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Life cycle assessment of residential apartment buildings: a case study of the environmental impacts on buildings in Sweden

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Abstract— This research paper focuses on the environmental impacts of construction buildings performing a Life Cycle Analysis (LCA). According to the Sweden Green Building Council for environmental certification, fifteen environmental factors and five impact categories are considered such as global warming potential, land use, mineral resource use, fossil resource use, and water consumption. The tools used performing LCA for this project are ReCiPe 2016 methodology, SimaPro® software to assess the impacts of construction and productions of different building materials. After analyzing with corresponding to 100% environmental damage among the five impact categories, the LCA results show that construction and production (55.75%) affects highly on the mineral resources compare to the global warming (40.03%). On the other hand, operation services have effects on all the five categories significantly but the water consumptions (96.80%) require the highest operation services. The key findings of the study are the global warming potential which is highly dependent on CO_2 emissions during construction and production of materials plus transportation frequencies from the start of the project to end-of-life. Moreover, energy sources for operational services need to be addressed to reduce the loss of natural gas, emissions from fossil fuels and to shift into green energy sources.

Keywords: Life cycle analysis (LCA), SimaPro®, Environmental impact categories, Residential building, Sustainable.

1. INTRODUCTION

THE construction industry plays an important role in the total amount of natural resource depletion and the production of negative environmental impacts. Therefore, there is an urgent need to mitigate these undesirable problems arising from the neglecting of the direct or indirect processes involved along with the chain supply of this sector. In 2015 the UN agreed at the Paris conference that the Earth's temperature should not increase more than 2°C. Several Swedish construction companies have used the Paris agreement as a reference point for their sustainability goals. Their goals include reducing their CO_2 emissions with 50% and their waste should be material recycled or minimized by 70% until 2020 compared to 2015 (United Nations. (2016).). From a life cycle perspective, the building industry is responsible for about 30% of global annual Greenhouse Gas (GHG) emissions and 40% of energy consumption (Unalan et al., 2016) [1]. Also, buildings are responsible for 32% of world resource depletion, 12% of water consumption, and 40% of waste to landfill (Langston et al., 2008) [2].

A shift of thinking in the perception of sustainable building design has arisen in the last decade, switching from the traditional creative and innovative approach to a restorative and regenerative one. This change of perception is founded on the facts that an enormous proportion of all the materials ever extracted along human history are in today's built environment (Kibert, 2007) [3], the turnover rate of buildings is considered relatively low (Beccali et al., 2013 [4]; Conejos et al., 2014 [5]; Sandin et al., 2014 [6]; Wilkinson et al., 2009 [7] , the price of materials extraction is increasing, as is the negative environmental impacts, due to the natural constraints of the more dilute and distant stocks of ores and other resources (Kibert, 2007) [3], and the understanding of the real value of the built environment in terms of sustainability and monetization of environmental impacts has improved through technological development and research in the field (Shindell, 2015 [8]; Viscusi, 2005 [9] ; Yeung, 2016 [10]).

This life cycle assessment study is focused on the assessment and interpretation of the next environmental indicators: global warming potential, land use, mineral resource use, fossil resource use, and water consumption. Also, this study will support to get a better understanding of their construction process to improve it for the future. The result will indicate and compare what materials should be minimized to construct more sustainable buildings.

