Life cycle assessment of Endless stair

1 Project description

The American Hardwood Export Council (AHEC) has managed the project 'Endless Stair' for their latest London Design Festival. Endless Stair, a towering structure composed of 15 Escher-like interlocking staircases made from American tulipwood cross laminated timber (CLT), was showcased at the entrance to Tate Modern from 13th September – 10th October 2013.The Endless Stair at the London Design Festival has been initiated and managed by the American Hardwood Export Council (AHEC). A towering structure composed of 15 Escher-like interlocking staircases made from American tulipwood cross laminated timber (CLT), Endless Stair is being showcased at the entrance to Tate Modern from 13th September to 10th October 2013.

The Life Cycle Assessment (LCA) of the Endless Stair builds on a two-year study, commissioned by AHEC and undertaken by PE INTERNATIONAL, to gather life cycle inventory data and assess environmental impacts associated with delivery of U.S. sawn hardwood into world markets. The study was carried out in compliance with ISO 14040 and ISO 14044 for LCA. The study involved an in-depth review of hardwood forestry and processing practices and a survey of the hundreds of U.S. companies engaged in the manufacture and export of hardwood products.

The LCA study of American sawn hardwood covered 19 species representing more than 95% of the hardwood harvested in the US by volume and more than 95% of the wood volume exported by AHEC members. In accordance with ISO requirements, the study was subject to critical review by an independent expert panel. The panel concluded that the substantial share of primary data collected ensured representative results for the US hardwood industry.

Potential environmental impacts of the Endless Stair have been studied applying the life cycle assessment (LCA) method. The full life cycle model has been built up in the GaBi 6 software system and databases by PE INTERNATIONAL. Results have been calculated using the CML impact assessment methods.The LCA of the Endless Stair combined life cycle inventory data on American sawn tulipwood from the earlier study with data gathered on-site during the process to fabricate and install the structure in Europe. This includes data collected during CLT production at Imola Legno in Italy, the fabrication of the stairs at Nüssli in Switzerland, and the installation at Tate Modern in London.

The full life cycle model was built using PE INTERNATIONAL's GaBi 6 software system and databases. Environmental impacts for the Endless Stair were calculated using the CML impact assessment methods. PE INTERNATIONAL's GaBi Envision modelling tool has been used to visualise impacts at different process stages. GaBi Envision also provides a mechanism to assess how alterations in certain parameters (such as timber types, kilning methods, transport scenarios) will influence overall impacts.

In addition to demonstrating the potential of tulipwood CLT, the Endless Stair forms part of AHEC's efforts to promote a more scientifically oriented approach to environmental issues in material specification and green building.

2 Life cycle assessment

Life cycle assessment (LCA) is a standardized scientific method for systematic analysis of flows (e.g. mass and energy) associated with the life cycle of a specified product, technology, service or manufacturing process system (ISO 2006). The approach aims at a holistic and comprehensive analysis of raw materials acquisition, manufacturing as well as use and End-of-Life (EoL).

According to the International Organization for Standardization (ISO) 14040/44 standard, an LCA study consists of four phases: (1) goal and scope; (2) life cycle inventory; (3) life cycle impact assessment; and (4) interpretation (ISO 2006).

The goal and scope stage of LCA outlines the rationale and anticipated use of the results of the study. It defines the systems' boundary in terms of technological, geographical, and temporal coverage, the attributes of the product system, and the level of detail and the complexity to be addressed. This stage also sets out data requirements and assumptions and other similar technical specifications.

The life cycle inventory (LCI) stage qualitatively and quantitatively analyses, for the product system being studied, the materials and energy used (inputs) as well as the products and by-products generated, the emissions into the environment, and the wastes to be treated (outputs).

A typical LCI contains a large quantity of data for a specific functional unit (such as a tonne of material or a defined structure like the Endless Stair). Data includes, for example, how many tonnes of material were required to make each functional unit, how many litres of oil are burnt to transport each functional unit, and how much pollutant is emitted to the atmosphere during the manufacture of each functional unit. There may also be data showing how much of each functional unit ends up in landfill, or is recycled or burnt at EoL.

The next stage, Life Cycle Impact Assessment, determines the extent to which each of these data items contributes to the various environmental "impact categories" such as global warming, acidification, or water pollution.

The final stage of LCA involves “interpretation”. The LCA may be used to understand and monitor potential environmental impacts of the product being studied. It may also be used to improve production or product performance by focusing on the identified “hot-spots” of the life cycle.

3 System boundaries

The following phases of the product life cycle have been analyzed:

Hardwood: production of the American tulipwood lumber including forestry, sawing, drying and transport processes in between;

Transport to Europe: transport of lumber to port (by truck), to Italy (by ship) and to ImolaLegno production site by truck (Imola);

Glue for CLT: production of edge glue (vinyl based) and face glue (epoxy resin based) for CLT,

Transport of glues for CLT: transport of edge and face glues by truck to ImolaLegno;

CLT ImolaLegno: Manufacturing of CLT considering also electricity consumption (a significant part from photovoltaic) and wooden waste recovery in on-site boiler;

Transport to Nussli: transport of CLT by truck from Italy to Nussli site in Switzerland;

Glues, metals, coatings etc: production of all other materials and components needed for the Endless stair structure, such as glue, coating, screws, nuts, bolts, concrete blocks, handrail and anti slip;

Transport of glues, metals, coatings etc: transport of all components by truck to Nussli manufacturing site;

Nussli: construction of the endless stair structure (stairs, balustrades, pillars) using CLT and all other materials/components. Electricity consumption and wood waste recovery for heating are also considered;

Transport to London: transport of the Endless stair components to the festival in London;

Design festival: construction of the concrete foundation for the Endless stair structure.The following phases of the Endless Stair life cycle have been analysed:

Hardwood: production of the American tulipwood lumber including forestry, sawing, drying and transport at each stage.

Transport to Europe: transport of lumber to port in the U.S. (by truck), to Italy (by ship), and to the Imola Legno production site by truck.

Glue for CLT: production of edge glue (vinyl based) and face glue (epoxy resin based) for CLT.

Transport of glues for CLT: transport of edge and face glues by truck to Imola Legno.

CLT Imola Legno: manufacturing of CLT considering also electricity consumption (a significant part from photovoltaic) and wooden waste recovery in the on-site boiler.

Transport to Nüssli: transport of CLT by truck from Italy to Nüssli site in Switzerland.

Glues, metals, coatings etc: production of all other materials and components needed for the

Endless Stair, such as glue, coating, screws, nuts, bolts, concrete blocks, handrail and anti-slip.

Transport of glues, metals, coatings etc: transport of all components by truck to Nüssli manufacturing site.

Nüssli: construction of the Endless Stair structure (stairs, balustrades, pillars) using CLT and all other materials/components. Electricity consumption and wood waste recovery for heating are also considered.

Transport to London: transport of the Endless Stair components to the London Design Festival.

Design Festival: construction of the 15.75 m3 concrete foundation for the Endless Stair.

4 Impact categories

The LCA study includes the following inventory flows and environmental categories: acidification potential, eutrophication potential, global warming potential, stratospheric ozone depletion, photochemical oxidant creation potential (smog formation), primary energy demand (total and non-renewable sources). In the selected impact categories the CML indicators were calculated.

