	1.86E-05	5.35E-06	2.12E-06	9.74E-08	1.11E-05
	Composting	8.48E-06	5.35E-06	2.12E-06	9.74E-08	9.06E-07
Natural Tree 5-year	Landfill	5.77E-05	2.68E-05	1.06E-05	4.87E-07	1.98E-05
	Incineration	9.31E-05	2.68E-05	1.06E-05	4.87E-07	5.53E-05
	Composting	4.24E-05	2.68E-05	1.06E-05	4.87E-07	4.53E-06
Natural Tree 10-year	Landfill	1.15E-04	5.35E-05	2.12E-05	9.74E-07	3.96E-05
	Incineration	1.86E-04	5.35E-05	2.12E-05	9.74E-07	1.11E-04
	Composting	8.48E-05	5.35E-05	2.12E-05	9.74E-07	9.06E-06

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[9] Lights and decorations are excluded from the use phase; refer to Section 2.3: Functional Unit.

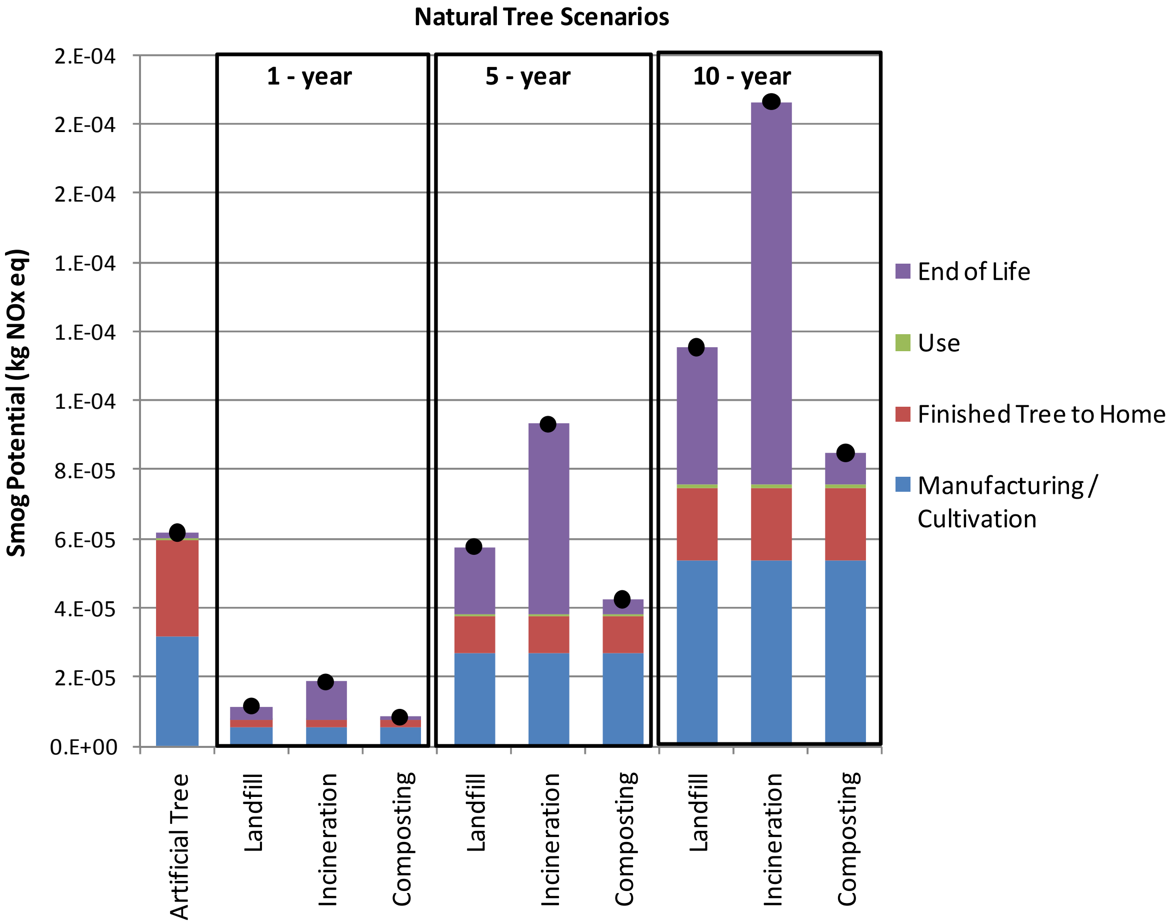


Figure 18: Smog Air of Artificial vs. Natural Tree by Life Cycle Stage

4.8.1 End-of-Life Scenario A. 100% Landfill

The artificial tree, used for only one year, when compared to a natural tree that is landfilled, results in roughly 5.4 times more smog (Table 21). However, when an artificial tree is kept for ten years, the smog impact of a natural tree purchased every year is approximately 1.9 times greater (Figure 18).

The smog potential associated with landfilling the natural tree is 34% of the overall smog potential of the landfilled natural tree. The smog for landfilling is associated with the energy (thermal and electric, 36%) required to operate the landfill, the surface sealing process (21%), the compactor (14%) and the CHP plant (13%). The smog credit received for producing electricity from landfill gas offsets approximately 16% of the smog emissions at the landfill.

4.8.2 End-of-Life Scenario B. 100% Incineration

The artificial tree, used for only one year, when compared to a natural tree that is landfilled, results in roughly 3.3 times more smog (Table 21). However, when an artificial tree is kept for ten years, the smog impact of a natural tree purchased every year is approximately 3.0 times greater (Figure 18).

The smog potential associated with incineration of the natural tree is 59% of the overall smog potential of the burned natural tree. The smog from incineration is primarily from emissions at the boiler stack (94% of emissions). The smog credit received for producing electricity and steam offsets approximately 20% of the smog emissions at the incinerator.

4.8.3 End-of-Life Scenario C. 100% Compost

The artificial tree, used for only one year, when compared to a natural tree that is composted, results in roughly 7.3 times more smog (Table 21). In 10 years, the AP of a natural tree is 1.4 times that of a single reused artificial tree (Figure 18). The smog impact of composting is small in magnitude; landfilling and incinerating result in 4 times and 12 times more smog emissions at End-of-Life, respectively.

4.9 Tree Manufacture & Cultivation

As shown in Sections 4.4 through 4.8, the most significant environmental impact (across all categories) is associated with the manufacture of the artificial tree and the cultivation of the natural tree.

4.9.1 Artificial Tree Manufacture

The artificial tree production (Figure 2) has several components including packaging and the production of the branches, metal fastener, metal hinge, tree pole, tree stand and top insert. As is shown in Figure 19, the largest impact from artificial tree production is the production of branches (between 44% and 70% of the total production impact). The packaging step also contributes, particularly to the EP (27%) and the non-renewable PED (10%). Note the packaging step has a negative GWP because the best available FEFCO datasets for cardboard and recycled paper (used in the tree packaging) have a GWP credit from its production. In other words, this data shows a greater carbon sequestration in the production of trees than carbon emissions during cardboard and paper production. Production of the tree pole, the metal hinge and the tree stand and top insert all contribute approximately 6% to 13% across the impact categories.

The environmental burden from the production of branches (Figure 20) is primarily attributed to the use of PVC granulate which contributes 43% to 67% of the total impact across the impact categories. The use of steel wire also significantly contributes to the environmental burden (28% to 41% across impact categories). Power and thermal energy used at the production plant in China has moderate to small contributions; the power grid carries between 4% and 18% of the total environmental burden, and the thermal energy from natural gas carries less than 2.5% across all impact categories.