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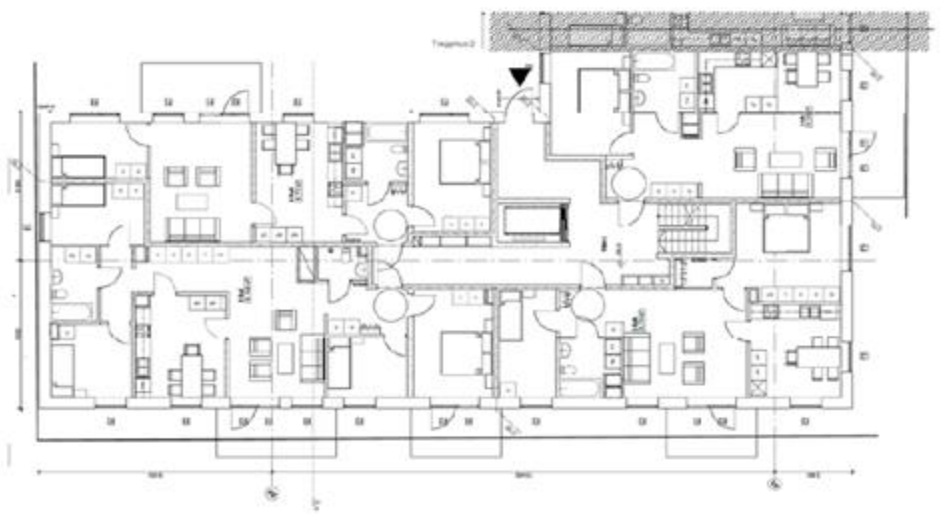

Fig. 1. Architectural drawing of part of the building plan.

2. LIFE CYCLE INVENTORY DATABASE

A life cycle inventory database is developed for this building project in Sweden and is used as the preliminary source of data provided by NCC Construction Company from Sweden with architectural drawing (see Figure 1). This life cycle analysis was focused on one of the multi-residential apartment buildings containing 66 apartments. To calculate the life cycle environmental impact software SimaPro® used for the project. The calculations from these can be used for a comparison between the present project and future upcoming projects. For making the study more time-efficient materials have been exchanged to similar materials already existing in SimaPro® (see Appendix 1).

In SimaPro® the production impact is included in the selected materials put into the program. This means that for this LCA, production and construction will be included in the same category for the analysis. The materials used in the construction can be seen below in Appendix 1. To make the analysis more inclusive also considering the excavation phase. A big excavation digger is included to remove landmasses to prepare for the substructure of the building (see Appendix 2). During the lifetime of the building, electricity and water usage will have an impact on the purpose of the LCA. How that is included can be observed in Appendix 3. For the maintenance and replacement, it is expected that the building will be repainted three times and that windows and doors will be replaced one time during the lifespan of 60 years. This is included in normal maintenance for the real estate owner and is something they should expect to do (see Appendix 4).

3. METHOD FOR IMPACT ASSESSMENT

The impact assessment methodology used for this LCA is ReCiPe 2016 midpoint (H). ReCiPe 2016 method was developed by RIVM, Radboud University, Norwegian University of Science and Technology and PRé Consultants and is the updated version of the original ReCiPe 2008. ReCiPe provides harmonized characterization factors both at midpoint and endpoint levels. Used the midpoint levels, looking at characterization factors located at the point after which the used environmental mechanism is identical for all environmental flows assigned to that impact category (Goedkoop et al. 2009) [11]. Moreover, the (H) - Hierarchist perspective was chosen, mainly because it offers a more balanced time perspective and a preventive and comprehensive management style which better suits on a functional unit (m²/year). The system boundary used in this study is based on the life-cycle stages defined according to the EN 15978:2011 standard.

ReCiPe divides the whole environmental impact of the life cycle into 17 different impact categories. The impact categories that ReCiPe 2016 midpoint (H) looks into are presented in the following Figure 2.

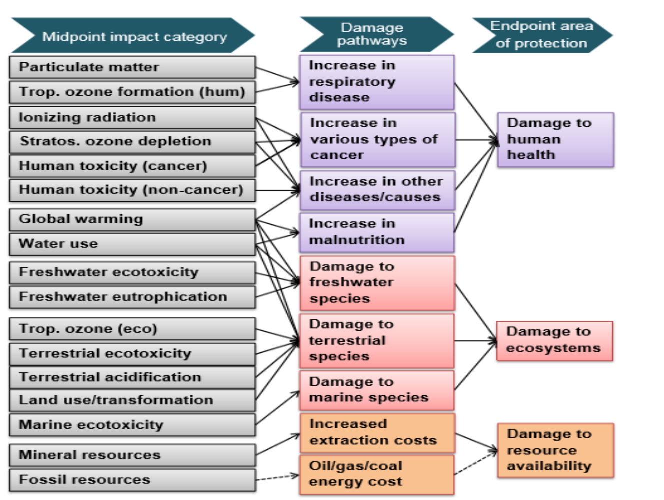

Fig. 2. Overview of the impact categories that are covered in the ReCiPe 2016 methodology and their relation to the areas of protection (Huijbregts, Mark AJ, et al., 2017) [12].