Acidification Potential (AP)

This is a measure of emissions that cause acidifying effects to the environment. This damages ecosystems, whereby forest dieback is the most well-known impact. Acidification has other damaging effects such as nutrients being washed out of soils or an increased solubility of metals into soils. Unit: kg SO_2-Equiv

Eutrophication Potential (EP)

This is a measure of emissions that cause eutrophying effects to the environment. Eutrophication is the enrichment of nutrients in a certain place. 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. This can lead, among others, to the destruction of the eco-system. Unit: kg Phosphate-Equiv.

Findings: The three most significant issues are the same as for acidification: transport to Europe, hardwood and CLT production. The "worst case" NO_x emissions estimate of the boiler used in Italy makes the CLT production phase even more significant.

Global Warming Potential (GWP)

This 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. Carbon stored in the final product and carbon removals from the atmosphere from biogenic sources are not modeled in this study. Therefore, biogenic carbon dioxide emissions are modeled as carbon neutral (no impact of the GWP) as they are offset by the uptake in biomass. Unit: kg CO_2-Equiv.

Ozone Layer Depletion Potential (ODP)

This is a measure that refers to the thinning of the stratospheric ozone layer as a result of emissions. This effect causes a greater fraction of solar UV-B radiation to reach the surface earths, with potentially harmful impacts to human and animal health, terrestrial and aquatic ecosystems etc. referring trichlorofluoromethane, also called freon-11 or CFC 11. Unit: kg CFC 11-Equiv.

Photochem. Ozone Creation Potential (POCP)

A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and volatile organic compounds (VOC) under the influence of UV light. Unit: kg Ethene-Equiv.

Primary energy demand from renewable and non-renewable resources (PED)

A measure of the total amount of primary energy extracted from the earth. It is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, uranium, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account. Unit: MJ net cal. value

Primary energy demand from non-renewable resources (PED non ren)

A measure of the total amount of non-renewable primary energy extracted from the earth. It is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, uranium, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account. Unit: MJ net cal. value

5 Main findings

The main findings can be summarized as follows:

Carbon footprint of 13.2 tonnes CO2 equivalent excluding carbon storage
The GWP of the Endless Stair, including all processes to extract, transport and process materials, and to fabricate, deliver and install the structure in London, is 13.2 tonnes of CO2 equivalent. This figure includes a significant offset of 9.9 tonnes of CO2 equivalent due to efficient waste management during the CLT production process. However, due to lack of data on the EoL of the Endless Stair, it excludes the biogenic carbon stored in the structure which is estimated at 14.5 tonnes of CO2.

Hardwood processing largest single factor contributing to carbon footprint
Not surprisingly, given that hardwood is by far the most visible component of the Endless Stair, hardwood production processes contribute a significant share of overall environmental impact. These make the single largest contribution to GWP, accounting for emissions of 7.6 tonnes of CO2 equivalent. A large part of this is due to use of electricity during sawing and to power fans during the kiln drying process. GWP during the hardwood lumber production process is significantly mitigated by burning of offcuts and other wood waste which contributes on average 90% of thermal energy production for kilning of hardwoods in the United States.

Efficient waste management significantly reduces some environmental impacts
During manufacturing at Imola Legno and Nüssli, those parts of the hardwood that could not be used in the structure were diverted for alternative products and to produce thermal energy. This use of material in other processes helps to avoid consumption of fossil fuel in other manufacturing systems. As a result, significant environmental savings are achieved in relation to global warming and non-renewable primary energy demand.

The downside of wooden waste energy recovery
Although wooden waste energy recovery reduces the carbon footprint, the NOx emissions of boilers may make a significant contribution to AP and EP. In the current LCA study a “worst case” estimation was used for NOx emissions resulting from wooden waste recovery in Italy to avoid hiding this potential impact.

Environmental impact of transport
Efficient processing and waste management at other stages of the supply has resulted in transport contributing a significant share of the overall impact of the Endless Stair in several impact categories, including AP, EP and GWP. Another factor increasing the role of transport is the relatively limited number of manufacturers capable of producing hardwood CLT and delivering such an innovative one-off exhibition project. This resulted in products having to be moved first to Italy and then to Switzerland before delivery to the UK.

Relatively high proportion of impact due to non-wood materials
A notable feature of the GWP of the Endless Stair is that a relatively high proportion is attributable to materials other than the CLT despite their low visibility. For example, the concrete footings used during installation in London, assumed to be locally sourced, had a GWP of 4.1 tonnes CO2 equivalent (around 260 kg CO2 equivalent per cubic meter). The GWP of all non-wood materials used by Nüssli in Switzerland to assemble the structure was 2.2 tonnes CO2 equivalent. The glues for CLT production also had a relatively significant contribution to GWP of 1.7 tonnes CO2 equivalent. This was due mainly to the need to use epoxy resin for face flue. This glue type would be replaced in industrial applications by polyurethane based glue which has around 30% less GWP and primary energy demand.

Use of solar energy leads to reduced environmental impact
Use of photovoltaic energy for electricity generation during CLT production at Imola Legno made a significant contribution to improved environmental performance across several impact categories.

Acidification Potential highly dependent on sulphur content of marine fuels
A large part of the AP of the Endless Stair is attributable to burning of marine fuels with high sulphur content during shipment from the United States into Europe. The extent to which this impact can be reduced for any materials shipped from overseas is very dependent on international progress to reduce sulphur content. Efforts are being made to progressively tighten requirements under the International Convention for the Prevention of Pollution from Ships (MARPOL). A target has been set that the sulphur content of any fuel oil used on board ships shall not exceed 0.5% from 2020 onwards. This target is a long way from being met internationally and the Endless Stair study uses a figure of 2.7% which is the assumed current global average.

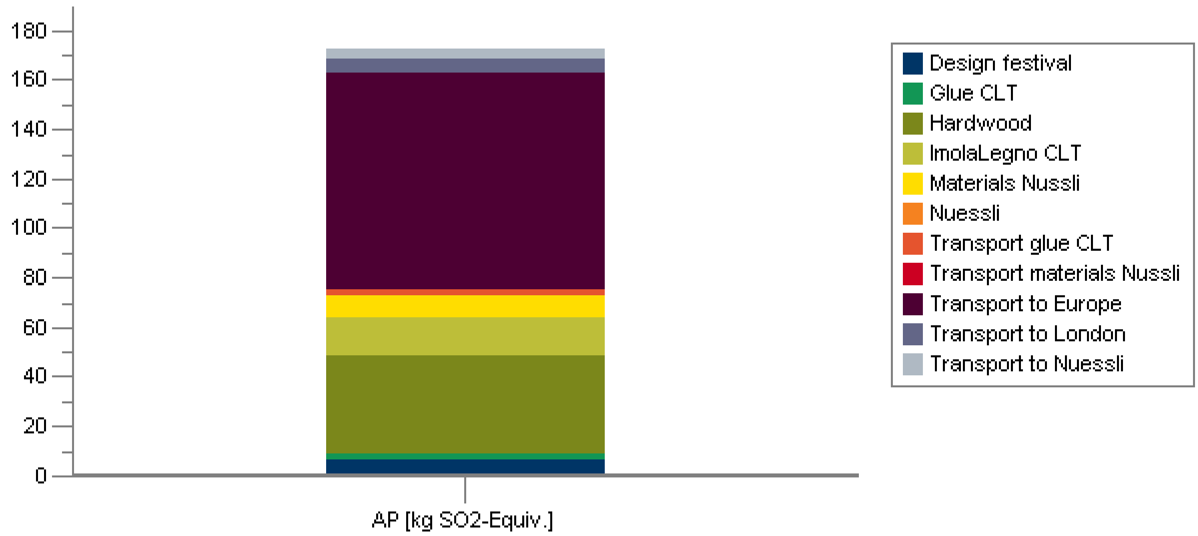
VOCs during drying need further investigation
Hardwood processing is identified as the most significant source of POCP for the Endless Stair. This is due primarily to emission of terpene VOCs during kiln drying. This finding highlights the need for more work to understand the specific impacts of terpene emissions within the context of the U.S. hardwood kilning facilities and the actions required to mitigate these impacts.

