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The climate impact of different building systems

A study regarding materials in residential buildings and their environmental impact

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Abstract

The climate impact of different building systems

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This report was done on behalf of Uppsala municipality with the aim to investigate how much the CO2-equivalent emissions differ between different building systems during the construction phase, considering the different choice of material used in the frames. Several multi-family houses with different building systems were therefore studied and compared by using previous LCA from collected climate reports regarding each construction project. Different scenarios of the residential development in Uppsala until year 2050, including multi- and single-family houses, were further on brought forward.

The impact that the choice of material had on the climate was then studied by comparing the scenarios with the climate goals set up by Uppsala municipality regarding the construction sector. This was discussed in order to investigate whether Uppsala municipality would reach the climate goals or not.

The conclusion of the study is that the building systems with wooden frames in general release less CO2-equivalent emissions than the ones with concrete frames. One of the reasons for this is that the production of the materials has different amounts of waste and the fact that concrete consists of cement, which causes a lot of emissions during the production of the material.

Another part of the report was to investigate if climate improved concrete could decrease the CO2-equivalent emissions from building systems with concrete frames. This was done by doing a case-study, where parts of the concrete frame for one of the building systems were replaced, which resulted in a small decrease of the emissions. It is however, in a larger perspective, important to reduce the emissions as much as possible and there is still room to continue the improvement of concrete.

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1. Introduction

The climate crisis is an ever present part of today's society. It is manageable, but it will require a large effort from all parts of society in order for us to overcome it (Climate action, 2019). One of the issues that will be faced and needs to be handled in this transition is the future constructions due to an increasing population.

Uppsala is a city located in one of the most expansive growth areas in Europe, which implies that more people will move to the city and that the population growth further on will increase (Uppsala kommun, 2019a). According to Uppsala municipality (2019b) and a planning documentation that Sweco (2013) has produced, the city will increase from around 225 000 to 340 500 inhabitants from year 2018 to year 2050. Further on, this growth results in an extended construction work in Uppsala will be required. At the same time, the municipality of Uppsala strives to become a fossil free city by year 2030 and a climate positive city by year 2050 (Uppsala klimatprotokoll, 2019). For these parts to be able to interact, it is interesting to discuss what part a sustainable construction can play in the pursuit of achieving the goals set by the municipality.

Today, the construction sector represents around 21% of the greenhouse gas emissions in Sweden (Boverket, 2019) and the majority, around 8%, of the climate impact during the construction of a building is caused by the manufacturing of building materials (Fossilfritt Sverige, 2018). In order to achieve the Uppsala municipality's goal of becoming a more environmentally friendly city, it is therefore also of interest to survey what climate impact the different types of materials used for the constructions have.

1.1 Aim and research questions

With the aforementioned aspects in mind, the aim of this report will be to investigate the amount of emissions that different building systems cause during the construction phase due to different choices of material of the frame. This will be done in order to study the ability to decrease the emissions caused by the building sector.

Further on, due to Uppsala expected growth, the aim is also to investigate how Uppsala can keep on being a sustainable city and still be able to build more residential buildings. Therefore, the report will investigate how the choice of material would affect the development of Uppsala in the future and the municipality's possibility to achieve their climate goals.

On this basis, the following are the research questions of the report:

- How do the CO_2-equivalent emissions differ between scenarios of Uppsala's residential development until 2050 based on different building systems?

- Further on, how will the different choice of material affect Uppsala municipality's achievement of its climate goals for the residential development until year 2050?

- How may another choice of building material for parts of the frame affect the CO_2-equivalent emissions?

1.2 Limitations and delimitations

One important limitation is the fact that a collection of more data about different building systems would have provided more credible results since a few different building systems were studied and are not representative for all different types of buildings. More detailed data regarding future residential building plans and population growth in Uppsala would have enabled more exact calculations. For instance, the data regarding the growth of inhabitants in different types of residential buildings in Uppsala is based on a report from year 2013 where the calculations are based on the population growth from year 2010. Although, it would be more exact if more updated data were used.

Another limitation is the fact that the study is based on how the emissions differ between building systems with different materials of the frame. Other factors and parts of the buildings will of course affect the total emissions as well, but this is something that will be discussed.

Several delimitations have also been considered. One of them is that the emissions being regarded in the research questions are the CO_2-equivalent emissions during the construction phase of an LCA, not the whole LCA. The report also investigates different types of wooden and concrete frames for multi-family houses, since these are the most common materials. Other types of frames will not be investigated.

In addition, it is not realistic that only one building system will be used for all residential buildings that will be built in Uppsala until year 2050, but a mix of different sorts. Since it is impossible to know exactly how this mix will look like, different scenarios based on the different systems will be calculated separately. This method also simplifies the comparison between the emissions for the different systems.

The single-family houses are delimited to one average building system for all calculations. The reason for this is that the main focus of the report, as mentioned before, is to compare wood and concrete frames. About 90% of the single-family houses are built in wood (see background section 2.3.1). The material may of course differ between different small houses, which can be considered as a limitation.

A delimitation has also been done for the calculations regarding the future development of Uppsala, where the year 2050 has been set for the calculations. The reason that the year 2050 has been in focus is because the climate goals extend to this year, which makes it interesting.