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4. RESULTS, INTERPRETATION & DISCUSSION

The results for the LCA seems reasonable (see Figure 3). The results from the LCA analysis indicates that the operational phase impacts the environment the most in four out of the five impact categories that are analyzed. The construction process has the highest impact on mineral resource use (see Figure 3). From (Appendix 5) table shows the percentages the different processes have compared to each other. The building analyzed network tree (see Appendix 6) shows that the construction phase comes second in carbon dioxide emissions and the materials concrete and aluminum stands for the majority of the emissions. A similar deviation can also be observed in other researchers have already performed LCA on buildings such as Adalberth et al. (2011) [13] and Norman et al. (2015) [14].

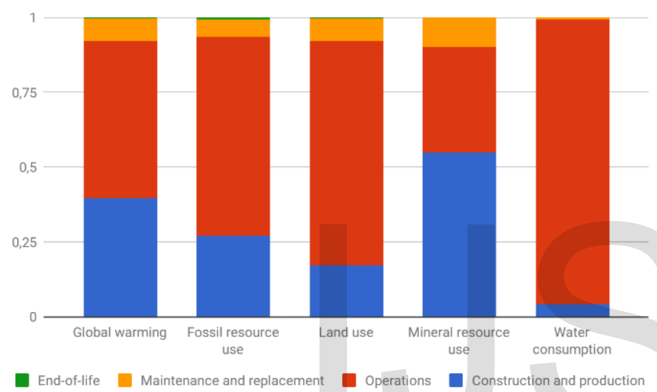

Fig. 3. Environmental impact assessment analysis of the building under the Midpoint impact.

4.1 Effect of Global Warming Potential

The global warming potential for the project is dominated by the fossil carbon dioxide emission that stands for 91% of the total emissions (see Figure 4). The process that influences the carbon dioxide emissions the most is operations (see Figure 5), where the heating is causing the largest amount of emissions (see Appendix 6). The hotspot materials discovered in the construction and production phase were concrete and aluminum.

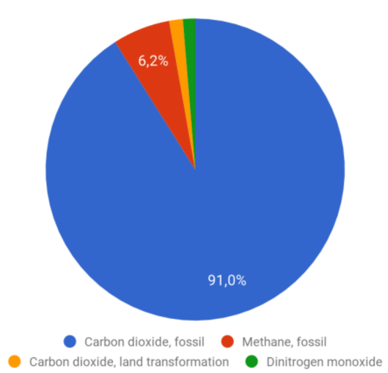

Fig. 4. Global warming potential of the project.

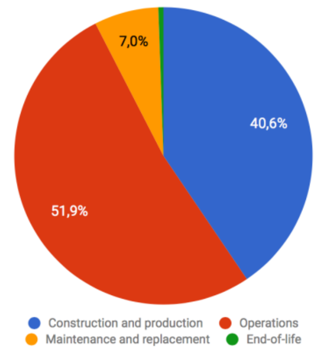

Fig. 5. CO_2 emissions per process.

4.2 Effect of Fossil Resource Use

The fossil resource use for the project is dominated by the natural gas that stands for 61.7% of the total (see Figure 6a). The second-largest impactor is crude oil at 19.1 %. The process that influences the natural gas use the most is operations with 87.2% and the second one is construction and production with 10.6% (see Figure 6b). The use of fossil fuels is the first most important source of greenhouse gas emissions. Therefore, the reduction of their consumption will help to decrease the emissions of greenhouse gases as well.