6 Overview of results

The following table and graphs describe the results and the contribution of each life cycle phase for different environmental impact categories.

	AP [kg SO2-Equiv.]	EP [kg Phosphate-Equiv.]	GWP [kg CO2-Equiv.]	ODP [kg R11-Equiv.]	POCP [kg Ethene-Equiv.]	PED [MJ]	PED non-ren [MJ]
Total	1,72E02	2,44E01	1,32E04	1,14E-05	4,74E01	1,09E06	1,61E05
Design festival	6,07E00	1,05E00	4,08E03	3,02E-07	7,06E-01	2,13E04	1,96E04
Glue CLT	2,91E00	3,77E-01	1,66E03	2,86E-07	5,54E-01	3,72E04	3,59E04
Hardwood	3,91E01	5,20E00	7,64E03	5,37E-06	4,38E01	9,88E05	1,27E05
ImolaLegno CLT	1,53E01	5,01E00	-9,90E03	2,13E-06	4,25E-01	-1,04E05	-1,59E05
Materials Nussli	9,50E00	6,48E-01	2,24E03	2,53E-06	7,63E-01	3,65E04	3,37E04
Nuessli	-2,22E-01	1,71E-01	-3,90E02	5,87E-07	3,95E-01	3,28E02	-2,58E03
Transport glue CLT	1,90E00	4,33E-01	4,59E02	8,02E-09	-5,96E-01	6,60E03	6,35E03
Transport materials Nussli	6,58E-02	1,58E-02	1,02E01	1,79E-10	-2,67E-02	1,47E02	1,42E02
Transport to Europe	8,76E01	9,22E00	5,86E03	1,40E-07	5,30E00	7,96E04	7,91E04
Transport to London	6,20E00	1,49E00	9,59E02	1,68E-08	-2,51E00	1,38E04	1,33E04
Transport to Nuessli	3,51E00	8,43E-01	5,42E02	9,48E-09	-1,42E00	7,81E03	7,52E03

6.1 Acidification

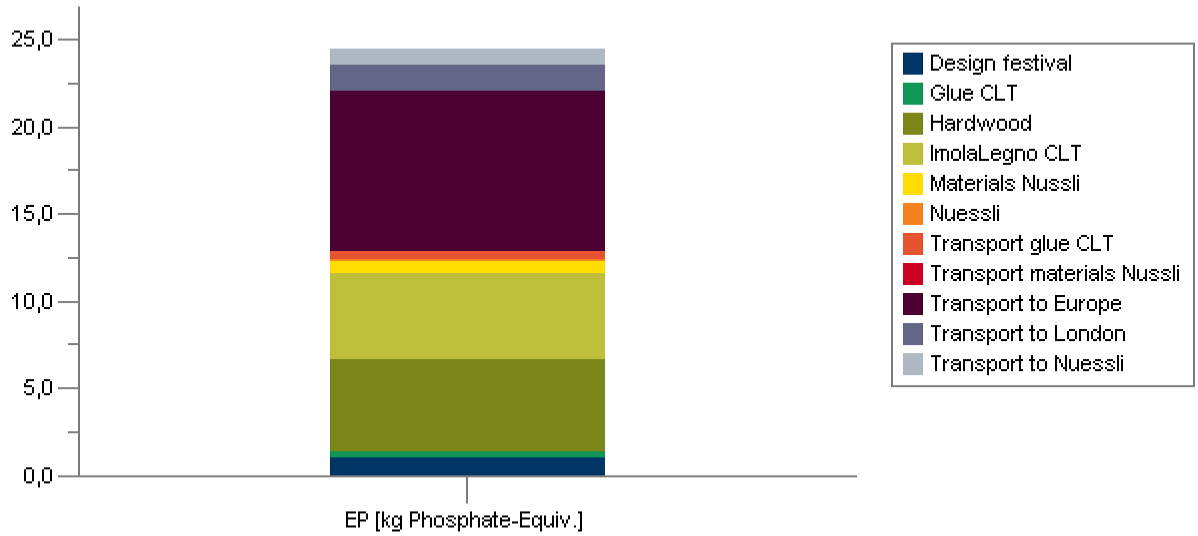


Total Acidification Potential of Endless Stair is 172 kg of SO2 Equivalent. 51% is due to emissions during shipping of tulipwood lumber from the United States to Europe and reflects the relatively high sulphur content of marine fuels. This study assumes sulphur content of 2.7% for the marine fuels used to ship tulipwood lumber from the United States to Italy.

23% of Acidification Potential of the Endless Stair is created during production of hardwoods. This is primarily due to emissions of sulphur dioxide and NOx during production of energy for sawing and kiln drying in the United States.

The 9% of Acidification Potential contributed by CLT production in Italy is due to the assumption of a "worst case" estimate for boiler NOx emissions in Italy.

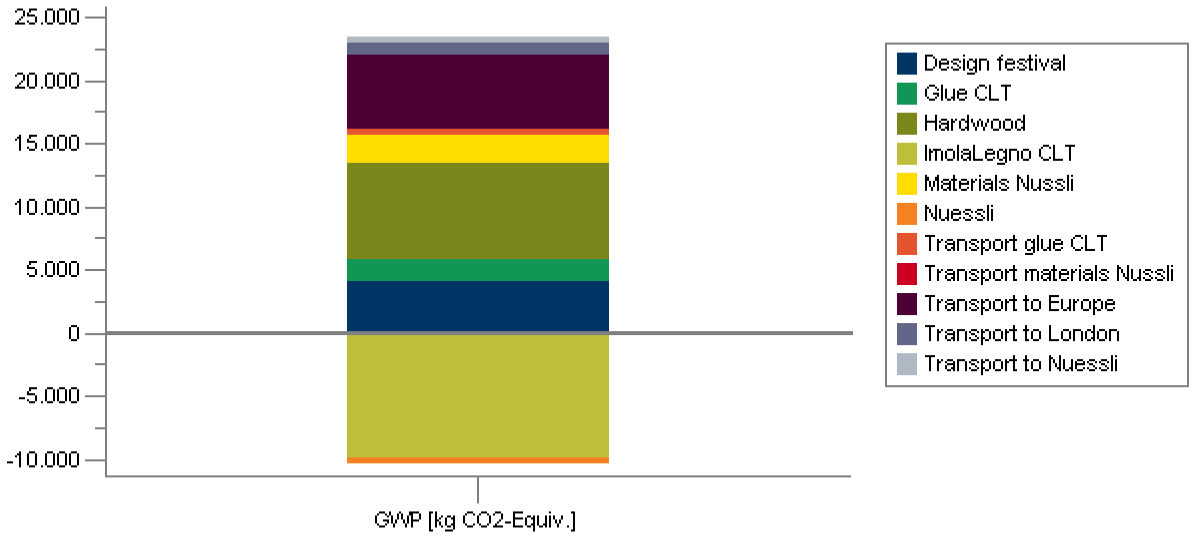
6.2 Eutrophication



Total Eutrophication Potential of the Endless Stair is 24.4kg of phosphate equivalent. Perhaps surprisingly, hardly any of the eutrophication associated with the Endless Stair is linked to the growth of tulipwood. Fertilisers are very rarely used to encourage growth of American hardwoods which thrive under natural conditions. Instead, nearly all eutrophication potential of the structure is due to NOx emissions during burning of fuels for transport and processing of materials.

