UNIVERSITY OF
SOUTHERN DENMARK

Faculty of Engineering

MSc. in Environmental Engineering

Life Cycle Assessment of SDU's TEK building and Carbon footprint account on a consumer product – TimberNest bench

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Thesis structure

The following study is made out of two different parts as follows: The first part is a Life Cycle Assessment of the SDU's TEK building (faculty of engineering) where the full life cycle of the building was analysed starting from raw material extraction to the end-of-life stage. The assessment was done for a better understanding of the environmental impacts that the building has during its lifetime. The second part consists of a CO_2 footprint account of a company product. The company is TimberNest, a Danish start-up company which is producing a bench for socializing. This CO_2 footprint account was made to see what are the CO_2 emissions that the bench is emitting during its life cycle and to help the company in becoming a CO_2 neutral business in the future.

Abstract

Worldwide, the building industry accounts for approximatively 40% of energy consumption and 33% of carbon dioxide emissions, making it one of the most demanding industries in the world. Denmark has increased its building sector in the past years and is a leader in eco-innovation and sustainable construction projects, therefore one of the best countries to invest.

This study thrives to analyse a particular building in Odense, the SDU's faculty of engineering (TEK building) which is part of the SDU's campus in Odense. It was built in 2015 by C.F. Moller architects company and it is stated to be a self-sustainable building made with long lasting materials and eco-friendly. The study is performed using a life cycle assessment method (LCA) to determine the environmental impacts over the whole life cycle of the building from raw material extraction to its end-of-life stage. In order to perform the Life Cycle Assessment, SimaPro software is used and the consequential approach is chosen for it.

Three scenarios are modelled along the way to understand which one has the less impacts over the environment and the results are showing three impact categories that stood out to be the most important ones.

Acknowledgment

Firstly, I want to thank Birgitte Lilholt Sørensen and Marianne Wesnaes for their guidance and help in conducting this Life-Cycle-Assessment. Furthermore, I would like to thank Teis Lenz for his help with data collection that made this study possible.

1. Introduction

1.1 SDU's TEK Building

The Faculty of Engineering (TEK) is part of the University of Southern Denmark, in Odense and is located in the south-eastern corner of the campus where the heating plant was previously located. The total size of the building is 20.000 m^2 with an area of 6.000 m^2 for laboratories. The new building connects the other parts of the University and the Mærsk McKinney Møller Institute.

The architects company that built TEK, C.F. Moller states that "the building is designed as one big envelope consisting of 5 buildings connected by bridges at multiple levels crossing the heart of the complex, a "piece of furniture" containing common functions, meeting-rooms and café/lounge areas. The many connections allow for more fluid boundaries, and more community and knowledge sharing.
The unusual appearance is a result of both adaption and distinctiveness in relation to the existing campus, which is a unique 1970s structuralist design by architects Krohn & Hartvig Rasmussen characterized by its linear layout and brutalist use of fair-faced concrete and weathered cor-ten steel cladding."

In the same document from C.F. Moller, it is said that "the building is designed as a glass house with an external screen or veil revealing and shading the glazing. The elegant and seemingly weightless screen is made from pre-fab panels of white CRC concrete (Compact Reinforced Composite, a special type of Fibre Reinforced High Performance Concrete with high strength) featuring circular openings with an underlying solar screen and natural ventilation. The eye-catching screen reflects the innovation and creativity that characterises the various institutes which the building unites, including institutes for diverse research on the subject of construction technology and industrialization. Here, the fiber-reinforced concrete architecturally demonstrates the possibilities of new materials."

According to the engineers and C.F. Moller company, the "TEK building at SDU meets the requirements for low energy class 2015 according to the strict Danish building codes. This means minimal energy consumption, good indoor climate and use of materials with a low environmental impact in a life cycle perspective. The composition of the façade screen is created from only seven different types of concrete panels, and the different diameters and layouts of the panels' perforation patterns have been optimized to act as a solar screen and glare protection, reducing direct sunlight by up to 50 percent, while still allowing unobstructed views from all interior spaces to the green surroundings." [1]

Even though the TEK building connects four other buildings, the one that will be dissected in this study for analysis is O42, the one with the concrete façade. The aim of this thesis is to assess the veridicality of the above said words, to see if the TEK building indeed is or not self-sustainable and built with good materials in order to meet the low energy standards stated by the Danish building regulations.

1.2 Hypotheses and research questions

Two hypotheses have been formulated for this thesis:

H1: Based on the fact that it is a new building constructed with the aim of being environmentally friendly, the TEK Building is sustainable in terms of energy consumption.

H2: TimberNest has the potential to become a CO_2 *neutral company by improving their production methods.*

In order to support the hypotheses, the following research questions have been formulated:

RQ1: In what degree do the materials used for the TEK building impact the building's life cycle?

RQ2: Does the fact that SDU's TEK is a new building have a significant impact on its sustainability?

RQ3: Which are the most important aspects that TimberNest should focus on, in order to become a CO_2 *neutral business?*

2. Literature review

In literature, there are many studies conducted on different buildings using Life Cycle Assessment (LCA). Regarding energy consumption, a study was made by Rachel Elizabeth Tapper Spiegel (2014) using Life Cycle Assessment on school buildings, based on two Norwegian building standards: The Passive House Standards (NS3701 – Norsk passivhusstandard for yrkesbygninger) and TEK10 Standard (Byggteknisk forskrift – TEK10). [2]

On the other hand, the term of "passive house" was developed in the 1980s by Professor Bo Adamson and Dr. Wolfgang Feist at The Passive House Institute, Germany. The term of passive house refers to the building design. A passive house should be designed based on the reduction of heat loss to minimum. To be sustainable, it should adopt some measures, such as extra insulation, airtightness and heat recovery. [2]

By comparing a school built as a passive house based on Passive House Standards, with the same school built based on TEK10 standards, the difference in life cycle performance for these two schools can be seen. After assessing and comparing both schools built as passive house in comparison with conventional building, the ones built with passive house standards are more efficient regarding energy consumption, but requires more materials and energy in the construction phase than the school built based on TEK10 standards. [2]

Another LCA study was conducted by the Concrete Innovation Centre (COIN Project report 36, 2011), on concrete used in building construction, focusing on the rooftop of passive houses. The aim was to find the best material used, considering some criteria: aesthetics, functionality, sustainability, energy efficiency, indoor climate and cost efficiency. The passive house roof construction assessed was made from concrete, vapour barrier, mineral wool insulation and bitumen welding. [3]

By using LCA as a tool assessment for buildings, in Spain, a survey by Zabalza et. al. (2013) was conducted based on eco-design building, with the aim to demonstrate how energy savings in construction and operation of buildings can be achieved, based on life cycle assessment techniques in designing buildings and refurbishment. Here, it an LCA was made on Valdespartera eco district, Zaragoza, Spain, where all the life cycle building stages were analysed in terms of Cumulative Energy Demand (CED) and Global Warming Potential (GWP). [4]

Further studies based on the design of buildings were made, one of them being conducted by Vaculikova et.al., (2014) They performed a Life Cycle Assessment of a Building Replacement with Re-use of selected materials, where the focus was on the renovation of the existing building stock in a sustainable stock. Here have been two scenarios developed, where an old house was replaced by a new one using new materials and second scenario where a new house was built by re-using old materials from demolition and extra material. LCA results demonstrate that the impact of material used can be marginal. [5]

A further study was made on Building Materials and Services in Hong Kong by Leung et.al. (2007) where 28 commercial buildings in Hong Kong were assessed, with the aim of finding the scale of materials and service systems which contribute the most to the environmental impacts. There were twenty material types identified and concrete, rebar, plaster, render and screed represented the dominant materials, together with 40 types of service systems where the most common were Heat, Ventilating and Air-conditioning Systems (HVAC). [6]

Gonçalves de Lassio et. al. (2016) performed a life cycle assessment of different building construction materials from a housing complex. The materials included cement, steel, wood and ceramics. The study highlighted the environmental impacts of these materials and the consumption of non-renewable energy and fossil fuels. As the authors concluded in their study, there is a need in acting over the production chain of building materials but also on the end-of-life stage to avoid landfilling and promote recycling. In the end, the study stated that it would be a good idea to look for other materials when it comes to buildings, materials like glass or plastics which have a higher recyclability rate. [7]
Ghose A. et. al. (2017) conducted a study on the environmental impacts that arise from the refurbishment of the building sector in New Zealand with a consequential life cycle assessment approach. They compared building refurbishment strategies in order to minimize the waste quantities on the construction site with the use of materials that can be recycled at the production site. The outcome revealed that recovery and re-use of materials can decrease the environmental impacts by around 20% compared to the strategies that used recycled materials. Here the decrease in impacts was of 5%. [8]

Another study was made in Finland by Miimu Airaksinen et. al. where they analysed an office building, performing a CO_2 footprint of it. As nowadays office buildings are more and more energy efficient, the heating use is going down, while the electricity use is increasing. While performing the CO_2 footprint, it came out that the materials play a huge role in the energy efficiency of a building and those should be considered, not only the use phase of the building. The results of the study showed that the lowest CO_2 emissions were achieved when renewable energy or nuclear power was used for electricity and heat production. [9]

In his doctoral thesis in 2001, Jacob Paulsen discussed the significance of the use phase for different building products. As in the European Union, the building sector accounts for about 40% of the energy use and generates around 40% of the total waste it is imperative to approach the building industry in a sustainable way by reducing the amount of resources for one product. Therefore it is crucial to consider the use phase of buildings. He concluded that in order to perform a comparison between building products, the choosing of materials has to be done in the planning phase of the building and then, the products can be compared in the use phase from an environmental point of view if life cycle inventory data exists, building data like lifetime or maintenance intervals exists. [17]

Moreover, Stefania Butera in her doctoral thesis studied the potential environmental impacts of construction and demolition waste (C&DW) in Denmark. The findings showed that C&DW has a variability when it comes to leaching mostly because of the ageing level of the chemicals or the source segregation. Leaching of chemicals like selenium or antimony is critical for C&DW and Polychlorinated Biphenyls (PCBs) are still present in C&DW nowadays even if not in critical amounts. The study speaks about the use of C&DW in road sub-bases and from an LCA perspective the waste stream does not provide any environmental benefits because there are environmental impacts related to leaching or transportation. Even though, C&DW has less impacts than landfilling but excluding toxicity impacts. Regarding the leaching from C&DW, the oxyanion leaching is responsible for the environmental toxicity impacts and it should be minimised. [10]

Gong et. al. (2011) conducted a comparative study on life cycle energy consumption and CO_2 emissions for three different residential building designs in Beijing. One is made out of concrete framework (CFC), the other is steel framework (SFC) and the last one is made out of wood framework (WFC). The study showed that over the whole life cycle of the buildings, the energy consumption of the CFC building is almost the same as the SFC one but both of them are 30% higher than the wood-made building. In terms of CO_2 emissions, the CFC building is 44% higher than the steel framework building and 49% higher than the wood framework one, making the CFC, the least environmentally friendly. The main contributor to these CO_2 emissions is the use of electricity. Summed up, the WFC building is the most environmentally friendly one and in order to have energy savings and less CO_2 emissions it is imperative to use energy-saving materials like natural wood. [11]

3. Methodology

3.1 Life Cycle Assessment methodology

The main method used in this thesis is the LCA method for assessing the environmental impacts of the TEK building. The figure below, shows the main steps that every LCA study must contain. This illustration is for a consequential LCA as the main approach for this study is the consequential one for understanding the different consequences of the environmental impacts involved. In the beginning the goal and scope of the study are defined, after that an inventory analysis is made and this includes all the processes and materials used in order to conduct the LCA. After the inventory analysis is done, it is followed by the impact assessment showing the environmental impacts of the product assessed, in this case the TEK building and after that, the last step is the interpretation of results.