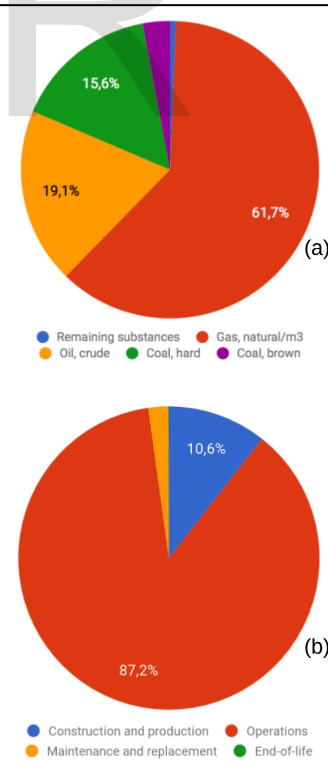

Figure 6: Fossil resource use (a); Natural gas emissions per process (b).

4.3 Effect of Land Use

According to the results, the land occupation is affected principally in the subgroup "occupation, forest, intensive" with 89.9% (see Figure 7a). The process that affects the most is operations with 74.9% followed by the construction and production stages with 17.2% (see Figure 7b). Land use is linked indirectly to other environmental impacts.

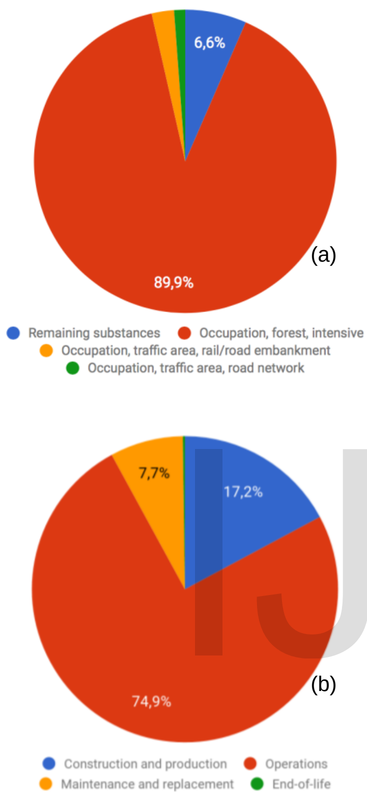

Fig. 7. (a) Land occupation; (b) Occupation of land divided into processes.

4.4 Effect of Mineral Resource Use

From the result analysis, the highest depletion indicator iron (26.11%) for the project is affected by the construction and production phase (see Figure 8a). The percentage of Iron used in the process of construction and production is 57% while operations require 39.4% of total Iron usage (see Figure 8b). The process that affected the aluminum the most is the construction and production phase (48.1%) and the maintenance and replacement phase (46%) (see Figure 8c).The reason for the high impact in the depletion of materials is due to using the raw materials in an initial phase, that's why mineral resource use is the highest in the construction and production phase compared to other phases.