1.3 Overview of the Structure

The report begins with a background section in which information regarding the continued presented parts of the report are presented. Further on, a methodology section describing the methods, data and calculations regarding the aim of the report is introduced. It is followed by the section results in which the results of the methods and calculations described in the methodology are presented. On this basis, a sensitivity analysis will further on be done followed by a discussion in which the results will be analyzed and discussed. Lastly, this will precede in a conclusion which will answer the research questions.

2. Background

2.1 Growth of Uppsala

As mentioned before, the population in Uppsala municipality is going to expand until year 2050. Further on, this will result in an increased construction of residential buildings (Uppsala kommun, 2016).

Although it is impossible to predict exactly how a city will grow and develop in the future, different sorts of forecasts are made frequently. Sweco Eurofutures has on behalf of Uppsala municipality analyzed how Uppsala can be expected to grow until year 2030 and year 2050. The results have been put together in the report *"Uppsala tillväxt - planeringsunderlag 2030/2050"* (Sweco, 2013). Uppsala is located close to Stockholm and the two cities are strongly connected by for example the labour market. Stockholm - Uppsala is the most leading area in Sweden regarding this aspect, with a strong centre in Stockholm (Sweco, 2013).

The report discusses two future growth scenarios of Uppsala. The first one, which is referred to as the "base-scenario", assumes that Stockholm will keep on being the strong centre in the region and that the integration between the cities will increase. The other scenario, "high", assumes that Uppsala will develop to become a second centre of the region. The two scenarios are presented more specific in *table 1* (Sweco, 2013).

Table 1. A compilation of the two growth scenarios of Uppsala, "high" and "base" (Sweco, 2013).

Base	High
A continued strong commuting development in the region.	A continued strong commuting development in the region.
Stockholm will strengthen its position on the common labor market.	Uppsala will grow to a more complete alternative to Stockholm, as well in business as in activities.
The development of Uppsala will primarily be related to population and consumption.	A more productivity driven growth and balance between working day and night population.
Uppsala will be more dependent on the commuting to Stockholm.	More incoming commuting from other parts of the county.
Stockholm will continue to be the main center of the region.	The region will grow into a more polycentric area. Uppsala becomes a strong northern core.
The population of Uppsala will be 283 480 in year 2050.	The population of Uppsala will be 340 480 in year 2050.

2.2 Climate goals

Uppsala municipality wants to take responsibility for the climate and be leading in climate and environmental issues. Furthermore, the goals set by the municipality is in order for the development of the city to be sustainable (Uppsala kommun, n.d). Documents of guidance and guidelines have been developed and formed a policy for sustainable development. One of these documents of guidance is an environmental and climate program. Its purpose is to reduce the negative environmental impact and maximize the positive impact and consists of ten phase goals (Uppsala kommun, 2018).

The program includes long-term climate and environmental goals (Uppsala klimatprotokoll, 2019). Specific goals for increasing the sustainable construction and management as well as increasing the use of more wood and climate neutral materials in the construction process can also be found in the program (Uppsala kommun, 2014). In *table 2*, the specific goals set by the municipality can be found. These goals will be referred to in the report and further on be discussed in the discussion section.

Table 2. An overview of the climate goals set by Uppsala municipality.

Climate goal	Until year	Source
The use of more wood and climate neutral materials in the construction process.	2030	Uppsala kommun, 2014
In urban construction projects produced by the municipality, half of completed building volume shall consist of wood.	2030	Uppsala kommun, 2014
The climate impact of concrete shall be reduced by at least 50% compared to the impact in year 2017.	2030	Uppsala kommun, 2014
The concrete shall be climate neutral at its latest.	2030	Uppsala kommun, 2014
The climate impact of the use of concrete shall be reduced by 50% for all concrete compared to the environmental product declaration for concrete used for the frame in constructions in year 2017.	2030	Uppsala kommun, 2014
Be a climate positive municipality by year 2050.	2050	Uppsala klimatprotokoll, 2019

2.3 House constructions

2.3.1 Buildings in general

The lifecycle of a building can be divided into different phases; in the first phase the house is built, in the second phase it is used and in the third and final phase, it is torn down. In order to build a sustainable building, it is important that the house can last for a long time. Since the climate issue has become an essential question in today’s society, the climate impact from the different phases is another important aspect (Växjö kommun, 2019). The lifecycle is presented in *figure 1*.

Figure 1. The different stages of the lifecycle of buildings (Boverket/Infab AB, 2019). Image used with the permission of Boverket.

Multi- and single-family houses are two of the most common residential buildings. Multi-family houses are defined as buildings consisting of three or more residential apartments (NE, 2019). One of the main parts of a building is the frame, which can be made of different materials. The most common frames today are concrete frames (Fossilfritt Sverige, 2018b). Frames can however also be made of wood. Regarding the climate impact of multi-family houses, studies made in recent years show that 30 to 50% of the total climate impact during the lifecycle occurs during the production of the material (Svensk betong, 2017).