38% of Eutrophication Potential is created during transport of tulipwood from the kilning location in the United States to Imola Legno in Italy. 20% is created during production of kiln dried sawn lumber in the United States. The "worst case" NOx emissions estimate of the boiler used in Italy makes the CLT production phase relatively significant, also accounting for 20%.

6.3 Global Warming



Hardwood production and transport to Europe (trucks and ship) are the main contributors. The relevant impact of the design festival is caused by the concrete consumption. Materials used to construct the Endless stair in Nussli have significant contribution mainly due to the metal parts (screws). Glues for CLT have more than 10% contribution because of the epoxy resin production for face flue. In Italy a significant avoided burden is considered (negative value) because of the on-site thermal recovery of the wooden waste: the produced energy substitutes the use of natural gas as fuel.Total Global Warming Potential (GWP) of the Endless Stair is 13.2 tonnes of CO2 equivalent. This figure comprises 23.1 tonnes due to emissions during all processes to extract and deliver materials, and to fabricate, deliver and install the structure at Tate Modern in London. This is offset by 9.9 tonnes of avoided GWP during the CLT production process at Imola Legno in Italy because of the on-site thermal recovery of the wooden waste. The energy produced substitutes for the use of natural gas as fuel. There is also a smaller offset of 390 kg of CO2 equivalent during the fabrication process at Nüssli, also due to diversion of waste materials to other processes.

It is estimated that about 14.5 tonnes of CO2 equivalent is stored in the CLT within the Endless Stair. However, due to lack of data on the EoL of the structure, this is not credited in the GWP of the structure.

The largest single contribution to GWP is at the hardwood processing stage which accounts for emissions of 7.6 tonnes of CO2 equivalent. A large part of this is due to use of electricity during sawing and to power fans during the kiln drying process. GWP during the hardwood lumber production process is significantly mitigated by burning of offcuts and other wood waste which contributes on average 90% of thermal energy production for kilning of hardwoods in the United States.

The fact that tulipwood is a relatively quick-drying hardwood species, requiring no more than 6 to 10 days in the kiln (compared to several months in the case of oak for example) means that GWP for tulipwood lumber is relatively low compared to other hardwoods.

The transport of tulipwood lumber from the kilning location in the United States to Imola Legno in Italy, including 880km by road and 7735 km by ship across the Atlantic into the Mediterranean, contributed 5.9 tonnes of CO2 equivalent.

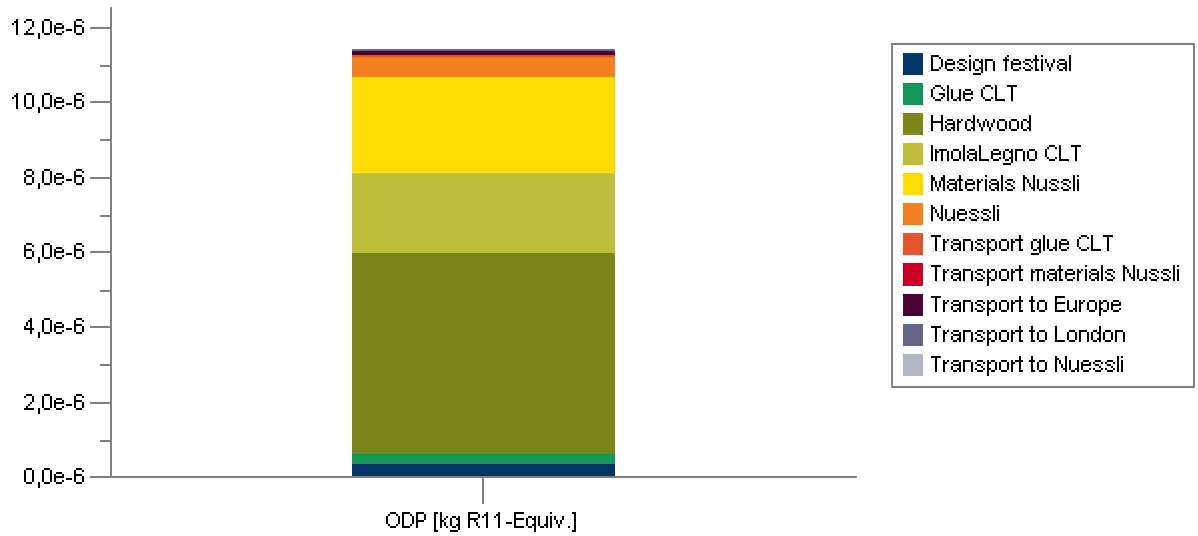
A further 1.5 tonnes CO2 equivalent was due to transport of CLT from Italy to Switzerland for fabrication and of the finished elements from Switzerland to London. Transport distances in Europe were increased due to the relatively limited number of manufacturers capable of producing hardwood CLT and delivering such an innovative one-off exhibition project.

A notable feature of the GWP of the Endless Stair is that a relatively high proportion is attributable to materials other than the CLT despite their low visibility. The 15.75 m3 of concrete footings used during installation in London, for which all materials are assumed to be locally sourced, had a GWP of 4.1 tonnes CO2 equivalent (around 260 kg CO2 equivalent per cubic meter). For comparison, the GWP (without stored carbon) of the 23m3 of tulipwood CLT at point of despatch from the Imola Legno facility in Italy was 5.8 tonnes CO2 equivalent (around 250kg CO2 equivalent per cubic meter).

The GWP of all non-wood materials used by Nüssli in Switzerland to assemble the structure was 2.2 tonnes CO2 equivalent. The metal screws made the largest contribution at this stage, but glues and coatings were also significant.