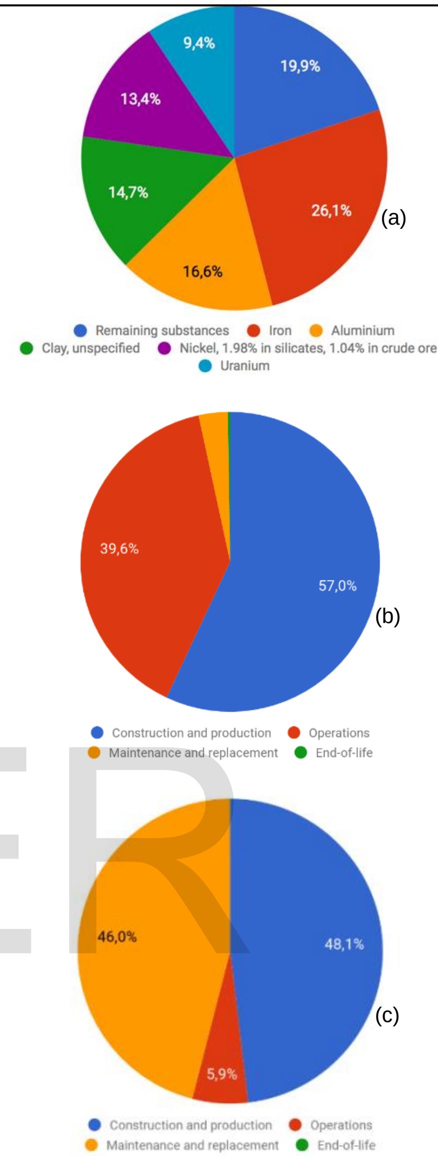

Fig. 8. (a) Mineral resource use; (b) Iron used in the processes; (c) Aluminum use in the processes.

4.5 Effect of Water Consumption

The project's water consumption is the highest during the operational phase of the lifetime (see Figure 9). The result seems valid to split over the lifetime since the operational phase should have the highest usage.

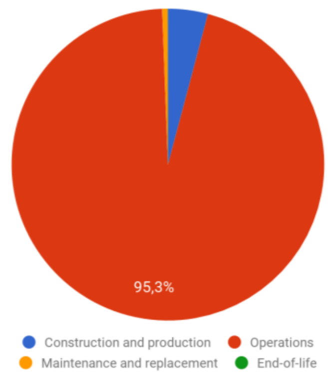

Fig. 9. Water consumption per m^2/year in processes.

5. STUDY CASE (SWEDEN VS. GERMANY)

To probe the robustness and consistency of the results, a case study built for comparing the energy use in the operational stage for our current case in Sweden with an additional case in Germany. It is visible (see Figure 10) the increment of the environmental impacts of global warming potential and fossil resource scarcities that are associated to the operation stage. The main reason is that Sweden has cleaner energy production in comparison to Germany, due to the sources for energy generation AGEB, 2017 [15]; SCB (a) [16] .

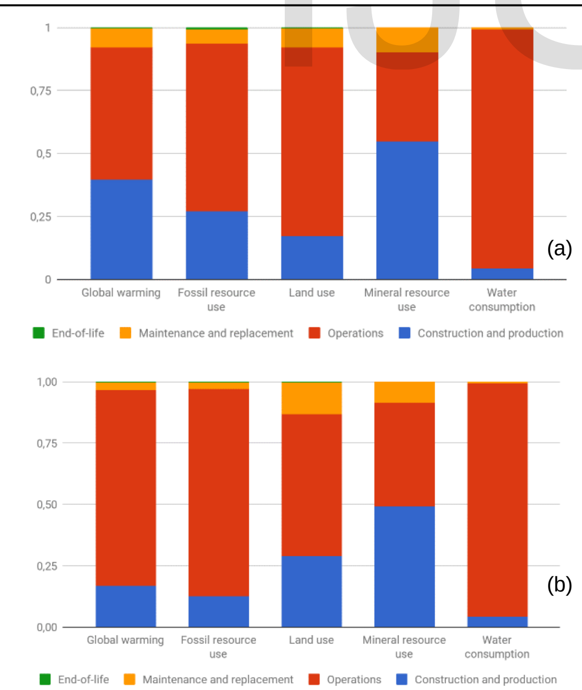

Figure 10: Environmental impact assessment Sweden (a) vs. Germany (b).

6. CONCLUSION

According to the assessment above, the operational phase of the project has the highest environmental impact and to lower the impact of the project the focus should be placed there. The choice of electricity and heating has the impact and the property owner should investigate different options before deciding. The material that affects the global warming potential of the project the most is concrete, both in the construction phase as well as in the disposal phase. One suggestion towards the construction company could be to select more environmentally friendly concrete mix for their projects, as a way to cut down their carbon dioxide emissions. In the maintenance and replacement phase, the choice of different materials in the building impact the depletion of materials and also this phase it's important for the economic issue. This LCA shows that they should strive to minimize the use of concrete and aluminum in their buildings and substitute them for more environmentally friendly options. By investigating other opportunities, the buildings will become more sustainable and future greener.