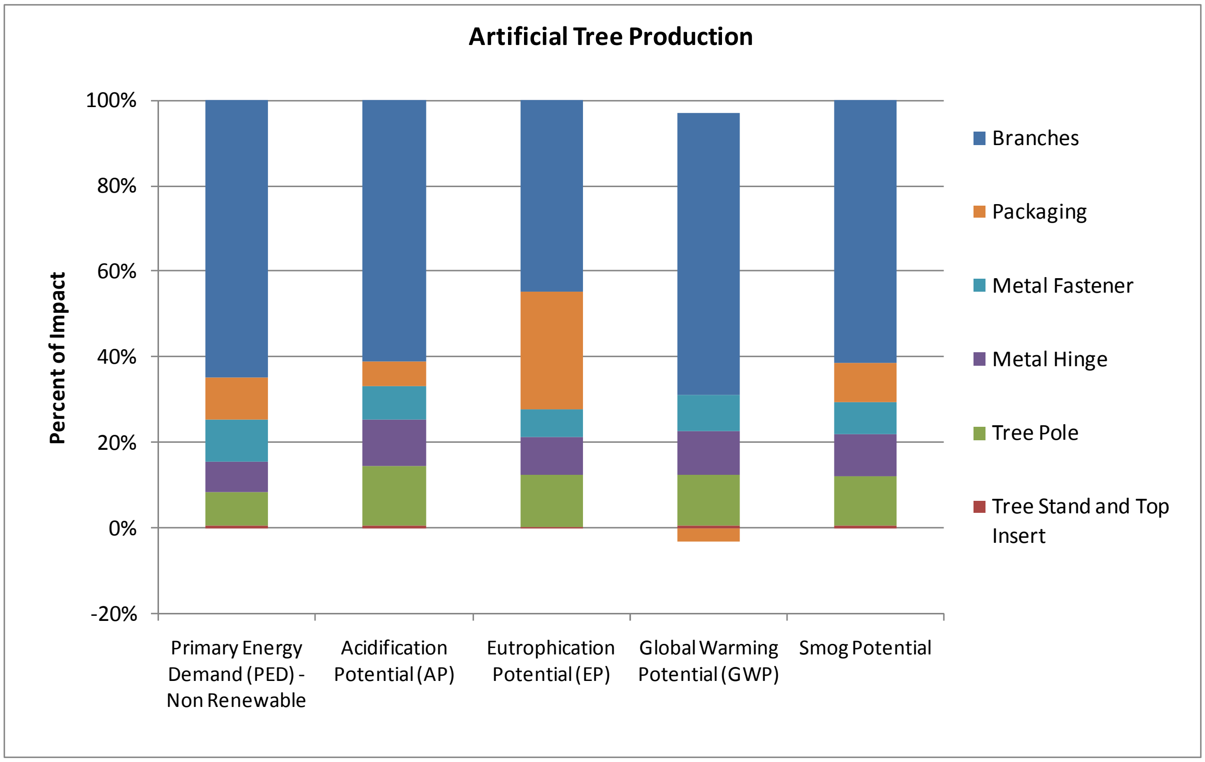


Figure 19: Breakdown of Impacts Associated with Artificial Tree Production

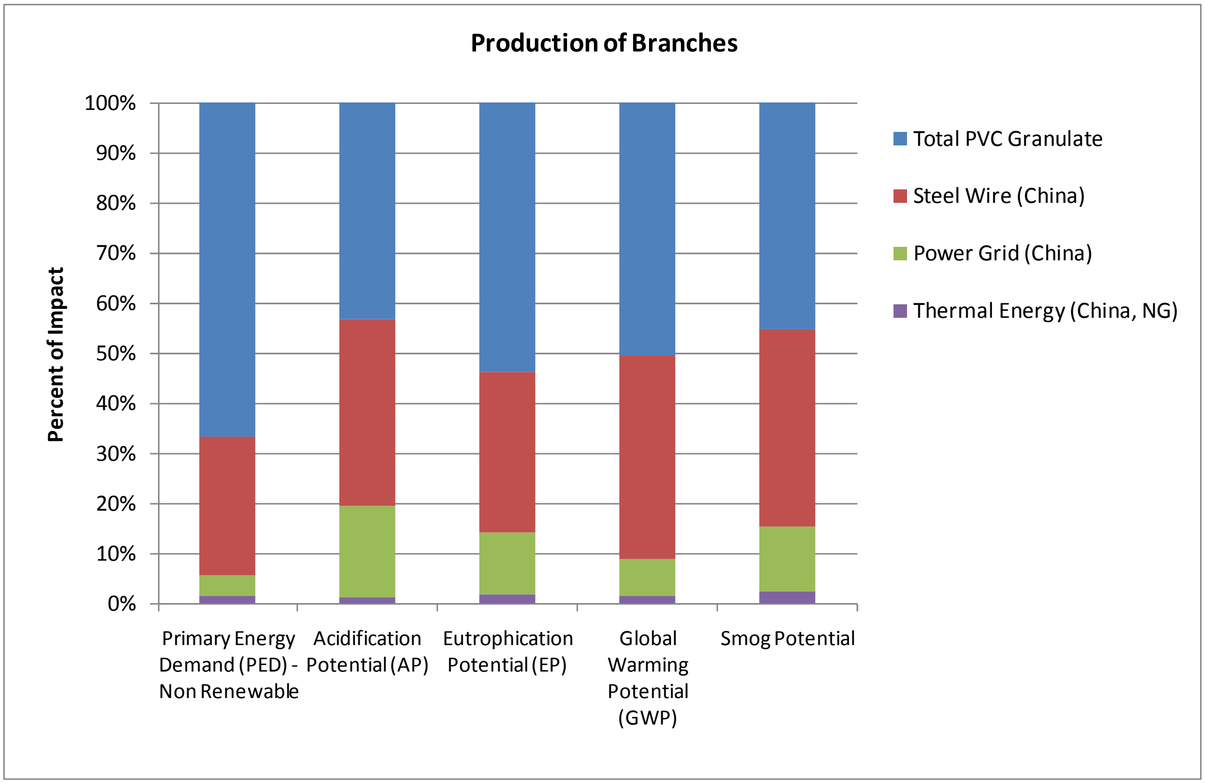


Figure 20: Breakdown of Impacts Associated with Production of Branches

4.9.2 Natural Tree Cultivation

Like the artificial tree, the primary burden of the natural tree lies with the cultivation life cycle stage, which includes on-farm activities such as cultivation, planting, maintenance, transport and packaging as well as the manufacture of the natural tree stand. As shown in Figure 21, the environmental burden is primarily associated with the agricultural processes on the farm. The packaging and on-farm transport, contribute minimally to the overall impact of the cultivation life cycle stage for the natural tree.

Note that the burden lies with cultivation for primary energy demand, acidification potential and smog potential. However, unlike the artificial tree, the production of a natural tree has environmental benefits. During cultivation, carbon dioxide is absorbed from the air and nitrogen is absorbed from the soil resulting in a net benefit associated with global warming potential and eutrophication potential, respectively. Thus, there is a net negative contribution for these two impact categories during cultivation.

During the natural tree manufacturing/cultivation, 56% of the PED is associated with the tree stand and 42% is associated with the agricultural processes. Of the 42% impact from agricultural processes, 85% is from the cultivation of the tree from years 4 to 11. Of the 56% impact from the tree stand, 96% is associated with the plastic part.

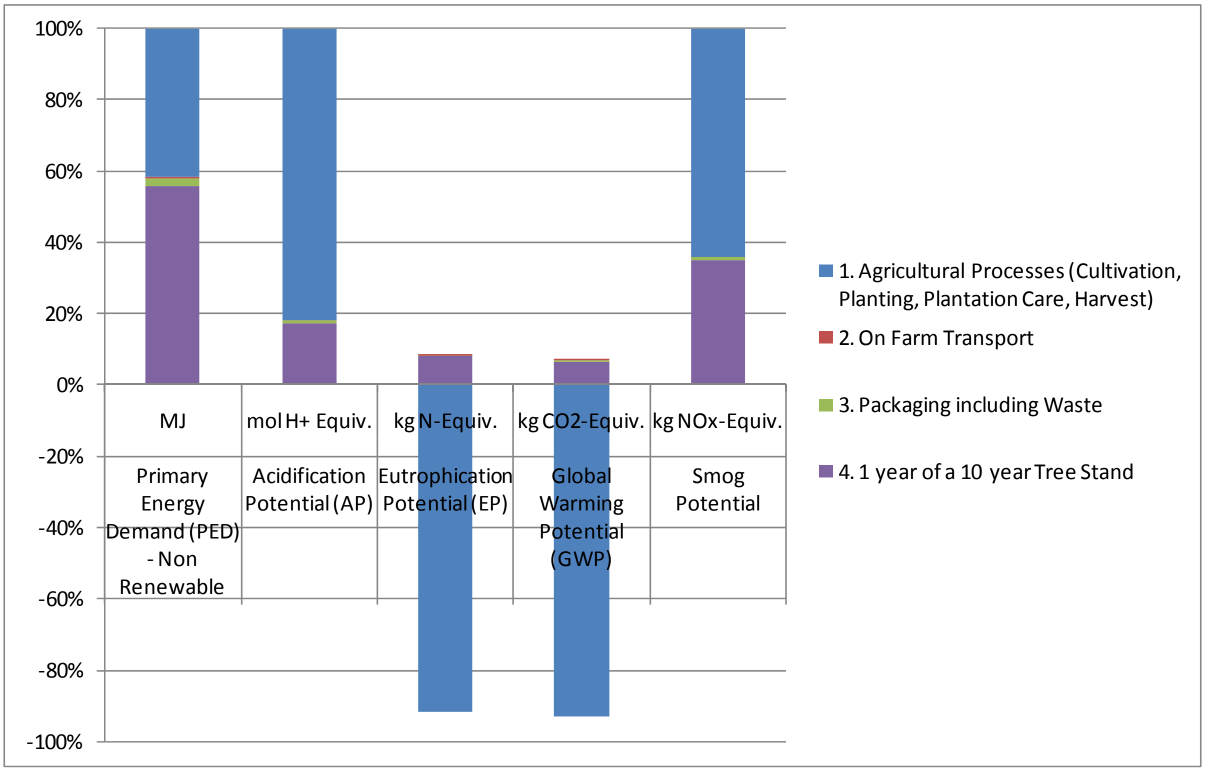


Figure 21: Breakdown of Impacts Associated with Natural Tree Cultivation

As mentioned in Sections 3.2.1.7 and 3.2.2, baling of the natural tree with polypropylene string is modeled to occur at the farm for transport to the retailer, but not from finished tree to home. The impact of baling a 15 kg natural tree is shown in Table 22. If the tree is baled a second time at the retailer for transport home these burdens can be added to the overall life cycle impact. The impact of the baling step is less than 1.5% of the overall natural tree life cycle across all impact categories and for all End-of-Life scenarios.

Table 22: Impact of Baling Christmas Tree

Impact Category	Units	Baling Tree
Primary Energy Demand (PED) - Non Renewable	MJ	0.653
Acidification Potential (AP)	mol H+ Equiv.	0.00347
Eutrophication Potential (EP)	kg N-Equiv.	1.98E-06
Global Warming Potential (GWP)	kg CO2-Equiv.	0.0190
Smog Potential	kg NOx-Equiv.	3.22E-08

4.10 Tree Transportation

As shown in Sections 4.4 through 4.8, the transportation during the life cycle stage "finished tree to home" is also a significant contributor to the overall environmental burden from the artificial and natural Christmas tree. As shown in Figure 22 and Figure 23, the car transport dominates the overall transportation impact. To better understand this impact, a sensitivity analysis was completed and is detailed in Section 5.

4.10.1 Artificial Tree Transportation

Transporting the finished artificial tree from China to a home in the US requires four steps: (1) truck transport from the factory in China to the port in China; (2) ship transport from China to the US; (3) truck transport from the US port to the US retailer; and (4) individual car transport from the retailer to home.

For the artificial tree (Figure 22), the car transport (despite the short travel distances compared to earlier truck and ship transportation steps) carries the majority of the Primary Energy Demand and Global Warming Potential burden. This is because transportation of bulk items in trucks and ships is efficient; the transportation burden of one individual tree when being transported among many is small. Conversely, car transportation is inefficient and the burden of the car transport is allocated entirely to the tree being transported. This assumes that the individual buying an artificial tree requires traveling 5 miles (roundtrip) in an average American car for the sole purpose of buying the tree. In other words, this trip is not combined with daily grocery shopping or other errands that could otherwise share the burden.

Conversely, for the impact categories of acidification potential, eutrophication potential, and smog potential, the transportation burden resides with the shipping of the trees from

China to the US (approximately 12,000 km). Acidification potential is high for shipping because of the use of heavy fuel oil, which has a higher sulfur content than gasoline and results in much greater SOx emissions. Acidification Potential, Eutrophication Potential, and Smog Potential are driven by the higher NOx from shipping. Increased NOx emissions during combustion are related to engine efficiency and the lack of stringent regulations on these emissions. It should also be remembered that acidification, eutrophication, and smog affect the local environmental in which they are released. The ship emissions are released over the ocean, whereas the car emissions occur in populated areas.

Additionally, because cargo ships travel carrying large quantities of goods, in this case – many Christmas trees, only a small portion of the cargo ship impact is allocated to each individual Christmas tree. Conversely, the primary energy demand and emissions (mostly carbon dioxide and methane) from car transport are 100% allocated to the purchase of a Christmas tree. This creates the high contribution to GWP and PED for the US car.

Note that the distance traveled by truck from US port to retailer varies depending upon where within the US the consumer resides; however this impact remains a small percentage of the overall transportation impacts, even for larger travel distances.

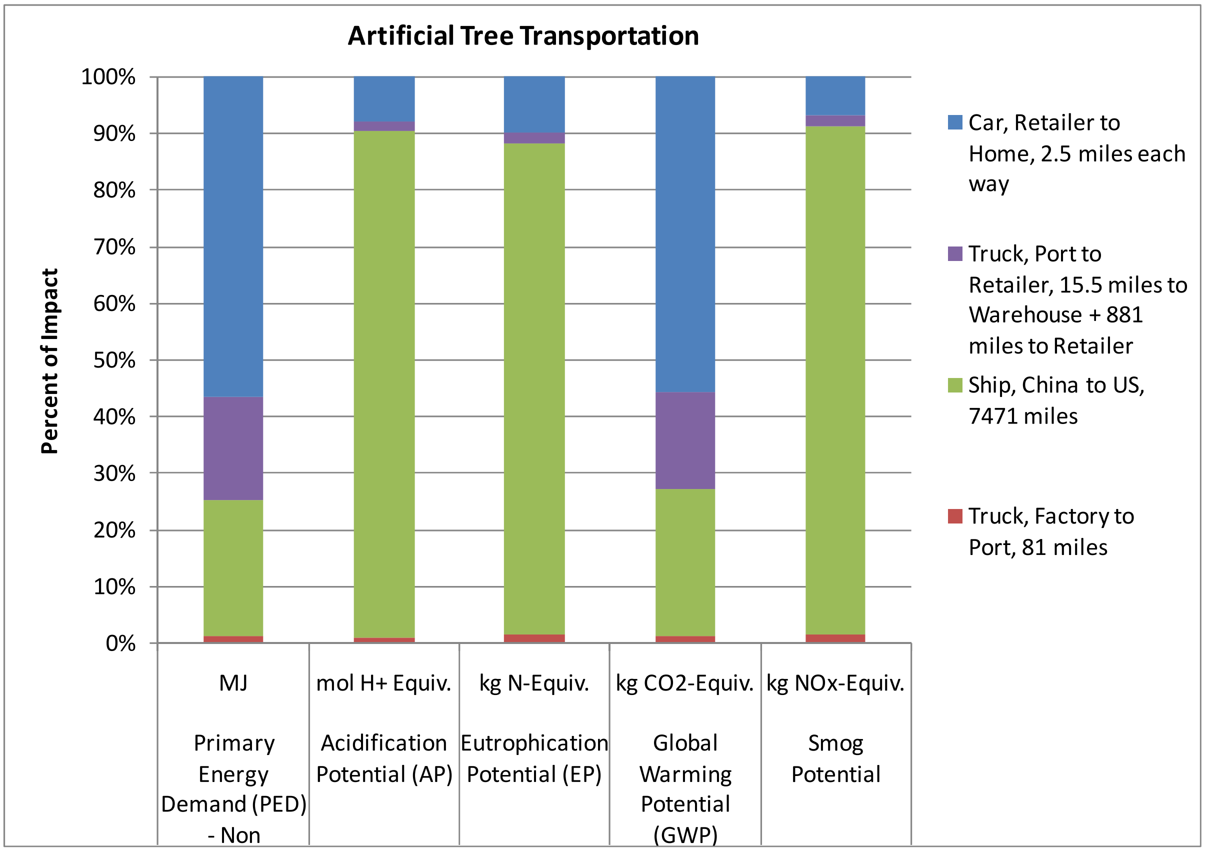


Figure 22: Transportation of Artificial Tree from Factory to Point of Use

4.10.2 Natural Tree Transportation

Because the natural tree is grown in the United States, the transportation from the grown tree to an individual's home for use only has two steps: (1) truck transport from the farm to the retailer, and (2) individual car transport from the retailer to home.