Today, about 10 000 single family houses are built in Sweden every year and about 90% of them are built in wood (Iva, Sveriges byggindustrier, 2014). There are different sorts of single-family houses, they can either stand alone or be linked together like for example a terrace house (Boverket, 2018). The knowledge regarding the climate impact from the production of these types of houses are limited (Iva, Sveriges byggindustrier, 2014).

2.3.2 Concrete

Concrete is one of the oldest and most used building materials both in Sweden and globally. The material has many advantages, such as high bearing capacity and a long life span which in general is more than 100 years. Concrete does not burn and can be cast both in advance and direct at the building site, which creates cost effective circumstances and flexibility (Fossilfritt Sverige, 2018b).

Ordinary concrete consists of around 80% stone (sand, stone or gravel), 14% cement and 6% water, although the composition may differ (Fossilfritt Sverige, 2018b).

Concrete is commonly used together with steel reinforcement in order to increase the strength of the building. However, the amount of reinforcement differs depending on which type of concrete, cast or prefabricated concrete, that is used for the building (Byggipedia, 2018).

From an LCA perspective, manufacturing of cement clinker is the main source of the concrete's climate impact during the production, which corresponds to about 90%. The other 10% comes from transports, production of the concrete and other sub-materials such as ballast and water. While concrete releases CO_2e during the production phase, it absorbs CO_2e during the operating phase. The absorption is made by a chemical process called carbonization. This process occurs naturally and spontaneously during the entire lifetime of the concrete. From an LCA-perspective, the carbonization will reduce the CO_2e emissions from the production phase with around 15 to 20% (Fossilfritt Sverige, 2018b).

When constructing a building, there are several ways of producing the concrete, but the two main categories are cast concrete and prefabricated concrete. The first one implies that fresh concrete is delivered to the building site where the cast work is done (Svensk betong, n.d). There are different ways of casting concrete and one of them is permanent formwork, which is defined as: "Formwork that remains in place once the concrete has set and becomes part of the structure." (OxfordReference, 2013).

Buildings with concrete frames can also be built with light curtain walls, which is the most common type of outer walls for new production of multi-family houses. (Pettersson & Strömberg, 2013). The outer walls consist of light curtain walls with slats of sheet metal and wood and supporting steel columns integrated in facade (Ivl, 2018).

Prefabricated concrete, as the word indicates, implies that complete building parts such as floor structures and walls are prefabricated and then delivered to the building site (Svensk Betong, n.d). The amount of steel and concrete needed for prefabricated building elements, as well as the waste, is less than for elements of cast concrete (Strängbetong, 2010).

According to a study of a private building in Hong Kong (Hong Dong, Jaillon, Chu & Poon, 2015), the use of prefabricated concrete decreased the CO_2e emission for the whole life cycle by 10%. This was mainly due to the different type of formwork. When molding the prefabricated concrete, formwork of steel was used instead of timber. This enabled a re-usage of the formwork up to 10 times more (Hong Dong, Jaillon, Chu & Poon, 2015).

During the recent 20 years, a lot has been done in order to reduce the climate impact caused by concrete. The reduce of emissions so far is mainly caused by development of the cement with for example a lower proportion of cement clinker (Svensk Betong, 2017).

2.3.3 Wood

The usage of wood as a building material is not a new technique. Frames of standing and lying timber in general have formed massive walls in houses since ancient times. Wood has always been close to man and craft as it is possible to process with different types of tools (Svenskt trä, 2017). Houses can be built with different kinds of wood and with different kinds of methods. A commonly used method of building houses consisting of wood is with volume elements. Volume elements means that parts of the construction are built and assembled in a factory to then be transported to the construction site and be put together into larger parts (Ahnfeldt & Celil, 2018).

Cross-laminated timber, abbreviated as CLT, is another material that is normally used in today house constructions of wood, which was introduced in Sweden during the late 1990s (Svenskt trä, 2017). CLT is a building component consisting of at least three layers of glued boards or planks made of softwood or hardwood, where every other layer is in 90-degree direction in relation to adjacent layers (Svenskt trä, 2017). Building systems with CLT mainly consist of walls and beams in wood (Träguiden, 2017).

One of the benefits of using CLT is that, in relation to its weight which is very light, CLT has higher load-bearing capacity than most other building materials. One can therefore build large constructions that can withstand high loads compared to for example other wood materials. Another benefit is that the thermal conductivity is much better for CLT than for concrete and steel (Svenskt trä, 2017).

From an environmental point of view, CLT has a lot of good qualities making it an advantageous material. It is recyclable and if used properly, it has a long life span. Further on, wood is a cyclically-adapted building material. During the manufacturing, the waste is minimal. The bi-products can however be used as energy. In addition, the material binds CO_2 during the its whole life span and creates climate-smart carbon dioxide storages (Svenskt trä, 2017). In one building system called Strandparken, it was shown that the building bound more CO_2e than it released during its lifespan (Folkhem, 2019). Lastly, after being used in one construction, it can be reused in new constructions or converted into energy in form of biofuel through combustion (Svenskt trä, 2017).