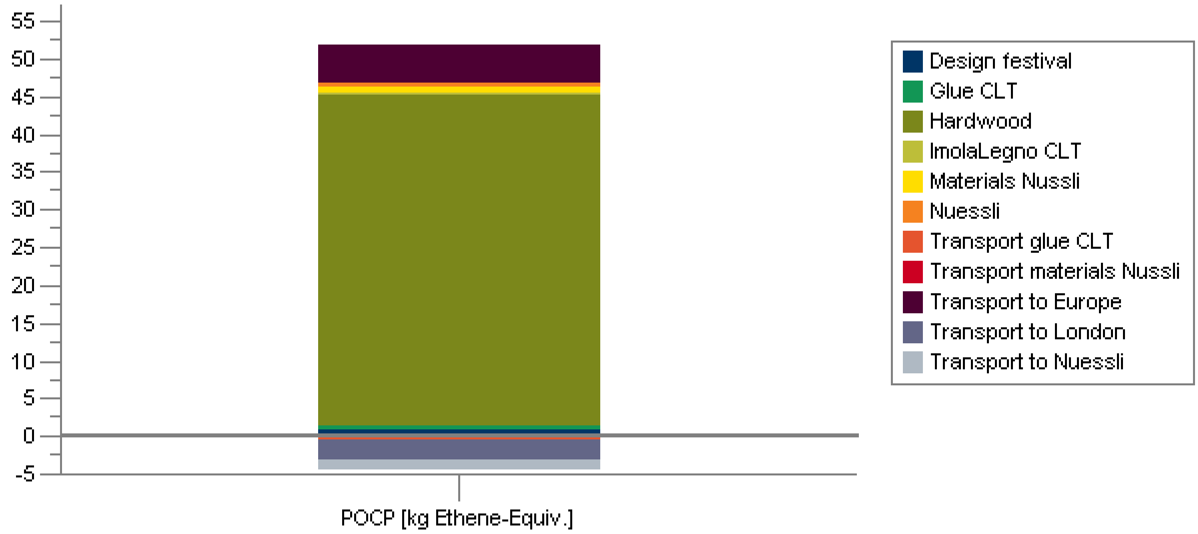
The glues for CLT production also had a relatively significant contribution to GWP of 1.7 tonnes CO2 equivalent. This was due mainly to the need to use epoxy resin for face flue. This glue type would be replaced in industrial applications by polyurethane based glue which has around 30% less GWP and primary energy demand.

6.4 Ozone layer depletion



47% of the negligible amount of Ozone Layer Depletion Potential attributable to Endless Stair is due to electricity consumption in the US hardwood supply chain. A further 22% is attributable to materials, notably metal screws, used by Nüssli to fabricate the structure. The use of solar energy for electricity at the Imola Legno plant in Italy significantly reduced the contribution (to only 19%) of the CLT production stage. zone layer depletion is mainly related to electricity consumptions in the hardwood supply chain and the CLT production is Italy. Metal parts of the stair system used in Nussli have also relevant contribution.

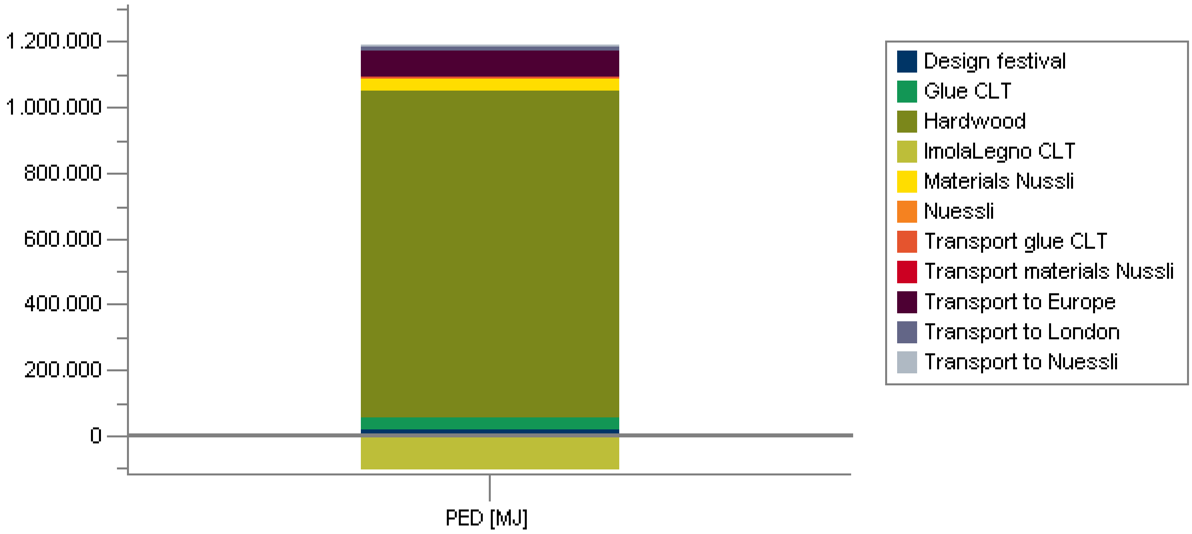
6.5 Photochemical ozone creation



Endless Stair has a POCP of 47.4kg of Ethene equivalent. Most is due to emissions of terpenes, which are VOCs released from wood resins. The terpenes are naturally released as trees grow, but processes in which wood is heated (such as a kiln drying) result in more significant emissions. In practice there is substantial variation in the level of VOC emissions between species and depending on drying times and other factors such as the mix of heartwood and sapwood.

Negative values of some transport processes are due to the negative characterisation factor of NO emissions (assigned by the reference CML method), as it can be oxidized into NO2 and thereby remove ozone on a very local scale.

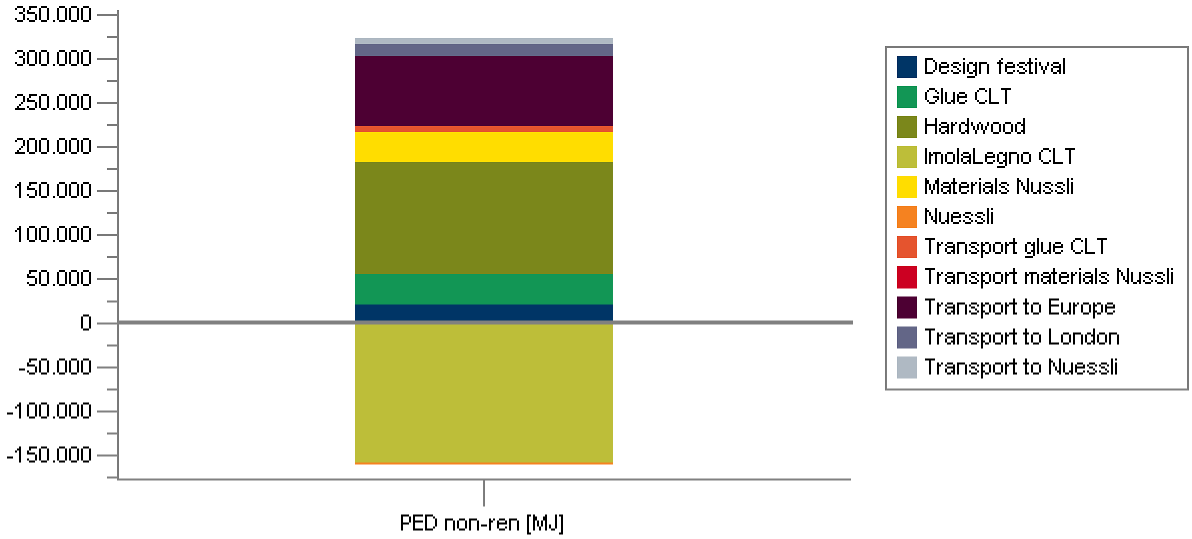
6.6 Primary energy demand



The total primary energy demand of the Endless Stair is 1.1 million MJ. This includes 1.2 million MJ offset by 0.1 million MJ due to avoided energy demand during the CLT production process as a result of the thermal recovery of wooden waste.

The hardwood production process accounts for around 1 million MJ of primary energy demand. This might seem odd but is readily explained by the fact that this figure includes the solar energy that trees absorb during photosynthesis.