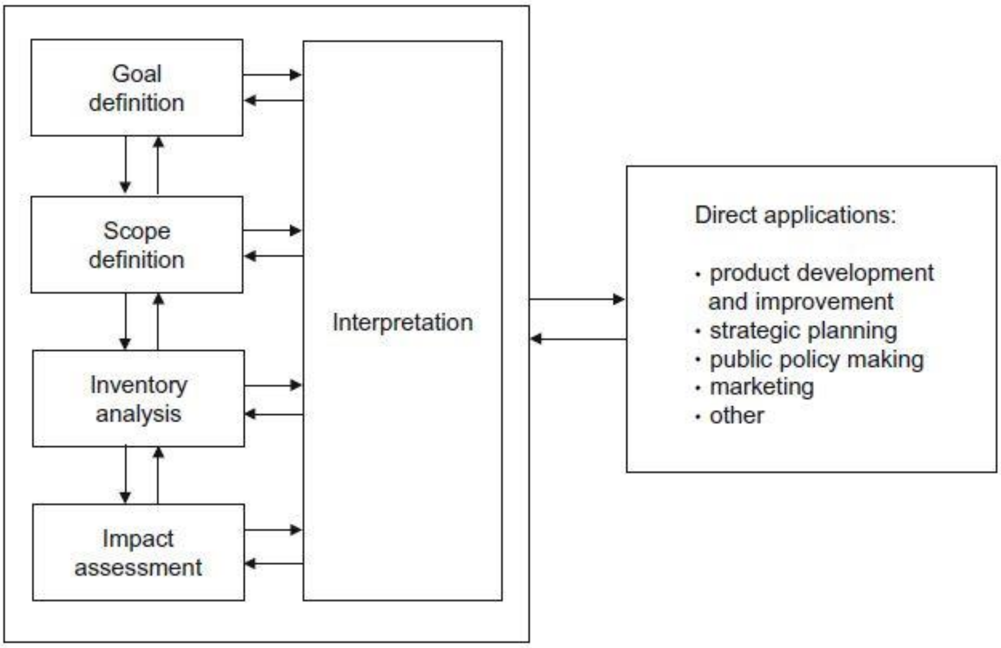


Figure 1 Framework of an LCA [12]

The TEK building is part of the SDU campus in Odense and it was built in 2015 which makes it a new building in accordance with the Danish building regulations. The building it is stated to be a self-sustainable one and environmentally friendly. The goal of this master thesis is to assess the materials used for the construction, the electricity and heat used during its lifetime in order to see the environmental impacts of TEK and if the building is self-sustainable in terms of energy consumption. This study is an internal one and will not be disclosed to the public, the results being communicated to the university staff only for internal use.

The scope definition determines what product systems are to be assessed and how this assessment should be done. [13] This is a stand-alone LCA study where the SDU's TEK building will be analysed based on data collected from stakeholders (university's technical service, companies providing the electricity and heat). The whole LCA study has a cradle-to-grave approach where all the life cycle stages are considered from the extraction of raw materials to the end of life stage of the building where the waste amounts are recycled, incinerated or landfilled.

The functional unit used in every LCA it is used to describe and quantify the function or performance of a product system. This is done to create a reference unit for the comparison of the product systems. [12] For this study, the functional unit used is 1 year of service for the TEK building, meaning the energy used in one year for electricity, water and heating systems.

The system boundaries used in this study are intended to set a more accurate approach over the LCA. The spatial boundary is Denmark, more explicitly Odense city while the temporal boundary is set by the functional unit – 1 year of service. These boundaries can be found in the process flow diagram (figure 2).

3.2 Inventory Analysis

In this chapter collected data as the basis of the assumptions for the calculation of environmental impacts in SimaPro is presented. Data from different sources from all processes of the studied product are listed in the following and compile an inventory of elementary flows. [12] The calculation of the environmental impact is made with SimaPro version 8.5.0, which is build up on the Database Ecoquery Ecoinvent 3.4.

The data for the study was obtained from the university's technical department and it includes quantities for the materials used during the building process, electricity, heat and water consumption for one year of service. The materials considered in this study are as follows:

concrete, wood, glass, ceramics, gypsum for plasterboards, stone wool for isolation, metals (steel, iron, aluminium, nickel), plastics (polyethylene and polystyrene) and a tank of 5000l of propylene glycol. Data collected will be afterwards divided for every life cycle stage. In the use stage of the building, electricity, heat and water will be used, while for the construction and end-of-life stages the building materials are used to make the model.

3.3 Process flow diagram

Below, the Process flow diagram (PFD) of the TEK building is shown for a better understanding of the life cycle of the building which goes from cradle-to-grave.

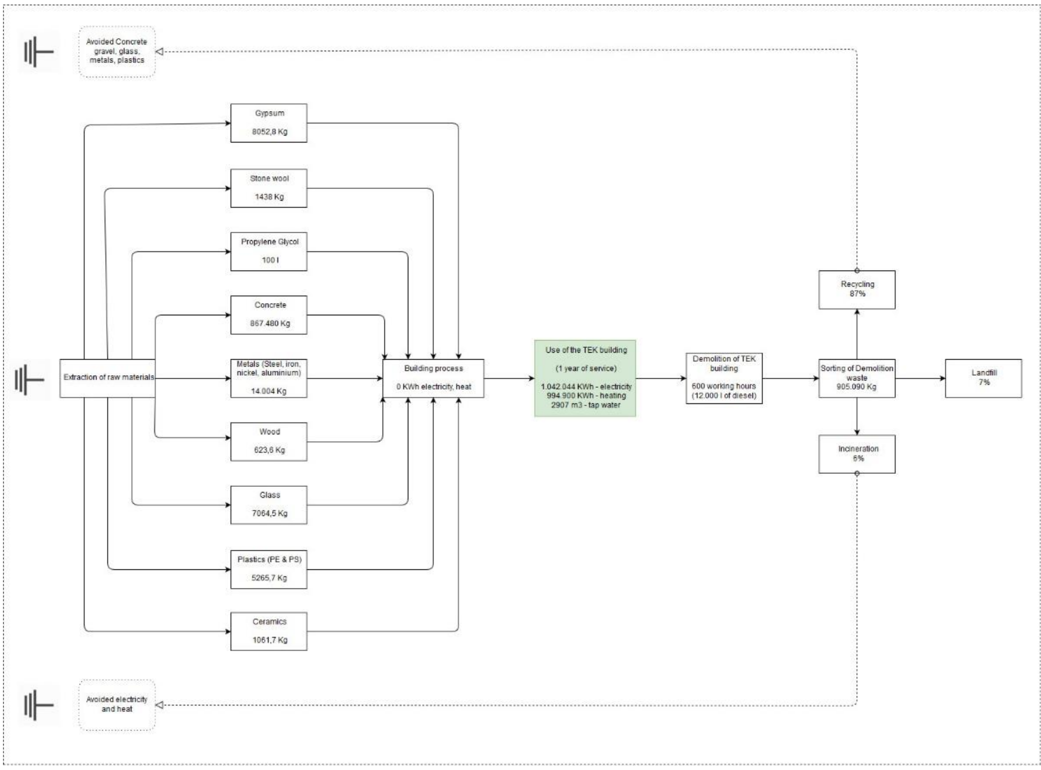


Figure 2 Process flow diagram of the TEK building

Figure 2 illustrates the PFD of the TEK building with all the life cycle stages included from extraction of raw materials to end-of-life stage “Demolition of TEK building”. As the functional unit is 1 year of service, all the weights of the materials are divided by 50, this being the lifetime of the building. For the construction of the building there was no energy consumption considered as it is too small to be relevant.

Considering the use phase, here the numbers for the use of electricity, heat and water are presented as follows: 1.042.044 KWh/year for electricity, 994.900 KWh/year for the heating system and 2907 m^3 of water, this water being tap water used in bathrooms and kitchens. The water used in the heating system is recycled over the whole heating system so it is not considered in the study.

For the demolition process an assumption was made regarding the demolition period in hours and fuel consumption. After this, there is a sorting process where all the materials are sorted to be either recycled, incinerated or landfilled. According to the Danish statistics on construction and demolition waste from 2015, 87% of the waste is recycled, while 7% is landfilled and the rest of 6% is sent for incineration. [13]

3.4 Life Cycle Impact Assessment

The life cycle inventory´s information on elementary flows is converted into scores of environmental impacts. The software SimaPro 8.5.0 is used to conduct the Impact Assessment. The setting "ILCD 2011 Midpoint+" with EC-JRC Global, equal weighting is used. The results of the assessment with the above-mentioned method can afterwards be allocated to areas of protection. Typically, these areas are human health, ecosystems & species (natural environment) and resources.

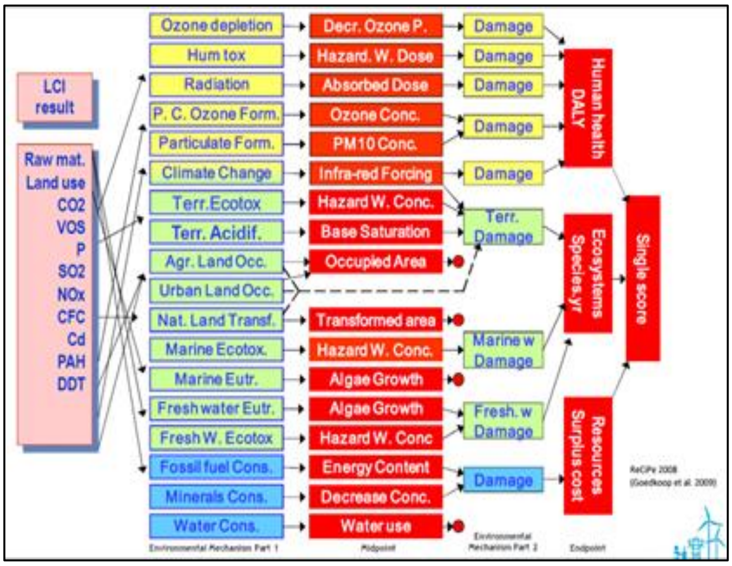


Figure 3 Endpoint Impact indicators (Larsen, 2017)

According to ISO 14040/14044 from 2006, characterization is a mandatory step in every LCA study alongside with classification. There are also optional steps in an LCA like normalization, weighting and grouping. For this particular study, characterization and normalization were chosen to be assessed. Characterization is about how much each impact indicator contributes to the overall assessment. Normalization is expressing the life cycle impact results which are relative to a reference system (person equivalent). [14]

In the characterization step, all the flows from the life cycle impact assessment are calculated according to how much they contribute to a certain impact. Then, all the elementary flows are multiplied with their characterization factor and then summed over all emissions to get an impact score for a specific impact category. [12] Concerning normalization step, this is done after the characterization and expresses the results using a common reference impact. As of this, normalization shows the total impact for a certain region (Demark for this study) and for a certain impact category e. g. climate change. [14] The final aim of this optional step is to reveal the environmental impacts which are associated with the European production and consumption, including impacts from trade. [14]

3.5 Scenario Development

In order to build the model for the TEK building in SimaPro, three scenarios were developed. The first one is the actual scenario where the building materials are considered with the actual energy, heat and water consumption in the use phase, the reference year being 2015-2016. Also, during the disposal stage, the data used is from the Danish statistics on construction and demolition waste from 2015. Here 87% of the waste is recycled, 7% is landfilled and 6% is incinerated. For the other two scenarios, the use stage of the building was modified as it follows: the electricity and heat consumption processes were modified.

Considering that for the actual scenario, the production of electricity is made up from 85% electricity mix for Denmark which has wind power, solar power, hydro power, coal and biomass. The rest of 15% is covered by solar power as they use solar panels on the building's roof. In the future scenarios, the percentages are changed being first 50% wind power and 50% solar power and then 100% wind power for the electricity production.