In this Life Cycle Analysis (LCA), all of the input data provided were replaced with the closest similar materials found on the SimaPro® software and perhaps in some cases, this difference could influence the results. Taking this into consideration, if the aforementioned issues had been solved, the results of the LCA would have been more accurate.

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APPENDICES

Appendix 1: Life cycle inventory of materials used in the construction (source: Brillinge building project, Uppsala, Sweden)

Construction and Production				
Given resource	Quantity	SimaPro® resource	Quantity	Comments
Substructure				
Ready mix concrete, excluding re-bar, C30/37	322.5 m3	Concrete. 30-32 MPA	322.5 m3	
Steel, reinforcement rebar, 4-40 mm	41 925 kg	Hot rolling, steel	41.925 ton	
Filter fabric N2	0.19 m3	Viscose fibre	7.36 kg	Calculated with the density of filter fabric 38.75 kg/ m3
EPS insulation in bottom floor EPS 100	129 m3	Polystyrene foam slab	25.8 ton	Density 20 kg/ m3
Macadam (8...16 mm)	193.5 m3	Gravel, round	368 ton	1.9 ton/ m3
Outer wall				
Ready mix concrete, excluding re-bar, C30/37	120.75 m3	Concrete, 30-32 MPA	120.75 m3	
Ready mix concrete, excluding re-bar, C30/37	269.52 m3	Concrete, 30-32 MPA	269.52 m3	
Facade expanded polystyrene, EPS insulation	471.66 m3	Polystyrene foam slab	1 550 kg	Density 3,2 kg/ m3
Steel, reinforcement rebar, 4-40 mm	10867,5 kg	Hot rolling, steel	10867.5 kg	
Filter fabric N2	0.07 m3	Viscose fibre	2.71 kg	Calculated with the density of filter fabric 38.75 kg/ m3
Combined EPS/Drainage insula-tion, 108 mm	483 m2	Polystyrene foam slab for perimeter insulation	158 kg	Thickness 102 mm; Density 3,2 kg/ m3
Insulation, EPS 100	48.3 m3	Polystyrene foam slab	966 kg	Density 20 kg/m3
Mineral thin-coat renders	67.38 m3	Powder coat, aluminium sheet	33 700m2	
Light expanded clay aggregate	202.14 m3	Lightweight concrete block, expand-ed clay	50 500 kg	Density 250 kg/ m3
Inner wall				
Ready mix concrete, excluding re-bar, C30/37	184.36 m3	Concrete, 30-32 MPA	763 m3	
Ready-mix concrete, excluding re-bar, C30/37	578.38 m3	Concrete, 30-32 MPA		
Concrete block, masonry, 350x250x500 mmm	132.2 m3	Concrete block	278 000 kg	Density 2100 kg/ m3
Gypsum plasterboard, 12.5x900/1200 mm	24 m2	Gypsum plasterboard	17 900 kg	Density 8.8 kg/m3
Gypsum plasterboard, 12.5x900/1200 mm	27 m2	Gypsum plasterboard		
Gypsum plasterboard, 12.5x900/1200 mm	140 m2	Gypsum plasterboard		
Gypsum plasterboard, 12.5x900/1200 mm	585 m2	Gypsum plasterboard		
Gypsum plasterboard, 12.5x900/1200 mm	1260 m2	Gypsum plasterboard		
Steel stud (per m2 of wall area), 95 mm, 400 mm spacing	24 m2	Steel, low-alloyed	78 400 kg	Thickness 5 mm; density 7700 kg/m3
Steel stud (per m2 of wall area), 95 mm, 400 mm spacing	27 m2	Steel, low-alloyed		
Steel stud (per m2 of wall area), 95	140 m2	Steel, low-alloyed		