6.7 Non-renewable primary energy demand

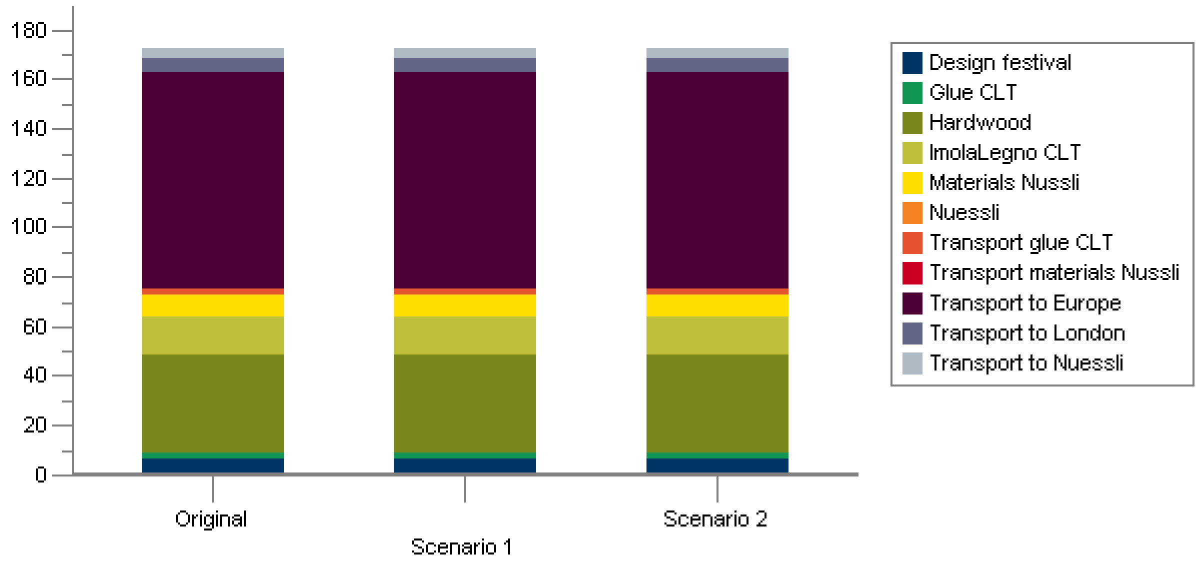


The total non-renewable primary energy demand of the Endless Stair is 0.16 million MJ. This includes 0.32 million MJ offset by 0.16 million MJ due to avoided energy demand during the CLT production process as a result of the thermal recovery of wooden waste. Energy consumption during hardwood production (mainly during kilning) and transport to Europe are the main factors contributing to non-renewable energy demand. However other issues are also significant, including the face glue for CLT, the materials used in Nüssli (notably the metal screws) and the concrete used during installation at the Design Festival.

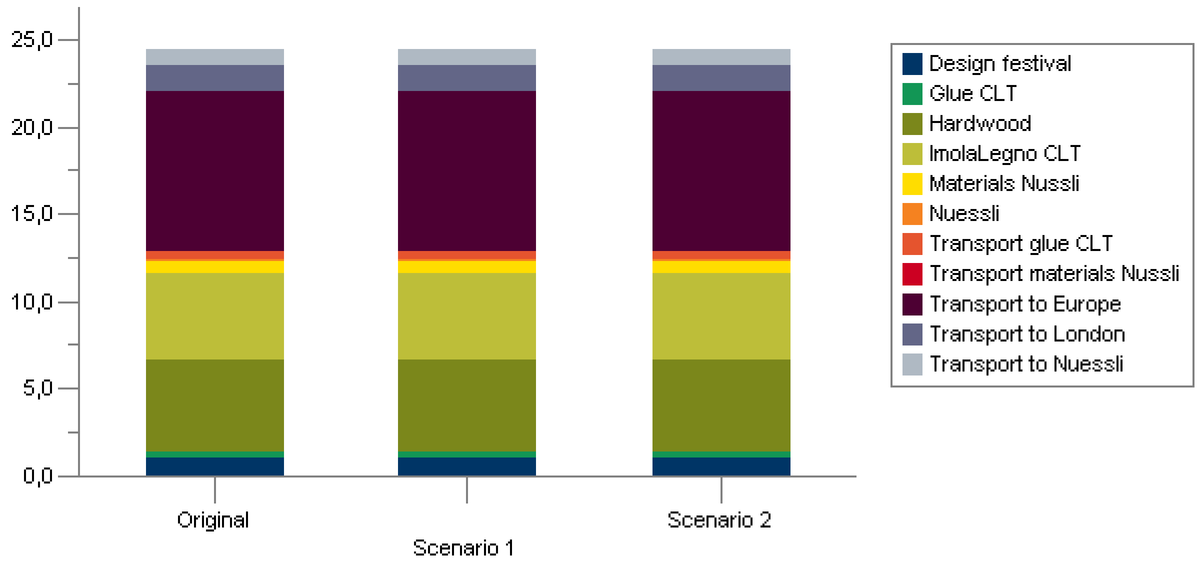
7 Comparison of new design scenarios

Designers have the possibility to define new scenarios with GaBi Envision and monitor the environmental peformance.