For the heat production, the actual scenario has a mix of coal (33%), wood chips (34%) and waste (33%) because the TEK building is taking its heat from Fjernvarme Fyn A/S, the district heating company in Odense and according to their data, they use three Combined Heat and Power (CHP) plants to produce heat. [19]

On the other hand, for the future scenarios, heat production is modelled as it follows: firstly, there is a share of 50% wood chips and 50% waste and then, in the last scenario there will be 100% waste used for heat production.

3.6 Assumptions for SimaPro

In order to build the model for SimaPro, assumptions were made. Firstly, the lifetime of the TEK building is considered to be 50 years for the structure materials like concrete, steel or iron. For the rest of the materials, an average of 25 years was considered as their lifetime. [17] For the calculations in the SimaPro software, regarding the functional unit of 1 year, the total amounts of building materials (BM) were divided by the lifetime of the building (LB) – 50 years, respectively 25 years.

$$\frac{BM}{LB} \tag{1}$$

For the electricity consumption over one year of service, an assumption was made as in Denmark most of the electricity is produced by renewable energy like windmills, solar or hydro power and biomass, around 60% and the rest of 40% being coal (30%) and natural gas. [18]

Although, because TEK was built in 2015 it has on the roof solar panels for electricity production. According to the data collected from the university regarding the amount of electricity produced by the solar panels on roof, they produce 15% of the total energy requirement for one year, the rest of 85% being covered by an electricity mix.

Another assumption was made on the end-of-life of the building where for one month of work to dismantle the building are necessary 200 working hours and the work is done with excavators, bulldozers and trucks for waste transportation. In total, three months is the time for full dismantling so 600 working hours.

For the machinery used in the demolition process, the fuel consumption was considered and assumed to be an average of 20l of diesel per working hour [18]. The total fuel consumption is calculated by multiplying the working hours (WH) with the hourly fuel consumption (FC/H)

$$WH \times FC/H \tag{2}$$

After the building is brought down, there is a sorting phase of the waste which takes place. At this point, 1% of the demolition waste is loss and goes to landfill. After the sorting process is done, 87% of the waste goes to recycling, 6% to incineration and 7% to landfill, in this 7% the loss of 1% is included. [13]

When it comes to the avoided products due to incineration of wood, here electricity and heat are the avoided processes. To model these processes in SimaPro an assumption was made as it follows: for the reuse of electricity, the total amount of wood that goes to incineration is multiplied with the percentage of wood that is incinerated (90%), the rest of 10% is considered as loss. For the reuse of heat, the same amount of wood that goes to incineration (W) is multiplied this time with the calorific value of wood, which is 18.5 MJ for dry wood.

$$W \times 18.5\ MJ \tag{3}$$

Uncertainties:

Due to the fact, that an LCA is based on assumptions and estimations, uncertainties are always present. Nevertheless, managing uncertainties allows to quantify and improve the precision of a study and the validity of its conclusions. [12]

1) Demolition of the building:
   Base scenario: 3 months used for the demolition of the whole building – 600 working hours in total.
   Sensitivity scenario: 6 months used for the demolition – 1200 working hours in total. After making this scenario, the results were too small to be taken into consideration so they are not presented in the report, as the only thing that was changed was the time of the demolition process.
   Sorting of the demolition waste:
   Base scenario: 87% recycling, 7% landfilling and 6% incineration.
   Sensitivity scenario could be: 95% of the waste goes to recycling and 5% to incineration, in this case the landfilling is avoided.

2) Functional unit:
   Base scenario: 1 year of service for the TEK building
   Sensitivity scenario could be with the whole lifetime of the building which is assumed to be 50 years.

4. Results

In the following chapter, the results obtained from the SimaPro calculations are presented as comparisons between the three scenarios modelled.

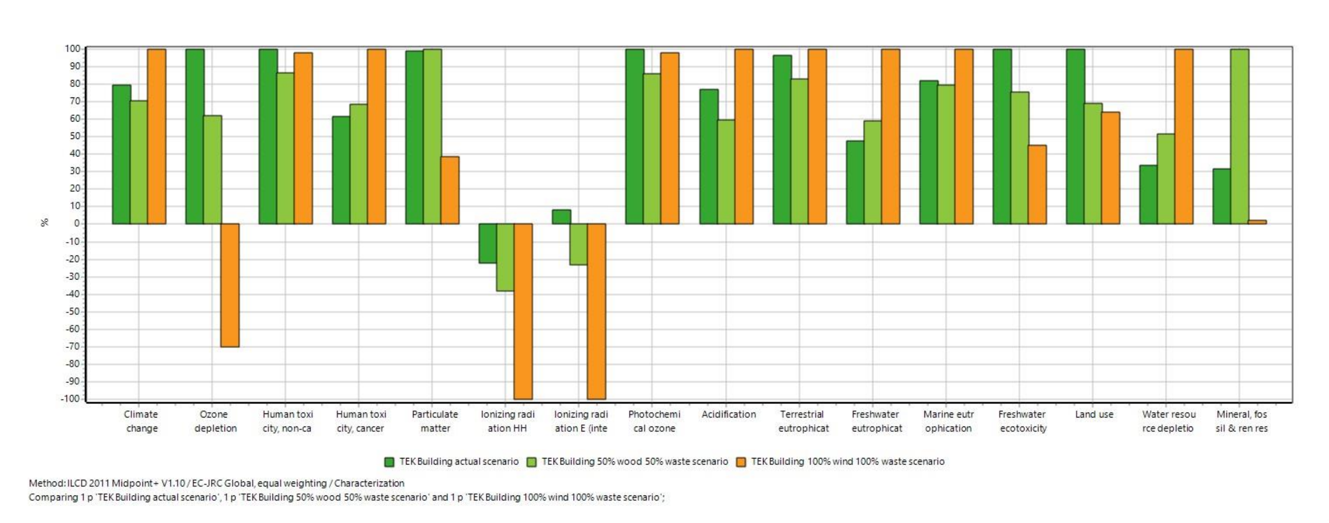


Figure 4 Comparison of the three scenarios

Figure 4 shows the comparison of all the scenarios assessed. It can be seen that the actual scenario has impacts on seven impact indicators compared with the other two scenarios. Comparing these three scenarios, the second one where TEK uses heat from Fjernvarme Fyn made out of 50% wood chips and 50% waste is the one that has less impacts over the environment for almost all the impact indicators.

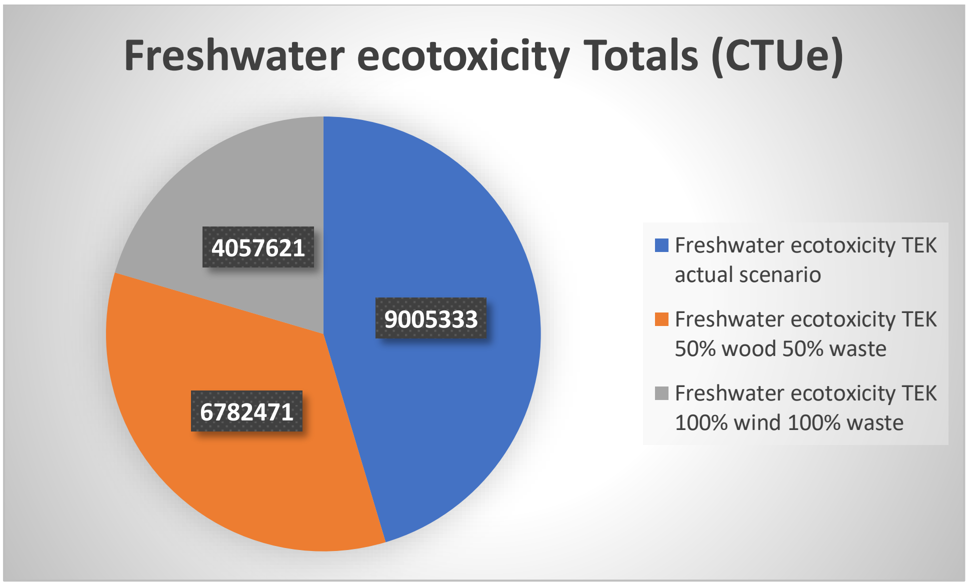


Figure 5 Freshwater ecotoxicity totals

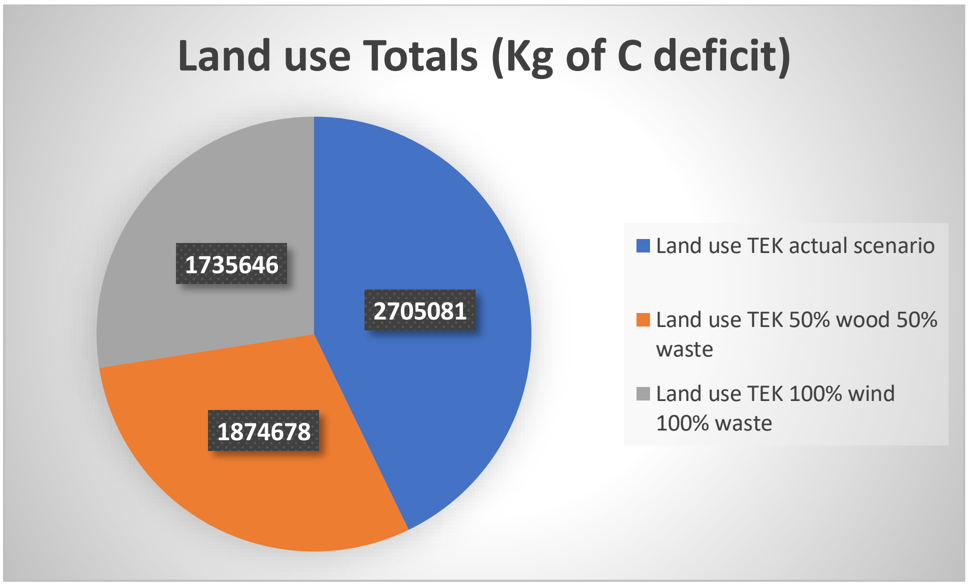


Figure 6 Land use totals

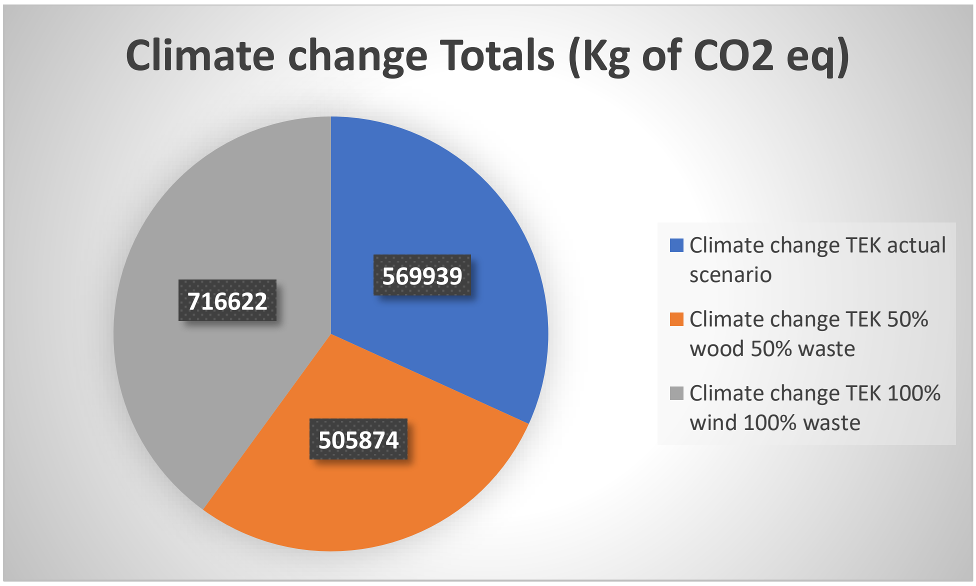


Figure 7 Climate change totals

Figures 5, 6 and 7 illustrates, the total numbers for the freshwater ecotoxicity, land use and climate change for all the scenarios. It can be seen that the actual scenario has the highest numbers for freshwater ecotoxicity and land use with a share of around 45%. On the other hand, climate change indicator has the highest share of around 40% for the third scenario.