Another important aspect is that there are not only advantages for the environment by using CLT, it also results in negative impacts on the environment. To be able to produce the strong and stable construction of CLT, adhesive is used in between the boards (Khachlouf, 2016). It is not only the fact that adhesive contains toxic chemicals which gives a negative impact on the surrounding environment that is a negative aspect, it also complicates the recycling of building materials due to that it is only the wood that is meant to be recycled and not the adhesive. Therefore, there is a reason to avoid gluing and instead use plugs or screws if it is possible. If adhesive although is being used, it should consist of natural ingredients (Ekobyggcentralen, n.d). This is of importance for the emissions even though the proportion of glue in CLT is almost negligible with its 1% of the total weight, because of the existing improvement opportunities (Svenskt trä, n.d).

In general, when using wood as a building material an essential aspect is that it is important to have a sustainable forestry, meaning that the deforestation from the forest does not exceed the growth (Svenskt trä, 2017).

3. Methodology

3.1 Method overview

To be able to answer the first research question, different scenarios of the residential development in Uppsala until year 2050 have been produced and compared. The scenarios include the total amount of multi- and single-family houses that have to be built until year 2050. Each scenario includes the CO_2e emissions caused by building one type of multi-family house and an average type of single-family house. The number of houses needed have been calculated by regarding the future growth of Uppsala, which was obtained by a forecast produced by Sweco (Sweco, 2013).

The course of action has been to firstly examine the CO_2e emissions during the first part of an LCA, being the construction phase. This has been made for the multi-family houses consisting of different types of frames, made of wood or concrete. This data has not been obtained by doing a new LCA, but by using previous LCA from the collected climate reports regarding each construction project. However, two of the building systems include garages and other local areas (LOA) which are areas not intended to be used for living in. In order to be able to do a comparison as equal as possible, the emissions from these building systems have been recalculated.

Secondly, the CO_2e emissions during the construction phase for the single-family houses have been calculated. These emissions have been calculated for an average single-family building system based on statistics and overall data.

The CO_2e emissions for the different scenarios have then been compiled in excel and further on compared with each other. In order to enable a discussion of the possibility for Uppsala municipality to fulfill the climate goals, the scenarios have also been compared with the goals regarding the construction sector.

Regarding the last research question, a case study on one of the building systems has been performed. The concrete that is used for flooring indoor in the building system has been replaced by climate improved concrete instead of standard concrete. A new value of the total emissions for the building has been calculated in order to investigate how it will differ. This has been done by using excel.

3.2 LCA

The data regarding the different building systems are based on a life cycle assessment, abbreviated as LCA. An LCA is a method which assesses the environmental impacts that products and services potentially could have and also the resource consumption of their entire life span. Regarding the building sector, the LCA is a significant part when evaluating the environmental sustainability of buildings. This approach creates a focus on the entire life cycle of the building and not only on the factors regarding the completed building or the construction phase separately.

A building's life cycle consists of the product stage, the construction process stage, the use stage and the end-of-life stage. These stages in an LCA are presented in *figure 2*.

Module	A1 - A3			A4 - A5		B1 - B7							C1 - C4				D
Life cycle stages	Product stage			Construction process stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundary stage
Processes	Raw material supply	Transport	Manufacturing	Transport	Construction-installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse, recovery and recycling potential

Figure 2. Own illustration of all phases in a building LCA, based on the LCA figure from IVL (Ivl, 2018). The blue area, phase B1 to D, is not being regarded in this report.

Due to the fact that one of the research questions in this report is to investigate how the CO_2e emissions during the construction phase of the LCA differ between different building systems the first two stages alone will be regarded and assessed. These two stages, being referred to as the construction phase, are also presented in figure 2.

The product stage refers to the materials being used in the construction and consists of the processes raw material supply, transport and also manufacturing of the materials. This represents the modules A1 to A3 in the LCA. Further on, the construction process stage refers to the transport and construction installation process of those materials. In the LCA, this is represented by the modules A4 and A5 (Trafik- og Byggestyrelsen, 2016). Due to the fact that the modules A1 to A5 is representing the construction phase, these modules are the ones being investigated in this report.

3.3 Data

In this section, the different data that has been used for the calculations in the report is presented.

3.3.1 Building systems

To enable to answer the first research question, previous construction projects of multi-family houses have been overlooked. The buildings regarded in the projects have been constructed relatively recently, more specific after year 2010.

One of the construction projects is part of a block named X[1], a new production of housing. The data has been received by the company in charge of the building and consists of LCA data and details regarding the construction. The specific building being regarded in report is a multi-family house with a frame consisting of a mix of cast and prefabricated concrete. The building consists of 153 apartments, garage, stores and day care and the *BOA* stands for 10807 m^2, while the *LOA* stands for 5174 m^2.

Another construction project whose data has been accessible from the website of IVL, Swedish Environmental Research Institute is Strandparken. The data regards one of three houses and is a newly produced multi-family house situated in Sundbyberg, outside of Stockholm. It consists of 33 apartments and the garage, ground floor and basement are made of prefabricated concrete. The floor structure and frame, above the basement, is made of CLT. The garage represents 27% of the total climate impact during the constructions phase (Ivl, 2016).

Furthermore, LCA data regarding a construction project named Blå jungfrun situated in Hökarängen in Stockholm has also been received from IVL. The construction report consists of one reference house, which is house number three in Blå jungfrun. It consists of 22 apartments and has no basement or garage. In the climate report, five different building systems have been applied on the reference house. The five building systems represent three concrete frame constructions and two wooden frame constructions. One cast concrete with permanent framework, one cast concrete with light curtain walls, one prefabricated concrete frame one volume element in wood and also one massive frame of CLT (Ivl, 2018).