Across all impact categories the car transport dominates (even for local travel conditions) with over 90% of the total impact across all categories (Figure 23).

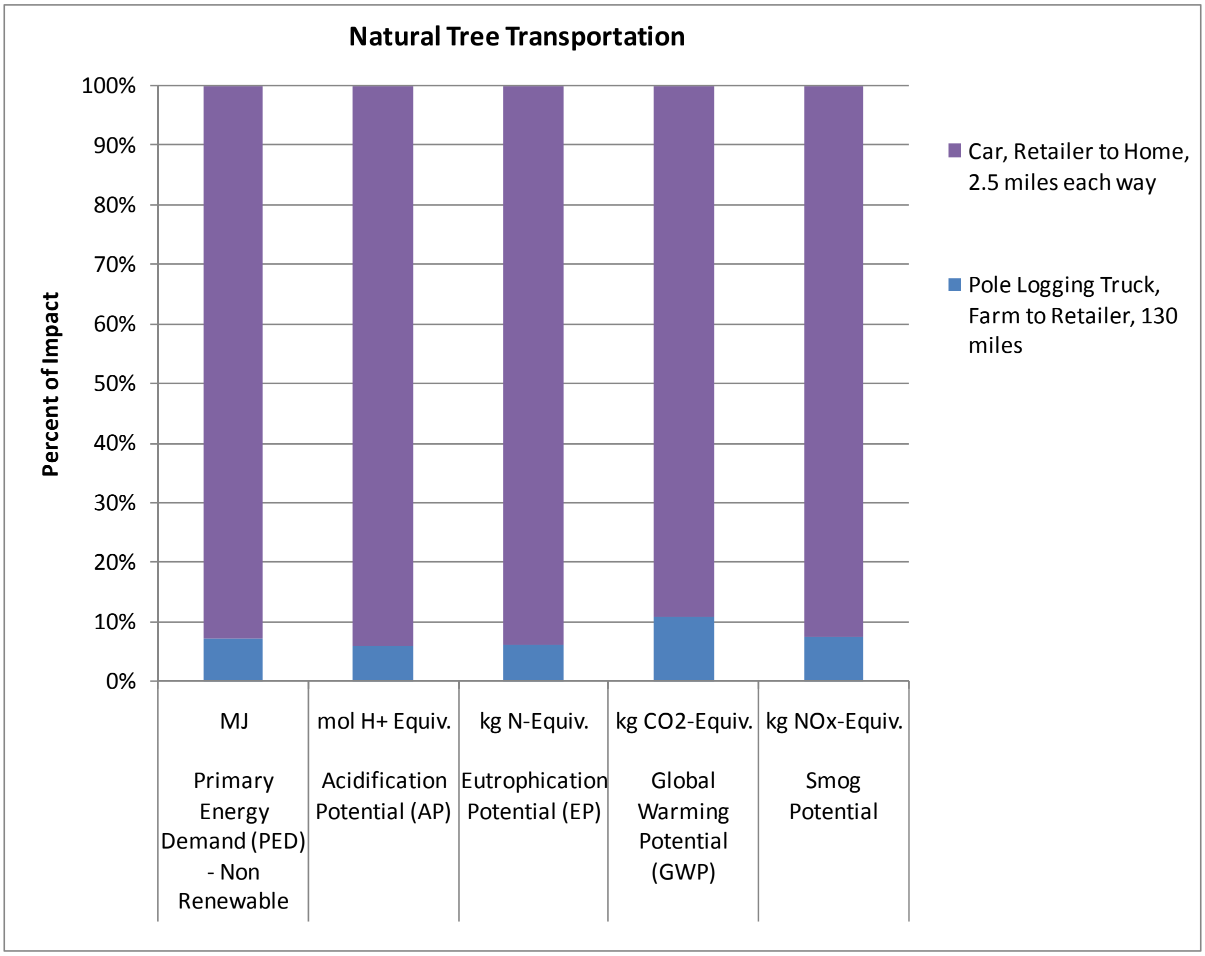


Figure 23: Transportation of Natural Tree from Farm to Point of Use

4.11 Tree Stand

The tree stand for the artificial tree is part of the artificial tree manufacture and assembly process. The artificial tree stand is made of injected molded PVC and weighs 0.41 kg. The tree stand contributes 6% to 10% of the environmental impacts of the artificial tree manufacturing and packaging phase. Since the tree stand is included in the product, it is assumed to have a lifetime equal to that of the artificial tree.

The natural tree stand is made separately from the cultivation of the tree. The tree stand is modeled to have a lifetime of 10 years, an average weight of 2.04 kg (FKF 2008, type Cynco C-144) consisting of 90% plastic and 10% metal (mainly screws). Note that the cultivation/manufacturing life cycle includes the agricultural processes and the manufacturing of the tree stand. Refer to Figure 21 for the breakdown of the tree stand relative to the cultivation of the natural tree.)

When comparing the tree stands, a comparison is made for the first year, and impacts for the full artificial tree stand are compared to impacts associated with 1/10th of the natural tree stand.

Table 23: Comparison of the Natural and Artificial Tree Stands

Impact Category	Units	Natural Tree Stand*	Artificial Tree Stand	Artificial Tree Stand/Natural Tree Stand
Primary Energy Demand (PED) - Non	MJ	16.57	22.07	1.33
Acidification Potential (AP)	mol H+ Equiv.	0.09	0.29	3.31
Eutrophication Potential (EP)	kg N-Equiv.	2.30E-04	1.76E-04	0.76
Global Warming Potential (GWP)	kg CO2-Equiv.	0.70	1.07	1.53
Smog Potential	kg NOx-Equiv.	1.88E-06	2.32E-06	1.24
*1-year of 10 year tree stand				

Table 24 summarizes the percent of impact attributed to the tree stand. When the overall life cycle is negative, no value is shown but a characterization of the tree stand's impact is summarized in the following text.

- The artificial tree stand contributes between 4% and 8% of the overall artificial tree life cycle impacts.

- For the landfilled natural tree, tree stand impacts (excluding GWP) range from 6% to 18%. The overall GWP impacts of the landfilled natural tree are negative; the sum of the life cycle GWP sources is 7.1 kg CO2-eq and of the sources, the tree stand contributes 10%.

- For the incinerated natural tree, tree stand impacts (excluding EP) range from 8% to 33%. The overall EP impacts of the incinerated natural tree are negative; the sum of the life cycle EP sources is 1.1E^{-3} kg N-equiv. and of the sources, the tree stand contributes 22%.

- For the composted natural tree, tree stand impacts (excluding EP) range from 24% to 40%. The overall EP impacts of the composted natural tree are negative; the sum of the life cycle EP sources is 4.2E^{-4} kg N-equiv. and of the sources, the tree stand contributes 55%.

Note that the AP for the artificial tree stand is nearly 3 times greater than the AP for the natural tree stand. The difference in AP is related to the difference in the environmental burden of the various raw materials and the quantities of each material used for the different tree stands. Additionally, the artificial tree stand is produced in China where the grid electricity is primarily from coal, which has a high AP burden. Conversely, the natural tree stand is modeled with US system boundaries where the electricity grid is cleaner and has a lower AP impact.

Table 24: Tree Stand as Fraction of Overall Tree Life Cycle

Impact Category	Units	Artificial Tree (% of AT Life Cycle)	Natural Tree Stand (% of NT Life Cycle)		
			Landfill	Incineration	Composting
Primary Energy Demand (PED) - Non	MJ	7.5%	17.7%	32.7%	33.8%
Acidification Potential (AP)	mol H+ Equiv.	4.9%	9.3%	8.1%	40.3%
Eutrophication Potential (EP)	kg N-Equiv.	3.9%	5.8%		
Global Warming Potential (GWP)	kg CO2-Equiv.	6.0%		13.7%	23.8%
Smog Potential	kg NOx-Equiv.	3.9%	16.3%	10.1%	28.4%

No value is shown above when the overall life cycle value is negative.

Note that the life span of the metal stand for the natural tree is independent of the natural tree and could last longer than ten years. The annualized impacts for the natural tree stand would subsequently be smaller the longer the tree stands are kept.

4.12 Tree Lights

This study compares unlit trees; tree lights (manufacturing, use and end-of-life) were excluded from this life cycle study because, like ornaments and other decorations, they were assumed to be comparable between the artificial and the natural tree. However, the electricity consumption of Christmas tree lights is estimated here to enable the reader to get a feeling for the relative impacts of a tree life cycle compared to that of the electricity consumed by Christmas tree lights.

A string of 50 incandescent Christmas lights uses 25 Watts (BRAIN 2000). This equates to 0.29 MJ PED non-renewable assuming 3.25 kW PED per kW electric in the US. During the 18 days the tree is used, assuming the lights are lit for 4 hours per day and that there are on average 400 lights per tree, the use of the Christmas tree lights results in approximately 170 MJ of non-renewable PED.

A string of 50 small LED Christmas lights uses 4 Watts (adapted from PHILIPS 2006) under the same conditions would use 27 MJ of non-renewable PED or 1/6th of the PED consumed burning incandescent lights.

Figure 24 shows the primary energy demand of one year of electricity consumption by either LED or incandescent lights together with the full life cycle impacts of either the natural or artificial Christmas tree. The artificial Christmas tree impacts are shown for a tree which is kept for 1 year, 5 years, or 10 years before disposal. The natural tree is shown for one year use followed by either landfill, incineration, or composting at end of life.

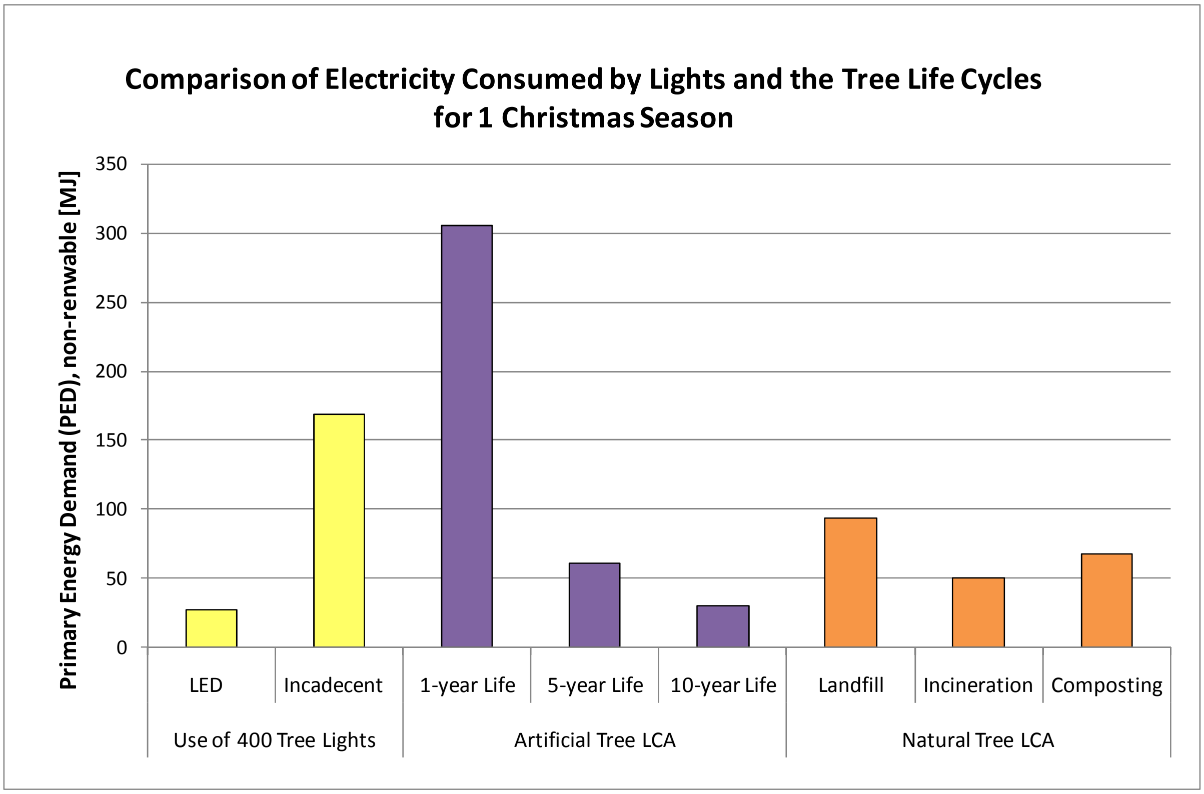


Figure 24: Comparison of Christmas Tree Light Electricity Consumption with Unlit Tree Life Cycles