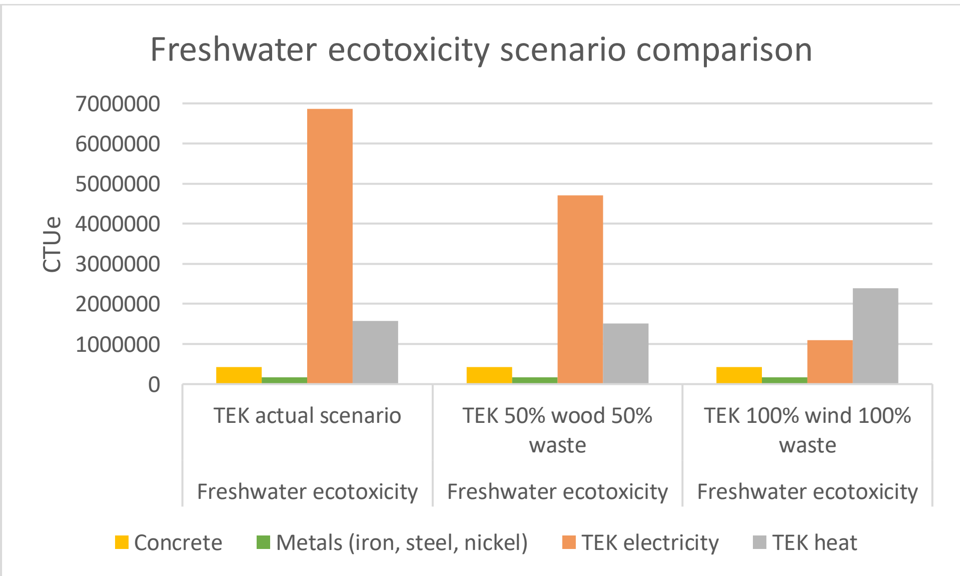


Figure 8 Freshwater ecotoxicity scenario comparison

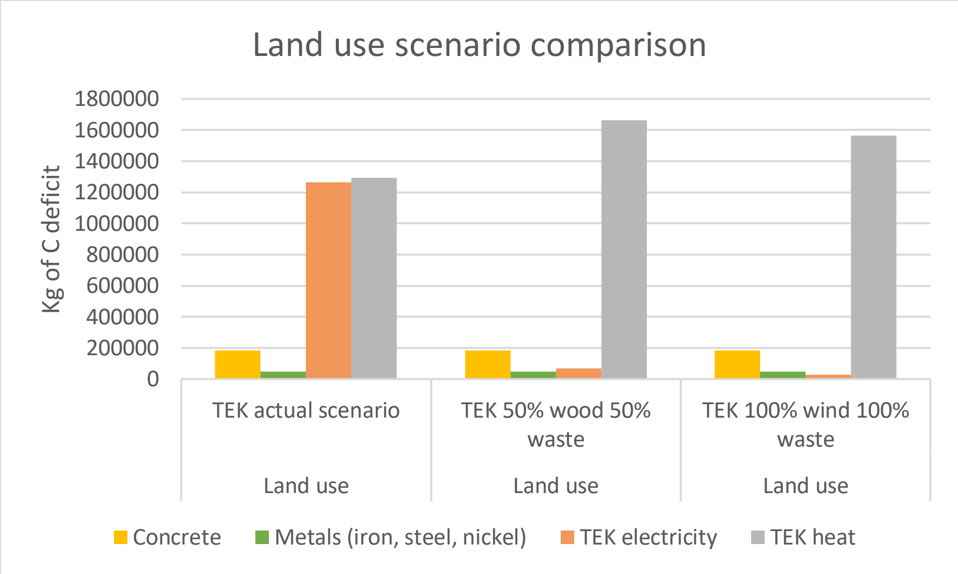


Figure 9 Land use scenario comparison

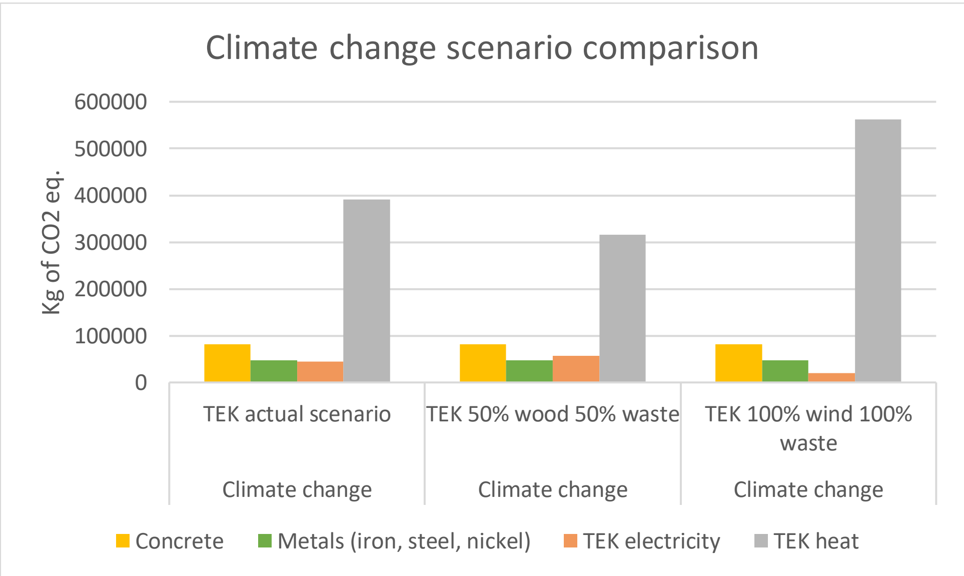


Figure 10 Climate change scenario comparison

Figures 8, 9 and 10 above are showing the comparison of the scenarios for every impact category. Here electricity and heat have the highest impacts over all the impact categories. For climate change, the shares for heat over the scenarios are almost the same with a slight change for the last scenario where the heat production has around 80% from the total. The detailed figures regarding the modelling in SimaPro can be found in the appendix – figures 14,15 and 16.

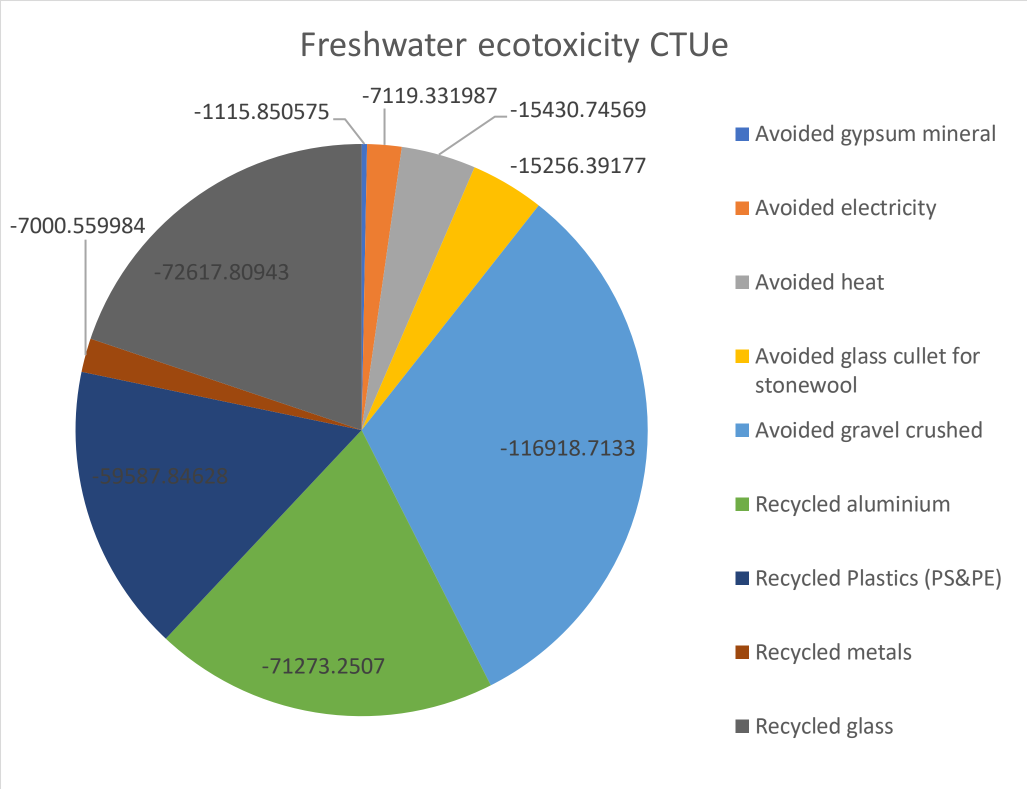


Figure 11 Freshwater ecotoxicity for the end-of-life stage (Recycling and avoided products)

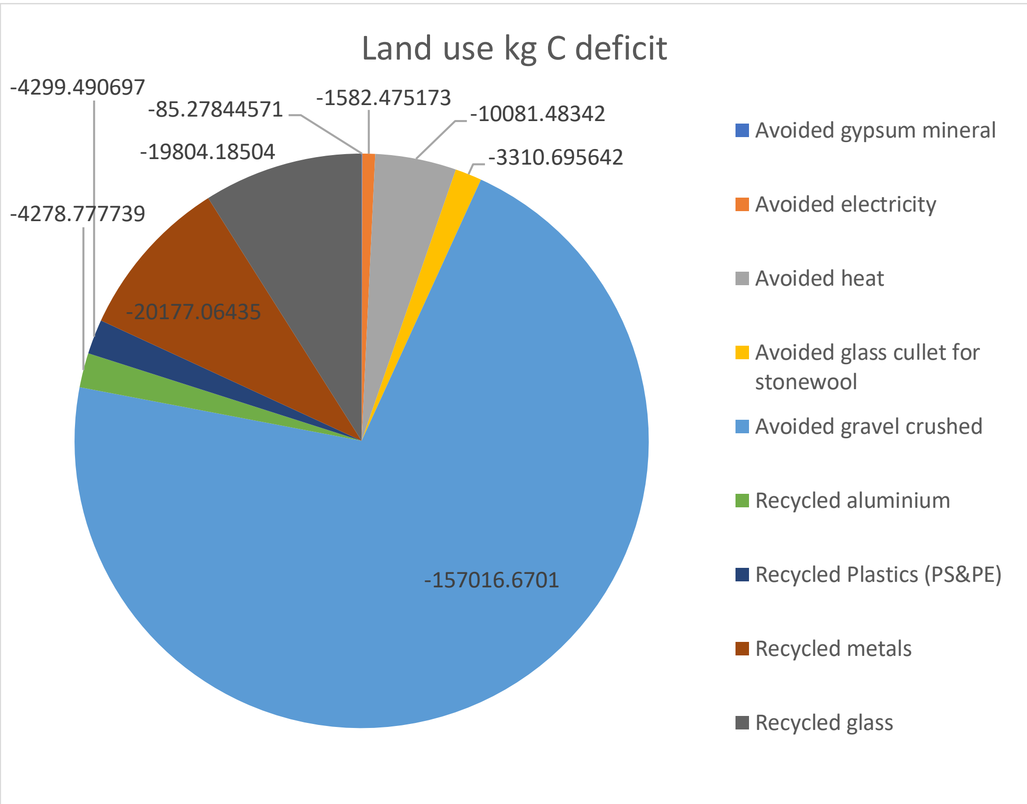


Figure 12 Land use for the end-of-life stage (Recycling and avoided products)