The data regarding Blå jungfrun shows that the system constructed with prefabricated concrete enables shorter building and installation processes compared to the ones with cast concrete. The emissions caused by the production of the material does also decrease when using prefabricated concrete, while the emissions caused by the transports are increasing slightly, compared to the building systems using cast concrete (Ivl, 2018).

3.3.2 Compilation of building systems

In the following compilations found in *table 3* and *table 4*, the values for each building system's CO_2e, A_{temp} and *BOA* are presented.

[1] Confidential source, due to that the information regarding this building was asked to be kept confidential, no source is being referred to.

Table 3. A compilation of the concrete frame building systems.

Project name	Frame (concrete)	A_{temp} [m^2]	BOA [m^2]	kg CO_2e/m^2 (A1-A5)	Sources
Building X	Concrete (mix cast and prefabricated, 50/50)	19826	10807	424	Confidential source
Blå jungfrun 1	Cast concrete with permanent framework	2198	1713	332	Ivl, 2018 Ståhl, 2019
Blå jungfrun 2	Cast concrete with light curtain walls	2198	1713	290	Ivl, 2018 Ståhl, 2019
Blå jungfrun 3	Prefabricated concrete frame	2198	1713	276	Ivl, 2018 Ståhl, 2019

Table 4. A compilation of the wooden frame building systems.

Projectname	Frame	A_{temp} [m^2]	BOA [m^2]	kg CO_2e/m^2 (A1-A5)	Sources
Strandparken	Wood (CLT)	3982	2732	265	Ivl, 2016
Blå jungfrun 4	Wood	2198	1713	223	Ivl, 2018 Ståhl, 2019
Blå jungfrun 5	Timber (CLT)	2198	1713	223	Ivl, 2018 Ståhl, 2019

Regarding building X and Strandparken, both include garages and other *LOA*. In order to enable an equal comparison of the different building systems, the values for the emissions are recalculated. For Strandparken, the garage makes up to 27% of the total climate impact. The new value of CO_2e/m^2 is therefore calculated by multiplying it by 0.73. It is represented in *table 5*.

Regarding building X, the *LOA* is subtracted from primary value of A_{temp}. The new value of the CO_2e/m^2 is then estimated by calculating the ratio between the new and old value of A-temp and multiplying it with the old value of the CO_2e/m^2. All the new values for building X are represented in *table 5*.

Table 5. The values for A_{temp} and CO_2e/m^2 for building X and Strandparken after the garages and LOA have been removed.

Project name	A_{temp} [m²]	Emissions [kg CO_2e/m^2]
Building X	14652	313. 35
Strandparken	-	193.45

Regarding the CO_2e/m^2 found in *table 3* and *table 4*, different companies have performed calculations by using the building sectors environmental calculation tool (BM). It is an environmental calculation tool for buildings which is common within the industry in Sweden, developed to enable consistent climate calculations in the building sector. The tool is based on LCA and contains a complete database consisting of the climate data regarding the existing building resources found in Sweden. By letting the user put in the amounts of several parts of the building, the BM calculates the climate impact of material production, transport and construction production for the materials included in the building (Ivl, 2019).

3.3.3 Constants for calculations regarding future scenarios

Another part of the aim and research questions is to investigate how a future scenario of Uppsala municipality might look. To be able to create a scenario of an expansion, data regarding the growth of Uppsala until year 2050 have been obtained. The data includes population growth in different kinds of residents and average living area per inhabitant for single-family houses as well as multi-family houses and has been based on the report from Sweco.

The calculations have been based on numbers from the scenario “high” from the report due to several reasons. Firstly, this scenario takes a higher number of inhabitants into account, which will give higher levels of CO_2e emissions. This makes it more interesting to investigate since it is important for Uppsala municipality to be prepared for the higher levels (Sweco, 2013). Secondly, this scenario is more in line with the municipality’s plans for future growth and decisions that have been made after the report from Sweco were publicated. These decisions regard for example an expansion of the southern parts of Uppsala including a new train station in Bergsbrunna (Uppsala kommun, 2018). This may strengthen Uppsalas position in the region and be a step towards becoming a more complete alternative to Stockholm, which is one of the aspects regarded in the scenario “high”.

For the calculations regarding the emissions for multi-family houses, constants like the living space per inhabitant for year 2050 and the population growth of people living in multi-family houses were used. The values of the constants are presented in *table 6.*

Table 6. Constants regarding multifamily houses.

Constans		Source
$LivSpace_{PERINH}$ [m^2]	37	Sweco, 2013
$PG_{MFH2050}$	101668	Sweco, 2013

For the calculations regarding the emissions for the single-family houses, no climate reports were found. Instead, an average value was calculated with constants like the number of houses built each year in Sweden and their total CO_2e emission. In addition, the amount of people living in a single-family house and the population growth of the total amount of people living in single-family houses by 2050 were also used. All the constants are presented in *table 7*.