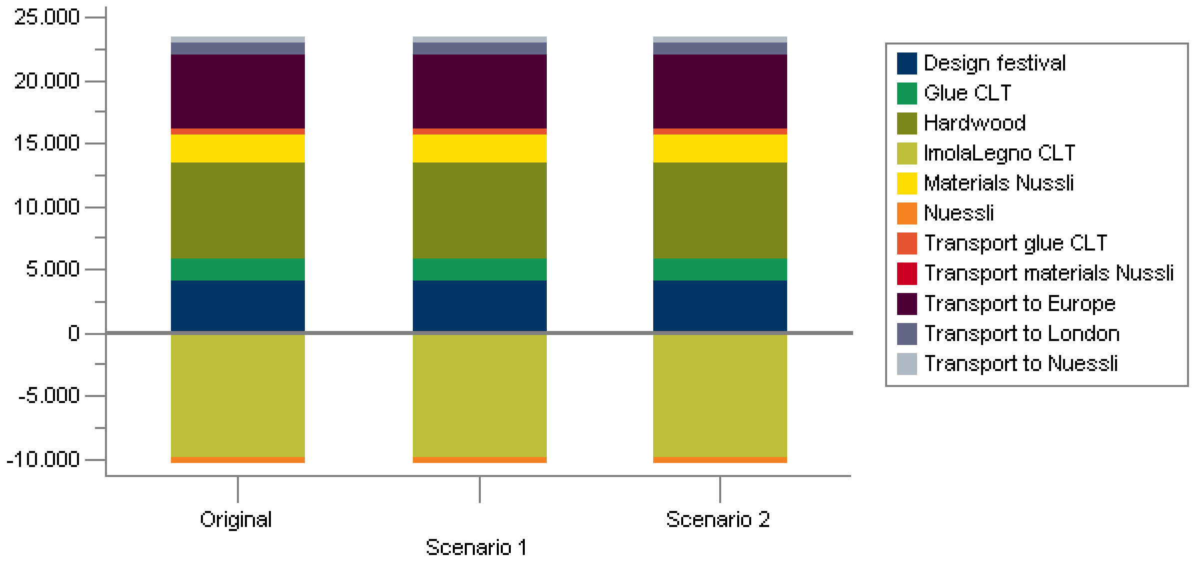
7.1 Acidification



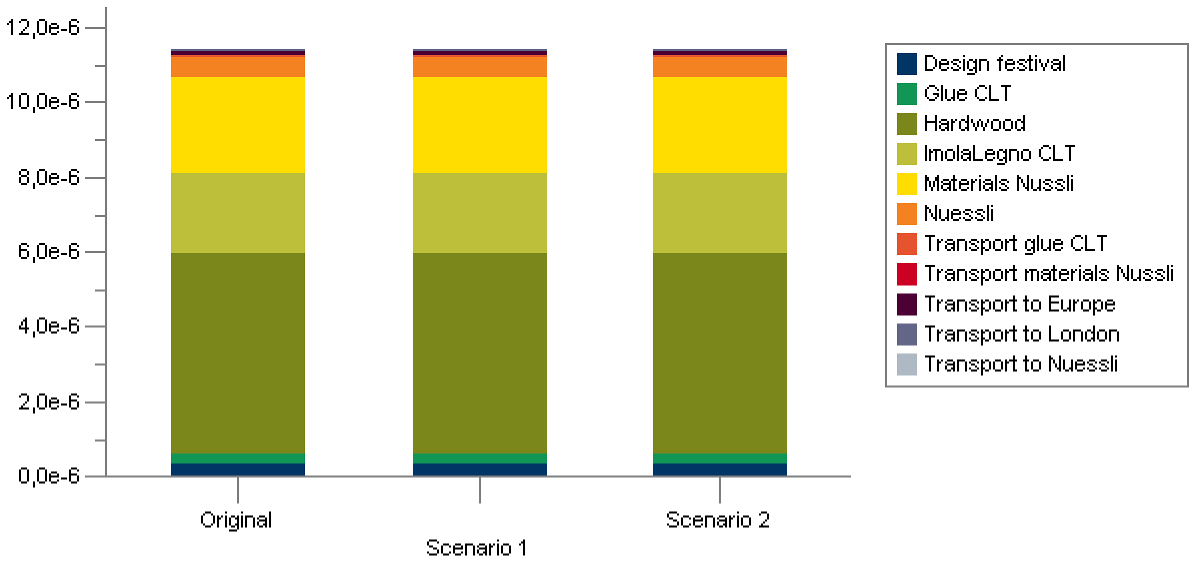
7.2 Eutrophication



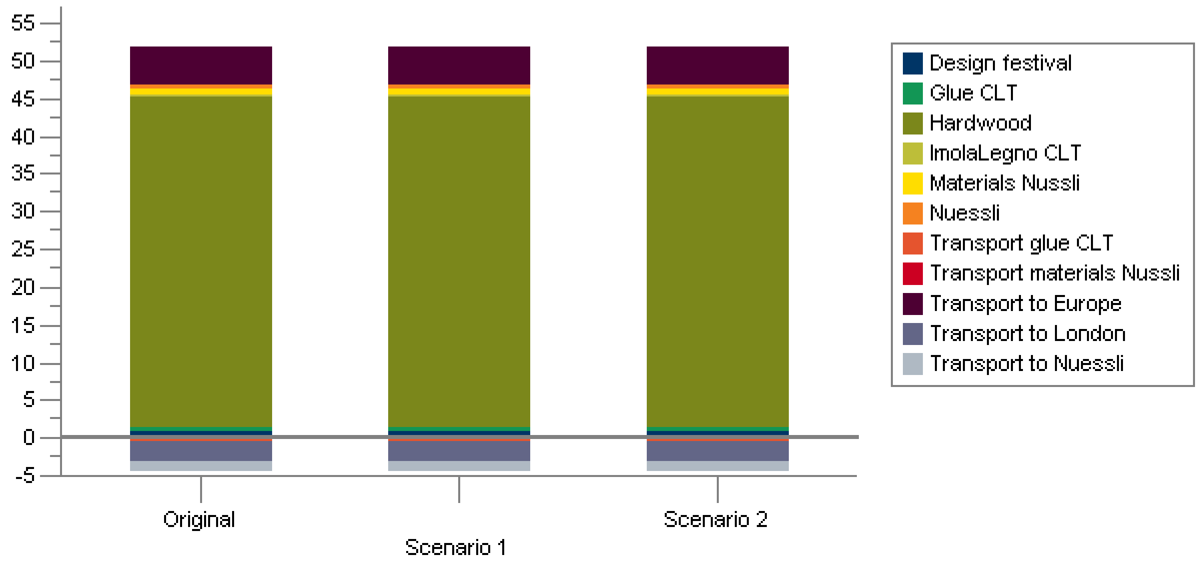
7.3 Global Warming



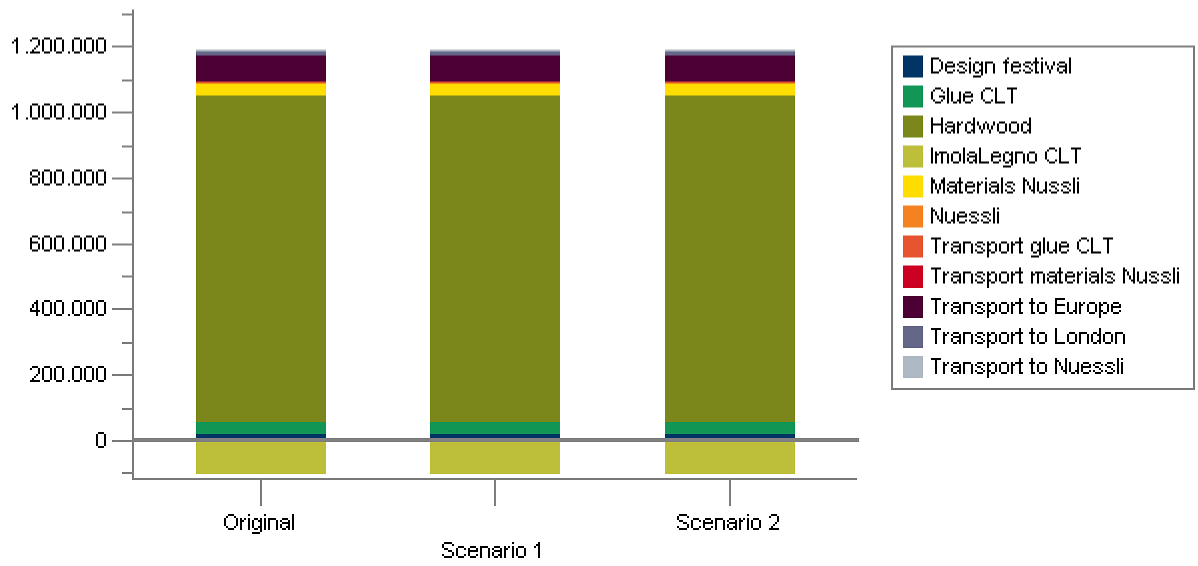
7.4 Ozone layer depletion



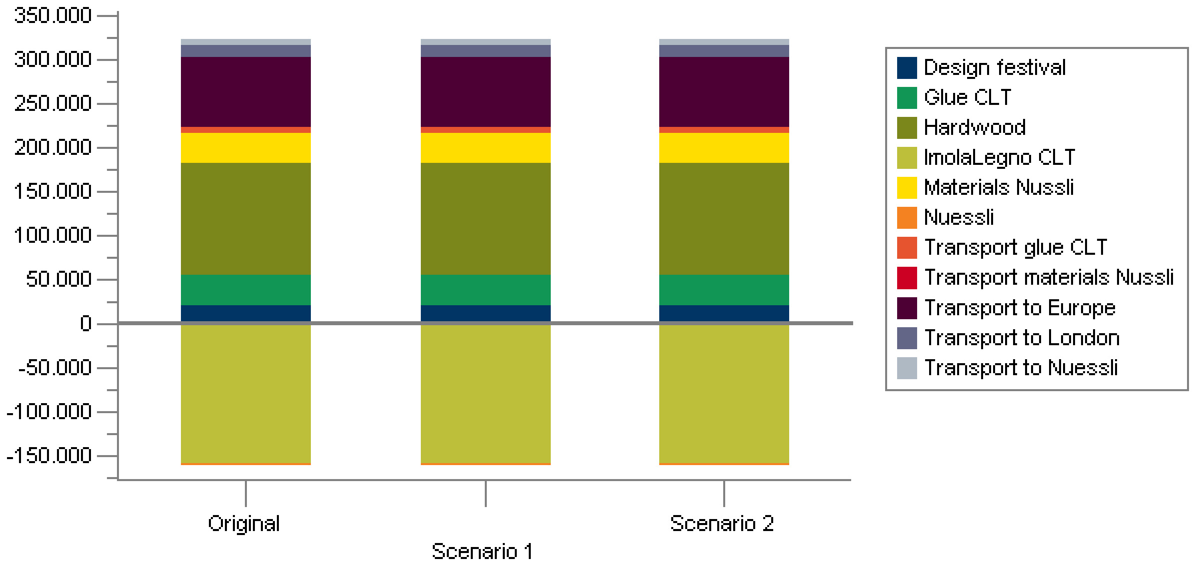
7.5 Photochemical ozone creation



7.6 Primary energy demand



7.7 Non-renewable primary energy demand



8 Data and parameters

Scenario parameters				
	Original	Scenario 1	Scenario 2	
Hardwood production United States				
Forest to sawmill	96,561	96,561		distance (km)
Sawmill to kiln	117,48	117,48		distance (km)
Kiln efficiency	53	53		%
Kiln thermal energy	25	25		kWh/day, MBF, inch
Kiln power	17	17		kWh/day, MBF, inch
Biomass for kiln thermal energy	90	90		%
Natural gas for kiln thermal energy	10	10		%
Transport to Europe				
Quantity	54,43	54,43		volume of American tulipwood lumber (m3)
Kiln to US pport	655	655		distance (km)
US port to Europe	7735	7735		distance (km)
Europe port to CLT production	225	225		distance (km)
Glues for CLT				
Edge glue	165,5	165,5		mass of vinyl based glue (kg)
Face glue	243,2	243,2		mass of epoxy resin based glue (kg)
Transport glues for CLT				
Edge glue	230	230		distance of edge glue supplier (km)
Face glue	1170	1170		distance of face glue supplier (km)
CLT ImolaLegno				
Selection and cross cutting				
Load	1	1		load (kW)
Time	50	50		working time (h)
Molding				
Load	45	45		load (kW)
Time	22	22		working time (h)
Edge gluing and lateral press				
Load	5	5		load (kW)
Time	150	150		working time (h)
Intermediate sanding				
Load	75	75		load (kW)
Time	8,5	8,5		working time (h)

Face gluing and cold press			
Load	1	1	load (kW)
Time	36	36	working time (h)
Panel trimming			
Load	20	20	load (kW)
Time	12	12	working time (h)
Final sanding			
Load	75	75	load (kW)
Time	4	4	working time (h)
Outputs			
CLT	23,025	23,025	volume of produced CLT (m3)
Waste to energy	9888	9888	mass of wooden waste for energy recovery (kg)
Waste to reuse	4245	4245	mass of wooden waste for reuse (animal care, wood based panels etc.) (kg)
On-site boiler			
CO	3,2	3,2	CO emission (gr/kg wood)
NOx	4,6	4,6	NOx emission (gr/kg wood)
Transport to Nussli			
Distance	600	600	distance (km)
Payload	15	15	truck payload (t)
Utilisation	0,63	0,63	utilisation ratio of truck
Nussli			