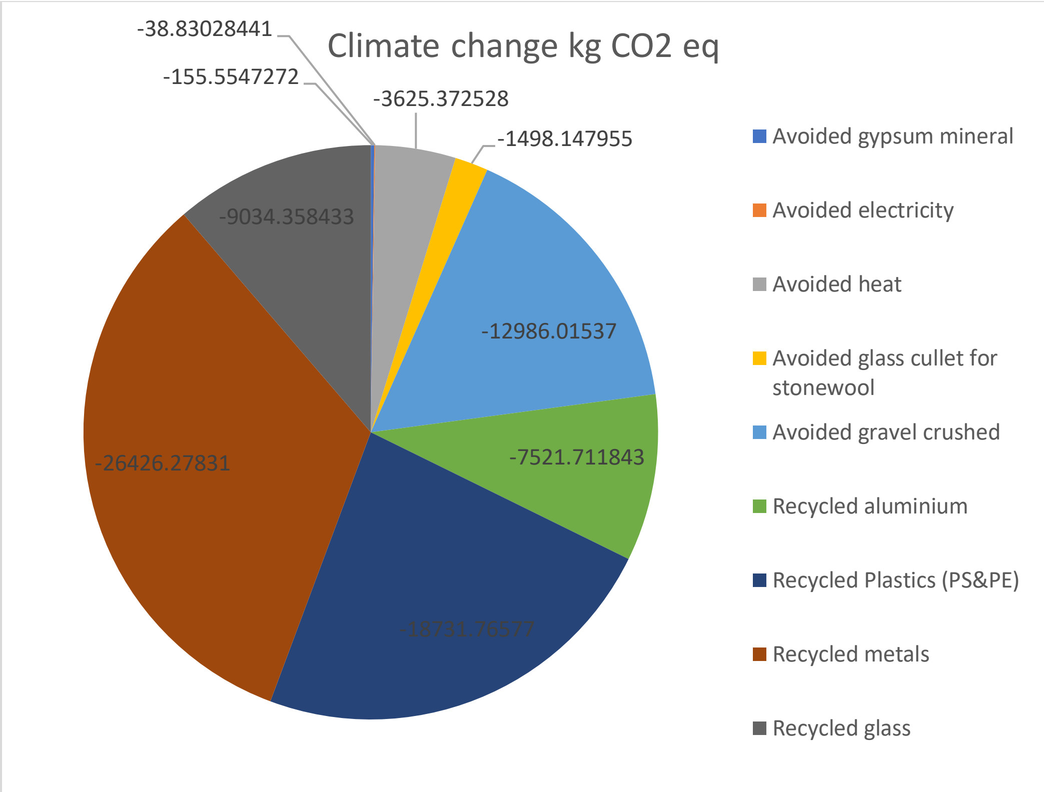


Figure 13 Climate change for the end-of-life stage (Recycling and avoided products)

Finally, figures 11, 12 and 13 show the values for the TEK building materials that are recycled and the ones that are avoided to be used in other products. The amount of concrete after demolition is used as gravel crushed for road sub-bases or pavements and "avoided gypsum mineral" refers to the gypsum that is avoided after the recycling of gypsum plasterboards. The processes "Avoided electricity" and "Avoided heat" refer to the avoided electricity and heat due to wood incineration. After the demolition of the building, the wood products are assumed to be incinerated.

5. Discussions and limitations

As Denmark is a country where the building sector is more and more eco-friendly and with low carbon emissions every year, the TEK building is not an exception. Three scenarios were modelled for the use stage of the building, focused on the use of electricity and heat inside the building in one year, in order to see which one is more convenient to be used in the future.

Overall the use of electricity and heat have the highest impacts over the environment due to the processes included in the production of these two. For the actual scenario, the electricity is made up from a country mix of renewable energy, coal and natural gas and the heat is provided by Fjernvarme Fyn also with a mix of waste, wood chips and coal. The impacts are comparable within the three scenarios with small differences for electricity and heat.

On the other hand, the production of concrete has a considerable impact as it is the material that has the highest share (Kg) in the construction stage of the building with 18072 m^3 which is around 43.372.280 Kg used for the whole building.

After assessing the TEK building scenarios using the SimaPro software, the results shown that three impact categories came out to be more important than the others. These impacts are Climate change, Freshwater ecotoxicity and Land use.

Climate change is one of the most important environmental impact indicator because of the CO_2 emissions that goes into the atmosphere and heats the planet. This impact is measured in Kg of CO_2 and in SimaPro the unit represents also the other greenhouse gases (CH_4, N_2O, CHF_3, SF_6, CCl_2F_2). Many of the greenhouse gases are present in the Earth's atmosphere contributing to the greenhouse effect (CO_2, CH_4, N_2O) alongside with water vapour.

The results show that the electricity and heat used by the TEK building in one year have the biggest impacts over climate change. Overall, the CO_2 emissions globally for electricity and heat production account for 25% of the total CO_2 emissions on the planet. [12]

The other impact, land use is present in the graphs with a share of around 20%. Land use refers to all anthropogenic activities for a given area, these activities include agriculture, forestry, mineral exploration or others. As the soil is a finite resource on Earth, the soil formation rate is substantially lower than soil depletion rate. [12]

The processes that have the biggest impacts on land use are electricity and heat, both due to the production of these two. As Denmark uses a mix of renewable energy and coal and biomass for the electricity production, all these processes have an impact on land use. The same happens regarding heat production. TEK building takes its heat from a local district heating plant in Odense (Fjernvarme Fyn) and this one is producing the heat with a mix of coal, wood chips and municipal waste. Here, the impact on land use is due to the coal mining, forestry for wood and onshore gas production.

Although, the model for land use in an LCA is still extensively discussed and not yet settled as the first operational models came out in 2010, until that year, land use was only an inventory flow. [12]

The last impact indicator to be discussed is freshwater ecotoxicity as this one has the highest impact over the three scenarios. Like for land use, the processes that are mostly affected are electricity and heat. This time, the freshwater ecotoxicity impact is due to the waste treatment of lignite or coal for heat production alongside with wood from forests. While the wood is burned for heat production, residues may end up in the nearby streams or lakes, polluting them.

5.1 Limitations

As in every LCA study, limitations are present regarding either data availability or its quality.

In this case, the main limitations were regarding data availability for the energy used during the construction of TEK. There was no data available for the energy consumption in this stage and the whole model would have been more accurate in terms of energy consumption to see if the building meets the Danish building regulations and if it is self-sustainable or not.

Another limitation that was important when the model was built it was about the end-of-life stage of the building. Here also, the data availability was the problem as assumptions had to be made in order to understand the potential waste quantities and energy usage during the demolition of the building. The transportation of materials from factory to construction site was not considered in the study as the data was not available, this being another important limitation in terms of energy and fuel consumption for a better assessment of the environmental impacts.

6. Conclusions

In the beginning of the study, two research questions regarding TEK building were addressed to be answered:

Firstly, *in what degree do the materials used for the TEK building impact the building's life cycle?*

The materials used for the construction of TEK are mainly concrete and glass. Concrete has the highest impact on the environment as its quantity is around 18.000 m^3. Other materials used in the building like iron, steel or gypsum for plasterboards are present in big quantities. Due to the recyclability of these materials, the impact over the life cycle of the building is not very high. The concrete can be reused after the demolition as gravel crushed for road pavements or sub-bases, avoiding the production of new gravel.

Secondly, *does the fact that SDU's TEK is a new building have a significant impact on its sustainability?*

The TEK was built in 2015 and the materials used are of a high quality to comply with the Danish and European regulations regarding environment and sustainability. Electricity and heat used in the building have the biggest share over the environmental impacts as TEK uses an electricity and heat mix during the use stage. The materials used have a significant impact over the sustainability of the building but considering that TEK is built with high quality materials like CRC (Compact Reinforced Composite) concrete or glass, it makes it more environmentally friendly than using other materials due to the high recyclability of concrete and glass.

7. Appendix

Inputs

Inputs from nature	Sub-compartment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comment

Add

Inputs from technosphere: materials/fuels	Amount	Unit	Distribution	SD2 or 2SD	Min	Max
Aluminium	1	p	Undefined			
Ceramics	1	p	Undefined			
Concrete	1	p	Undefined			
Gypsum	1	p	Undefined			
Metals (iron, steel, nickel)	1	p	Undefined			
Plastics (PS&PE)	1	p	Undefined			
Propylene glycol	1	p	Undefined			
Stone wool	1	p	Undefined			
Wood	1	p	Undefined			
Glass	1	p	Undefined			
TEK water	1	p	Undefined			
TEK Demolition	1	p	Undefined			

Add

Inputs from technosphere: electricity/heat	Amount	Unit	Distribution	SD2 or 2S
TEK electricity	1	p	Undefined	
TEK heat	1	p	Undefined	

Add

Figure 14 TEK building SimaPro model inputs

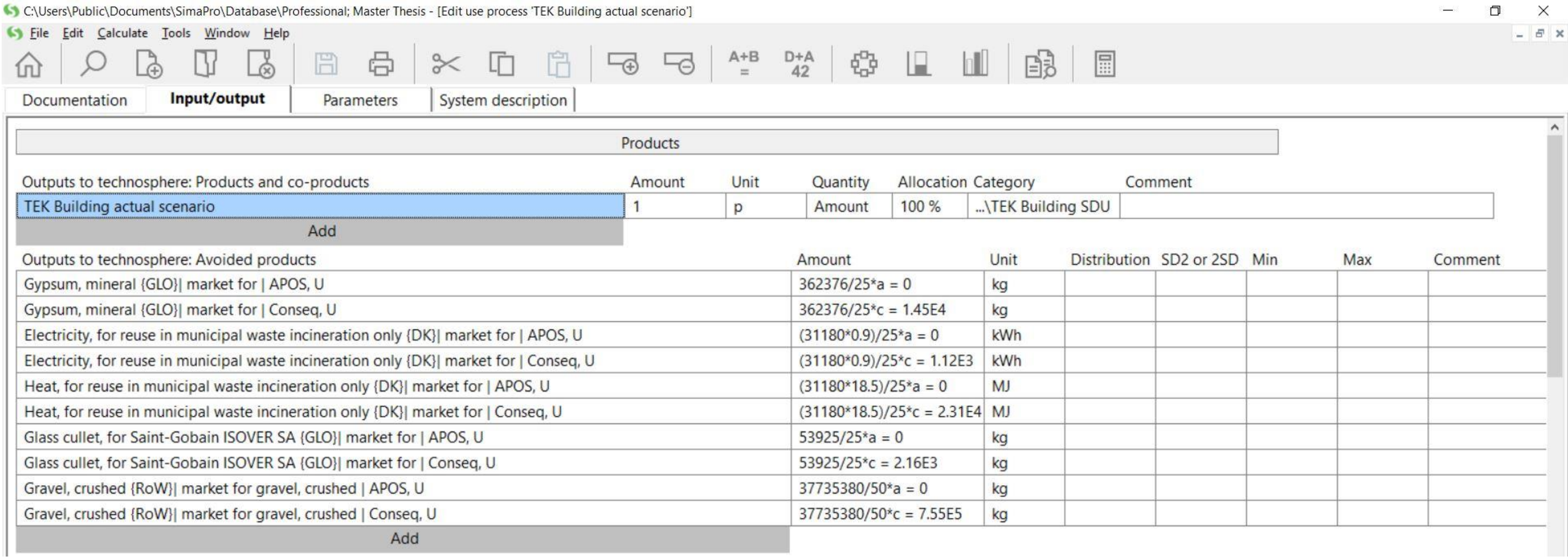


Figure 15 TEK building SimaPro model outputs

Outputs to technosphere: Waste and emissions to treatment	Amount	Unit	Distribution	SD2 or 2SD	Min	Max	Comr
Aluminium (waste treatment) {GLO}| recycling of aluminium | APOS, U	19288/50*a = 0	kg					
Aluminium (waste treatment) {GLO}| recycling of aluminium | Conseq, U	19288/50*c = 386	kg					
Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | APOS, U	236955/25*a = 0	kg					
Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Conseq, U	236955/25*c = 9.48E3	kg					
Steel and iron (waste treatment) {GLO}| recycling of steel and iron | APOS, U	591506/50*a = 0	kg					
Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Conseq, U	591506/50*c = 1.18E4	kg					
Packaging glass, white (waste treatment) {GLO}| recycling of packaging glass, white | APOS, U	167780/25*a = 0	kg					
Packaging glass, white (waste treatment) {GLO}| recycling of packaging glass, white | Conseq, U	167780/25*c = 6.71E3	kg					
Shavings, hardwood, loose, measured as dry mass {GLO}| market for | APOS, U	31180/25*a = 0	kg					
Shavings, hardwood, loose, measured as dry mass {GLO}| market for | Conseq, U	31180/25*c = 1.25E3	kg					
Inert waste, for final disposal {RoW}| market for inert waste, for final disposal | APOS, U	5862629/25*a = 0	kg					
Inert waste, for final disposal {RoW}| market for inert waste, for final disposal | Conseq, U	5862629/25*c = 2.35E5	kg					
Add							

Figure 16 TEK building SimaPro model Outputs – waste and emissions to treatment

References

[1] C. F. M. D. A/S, “SDU TEK Building,” 2015. [Online]. Available: https://www.skyfish.com/p/cfmollerarchitects/1472116?predicate=label&direction=desc. [Accessed: 14-May-2019].