In the context of the overall tree life cycle (refer to Table 16):

- For the <u>artificial tree</u>, incandescent and LED lights equate to 55% and 9% of the overall artificial tree PED impact, respectively.
- For the <u>landfilled natural tree</u>, LED lights equate to 29% of the overall natural tree PED impact. If incandescent lights are used, the PED impact of the lights is 1.8 times the impact of the natural tree life cycle.
- For the <u>incinerated natural tree</u>, LED lights equate to 53% of the overall natural tree PED impact. If incandescent lights are used, the PED impact of the lights is 3.3 times the impact of the natural tree life cycle.

- For the composted natural tree, LED lights equate to 40% of the overall natural tree impact. If incandescent lights are used, the PED impact of the lights is 2.5 times the impact of the natural tree life cycle.

Overall, the impact of the use of Christmas tree lights is significant when compared to the life cycle of either a natural or artificial tree and there is a significant PED benefit associated to using LED lights over incandescent lights. Please note that the choice of Christmas lights has no effect on the absolute difference between an artificial or natural tree life cycle, but it will affect a relative (percentage) comparison as the inclusion of lights increases the total impacts of both trees.

4.13 Trees in Context

According to the Union of Concerned Scientists (UCS 2006), the average American's share of carbon dioxide emissions is 19.78 tons per year (17,950 kg CO_2 equivalent per capita per year). This equates to approximately 49 kg CO_2 equivalent per capita per day. When considering the life cycle impact of purchasing a natural Christmas tree, as seen in Table 25, the impact of the natural tree is less than 15% of the average American's daily GWP emissions. For the artificial tree, assuming worst case scenario (the tree is only kept for one year) the tree's impact is less than 40% of the average American's daily GWP emissions.

Table 25: GWP Impacts Compared to US Per Capita Emissions

	Life Cycle Impacts			
	Artificial Tree	Natural Tree		
		Landfill*	Incineration	Composting
GWP [kg CO2-Equiv.]	18.6	7.1	5.1	4.7
% of impact	37.8%	14.5%	10.4%	9.5%
Fraction of Daily Emissions	3/8	1/7	1/9	1/10

*GWP Sources Only (the life cycle of the landfilled natural tree is negative)

Note that Christmas trees are used on an annual basis and therefore the use of the Christmas tree can be considered in the context of an individuals' annual carbon footprint. The impact of the tree life cycle, for all scenarios, is less than 0.1% of a person's annual carbon footprint and therefore is negligible within the context of the average American's lifestyle.

5 SENSITIVITY AND BREAK EVEN ANALYSIS

5.1 Transportation

Given the importance of transportation to the results of this study, sensitivity analyses were run to examine the influence of the chosen transportation distances. For most of the above mentioned environmental indicators, the use of a personal car had the most significant effect of all the transportation segments. The car impacts are modeled assuming the only reason for driving the car is to purchase a Christmas tree. If the consumer purchases other goods, or runs other errands as part of the same trip, the impacts associated with the car should be divided among the multiple purposes of the trip. The following sections show the number of years an artificial tree needs to be kept in order to have equivalent environmental impacts of a natural tree bought each year for the same number of years. This break even sensitivity is run for all End-of-Life scenarios.

5.1.1 End-of-Life A: 100% Landfill

Figure 25 shows the number of years an artificial tree needs to be kept in order to have equivalent environmental impacts of a natural tree bought each year for the same number of years. This is referred to the "break-even". In this figure, it is assumed that the consumer would drive the same distance to purchase either a natural or artificial tree. For primary energy demand, acidification potential, eutrophication potential and smog potential the shorter the distance traveled to purchase a tree, the longer an artificial tree must be kept. However, eutrophication potential is hardly dependent on the distance driven for the landfilled natural tree. The benefits of using an artificial tree instead of a natural tree accumulate faster where the consumer would need to travel long distances each year to acquire a new natural tree. As a reminder, the default distance assumed in the results presented earlier was 2.5 miles each way (5 miles round trip). For a 2.5 one-way trip purchase, the break-even distance varies between 1 and 7 years depending on the impact category of interest.

Initially, global warming potential (GWP) for the landfilled natural tree is negative, in other words the life cycle of a landfilled natural tree that is a GWP sink. Therefore, the more natural trees purchased, the greater the environmental global warming benefit (the more negative GWP becomes). However, with increased transport to pick up the natural tree, the overall landfilled natural tree life cycled becomes less negative. When car transport becomes greater than 5 miles (one-way), the overall life cycle of the natural tree is no longer negative, and there is a positive GWP contribution. If transport is less than 5 miles, the more natural trees purchased, the greater the environmental GWO benefit (the more negative GWP becomes). For car transport greater than 5 miles, the more natural trees purchased the greater the contribution to GWP. Therefore, a break-even distance can be calculated for distances greater than 5 miles.

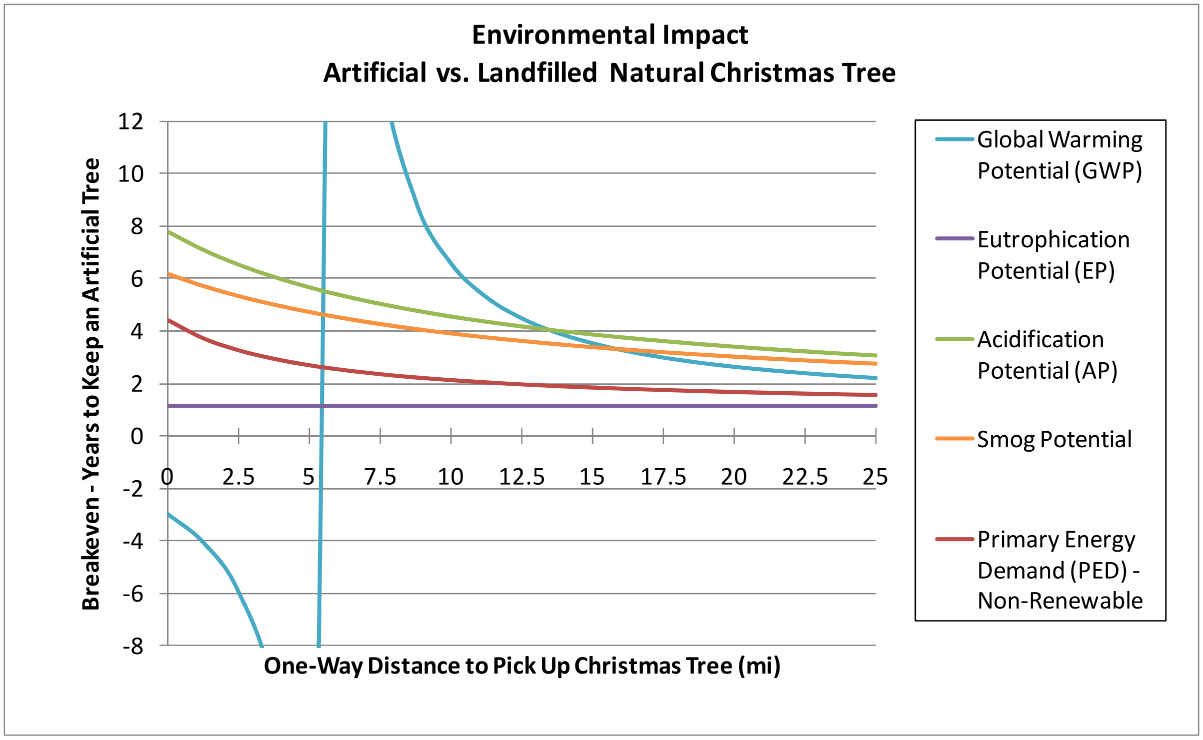


Figure 25: Sensitivity of Consumer Car Distance, Break-Even Years (A)

Assuming the same one-way distance for artificial and natural trees and round trip transport occurs. Natural tree landfilled at End-of-Life.

Table 26 expands upon the analysis of Global Warming Potential from Figure 25 by presenting the number of years to break even when the distance the consumer travels to purchase an artificial tree is different from that for a natural tree. Here it can be seen that when the distance driven to purchase the natural tree is short (but greater than 5 miles) and the distance driven to purchase an artificial tree is long, the break-even number of years to keep an artificial tree is at the highest extreme. Short distance for an artificial tree coupled with a long distance for a natural tree provides the opposite extreme; the break even number of years to keep the artificial tree small. However, when the distance traveled for the natural tree is less than or equal to 5 miles, there is no breakeven point. For the base case, no GWP break-even point exists, and the natural tree is always has less GWP compared to the artificial tree l.

Table 26: GWP Sensitivity of Consumer Car Distance, Break Even Years (A)

Assuming the different one-way distance for artificial and natural trees and round trip transport occurs. Natural tree landfilled at End-of-Life.

Number of years one must reuse an artificial tree in order for it to have an equivalent carbon footprint to a yearly natural tree

		One-Way Distance by Car to Purchase an Artificial Tree [miles]												
		0	**1.25**	**2.5**	**3.75**	**5**	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**
One-Way Distance by Car to Purchase a Natural Tree [miles]	**0**	-3.0	-3.2	-3.4	-3.6	-3.8	-4.3	-4.7	-5.1	-5.5	-6.0	-6.4	-6.8	-7.3
	1.25	-3.8	-4.1	-4.3	-4.6	-4.9	-5.4	-6.0	-6.5	-7.1	-7.6	-8.1	-8.7	-9.2
	2.5	-5.2	-5.6	-5.9	-6.3	-6.7	-7.4	-8.2	-8.9	-9.7	-10.4	-11.2	-11.9	-12.7
	3.75	-8.3	-8.9	-9.5	-10.1	-10.7	-11.9	-13.1	-14.3	-15.5	-16.7	-17.9	-19.1	-20.3
	5	-20.6	-22.1	-23.6	-25.1	-26.6	-29.5	-32.5	-35.5	-38.5	-41.4	-44.4	-47.4	-50.3
	6.25	42.6	45.7	48.8	51.8	54.9	61.1	67.2	73.4	79.5	85.7	91.8	98.0	104.1
	7.5	10.5	11.2	12.0	12.7	13.5	15.0	16.5	18.0	19.5	21.1	22.6	24.1	25.6
	10	6.0	6.4	6.8	7.3	7.7	8.6	9.4	10.3	11.1	12.0	12.9	13.7	14.6
	12.5	4.2	4.5	4.8	5.1	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6	10.2
	15	3.2	3.4	3.7	3.9	4.1	4.6	5.1	5.5	6.0	6.5	6.9	7.4	7.8
	17.5	2.6	2.8	3.0	3.2	3.4	3.7	4.1	4.5	4.9	5.2	5.6	6.0	6.4
	20	2.2	2.4	2.5	2.7	2.8	3.1	3.5	3.8	4.1	4.4	4.7	5.0	5.4
	22.5	1.9	2.0	2.2	2.3	2.4	2.7	3.0	3.3	3.5	3.8	4.1	4.4	4.6
	25	1.7	1.8	1.9	2.0	2.1	2.4	2.6	2.9	3.1	3.4	3.6	3.8	4.1

5.1.2 End-of-Life B: 100% Incineration

Figure 26 shows the number of years an artificial tree needs to be kept in order to have equivalent environmental impacts of a natural tree bought each year for the same number of years. This is referred to the “break-even.” In this figure, it is assumed that the consumer would drive the same distance to purchase either a natural or artificial tree. For primary energy demand, acidification potential, global warming potential and smog potential the shorter the distance traveled to purchase a tree, the longer an artificial tree must be kept. The benefits of using an artificial tree instead of a natural tree accumulate much faster where the consumer would need to travel long distances each year to acquire a new natural tree. As a reminder, the default distance assumed in the results presented earlier was 2.5 miles each way (5 miles round trip). For a 2.5 one-way trip purchase, the breakeven distance varies between 3 and 7 years depending on the impact category of interest.