Table 7. Constants used to calculate the total emission for single-family houses.

Constants		Source
$SFH_{PER\ YEAR}$	10 000	Iva, Sveriges byggindustrier, 2014
CO_2e_{PY} [kton]	300-500	Iva, Sveriges byggindustrier, 2014
$People_{PER\ SFH2050}$	2.3	Sweco, 2013
$PG_{SFH2050}$	41024	Sweco, 2013

Regarding the CO_2e emission each year, the mean value 400 kton CO_2e is used for the calculations.

3.3.4 Constants for climate improved concrete

For calculations regarding emissions when building X is built with climate improved CFI instead of standard CFI, the constants presented in *table 8* are used. The data regarding the two types of concrete were collected from environmental product declarations, while the data regarding building X and material used for it were collected from the climate report of the building.

Table 8. Constants used to calculate the total emission for building x using climate improved CFI.

Constants	Standard	Climate improved	Sources
Emission$_{(A1-A3)}$/ weight	0.105	0.093	The norwegian EPD foundation & Svensk betong, 2017b The norwegian EPD foundation & Svensk betong, 2017a
Weight CFI [kg]	17461385	17144038	Confidential source
Weight/m^3 [kg/m^3]	2394	2350	The norwegian EPD foundation & Svensk betong, 2017b The norwegian EPD foundation & Svensk betong, 2017a

3.4 Calculations

To be able to estimate the total amount of CO_2e emission for Uppsala's residential development until year 2050, a few calculations have been made for both multi- and single-family houses. In the last section, calculations regarding the climate improved concrete are presented.

3.4.1 Equations for multi-family houses

For the multi-family houses, the total CO_2e emission were calculated for each building system by using *equations (1)* to *(4)*. Firstly, the amount of people living in one building was calculated, then the number of houses needed for year 2050. Further on, the emissions for one building and finally the total emissions for all houses were compiled. All the parameters used in the equations are presented in *table 9*.

Table 9. Definitions of the parameters used in the equations for the multi-family houses.

$People_{PH}$	Amount of people per multi-family house
$LivSpace_{PERINH}$	Living space per inhabitant
MFH_{2050}	Number of houses needed until year 2050
$PG_{MFH2050}$	Population growth in multi-family houses until year 2050
$Emission_{PMFH}$	Total amount of emissions per house
$TOT_{EMISSION\ MFH}$	Total amount of emissions for multi-family houses

In *equation (1)*, the amount of people per building was calculated by dividing the living area for the house by the living space per inhabitant for multifamily houses:

$$People_{PH} = BOA \,/\, LivSpace_{PERINH} \qquad (1)$$

To calculate the amount of multi-family houses needed for year 2050, the amount of people that will be living in multi-family houses in year 2050, PG_{MFH_2050}, was divided by the amount of people per building as in *equation (2)*.

$$MFH_{2050} = PG_{MFH2050} \,/\, People_{PH} \qquad (2)$$

The total CO_2e emission per multifamily house was then calculated by *equation (3)*.

$$Emission_{PMFH} = A - temp \cdot CO_2e/m^2 \qquad (3)$$

Lastly, the CO_2eemission for the total amount of multi-family houses that will be built until year 2050 was calculated by *equation (4)*.

$$TOT_{EMISSIONMFH} = MFH_{2050} \cdot Emission_{PMFH} \qquad (4)$$

3.4.2 Equations for single-family houses

To be able to calculate the CO_2e emissions from all single-family houses built until year 2050, an average amount of the CO_2e emission for a single-family house was calculated. Further on, the total emission was calculated by using the number of houses needed for year 2050. All the parameters used in the equations are presented in *table 10*.

Table 10. Definitions of the parameters used in the equations for the single-family houses.

CO_2e_{PYPH1}	Amount of CO_2e per year during phase 1 (A1 to A5)
CO_2e_{PY}	Amount of CO_2e per year
$Emission_{PER\ SFH}$	Total amount of emissions per single-family house
$SFH_{PER\ YEAR}$	Number of single-family houses per year
SFH_{2050}	Number of single-family houses needed until year 2050
$PG_{SFH2050}$	Population growth in single-family houses until year 2050
$People_{PER\ SFH2050}$	Amount of people per single-family house in year 2050
$TOT_{EMISSIONSFH}$	Total amount of emissions for single-family houses

The data of the total emissions for single-family houses was given per year and represents the whole LCA. Since this report only examines the construction phase (A1 to A5), the emissions were recalculated. For the single-family houses, 15% of the CO_2e emissions are caused during the construction phase, resulting in the total emissions from single-family houses each year during the construction phase calculated by *equation (5)*.

$$CO_2e_{\,PYPH1} = 0.15 \cdot CO_{2\ PY} \tag{5}$$

In order to get the emission per house, the emissions each year during the construction phase was divided by the number of single-family houses built each year, shown in equation (6).

$$Emission_{PER\,SFH} = CO_2e_{\,PYPH1} \;/\; SFH_{\,PER\,YEAR} \tag{6}$$

To calculate the number of single-family houses needed for year 2050, the total amount of people that will be living in single-family houses in year 2050 was divided by the amount of people living in one house, seen in equation (7).

$$SFH_{2050} = PG_{SFH2050} \,/\, People_{PER\,SFH2050} \tag{7}$$

Finally, the total CO_2e emissions for all the single houses built until year 2050 was calculated by multiplying the needed number of single houses with the emissions per house. This is shown in equation (8).

$$TOT_{EMISSIONSFH} = SFH_{2050} \cdot Emission_{PER\ SFH} \quad (8)$$

3.4.3 Equations for climate improved concrete

In order to investigate the building X's climate impact during the construction phase when the floor indoor is built with climate improved concrete instead standard concrete as in the original case, some calculations were done. All the parameters used in the equations are presented in *table 11*.