[2] R. Spiegel, “Life Cycle Assessment of a new School Building designed according to the Passive House Standard,” no. June, p. 85, 2014.

[3] T. E. Kalbakk, “LCA on case study – concrete,” 2011.

[4] I. Zabalza, S. Scarpellini, A. Aranda, E. Llera, and A. Jáñez, “Use of LCA as a tool for building ecodesign. A case study of a low energy building in Spain,” *Energies*, vol. 6, no. 8, pp. 3901–3921, 2013.

[5] M. Vaculikova, M. Stepan, J. Hodkova, and A. Lupise, “Simplified and Detailed Life Cycle Assessment of a Building Replacement with Re-use of Selected Materials,” vol. 15978, no. 2, 2014.

[6] W. LEUNG and W. K. TAM, “Developing a Life Cycle Assessment Tool for Commercial Builidngs in Hong Kong,” pp. 1057–1062, 2007.

[7] J. G. Gonçalves de Lassio and A. Naked Haddad, “Life cycle assessment of building construction materials: case study for a housing complex,” *Rev. la construcción*, vol. 15, no. 2, pp. 69–77, 2016.

[8] A. Ghose, M. Pizzol, and S. J. McLaren, “Consequential LCA modelling of building refurbishment in New Zealand- an evaluation of resource and waste management scenarios,” *J. Clean. Prod.*, vol. 165, no. September 2018, pp. 119–133, 2017.

[9] M. Airaksinen and P. Matilainen, “A Carbon footprint of an office building,” *Energies*, vol. 4, no. 8, pp. 1197–1210, 2011.

[10] S. Butera, “Environmental Impacts Assessment of Recycling of Construction and Demolition Waste,” 2015.

[11] X. Gong, Z. Nie, Z. Wang, S. Cui, F. Gao, and T. Zuo, “Life cycle energy consumption and carbon dioxide emission of residential building designs in Beijing: A comparative study,” *J. Ind. Ecol.*, vol. 16, no. 4, pp. 576–587, 2012.

[12] M. Z. Hauschild, R. K. Rosenbaum, and S. I. Olsen, *Life Cycle Assessment: Theory and Practice*. 2017.

[13] Danish Environmental Protection Agency, *Affaldsstatistik 2015 [Waste statistics 2015]*, no. 1955. 2017.

[14] L. Benini, L. Mancini, S. Sala, E. Schau, S. Manfredi, and R. Pant, *Normalisation method and data for Environmental Footprints*. 2014.

[15] N. Østergaard *et al.*, “Data Driven Quantification of the Temporal Scope of Building LCAs,” *Procedia CIRP*, vol. 69, no. May, pp. 224–229, 2018.

[16] M. Klanfar, T. Korman, and T. Kujundžić, “Fuel consumption and engine load factors of equipment in quarrying of crushed stone,” *Teh. Vjesn. - Tech. Gaz.*, vol. 23, no. 1, pp. 163–169, 2016.

[17] Jacob Paulsen, "Life Cycle Assessment for Building Products - The significance of the usage

phase", Doctoral Thesis, 2001

[18] Electricity sector in Denmark, Accessed 14 May 2019, https://en.wikipedia.org/wiki/Electricity_sector_in_Denmark

[19] Fjernvarme Fyn heat mix, Accessed 14 May 2019, https://www.fjernvarmefyn.dk/viden-om-fjernvarme/?

TimberNest Bench CO_2 footprint account

Contents

Abstract

In the last decades, one of the biggest challenges of the humankind is related to environment and the protection of it. Greenhouse gas emissions are a concerning problem with every day that passes for the generations to come, so the main objective is to keep track of these and lower them as much as possible. The scope of this report is to evaluate the CO_2 footprint of a given product, in this case a wooden bench. The company interested in this footprint account is TimberNest, a Danish start-up company which, like many other companies in the market, they want to become a CO_2 neutral firm as soon as possible. To assess the carbon dioxide emissions for this bench, a Life-Cycle Assessment (LCA) approach was chosen. By doing this, a certain environmental impact indicator was considered (Climate change) as being the most important one. The software used for this paper is SimaPro where all the processes from raw material extraction to disposal stage were considered. In order to do this assessment, we created four scenarios. The first two scenarios are represented by the benches made out of Douglas Pine and Oak, both having the same disposal procedures: incineration of wood and recycling of screws. The other two scenarios have just recycling as the main disposal type, resulting in less greenhouse gas emissions.

1. Introduction

Nowadays, environmental care is an important topic in the industry due to global climate change, which already has considerable effects on our planet. The consumer behaviour has changed in the recent years in terms of consumption, how they should treat the waste or what they should buy or consume. Many people start to realize that global warming is a bad thing for our living having many side effects such as: glaciers are melting, rising temperature, accelerated sea level and so on. All these side effects occurred due to greenhouse gases produced especially by the industry.

For our Master thesis we are making a CO_2 footprint account of a company product and by that, we want to present the environmental impacts caused by producing, utilization and the post-consumer usage related to that product.

The company Is called TimberNest, a Danish start-up company located in Odense. Their first concept was created in 2016 as a university project in collaboration with the Danish music festival Tinderbox. Since then, more social furniture has been developed for an even greater audience including other Danish festivals, companies, municipalities, and private people.

Figure 17 TimberNest bench [9]

TimberNest's vision is to create value and empathy for humans, adults and children alike, through the creation of relations through the physical meeting. We believe that the physical meeting and social recognition is more important than ever. The company's products therefore live up to the requirement for creating a frame for being together in a natural way.

The analysed product is an innovative bench as in the figure up. The product has been evaluated throughout the life-cycle stages, from the raw material extraction stage, to production, use and disposal stage. The bench is made from Douglas Pine or Oak, used for the sitting planks, purchased from another company in Denmark and then just assembled and painted in the company's factory. The provenience of wood is from Danish forests, so, in this way the transportation distances are avoided, having less impacts on the environment. Beside of the wood used for sitting planks, in the construction of the bench they use for the sides of the bench Plywood, which is imported from Finland. Moreover, they also use two types of stainless-steel screws and two types of water-based paint for the preservation of wood.

The lifespan of one bench is 5 years, according to the company, and then as disposal types are mostly incineration for wood, and recycling for screws.

The CO_2 footprint account will help the company to improve the design, materials used in construction of the bench, types of treatment of the product and developing a sustainable business plan towards a lower environmental impact. The aim of the company is to become a CO_2 neutral company. Regarding this, in the following steps, different scenarios were created in order to find solutions to lower the environmental impacts and reduce the greenhouse gas emissions.

2. Methodology

In this section are described the methods and principles used to measure the Greenhouse gases produced by the wooden bench. Our aim is to provide a comprehensive carbon accounting for TimberNest, following the right standards guide related to CO_2 footprint for a product, and help them to develop a sustainable product.

2.1 Emissions scopes

In order to do this CO_2 accounting, first we must identify and categorize the Greenhouse gas emissions released by the company product. The emissions are classified in three scopes [14]

Scope 1 – Direct Greenhouse emissions, which came from company activities and resources they own. The emissions are classified as following:

- Production of electricity, heat and steam by combustion of different fuels through furnaces, boilers, turbines and so on.
- Different kind of transportation, materials, products, waste or employees. Emissions are released by combustion of fossil fuels using ships, trains, trucks, airplanes, cars or buses.
- Physical or chemical processing – when the company is producing different kind of products as aluminum, cement, ammonia, adipic acid or they are treating the waste.
- Fugitive emissions consists in different types of releases, intentional or unintentional. Some examples could be emissions from mines, different leaks during transportation of different good by sealing etc. [14]

  In this first scope of emissions TimberNest does not fit due to its activity: they do not produce electricity or other activities presented above. Regarding the first scope, it was presented anyway for a better understanding of the emissions that are emitted by a company.

Scope 2 – Electricity Greenhouse gas emissions, are released by a company which purchase electricity from the grid or independent power generators and then resell to consumers. These emissions appear in the atmosphere through transmission and distribution of the electricity. [14]

As a company, TimberNest produces emissions by consumption of electricity. They are using electrical screw drivers to assembly the bench, but moreover, they are using electricity for lighting or other daily uses.

Scope 3 – Other indirect Greenhouse gas emissions, results from production of materials that are purchased by the company from a supplier and used in their activity or project. [15]

The company has its own suppliers for materials as: Oak and Douglas Pine for planks, birch plywood for the sides, screws for assembling and paints for the preservation of wood. In this way, they avoid emissions produced by using electricity, heat and fossil fuels in the following product stages:

- extraction of raw materials (chopping down and logging the trees, extraction of iron ore, extraction of materials for chemicals substances used for paints)
- production of the bench (sitting planks, sides, screws and wood preservation paints)
- transportation of materials to consumer.

Regarding Scope 3, this is an optional one, compared with the first two scopes, but it is very helpful to account all greenhouse gas emissions related to activities of a company. [14]

In the figure below, are illustrated all these three scopes, describing the provenience of all Greenhouse gas emissions emitted by the company activities and also the boundaries of all scopes.

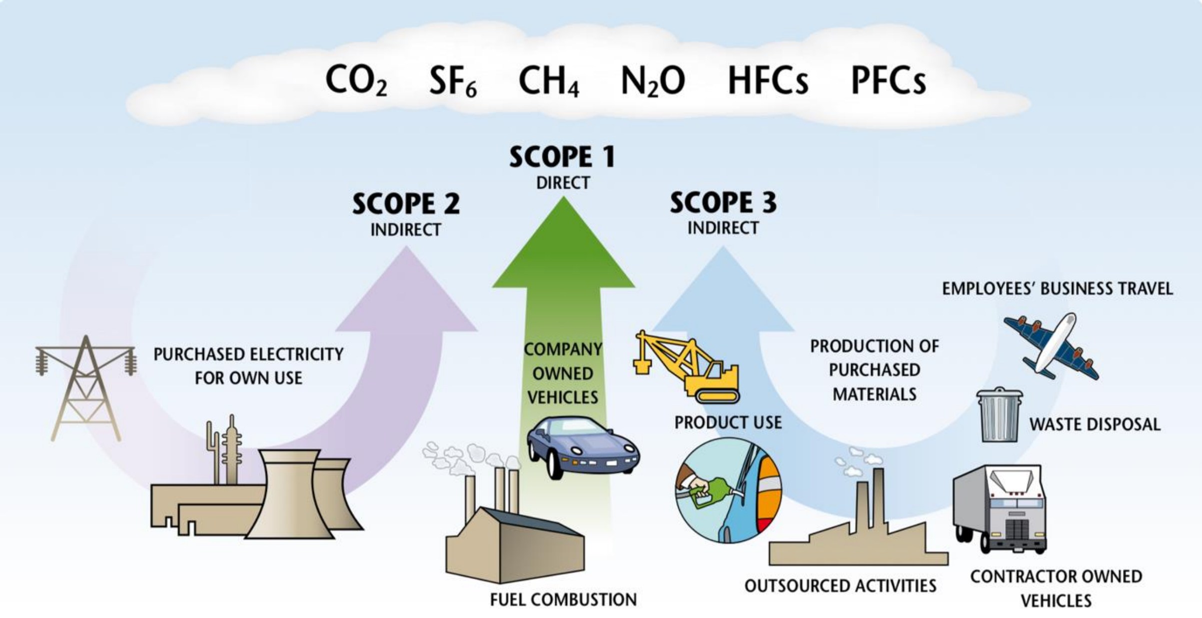


Figure 18 GHG emissions scopes [14]

2.2 ISO Standards/CO_2 footprint of a product

International Organization for Standardization (ISO) represents a worldwide federation, independent and non-governmental organization with a member agenda consists in 164 national standards bodies. In the ISO structure the members are classified in three categories: member bodies, correspondent members and subscriber members. Every member ISO represents its country and contribute with knowledge and skills to improve the International Standards to support innovative solutions for actual and future global challenges [8].