Eutrophication potential for the incinerated natural tree is negative; in other words the life cycle of a natural tree that is incinerated is an eutrophication sink. Therefore, the more natural trees purchased, the greater the environmental eutrophication benefit (the more negative eutrophication becomes). There is no breakeven distance for eutrophication; the incinerated natural tree option always has less EP than an artificial tree.

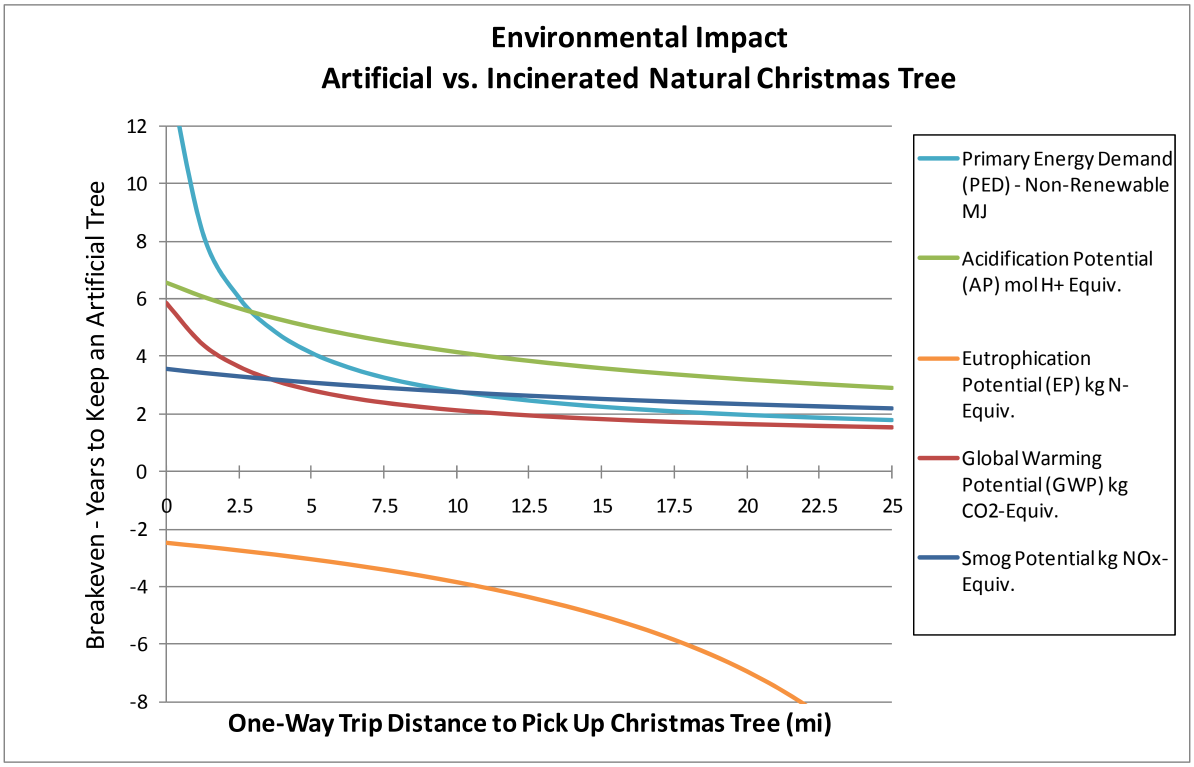


Figure 26: Sensitivity of Consumer Car Distance, Break-Even Years (B)

Assuming the same one-way distance for artificial and natural trees and round trip transport occurs. Natural tree incinerated at End-of-Life.

Table 27 expands upon the analysis of Global Warming Potential from Figure 26 by presenting the number of years to break even when the distance the consumer travels to purchase an artificial tree is different from that for a natural tree. Here it can be seen that when the distance driven to purchase the natural tree is short, and the distance driven to purchase an artificial tree is long, the break-even number of years to keep an artificial tree is at the highest extreme. A short distance for an artificial tree coupled with a long distance for a natural tree provides the opposite extreme; the break even number of years to keep the artificial tree small. For the base case, for GWP, the break-even point is when an artificial tree is kept for more than 3.6 years (effectively, when the 4th natural Christmas tree is purchased).

Table 27: GWP Sensitivity of Consumer Car Distance, Break Even Years (B)

Assuming the different one-way distance for artificial and natural trees and round trip transport occurs. Natural tree incinerated at End-of-Life.

Number of years one must reuse an artificial tree in order for it to have an equivalent carbon footprint to a yearly natural tree

		One-Way Distance by Car to Purchase an Artificial Tree [miles]												
		0	**1.25**	**2.5**	**3.75**	**5**	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**
One-Way Distance by Car to Purchase a Natural Tree [miles]	**0**	5.8	6.3	6.7	7.1	7.5	8.4	9.2	10.1	10.9	11.7	12.6	13.4	14.3
	1.25	4.1	4.4	4.7	5.0	5.3	5.9	6.5	7.1	7.7	8.3	8.9	9.5	10.0
	2.5	3.2	3.4	3.6	3.9	4.1	4.5	5.0	5.5	5.9	6.4	6.8	7.3	7.8
	3.75	2.6	2.8	3.0	3.1	3.3	3.7	4.1	4.4	4.8	5.2	5.6	5.9	6.3
	5	2.2	2.3	2.5	2.6	2.8	3.1	3.4	3.7	4.1	4.4	4.7	5.0	5.3
	6.25	1.9	2.0	2.2	2.3	2.4	2.7	3.0	3.2	3.5	3.8	4.1	4.3	4.6
	7.5	1.7	1.8	1.9	2.0	2.1	2.4	2.6	2.9	3.1	3.3	3.6	3.8	4.1
	10	1.5	1.6	1.7	1.8	1.9	2.1	2.3	2.5	2.8	3.0	3.2	3.4	3.6
	12.5	1.3	1.4	1.5	1.6	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3
	15	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.1	2.3	2.5	2.6	2.8	3.0
	17.5	1.1	1.2	1.3	1.4	1.4	1.6	1.8	1.9	2.1	2.3	2.4	2.6	2.7
	20	1.0	1.1	1.2	1.3	1.3	1.5	1.6	1.8	1.9	2.1	2.2	2.4	2.5
	22.5	1.0	1.0	1.1	1.2	1.2	1.4	1.5	1.7	1.8	1.9	2.1	2.2	2.4
	25	0.9	1.0	1.0	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.1	2.2

5.1.3 End-of-Life C: 100% Compost

Figure 27 shows the number of years an artificial tree needs to be kept in order to have equivalent environmental impacts of a natural tree bought each year for the same number of years. This is referred to the "break-even" point. In this figure, it is assumed that the consumer would drive the same distance to purchase either a natural or artificial tree. For primary energy demand, acidification potential, global warming potential and smog potential the shorter the distance traveled to purchase a tree, the longer an artificial tree must be kept. The benefits of using an artificial tree instead of a natural tree accumulate much faster where the consumer would need to travel long distances each year to acquire a new natural tree. As a reminder, the default distance assumed in the results presented earlier was 2.5 miles each way (5 miles round trip). For a 5 mile round trip purchase, the breakeven distance varies between 4 and 8 years depending on the impact category of interest.

Eutrophication potential for the composted natural tree is negative, in other words the life cycle of a natural tree that is composted is an eutrophication sink. Therefore, the more natural trees purchased, the greater the environmental eutrophication benefit (the more negative eutrophication becomes). There is no breakeven distance for eutrophication; the composted natural tree option is always has less EP than an artificial tree.

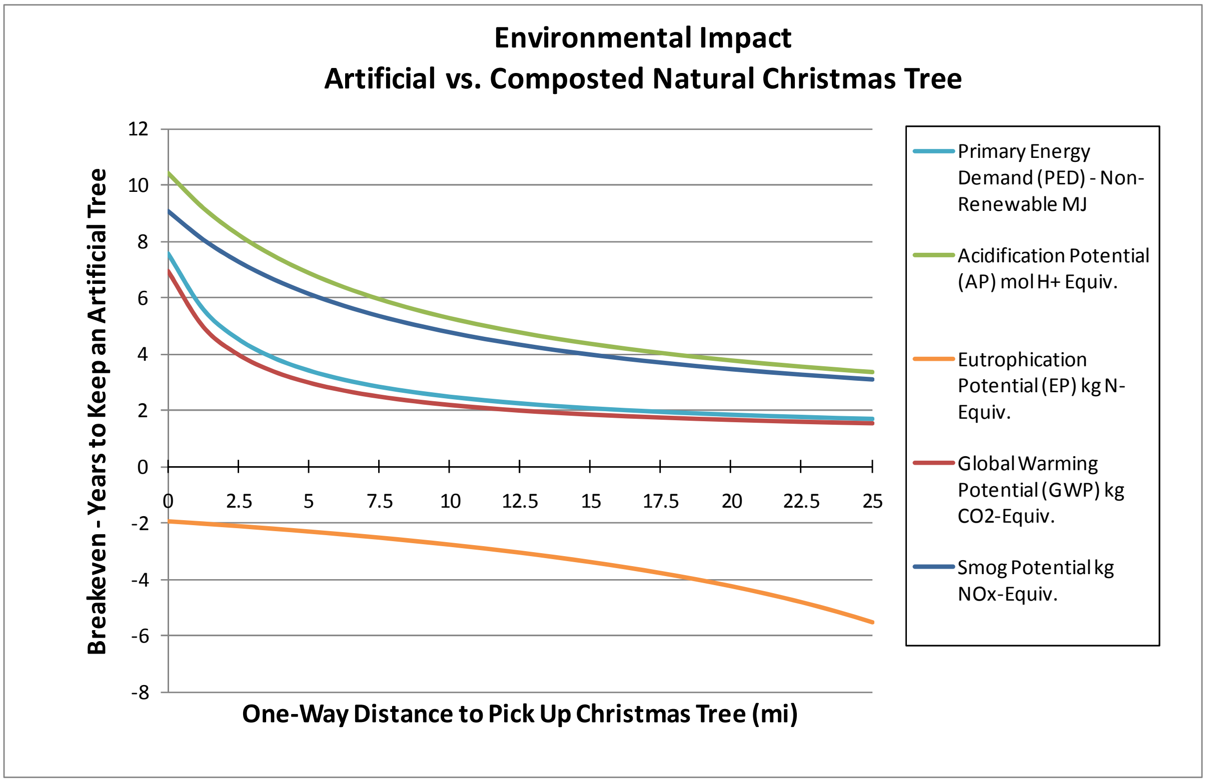


Figure 27: Sensitivity of Consumer Car Distance, Break-Even Years (C)

Assuming the same one-way distance for artificial and natural trees and round trip transport occurs. Natural tree composted at End-of-Life.

Table 28 expands upon the analysis of Global Warming Potential from Figure 27 by presenting the number of years to break even when the distance the consumer travels to purchase an artificial tree is different from that for a natural tree. Here it can be seen that when the distance driven to purchase the natural tree is short, and the distance driven to purchase an artificial tree is long, the break-even number of years to keep an artificial tree is at the highest extreme. A short distance for an artificial tree coupled with a long distance for a natural tree provides the opposite extreme; the break even number of years to keep the artificial tree small. For the base case, for GWP, the break-even point is when an artificial tree is kept for more than 4 years.