Sanding			
Load	7	7	load (kW)
Time	24	24	working time (h)
Waste	50	50	mass of wooden waste (kg)
Cutting of ballustrade - post			
Load	8,5	8,5	load (kW)
Time	7,7	7,7	working time (h)
Waste	171	171	mass of wooden waste (kg)
Planing of ballustrade - post			
Load	5,2	5,2	load (kW)
Time	3,3	3,3	working time (h)
Waste	35	35	mass of wooden waste (kg)
Chamfer ballustrade - posts			
Load	7,4	7,4	load (kW)
Time	7	7	working time (h)
Waste	4	4	mass of wooden waste (kg)
Cutting of pillars			
Load	7,7	7,7	load (kW)
Time	5	5	working time (h)

Waste	60	60	mass of wooden waste (kg)
Milling of threads			
Load	4	4	load (kW)
Time	33	33	working time (h)
Waste	21	21	mass of wooden waste (kg)
Milling of ballustrade - solid			
Load	4	4	load (kW)
Time	16	16	working time (h)
Waste	20	20	mass of wooden waste (kg)
Chamfer miter joint per step			
Load	7	7	load (kW)
Time	7	7	working time (h)
Waste	25	25	mass of wooden waste (kg)
Chamfer miter joint per ballustrade - solid			
Load	7	7	load (kW)
Time	7	7	working time (h)
Waste	25	25	mass of wooden waste (kg)
Cutting infill piece			
Load	7,7	7,7	load (kW)
Time	18	18	working time (h)
Waste	374	374	mass of wooden waste (kg)
Planing infill piece			
Load	13	13	load (kW)
Time	18	18	working time (h)
Waste	20	20	mass of wooden waste (kg)
Milling infill piece (drilling holes)			
Load	4	4	load (kW)
Time	26	26	working time (h)
Waste	5	5	mass of wooden waste (kg)
Materials to Nussli			
Antislip	40	40	mass of antislip (kg)
Concrete block mass	310,5	310,5	mass of one precast concrete block (kg)
Concrete block number	10	10	number of precast conceret blocks
Coating	100	100	mass of coating (kg)
Glue	16	16	mass of glue (kg)
Handrail mass	1	1	mass of handrail (kg/m)
Handrail length	100	100	lenght of handrail (m)
Screws, nuts, bolts	245	245	mass of metal parts (kg)
Transport materials to Nussli			
Antislip	100	100	distance (km)
Coating	570	570	distance (km)

Concrete block	20	20	distance (km)
Glue	640	640	distance (km)
Handrail	130	130	distance (km)
Screws, nuts, bolts	100	100	distance (km)
Transport to London			
Distance	1050	1050	distance (km)
Payload	17,3	17,3	truck payload (t)
Utilisation	0,7	0,7	utilisation ratio of truck
Design festival			
Volume	1,575	1,575	volume of concrete block (m3)
Number	10	10	number of blocks
Electricity	0	0	electricity (kWh)