International Standards provide a guideline with specifications applicable worldwide for different products, services and systems, in order to ensure the quality, safety and efficiency. Until this moment, ISO has published 22547 International Standards and related documents, comprising all industries starting with technology, food safety, agriculture ending with healthcare [8].

For this CO_2 footprint account of the TimberNest bench it is used the ISO 14067:2018. This ISO standard was developed by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 7, *Greenhouse gas management and related activities*. The ISO 14067:2018 is the revised version of the previous one ISO 14067:2013 and is the main standard for quantification of carbon footprint of a product [3].

CO2 footprint of a product (CFP) represents the sum of all Green House Gases emissions (GHG emissions) and GHG removals of a specific product. The results are expressed as CO2 equivalent per functional unit by doing a life cycle assessment using a single impact category of climate change [3].

Green House Gases represent a large category of gaseous constituent in the atmosphere which can be divided in natural gases or anthropogenic. These gaseous constituents can absorb or emit radiations at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, atmosphere and clouds [3].

Carbon Dioxide (CO_2) – it is released in the atmosphere especially through combustion and from production of glass, cement, aluminium or steel.

Methane (CH_4) – results from incineration and decomposing of biomass (e.g. wood) and from fossil industry by refining of petrol and production of natural gas.

Nitrous Oxide (N_2O) – spread in the atmosphere by combustion of solid waste, transport sector and from agriculture by using of fertilizers.

Hydrofluorocarbon-23 (CHF_3) – appears in form of by-product from industrials processes as air conditioning, refrigeration and insulation

Sulphur Hexafluoride (SF_6) – the main use in insulation and electronic systems. [15]

Chlorofluorocarbon-12 (CCl_2F_2) – the main uses in refrigeration, blowing agents, solvents [13]

From all Greenhouse gases described above, for Climate Change is accounting just CO_2, because the other gases contribute to other environmental impact categories.

Land Use (LU)

Refers to all human activities related to land use within a relevant range. [3]

Direct land use (dLUC)

Refers to change in using the land by humans throughout a relevant range. [3]

In this report, were not considered Land Use and Direct Land Use, because are very complex and requires a lot of time of investigations to determine the environmental impacts caused by the company activities.

2.3 Life Cycle Assessment Approach

The aim of this CO_2 footprint is to approach the environmental impact of the TimberNest bench but focusing only on the impact category of climate change, using a consequential Life-Cycle-Assessment approach. Products play a key role in the attempts to reduce the total environmental impact of human activities. All environmental impacts can be tracked to the consumption, respectively need of products [1]. Life Cycle Assessment (LCA) is a standard method for comparing the environmental impacts of providing, using and disposing of a product or providing a service throughout its life cycle. LCA identifies the material and energy usage, emissions and waste flows of a product, process or service over its entire life cycle to determine its environmental performance [2]. An LCA can give an answer to the question if there is a more environmentally friendly substitution for the ordinary product which fulfills the same need. Meaning, it helps in decision making if the aim is to choose the most environmentally friendly product. The software used for this report in order to assess the environmental impacts (climate change) is SimaPro 8.5.0.0.

2.4 Goal Definition

Since its foundation in 2016, TimberNest wants to change the way of socializing by introducing a new concept called natural socializing through their products which are benches. Those benches are supposed to connect people and break the social media barriers nowadays.

With this CO_2 footprint account, the company wants to know what are the CO_2 emissions of their products in order to become a CO_2 neutral company in the future. To do so, the company has to be provided with information about the environmental impacts of their products and see which are the alternatives for a better management of these emissions.

2.5 Scope Definition and Functional Unit

The scope definition determines what product systems are to be assessed and how this assessment should take place [5]. The functional unit describes and quantifies the service performance of the product systems. This is to create a reference unit to be able to compare the product systems [1]. For this report, the functional unit is one bench, which is used either by municipalities, rented for concerts or domestic use by individuals. It is also considered a lifetime of 5 years before disposal.

TimberNest Bench					
Scenario	Wood Type	% Sent to recycling	% Sent to incineration	Incineration avoids	Recycling avoids
1. Oak Incineration	Oak	0%	100%	Waste from UK	-
2. Oak Recycling	Oak	80%	20%	Waste from UK	Gypsum production
3. Douglas Pine Incineration	Douglas Pine	0%	100%	Waste from UK	-
4. Douglas Pine Recycling	Douglas Pine	80%	20%	Waste from UK	Gypsum production

Table 1. TimberNest bench scenarios

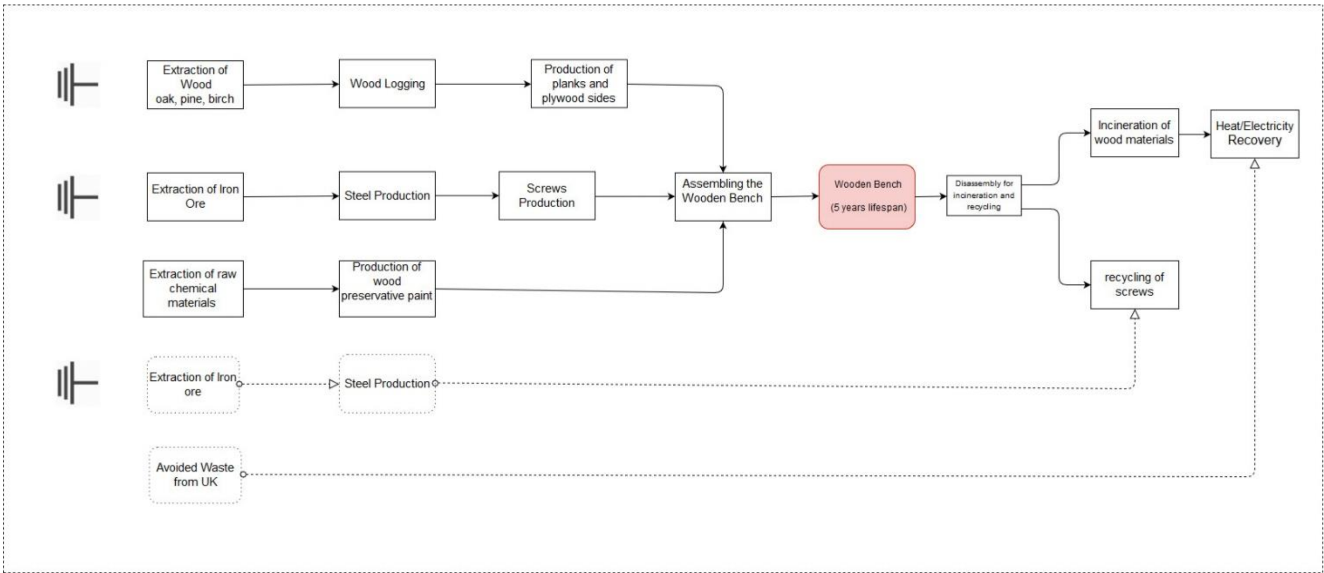


Figure 19 Process flow diagram for the incineration scenario

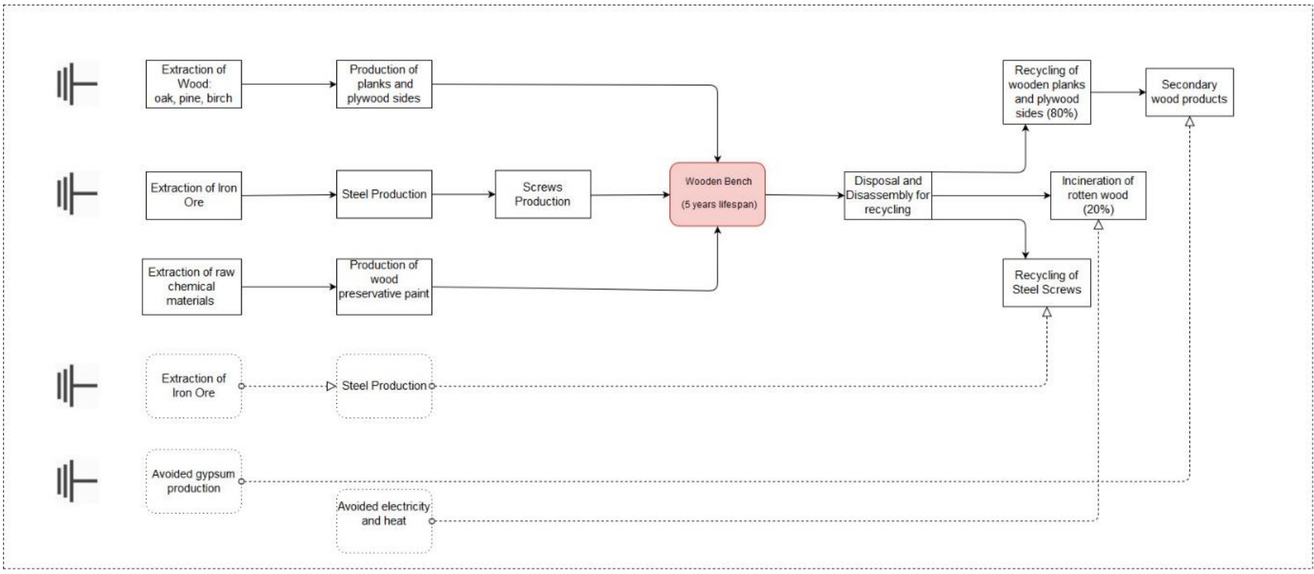
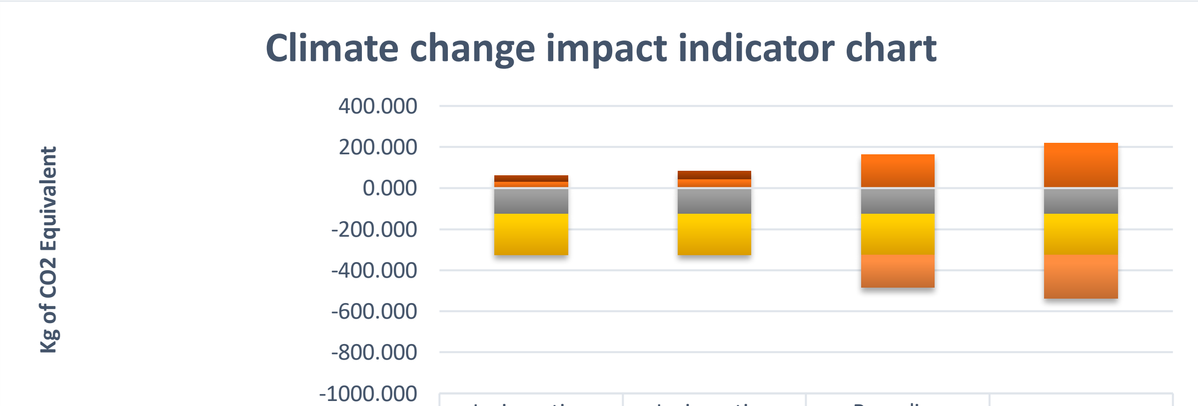


Figure 20 Process flow diagram for the recycling scenario

Figures 3 and 4 are illustrating the process flow diagrams for both the douglas pine and oak benches. The full-line polygons represent processes, the dotted polygons are avoided products that are avoided through recycling of materials and the arrows are flows. In the first one is presented the incineration scenario cradle-to-grave with all the life-cycle stages from extraction of raw materials until the disposal stage where the wooden materials are incinerated and the screws are recycled. For the recycling scenario, the processes are almost the same with the exception that here, the wooden parts from the benches are recycled. The wood is recycled through post-consumer recycling, meaning that it is aged, its properties are changed and the wood is biologically contaminated [18]. By doing this, not 100% of the wood will be recycled since it can rot if it is left outside, an assumption was made where 80% is recycled and 20% incinerated. [18]

3. Results

In the following chapter the results from SimaPro are assessed. These results express the CO_2 footprint of the TimberNest bench through the impact category of Climate change. There were assessed four scenarios for the bench, two of them regarding the actual disposal situation where the wood is incinerated and the screws are recycled. The other two were made to see what will happen if all the materials used for the bench will be recycled and how the environmental impact of CO_2 will look like.