Table 28: GWP Sensitivity of Consumer Car Distance, Break-Even Years (C)

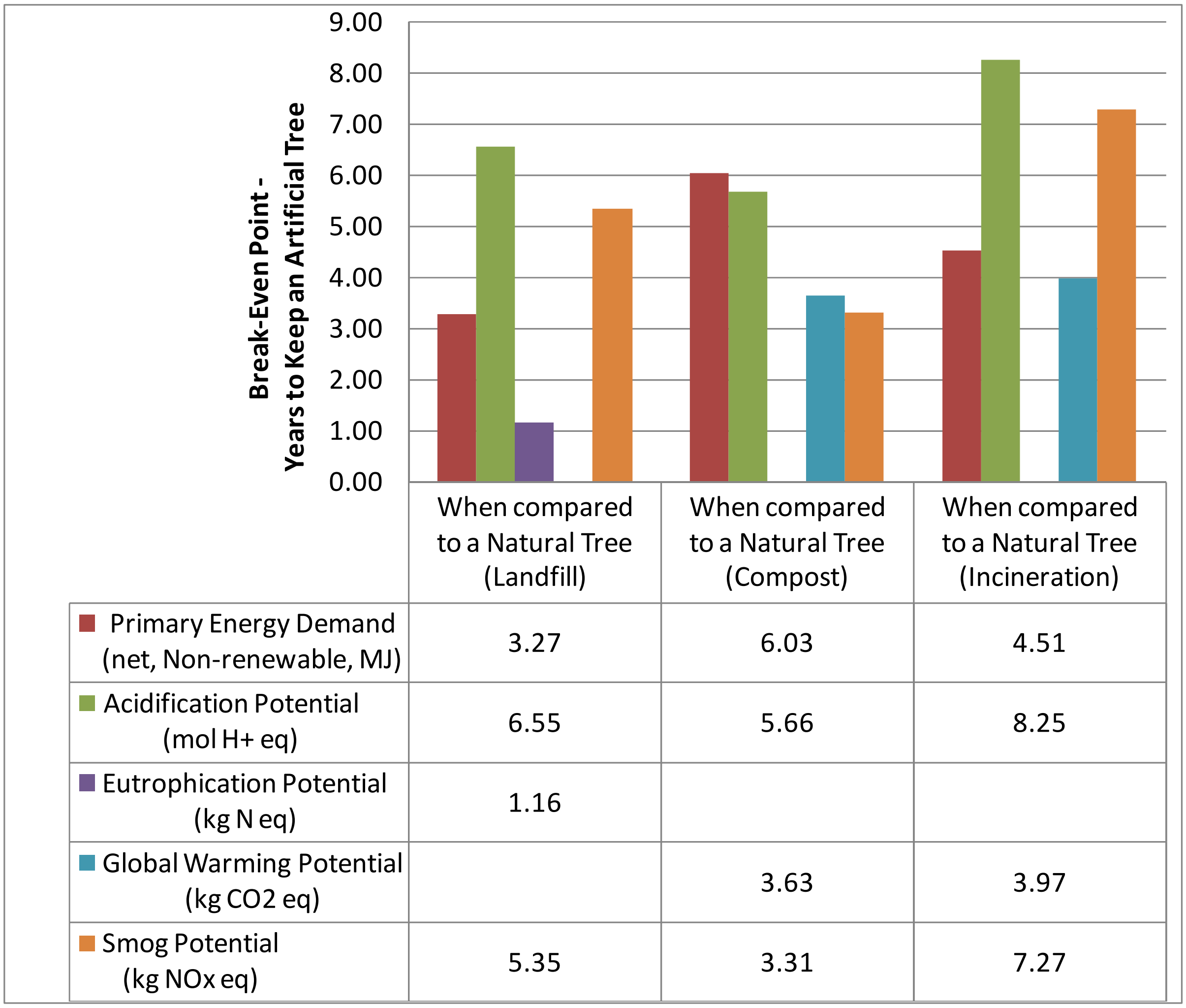
Assuming the different one-way distance for artificial and natural trees and round trip transport occurs. Natural tree composted at End-of-Life.

Number of years one must reuse an artificial tree in order for it to have an equivalent carbon footprint to a yearly natural tree

		One-Way Distance by Car to Purchase an Artificial Tree [miles]												
		0	**1.25**	**2.5**	**3.75**	**5**	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**	**22.5**	**25**
One-Way Distance by Car to Purchase a Natural Tree [miles]	**0**	6.9	7.4	7.9	8.4	8.9	9.9	10.9	11.9	12.9	13.9	14.9	15.9	16.9
	1.25	4.6	5.0	5.3	5.6	6.0	6.6	7.3	8.0	8.6	9.3	10.0	10.6	11.3
	2.5	3.5	3.7	4.0	4.2	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5
	3.75	2.8	3.0	3.2	3.4	3.6	4.0	4.4	4.8	5.2	5.6	6.0	6.4	6.8
	5	2.3	2.5	2.6	2.8	3.0	3.3	3.6	4.0	4.3	4.6	5.0	5.3	5.7
	6.25	2.0	2.1	2.3	2.4	2.6	2.8	3.1	3.4	3.7	4.0	4.3	4.6	4.8
	7.5	1.7	1.9	2.0	2.1	2.2	2.5	2.7	3.0	3.2	3.5	3.7	4.0	4.2
	10	1.5	1.6	1.7	1.8	1.9	2.1	2.3	2.5	2.8	3.0	3.2	3.4	3.6
	12.5	1.4	1.5	1.6	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4
	15	1.3	1.4	1.4	1.5	1.6	1.8	2.0	2.2	2.4	2.5	2.7	2.9	3.1
	17.5	1.2	1.2	1.3	1.4	1.5	1.7	1.8	2.0	2.2	2.3	2.5	2.7	2.8
	20	1.1	1.1	1.2	1.3	1.4	1.5	1.7	1.8	2.0	2.1	2.3	2.5	2.6
	22.5	1.0	1.1	1.1	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.1	2.3	2.4
	25	0.9	1.0	1.1	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2.0	2.1	2.3

5.1.4 Summary of Break-Even Analysis

By normalizing the total life cycle impacts for each natural tree EoL option to that of the artificial tree, the number of years an artificial tree must be reused before it has equivalent impacts to the natural tree can be calculated. These values are presented in Figure 28 for the base case when individual car transport distance for tree purchase is 2.5 miles each way. Because the natural tree provides an environmental benefit in terms of Global Warming Potential when landfilled, and Eutrophication Potential when composted or incinerated, there is no number of years one can keep an artificial tree in order to match the natural tree impacts in these cases. The term break-even doesn't make sense in these cases so no value is shown in Figure 28. For all other scenarios, the artificial tree has less impact provided it is kept and reused for a minimum between 2 and 9 years, depending upon the environmental indicator chosen.



	When compared to a Natural Tree (Landfill)	When compared to a Natural Tree (Compost)	When compared to a Natural Tree (Incineration)
🟥 Primary Energy Demand (net, Non-renewable, MJ)	3.27	6.03	4.51
🟩 Acidification Potential (mol H+ eq)	6.55	5.66	8.25
🟪 Eutrophication Potential (kg N eq)	1.16		
🟦 Global Warming Potential (kg CO2 eq)		3.63	3.97
🟧 Smog Potential (kg NOx eq)	5.35	3.31	7.27

Figure 28: Break-Even Number of Years to Keep an Artificial Tree

A landfilled natural tree has less GWP than an artificial tree. In addition, a composted or incinerated natural tree has less EP than an artificial tree.

6 CONCLUSIONS AND RECOMMENDATIONS

The following major conclusions and recommendations are presented as a result of the above Life Cycle Assessments comparing the most commonly purchased artificial tree manufactured at a large facility in China to the most commonly purchased natural tree, a Fraser fir. Each tree represents approximately 20% of the US artificial and natural tree market, respectively.

Understanding that there are a wide range of Christmas tree products available (for both natural and artificial trees), the study goal does not include the comparison of every species of natural tree to every model of artificial tree available on the market. It also does not compare the average artificial tree to the average natural tree. Rather, the two products are chosen because they are the most common artificial and natural Christmas tree purchased in the United States. **Therefore, the conclusions drawn from this study are specific to the modeled natural and artificial tree systems assessed using the previously defined scope and modeling methodologies.** Alternative choices in the scope of the assessment or the life cycle methodologies applied may yield different results.

For example, including the production and use of lights and other tree decorations in this study would lessen the relative (percentage) difference in environmental impacts between the two tree types; the absolute difference will always remain the same[10]. It should also be noted that other environmental health and safety concerns such as toxicity, noise, and land-use are worthy of consideration, but not addressed in this report due to the lack of appropriate LCA-based North American methodologies.

6.1 Conclusions

The study looked at a range of environmental impacts: global warming potential (carbon footprint), primary energy demand, acidification potential, eutrophication potential, and smog potential. The following conclusions are drawn from this LCA and sensitivity analysis.

6.1.1 Artificial Tree

For most commonly purchased artificial Christmas tree, this study found that:

- The overall life cycle global warming potential (carbon footprint) for the most common unlit artificial tree across its lifetime is 18.6 kg CO_2 equivalent. Likewise, the primary energy demand is 305 MJ, acidification potential is 6.15 mol H+ equivalent, eutrophication potential is 4.62E-03 kg N-equivalent, and smog potential is 6.16E-05 kg NOx equivalent.

- The most significant environmental impact (across all categories) is associated with the manufacturing life cycle stage (51-77%);

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[10] This assumes the lights and other tree decorations are the same for both an artificial and a natural tree.

- Within the manufacturing process, the majority of the burden is associated with the production of the tree branches (raw material impacts and process energy) (44-71%);

- Following the production of trees, the transportation of the tree from the point of purchase to the consumer's home is the next most environmentally significant stage of the tree's life cycle (18-46%);

- Use and End-of-Life phase impacts for the unlit tree are small across all impact categories (0-11% combined) when compared to the manufacturing and finished tree to home life cycle stages;

- The longer the consumer keeps an artificial tree, the less significant the annual environmental impact associated with the life cycle of the artificial tree; and

- The electricity consumption during use of 400 incandescent Christmas tree lights during one Christmas season is 55% of the overall Primary Energy Demand impact of the unlit artificial tree studied, assuming the worst-case scenario that the artificial tree is used only one year. For artificial trees kept 5 and 10 years respectively, the PED for using incandescent lights is 2.8 times and 5.5 times that of the artificial tree life cycle (refer to Section 4.12).

6.1.2 Natural Tree

For the most commonly purchased natural Christmas tree, this study found that:

- The overall impacts of the natural tree are significantly influenced by the chosen End-of-Life treatment. Each End-of-Life treatment re-releases and sequesters varying amounts of carbon dioxide that was initially taken up into the biomass during tree growth (refer to Sections 3.2.4.1, 3.2.4.2, and 3.2.4.3);

- The overall life cycle global warming potential (carbon footprint) for the most common unlit natural tree across its lifetime therefore ranges between -3.13 kg CO_2 equivalent (if landfilled) and 5.12 kg CO_2 equivalent (if incinerated). Likewise, the EoL-dependent range of other impacts for the natural tree life cycle across the other impacts evaluated is 50.6-93.4 MJ primary energy demand, 0.94-1.09 mol H+ equivalent acidification potential, -0.00218-0.00397 kg N-equivalent eutrophication potential, and 1.15E-05-8.48E-06 kg NOx equivalent smog potential.