Table 11. Definitions of the parameters used in the equations for the climate improved concrete.

Emission $_{ci}$/weight	Amount of emissions per weight for A1-A3, here amount of CO_2e/kg
Emission CFI$_{st\ (A1\text{-}A3)}$	Emissions for the concrete using for flooring indoor when using standard concrete
Emission CFI $_{ci\ (A1\text{-}A3)}$	Emissions for the concrete using for flooring indoor when using climate improved concrete
TOT $_{emi\ ci}$	Total amount of emissions for the construction phase A1-A5 of building X when the buildings using climate improved concrete for CFI.
TOT $_{emi\ st}$	Total amount of emissions for the construction phase A1-A5 for building X when using standard concrete for CFI.

Since the weight of 1 m^3 of climate improved concrete differs from to standard concrete according to the environmental product declaration for concrete aimed for flooring indoor, the same weight proportion was reduced from the total weight of new case with climate improved concrete for CFI. The weight for the climate improved CFI was calculated by multiplying the weight of the standard CFI by a factor of 0.98 (The Norwegian EPD & Svensk Betong, 2017a,b). This results in that the same volume of concrete was used for both cases. This step is not shown in the calculations.

After this, the total emissions for phase A1-A3 caused by climate improved CFI as well as standard CFI was calculated by *equation (9)* and *equation (10)*.

$$Emission\ CFI_{\ st(A1-A3)} = (Emission_{\ st\ (A1-A3)}/weight) \cdot weight_{\ CFI} \tag{9}$$

$$Emission\ CFI_{\ ci\ (A1-A3)} = (Emission_{\ ci\ (A1-A3)}/weight) \cdot weight_{\ CFI} \tag{10}$$

The difference between emissions when using standard CFI compared to climate improved CFI in phase A1-A3 was calculated by *equation (11).*

$$Difference_{\ emi\ (A1-A3)} = Emission\ CFI_{\ st(A1-A3)} - Emission\ CFI_{\ ci\ (A1-A3)} \tag{11}$$

The total emissions for building X during the construction phase when using climate improved CFI instead of standard CFI was then calculated by *equation (12)*.

$$TOT_{\ emi\ ci} = TOT_{\ emi\ st} - Difference_{\ em\ CFI\ (A1-A3)} \tag{12}$$

4. Results

In the following part of the report, the results intended to be used for the purpose of answering the research questions will be described. A sensitivity analysis is included as well in this section.

4.1 Result 1 - scenarios for Uppsala 2050

Regarding the first research question, different scenarios for Uppsala residential development until year 2050 were brought forward. The scenarios are defined as the municipality using one type of multi-family houses of a different building system and an average single-family house for their future residential development. In *figure 3*, the total CO_2e emissions until year 2050 for each scenario are compiled.

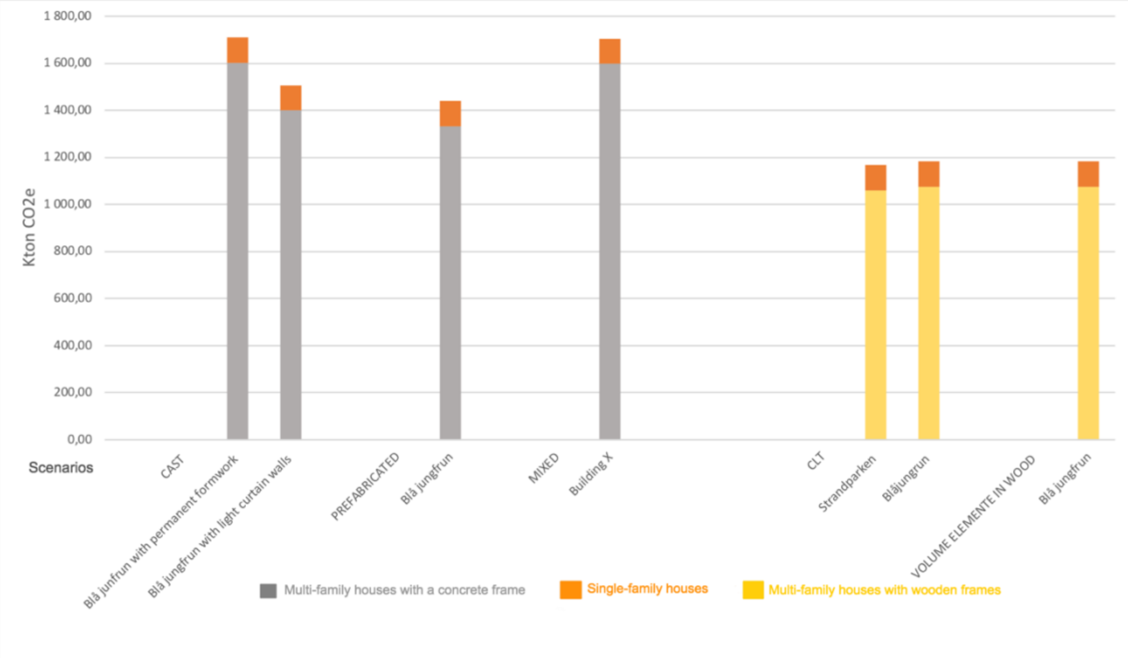

Figure 3. A compilation of the emissions from the different scenarios of Uppsala's residential development until year 2050.