	Incineration Pine	Incineration Oak	Recycling Pine	Recycling Oak
Waste wood, post-consumer	0.000	0.000	-158.789	-211.719
Transport, freight, inland waterways, barge	29.120	39.127	0.000	0.000
Production of Plywood sides	-199.754	-199.754	-199.754	-199.754
Production of wooden planks	-125.032	-125.032	-125.032	-125.032
Emissions of CO2 biogenic	32.844	43.860	164.220	219.300

Figure 21 Climate change chart for all scenarios

Figure 5 above, shows the most relevant SimaPro processes for all four scenarios considered. The first three processes: "Emissions of CO_2 biogenic", "Production of wooden planks" and "Production of Plywood sides" are the most important ones as they have the highest impacts on environment. "Emissions of CO_2 biogenic" it refers to how many Kg of CO_2 are contained in the wood used for one bench; therefore this amount can be emitted into the atmosphere. "Transport, freight, inland waterways, barge" is the process selected in SimaPro to define the transportation of waste from the United Kingdom to Denmark. For the incineration scenarios considered, the assumption is that in Denmark, in order to fulfil the amounts for the incineration plants across the country there is a need to import waste from the United

Kingdom by ship. [17] Even though, the numbers for "Transport, freight, inland waterways, barge" from the incineration scenarios are very small compared with the other processes. For the last line, "Waste wood, post-consumer" this process is used in SimaPro to define what happens with the wooden materials from the bench when they are recycled. Post-consumer recycling refers to the alternative of aging the wood with the side effect of changing inherent properties. [18]

In the recycling scenarios there is also a line called "Gypsum, mineral" which refers to the avoided amount of gypsum. According to Erlandsson and Sundquist, one of the best alternatives to wood recycling is to replace the gypsum in particle boards as these are made with gypsum, so the wood shavings can replace it in the future. The line "Gypsum, mineral" is also not presented in the figure above because the results that came out for this process are too small.

For all four scenarios, the other processes are too small to be taken into consideration and this is the reason why they are not presented here. A more detailed figure with all the results including the ones that are not here can be found in the appendix (Figure 6).

4. Discussions/Limitations

The overall assessment of the environmental impacts for both TimberNest benches made out of Douglas Pine respectively Oak, shows that the oak and the douglas pine bench in the recycling scenarios they have the same impact. For the incineration scenarios although, the douglas pine bench is more environmentally friendly. An assumption was made considering the difference between the recycling scenarios that the oak has a higher density and also the energy content is higher and these could be the reasons why the other one is better. Considering plywood which is used for the sides, this one is made out of laminated wood (birch) and is harder to recycle but not impossible, therefore it is burned for now in the actual situation of disposal. In the near future, TimberNest intends to recycle every single material that they use for their benches.

The company also uses two water-based paints for their product both of them being for wood preservation. The paints which are used for wood treatment are Flügger Impredur Træolie and Flügger 04 Wood Tex Opaque. Regarding the calculations in SimaPro, we had some limitations in finding the chemical substances from the paint in the software used. The chemical components of these two paints are as follows: Hydroxyphenyl-benzotriazol derivate, 3-Iod-2-propynylbutylcarbamat, Cobaltbis (2-ethylhexanoat), Kvaternære ammoniumforbindelser, benzyl-C12-16-alkyldimethyl, chloride, 1,2-Benzisothiazol-3(2H), 5-Chlor-2-methyl-2H-isothiazol-3-on/2-Methyl-2H-isothiazol-3-on, 2-Methyl-2H-isothiazol-3-on. [10] We tried to find in SimaPro a similar product which has in composition these types of substances or at least some of them, but what we found is a product called “wood preservative for outdoor use”. This product is water-based, we do not know the composition, but we assumed that it is the same type as the product used for the TimberNest bench. Furthermore, in what concerns the two types of screws used for the assembling process of the bench, we could not find the exact material used, because they are made from steel and some protection layer. For the calculations it was chosen two types of steel: chromium steel and reinforced steel.

Finally, the TimberNest bench has two different designs, when the bench is placed directly on concrete/bitumen or other hard surface, and when the base is soft as grass, sand etc. The difference between these two situations is represented by using steel and rubber for the bench sole when the product is placed on a hard ground, to protect the wood when is used, while in the case of soft base the bench does not have any protection. In our calculations we did not take in consideration the extra material used in bench composition, because having less materials used for the product than wood and screws, the results will be better for Climate Change.

5. Conclusions

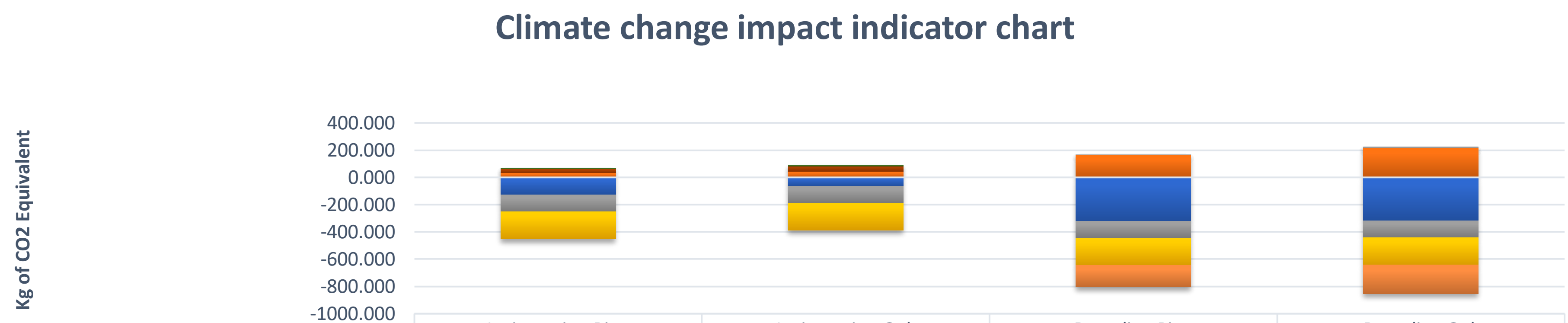
In a nutshell, the findings relating the bench show that, the best solutions to become a CO_2 neutral company are to improve the disposal solutions for their benches and this could be by recycling all the materials contained in one bench. Moreover, regarding the materials which are used in these benches, the plywood used for sides is a good material and it can be used in the future as it can be recycled like the other materials. Plywood is made out of thin birch wood layers that can be recycled afterwards. In addition, to have less greenhouse gas emissions, it is recommended to recycle the wood, not just the screws.

To become a CO_2 neutral company, maybe it is impossible, but at least it could lower the emissions, by having a Circular Economy. Old components can be reused in other new products, instead of making another by-product as wood pellets for example, and in this way less energy is used in that specific process.

6. Appendix

Greenhouse gas	Chemical formula	Global Warming Potential, 100-year time horizon	Atmospheric lifetime (years)
Carbon Dioxide	CO_2	1	100
Methane	CH_4	25	12
Nitrous Oxide	N_20	298	114
Chlorofuorocarbon-12 (CFC-12)	CCl_2F_2	10,900	100
Hydrofluorocarbon-23 (HFC-23)	CHF_3	14,800	270
Sulphur Hexafluoride	SF_6	22,800	3,200

Table 2. Principal Greenhouse gases [4]



	Incineration Pine	Incineration Oak	Recycling Pine	Recycling Oak
Wood ash mixture, pure	0.000	0.000	0.310	0.413
Waste wood, post-consumer	0.000	0.000	-158.789	-211.719
Avoided Gypsum, mineral	0.000	0.000	-0.010	-0.010
Waste from UK	3.482	3.482	0.000	0.000
Waste from UK	0.000	0.000	0.000	0.000
Avoided steel production	0.000	0.000	0.000	0.000
Electricity, low voltage	0.191	0.191	0.191	0.191
Transport, freight, inland waterways, barge	29.120	39.127	0.000	0.000
Production of Wood Tex Paint	0.002	0.002	0.002	0.002
Production of Paint Impredur Tree Oil	0.005	0.005	0.005	0.005
Production of screws	0.000	0.000	0.000	0.000
Production of Plywood sides	-199.754	-199.754	-199.754	-199.754
Production of wooden planks	-125.032	-125.032	-125.032	-125.032
Emissions of CO2 biogenic	32.844	43.860	164.220	219.300
Total	-127.765	-62.678	-320.037	-318.179

Figure 22 Climate change chart with all processes included

References

[1] Bo Weidema, ,. H. (2004). *The Product, Functional Unit and Reference Flows in LCA.* Danish MInistry of the Environment, Environmental Protection Agency.

[2] Dr. Chris Edwards, J. M. (2011). *Life Cycle Assessment of Supermarket Carrier Bags* . Deanery Road, Bristol, BS1 5AH : Environment Agency, Horizon House.

[3] *Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification*, ISO 14067:2018

[4] IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

[5] Hauschild, R. O. (2017). *Life Cycle Assessment Theory and Practice.* Springer

[6] Larsen, H. F. (2017, Oktober), *Life Cycle Impact Assessment Odense*

[7] Lorenzo Benini, L. M. (2014). *Normalisation method and data for Environmental Footprints.* Ispra, Italy: European Commision

[8] All about ISO (International Organization for Standardization), Accessed 6th March 2019. www.iso.org

[9] TimberNest vision, Accesed 14th March 2019. www.timbernest.dk

[10] Impredur Tree oil/Wood Tex Opaque data factsheet, Accessed 6th March 2019. www.flugger.dk

[11] Densities of seasoned & dry wood, Accessed 20th March 2019. https://www.engineeringtoolbox.com/wood-density-d_40.html

[12] Wood Energy: List and values of wood fuel parameters - Part 2. Accessed 20th March 2019. http://www.woodenergy.ie/woodasafuel/listandvaluesofwoodfuelparameters-part2/

[13] Lea Bredsdorff, Elsa Nielsen, Danish Ministry of the Environment, 2014, *Chlorofluorocarbons: CFC-11, CFC-12, CFC-113, HCFC-21, HCFC-31, HCFC-133a*

[14] The Greenhouse Gas Protocol, 2014, Revised Edition

[15] Agence Française de Développement, *The AFD Carbon Footprint Tool for projects*, 2017

[16] Jean-Pierre Barette; Claude Hazard et Jérôme Mayer (1996). *Mémotech Bois et Matériaux Associés. Paris: Éditions Casteilla. p. 22*

[17]Importing waste from UK, Accessed 31st March 2019 https://zerowasteeurope.eu/2017/10/copenhagen-goes-all-in-on-incineration-and-its-a-costly-mistake/

[18] Erlandsson and Sundquist (2014) – Environmental Consequences of different recycling alternatives for wood waste