- The natural tree cultivation phase is a nitrogen and carbon sink, therefore a net benefit for eutrophication potential and global warming potential (carbon footprint), respectively. This is because during tree growth, the natural tree absorbs nitrogen from the soil and carbon dioxide from the air;

- The downstream life cycle phases determine if the overall life cycle of the natural tree is a nitrogen or carbon sink, or conversely, a nitrogen or carbon source;

- The tree stand is a significant contributor to the overall impact of the natural tree life cycle with impacts ranging from 3% to 41% depending on the impact category and End-of-Life disposal option (refer to Table 23);

- The transport distance traveled to purchase the annual Christmas tree is a significant factor in the tree's overall life cycle; and

- The life cycle Primary Energy Demand impact of the natural tree is 1.5 - 3.5 times less (based on the End-of-Life scenario) than the use of 400 incandescent Christmas tree lights during one Christmas season.

6.1.3 Artificial Tree vs. Natural Tree

When comparing the most commonly purchased artificial to the most commonly purchased natural Christmas tree, this study found that:

- The break-even years to keep an artificial tree, such that the impacts are comparable to the natural tree purchased annually, is dependent on the End-of-Life option for the natural tree and the environmental impact category investigated;

- The break-even number of years to keep an artificial tree is less than 9 years for all End-of-Life scenarios and impact categories, except for global warming potential when comparing against landfilled natural trees, and eutrophication potential when comparing against composted or incinerated natural trees as the natural tree is always preferred for these criteria.);

- If the natural tree is incinerated or composted, the natural tree always has a smaller eutrophication potential than the artificial tree;

- If the natural tree is landfilled, the natural tree always has a smaller global warming potential than the artificial tree for the baseline scenario (2.5 mile one-way car transport). In other words, there is no break-even distance for the landfilled natural tree;

- The break-even number of years for Global Warming Potential is 3.6 and 4.0 years for an incinerated and composted natural tree, respectively. In other words, if the artificial tree is kept more than 4 years, the Global Warming Potential associated with the artificial tree is less than a natural tree purchased every year for more than 4 years; and

- The impact of the tree life cycle, for all scenarios, is less than 0.1% of a person's annual carbon footprint and therefore is negligible within the context of the average American's lifestyle.

6.2 Recommendations

Based on the findings of this LCA and sensitivity analysis it is recommended that:

- Consumers who purchase artificial trees should keep the tree for several years or donate their old trees when they want to upgrade to a newer model.

- Because the differences in environmental impact between natural and artificial trees are heavily influenced by consumer car transportation, environmentally-conscious consumers should focus on minimizing car travel rather than choosing their tree type based upon its production method.

    - Consumers should carpool, combine errands into fewer trips, and otherwise attempt to minimize unnecessary car travel. Carpooling is highly recommended to reduce environmental impact when driving to pick up a natural tree at a distant location.

    - Mail-order/delivery of natural or artificial Christmas trees can replace inefficient car usage with efficient truck and rail transportation.

- Next steps could consider if there is an environmental benefit for individuals who purchase natural trees to reuse their tree material as mulch or in other applications after the holiday season in order to gain additional benefit from past-season Christmas trees before their ultimate disposal and decomposition.

- Consumers who wish to celebrate the holidays with a Christmas tree should do so knowing that the overall environmental impacts of both natural and artificial trees are extremely small when compared to other daily activities such as driving a car. Neither natural nor artificial Christmas tree purchases constitute a significant environmental impact within most American lifestyles.

7 APPENDIX - CRITICAL REVIEW REPORT

Peer Review Committee Summary

Comparative Life Cycle Assessment of an Artificial Christmas Tree and a Natural Christmas Tree

Performed by thinkstep for the American Christmas Tree Association

Peer Review Committee[11]:

H Scott Matthews, Chair (Carnegie Mellon University)
Mike Levy (American Chemistry Council, Plastics Division)
Eric Hinesley (North Carolina State University)

Background

The committee was delivered a copy of this report (as well as a draft press release for the client) on September 28, 2010. This document summarizes the individual and collective comments of the committee about this Life Cycle Assessment.

The report primarily focuses its review comments into the following categories, as detailed below.

- Is the methodology consistent with ISO 14040/14044?
- Are the objectives, scope, and boundaries of the study clearly identified?
- Are the assumptions used clearly identified and reasonable?
- Are the sources of data clearly identified and representative?
- Is the report complete, consistent, and transparent?
- Are the conclusions appropriate based on the data and analysis?

Overview

The committee finds the submitted report to be of high quality in terms of documentation and modeling. All areas that were problematic in previous drafts seem to be updated. It is ready for public release. The Peer Review Committee's comments were also aimed to ensure the press release for public use is consistent with the findings in the full report. We have thus made several final recommendations to ensure that thinkstep's work is adequately represented.

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[11] Members of the committee were not engaged or contracted as official representatives of their organizations and acted as independent expert peer reviewers.

Methodology and Goal/Scope Comments

- Is the methodology consistent with ISO 14040/14044?

The committee finds that the study is consistent with the ISO LCA standard. While there are minor issues, as noted below, it adequately represents a cradle to grave comparative assessment of two product systems.

- Are the objectives, scope, and boundaries of the study clearly identified?

The committee finds that these issues are clearly identified. Within this overall issue we have considered whether the goal and scope unambiguously state the following:

- Reasons for carrying out the study
- Intended application and audience of the study

ACTA is an industry group comprised of artificial tree manufacturers. It is expected that the study will be released and marketed to the public (and be part of a press release and presumably an information campaign).

- Whether the results will be used in comparative assertions intended to be disclosed to the public

The study presumes to support comparative assertions intended for public release, and is written as such, and has engaged an external review panel.

The committee also assessed whether the goal and scope clearly describe:

- The function and system boundaries of the product systems to be compared

The function and system boundaries are explicit. A comparison such as this one that is rooted in tradition and personal preferences is difficult. However the study notes this limitation and capably makes a comparison of tress that are not otherwise equal. It instead compares the most popular of each type.

- The functional unit and allocation procedures to be used

The functional unit (using one of each tree type for one year – and associated 1, 5, 10 year comparisons) is explicit in the study. Likewise the allocation methods have been sufficiently detailed.

- The LCIA methodology and types of impacts to be analyzed

The Life Cycle Impact Assessment (LCIA) method, TRACI, is sufficiently documented. The rationale behind the impact measures chosen is clearly stated.

- The data quality requirements

The data quality requirements are explicitly provided, as is a discussion on uncertainty.

- The values choices, and limitations of the study

There are no issues associated with values choices given the limited LCIA effort done. There are significant limitations to this study, and they are carefully discussed.

Study Assumption and Conclusion Comments

The committee assessed how the study has been conducted and reported, using the following categories.

- Are the assumptions used clearly identified and reasonable?

The committee finds that the report has been well written and that the assumptions are reasonable. As noted above, the report openly says that it is impossible to compare completely identical natural and artificial trees. While this is a tough assumption to make, the committee agrees it is appropriate and possibly the only option to do such an analysis. Similarly, the end of life (EOL) phase considers all options.

- Are the sources of data clearly identified and representative?

The committee finds that data sources have been very well and clearly identified. Ideally, the manufacturing data for artificial trees would come from multiple plants to identify potential variability. However since the plant studied is the major source for the type of artificial tree modeled, the data is appropriate and relevant.

Likewise since the natural tree studied is produced in various locations with different agricultural practices, it is hard to gather appropriate data and build models. We feel the authors have done a credible job at mixing available data sources and maintaining a representative model.

- Is the report complete, consistent, and transparent?

The report is complete, consistent and transparent. We are pleased to see several sections adding important context to the choice of a tree, and that even the press release mentions these factors.

- Are the conclusions appropriate based on the data and analysis?

The conclusions are appropriate.

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9 APPENDIX - DESCRIPTION OF AGRARIAN MODEL

The agrarian model was developed to address the complexity of assessing the environmental impact of agriculture-based products. Complications arise because clients are often not able to provide agriculture specific processes, reliable agro-databases for industry are missing, data collection is expensive and the concept of "average" dataset is difficult to define for most agricultural products. Unlike industrial processes, agrarian systems have no technically determined border to the environment, have a complex and indirect dependence of outputs (harvest, emissions) from the input (fertilizers, location conditions, etc.), vary by climatic region, and vary by soil type (location dependent). Additionally, there are large quantities of farms with a variety of agricultural practices subject to annual weather variation, and variation in pests, parasites, diseases and weeds.

To address these complications and provide a robust method for estimating the environmental impact of agrarian systems, a model for agrarian and plantation processes was developed and implemented in the GaBi software.

The agrarian model:

- ► Can model different locations worldwide farming systems; it accounts for:
    - Variations in rainfall and temperature, soil;
    - Chemical fertilizer and manure use ;
    - Use of agrochemicals (pesticides, herbicides, fungicides, etc.); and
    - Mechanical operations (ploughing, seeding, harvesting, irrigation, etc.).
- ► Covers a range of environmental issues:
    - Considers land use changes (deforestation, slash and burn);
    - Carbon sequestration (the carbon balance is properly assessed); and
    - Covers impacts such as eutrophication, which play a major role in agricultural production systems.
- ► The model is technically robust and comprehensive; accounting for:
    - All renewable energy in the biomass (particularly relevant for crops grown for energy);
    - Emissions from erosion, fire clearing and background emissions (soil emissions that would occur whether a crop was planted or not); and
    - The balance of nutrient transfers within crop rotations and the use of cover crops.

- ► The model also accounts for the nitrogen cycle. This is the most complex aspect of the model and affects a number of key emissions having environmental relevance in most LCA studies including NO^{3-} in water and N_2O, NO and NH_3 into air:
  - Many forms of N involved;
  - N-based emissions affect several important impact categories;
  - Small differences of input can lead to large variations in LCA-relevant emissions and outputs;
  - Important balance numbers are known only imprecisely; and
  - Coupled over mass balance.
- ► The model also accounts for time dependent features such as rainfall and fertilizer application during parts of the plant growth cycle**.**
- ► The model accounts for storage of renewable energy in the biomass and carbon dioxide uptake in the biomass:
  - The product bound CO_2 has directly to be accounted as 100% on the input side comparable to CO_2 emissions into air on the output side;
  - The CO_2 quantities from renewables emitted during later stages in the life cycle (e.g. burning, composting,…) have to be accounted as emissions to air;
  - This means, over the life cycle all bound CO_2 is released as CO_2 at a later stage; (However, if landfilled, the carbon sequestered may not be re-released within the 100 year timeframe of global warming potential indicators.)
  - Other carbon emissions (e.g. CH_4 and CO) during biomass production, conversion and End-of-Life are considered as well; and
  - The storage of renewable energy (e.g. sun-light) in agro-products is considered as “lower calorific value” on the input side.

10 APPENDIX - LCIA DESCRIPTIONS

Life Cycle Impact categories included in this report were based on Impact categories and methods appropriate for use in North America. The current state of the science of life cycle impact methodology consists of the US EPA TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts) impact assessment methodology. The following is a summary description of the methods and applicable references.

TRACI Impact Categories referenced in this report:

- Acidification
- Eutrophication
- Global Warming
- Photochemical Smog

Primary energy demand (PED) is not included in the TRACI methodology but is a measured quantity. A detailed description PED and of the TRACI impact categories used in this report are described below.

10.1 Primary Energy Demand

Primary energy demand (PED) is a measure of the total amount of primary energy associated with the product. This is a measure of both the “feedstock energy” within the product (energy which would be released upon combustion) plus all other energy used during the product lifecycle. PED can be 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. From an environmental standpoint, the energy demand for non-renewable resources is more important than the total primary energy demand which includes renewable resources. The unit system used for PED is MJ (mega joules).

10.2 Acidification Potential

Acidification refers literally to processes that increase the acidity (hydrogen ion concentration) of water and soil systems. The common mechanism for acidification is deposition of negatively charged ions (anions) that are then removed via leaching, or biochemical processes, leaving excess (positive) hydrogen ion concentrations (H+) in the system. The major acidifying emissions are oxides of nitrogen (NOx) and sulfur dioxide (SO2), as well as ammonia emissions that lead to ammonium deposition. Acid rain generally reduces the alkalinity of lakes; changes in the alkalinity of lakes, related to their acid neutralizing capacity (ANC) are used as a diagnostic for freshwater systems analogous to the use of H+ budgets in terrestrial watersheds (Schlesinger 1997). Acid deposition also has deleterious (corrosive) effects on buildings, monuments, and historical artifacts.