ISSN 2229-5518

mm, 400 mm spacing				
Steel stud (per m2 of wall area), 95 mm, 400 mm spacing	585 m2	Steel, low-alloyed		
Steel stud (per m2 of wall area), 95 mm, 400 mm spacing	1260 m2	Steel, low-alloyed		
Floors				
Ready-mix concrete, excluding rebar, C30/37	5030 m2	Concrete, 30-32 MPA	1 510 m3	Floor thickness of 0.3 m is estimated
Steel, reinforcement rebar, 4-40 mm	113175 kg	Hot rolling, steel	113 175 kg	
Wood flooring, conifer	40.83 m3	Sawnwood, board, hardwood, dried (u=10%), planned	40.38 m3	
Other				
Glass wool insulation, 42 mm	650 m3	Glass wool mat	9 750 kg	Density 15 kg/m3
Balcony, reinforces concrete element	537 m2	Concrete block	241 000 kg	Balcony slab thickness estimated to 0,2 m
Concrete stairs slab, B35 M60	15.96 m3	Concrete block		
Interior paint, Fluegger SCHÖNER WOHNEN polarweiss	951 kg	Alkyd paint, white, without solvent, in 60% solution state	951 kg	
Steel structures, 78000 kg/m3	0.28 m3	Steel, low-alloyed	2184 kg	Density 7800 kg/m3
Balcony security door 105/80	69 st	Door, outer, wood-aluminium	19.37 m2	Height 2.05 m, width 1.05 m
Fully reversible window with aluminium cladding	291 st	Window frame, aluminium, U=1.6 W/m2K	291 m2	Estimated window area 1 m2
Ventilation system with steel pipes, room area m2	20 m2	Ventilation duct, steel, 100x50 mm	40 m	
Elevator, 630 kg capacity	4 st	source: Wendin, Marcus. (2016) [20]	3 730 kg	
		Door, inner, wood	706 m2	Added from calculations on drawings

Appendix 2: Life cycle inventory for excavation

Excavation		
SimaPro® resource	Quantity	Comments
Excavation, hydraulic digger	3 810 m3	Amount of soil removed from site to build the substructure

Appendix 3: Life cycle inventory for operations

Operations		
SimaPro® resource	Quantity	Comments
Electricity, low voltage {SE}	22 900 000 kWh	Calculated from the restriction of Miljöbyggnad Silver [19] per m2, time period of 60 years
Tap water	426 000 000 kg	Based on the average use in a Swedish household SCB (b) [17], time period 60 years
Heat, district or industrial, natural gas {SE}	14 300 000 kWh	Calculated from the restriction of Miljöbyggnad Silver [19] per m2, time period of 60 years

ISSN 2229-5518

Appendix 4: Life cycle inventory for maintenance and replacement

Maintenance and replacement		
SimaPro® resource	Quantity	Comments
Window frame, aluminium, U=1.6 W/m2K	291	Assuming window replacement every 30 years
Alkyd paint, white, without solvent, in 60% solution state	2 850 kg	Assuming entire repainting every 15 years
Door, inner, wood	706 m2	Assuming door replacement every 30 years
Door, outer, wood-aluminium	19.37 m2	Assuming door replacement every 30 years

Appendix 5: Environmental impact assessment analysis results in different phases.

Impact category	Unit	Total	Construction and production	Operations	Maintenance and replacement	End-of-life
Global warming	kg CO2 eq/m2/year	12.204	4.885	6.432	0.941	0.063
		100%	40.03%	52.71%	7.71%	0.51%
Fossil resource use	kg oil eq/m2/year	3.410	0.924	2.265	0.199	0.022
		100%	27.09%	66.42%	5.84%	0.65%
Land use	m2a crop eq/m2/year	2.153	0.370	1.613	0.166	0.005
		100%	17.17%	74.89%	7.72%	0.22%
Mineral resource use	g Cu eq/m2/year	0.084	0.0467	0.030	0.008	0.000
		100%	55.75%	35.82%	9.91%	0.12%
Water consumption	m3/m2/year	1.416	0.059	1.371	0.008	0.000
		100%	4.20%	96.80%	0.59%	0.02%

Appendix 6: Network tree over carbon dioxide emissions for the building for the entire lifespan by SimaPro®.