The stressor-effects for acidification have three stages. Emissions lead to deposition (via a complex set of atmospheric transport and chemistry processes), which in turn can lead to a variety of site-dependent ecosystem impacts – damages to plant and animal populations (via a complex set of chemical and ecological processes). Deposition occurs through three routes: wet (rain, snow, sleet, etc.), dry (direct deposition of particles and gasses onto leaves, soil, surface water, etc.) and cloud water deposition (from cloud and fog droplets onto leaves, soil, etc.).

As described in Norris (2002), the acidification model in TRACI makes use of the results of an empirically calibrated atmospheric chemistry and transport model to estimate total North American terrestrial deposition of expected H+ equivalents due to atmospheric emissions of NOx and SO2, as a function of the emissions location.

The resulting acidification characterization factors are expressed in H+ mole equivalent deposition per kg emission. Characterization factors take account of expected differences in total deposition as a result of the pollutant release location. Factors for acidification are available for each US state. In many LCIA applications the location of the emission source will be known with less precision than the state level for processes within the Life Cycle Inventory. Therefore, additional characterization factors were developed for each of four US regions, for two larger regional divisions (either east or west of the Mississippi river), and for the US as a whole. For each of these larger regions, the composite factor was created using an annual emissions-weighted average of its constituent states.

As reported in (Norris 2002), regional characterization factors range from roughly 20% of the US average to 160% of the US average, and deviation from the US average is variable between SO2 and NOx; that is, the effect of source region upon a characterization factors' deviation from the national average values varies somewhat between SO2 and NOx. Although the majority of acidic deposition in North America stems from emissions of NOx (NO and NO2) and SO2 (including SOx as SO2), significant amounts are also due to emissions of ammonia, and trace amounts from emissions of HCl, and HF. TRACI adopts US average characterization factors for these trace emissions, based on their H+ formation potentials per kg emitted in relation to SO2.

The benefits of the new TRACI method for characterization of acidifying emissions, relative to prior non-regionalized method like Heijungs et al. (1992), are the increased ability for LCIA results to take into account location-based differences in expected impact. These benefits stem from the fact that the TRACI acidification factors pertain to a focused midpoint within the impact chain – total terrestrial deposition -- for which there is considerable, well-understood, and quantifiable variability among source regions.

There are at least two ways in which the regional variability in deposition potential can have an impact on the acidification potential. In the event that the alternatives have their processes (and thus their emissions) clustered in different regions, the overall deposition potentials for both SO2 and NOx can vary by as much as a factor of 5 or more (see Norris 2002). Another possibility is that the alternatives have their processes predominantly clustered in the same regions. If this is the case, then the relative deposition potentials of a kg of NOx versus SO2 emissions can vary by nearly a factor of two from one region to another. In this instance, using the region-appropriate characterization factors may be important to the overall study outcome.

The modeling stops at the midpoint in the cause-effect chain (deposition) because in the US there is no regional database of receiving environment sensitivities (as is available in Europe). Thus, the source region-based variability in total terrestrial deposition has been captured, but not the receiving region-based variability in sensitivity or ultimate damage. Future advances of the TRACI acidification method may address regionalized transport and deposition of ammonia emissions, and investigate the potential to account for regional differentiation of receiving environment sensitivities.

Units of Acidification Results: H+ moles equivalent deposition/kg emission

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10.3 Eutrophication Potential

“The most common impairment of surface waters in the US is eutrophication caused by excessive inputs of phosphorus (P) and nitrogen (N). Impaired waters are defined as those that are not suitable for designated uses such as drinking, irrigation, by industry, recreation, or fishing. Eutrophication is responsible for about half of the impaired lake area, 60% of the impaired rivers in the US, and is also the most widespread pollution problem of US estuaries” (Carpenter et al, 1998).

Eutrophication means fertilization of surface waters by nutrients that were previously scarce. When a previously scarce (limiting) nutrient is added, it leads to proliferation of algae. This may lead to a chain of further consequences, potentially including foul odors or taste, death or poisoning of fish or shellfish, reduced biodiversity, or production of chemical compounds toxic to humans, marine mammals, or livestock. The limiting nutrient issue is key to characterization analysis of P and N releases within LCIA. If equal quantities of N and P are released to a freshwater system that is strictly P-limited, then the characterization factors for these two nutrients should account for this fact (e.g., the characterization factor for N should approach zero in this instance).

Prior to utilization of TRACI, it is important to determine the actual emissions that will be transported into water. As an example, fertilizers are applied to provide nutrition to the vegetation that covers the soil and therefore, only the run-off of fertilizer makes it into the waterways. The over-application rate is highly variable and may depend on soil type, vegetation, topography, and even the timing of the application relative to weather events. The TRACI characterization factors for eutrophication are the product of a nutrient factor and a transport factor. The nutrient factor captures the relative strength of influence on algae growth in the photic zone of aquatic ecosystems of 1 kg of N versus 1 kg of P, when each is the limiting nutrient. The location or context-based “transport factors” vary between 1 and zero, and take account of the probability that the release arrives in an aquatic environment (either initially or via air or water transport) to which it is a limiting nutrient. The TRACI characterization method for eutrophication is described in more detail in the companion paper (Norris 2002).

The characterization factors estimate the eutrophication potential of a release of chemicals containing N or P to air or water, per kg, relative to 1 kg N discharged directly to surface freshwater. The regional variability in the resulting eutrophication factors shows that the source location will influence not only the relative strength of influence for a unit emission of a given pollutant, but it will also influence the relative strength of influence among pollutants. The benefits of the new TRACI method for characterization of eutrophying emissions, relative to a prior non-regionalized method like Heijungs et al. (1992) are increased ability for life cycle impact assessment results to take into account the expected influence of location on both atmospheric and hydrologic nutrient transport, and thus the expected influence of release location upon expected nutrient impact. The combined influence of atmospheric transport and deposition along with hydrologic transport can lead to total transport factors differing by a factor of 100 or more (Norris 2002).

As with both acidification and photochemical oxidant formation, TRACI provides characterization factors for nine different groups of US states which are known as Census Regions, (see, for example, http://www.eia.doe.gov/emeu/reps/maps/us_census.html) for eastern and western regions, and for the US as a whole, for use when the location of the release is not more precisely known. For each of these larger regions, the composite factor was created using an average of those for its constituent states.

Units of Eutrophication Results: Nitrogen equivalents/kg emission

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10.4 Global Warming Potential

Global climate change refers to the potential change in the earth's climate caused by the build-up of chemicals (i.e. "greenhouse gases") that trap heat from the reflected sunlight that would have otherwise passed out of the earth's atmosphere. Since pre-industrial times atmospheric concentrations of CO_2, CH_4, and N_20 have climbed by over 30%, 145% and 15%, respectively. While "sinks" exist for greenhouse gases (e.g. oceans and land vegetation absorb carbon dioxide), the rate of emissions in the industrial age has been exceeding the rate of absorption.

Simulations by researchers within the research community of global warming are currently being conducted to try to quantify the potential endpoint effects of these exceedences, including increased droughts, floods, loss of polar ice caps, sea level rise, soil moisture loss, forest loss, change in wind and ocean patterns, changes in agricultural production, decreased biodiversity and increasing occurrences of extreme weather events.

TRACI uses Global Warming Potentials (GWPs) - a midpoint metric. The global warming potentials (GWPs) are based on recommendations contained within the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) (IPCC 2001) to adhere to the international agreement by parties of the United Nations Framework Convention on Climate Change (UNFCCC) (FCCC 1996) (EPA 2004):

The 100-year time horizons are recommended by the IPCC and are used by the US for policy making and reporting, (EPA 2004) and are adopted within TRACI. The final sum, known as the Global Warming Index (GWI), indicates the potential contribution to global warming.

Units of Global Warming Potential Results: CO_2 equivalents/kg emission

References

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10.5 Photochemical Smog Creation Potential

Ozone (O3) is a reactive oxidant gas produced naturally in trace amounts in the earth's atmosphere. Rates of ozone formation in the troposphere are governed by complex chemical reactions, which are influenced by ambient concentrations of oxides of nitrogen (NOx), volatile organic compounds (VOCs), the mix of OCs, temperature, sunlight, and convective flows. In addition, recent research in the Southern Oxidants Study (e.g., Chameides and Cowling 1995) indicates that carbon monoxide (CO) and methane (CH4) can play a role in ozone formation.

There are over 100 different types of VOC emitted to the atmosphere, and they can differ by more than an order of magnitude in terms of their estimated influence on photochemical oxidant formation (e.g., [Carter 1994]). Further complicating the issue is the fact that in most regions of the US, ambient VOC concentrations are due largely to biological sources (trees). For example, in urban and suburban regions of the US at midday, biogenic VOCs can account for a significant fraction (e.g., 10-40%) of the total ambient VOC reactivity (NRC 1991). In rural areas of the eastern US, biogenic VOCs contribute more than 90% of the total ambient VOC reactivity in near-surface air.

Ozone in the troposphere leads to detrimental impacts on human health and ecosystems. The mid-point associated with photochemical oxidant formation is the formation of ozone molecules (O3) in the troposphere.

Conventional smog characterization factors for LCIA have been based on European modeling of the relative reactivities among VOCs, and have neglected NOx entirely. This neglect of NOx is a highly significant omission: throughout the past decade, numerous US studies have found spatial and temporal observations of near-surface ozone concentrations to be strongly correlated with ambient NOx concentrations, and more weakly correlated with anthropogenic VOC emissions (see, for example, NRC 1991, Cardelino and Chameides 1995). Another omission in all existing smog characterization factors has been the potential influence of emission location.

The approach to smog characterization analysis for VOCs and NOx in TRACI has the following components: (1) relative influence of individual VOCs on smog formation; (2) relative influence of NOx concentrations versus average VOC mixture on smog formation; (3) impact of emissions (by release location) upon concentration by state; and (4) optional methods for aggregation of effects among receiving states – either by area or population-weighted area.

To characterize the relative influence on O3 formation among the individual VOCs, Carter's latest maximum incremental reactivity calculations are used (Carter 2000). These reflect the estimated relative influence for conditions under which NOx availability is moderately high and VOCs are at their most influential upon O3 formation. For the relative influence of NOx emissions in comparison to the base reactive organic gas mixture a mid-range factor of 2 is used, which is in agreement with empirical studies on regional impacts for the eastern US (e.g., Cardelino and Chameides 1995), and is at the middle of a range of model-based studies (Rabl and Eyre 1997, Seppälä 1997).

The influence of NOx emissions upon regional ambient levels has been modeled using source/receptor matrices that relate the quantity of seasonal NOx emissions in a given source region to changes in ambient NOx concentrations in each receiving region across North America. These source/receptor matrices were obtained from simulations of the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model (Shannon 1991, 1992, 1996). Source and receptor regions are the contiguous US states, plus Washington, D.C., plus the 10 Canadian Provinces, plus northern Mexico. Recent empirical research (e.g., St. John et al. 1998, Kasibhatla et al. 1998) shows that average O3 concentrations exhibit strong and stable correlations with regional ambient NOx concentrations.

The assumption was made that VOC emission impacts on regional O3 concentrations have the same spatial distribution as the ambient NOx concentration impacts (i.e., similar regional transport for VOCs and NOx). Finally, the outcome of the source/transport modeling is proportional to estimated O3 concentration impacts (g/m2) per state, given an assumed linear relationship between the change in concentration in NOx (with VOC-concentrations converted to NOx equivalents).

Finally there is the question of how to aggregate the effects of estimated changes in smog concentration by state. Exposures leading to human health impacts will be related to the product of state level ambient concentrations times state populations, assuming uniform population density within a state, assuming linear relationship between dose and risk of impact. Damages from impacts on forest and agricultural productivity are related in part to the scale of sensitive agricultural and forest output per state. In the present version of TRACI, human health impacts are addressed, scaling the state level concentration outcomes by state population before aggregating across states. The TRACI method for photochemical oxidant formation is described in more detail in the companion paper (Norris 2002).

Units of Smog Formation Results: kg NOx equivalents/kg emission

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