It becomes clear in figure 3 that, in general, the scenarios including building systems with concrete frames release more CO_2e emissions in comparison with the building systems with a wooden frame. The scenarios including building systems of wooden frames have the least emissions and they are all at a relatively similar level, barely 1200 kton CO_2e.

Regarding all scenarios, the scenario including Blå Jungfrun with a frame made of cast concrete with permanent framework has the highest amount of emissions, while Strandparken without the garage has the lowest amount of emissions.

In a comparison between the scenarios including the building systems with concrete frame, the scenarios with building X and the building system with a frame made of cast concrete with permanent formwork has the highest CO_2e emissions. The scenario including the building system with the prefabricated concrete frame has the lowest amount of emissions in the comparison between the concrete building systems.

The emissions from the single-family houses are the same for each scenario since an average value of the emission was calculated.

If the municipality would choose the scenario including Strandparken, which is the one with the least emissions, they would save 272 kton CO_2e in comparison with choosing the building system with least emissions among the concrete frames. The exact values for the emissions for the new calculation is shown in *appendix A.*

For a clearer comparison between the scenarios including wooden or concrete frames, the CO_2e emissions for the two different types of frames are merged and plotted in a boxplot in *figure 4*.

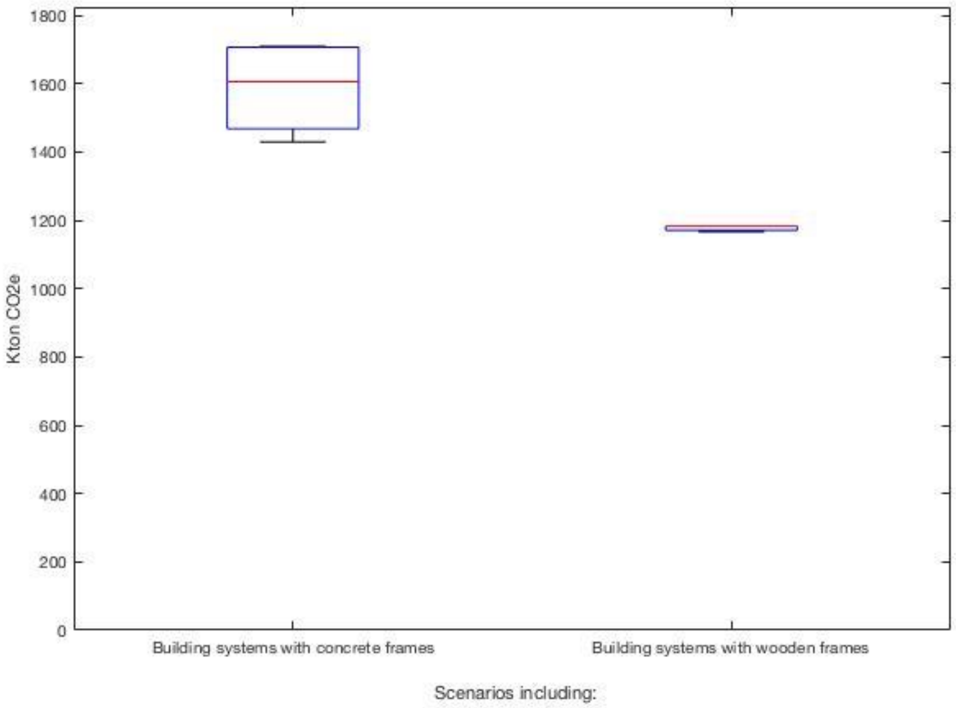

Figure 4. A boxplot presenting the median value of the CO_2e emissions for building systems with concrete versus wooden frames until year 2050 in Uppsala. Please consider that only three data points were used for the wooden frames.

In *figure 4,* it is even more clear that the emissions from the scenarios including building systems with wooden frames in general is much less than the ones with a concrete frame. The median value of the CO_2e emissions for the scenarios including building systems with concrete frames until 2050 is around 1600 kton, while it is just above 1200 kton CO_2e emissions for the scenarios including building systems with wooden frames. For the concrete frames, the values are more spread than the wooden frames, resulting in a larger box seen in *figure 4.*

4.2 Result 2 - climate improved concrete

For the second research question, parts of the concrete frame of building X was changed to climate improved concrete and the emission were recalculated. According to the results, the emission would decrease by approximately 5.2% by doing this. The result is presented in *figure 5* together with the results from the original calculations for the scenario.

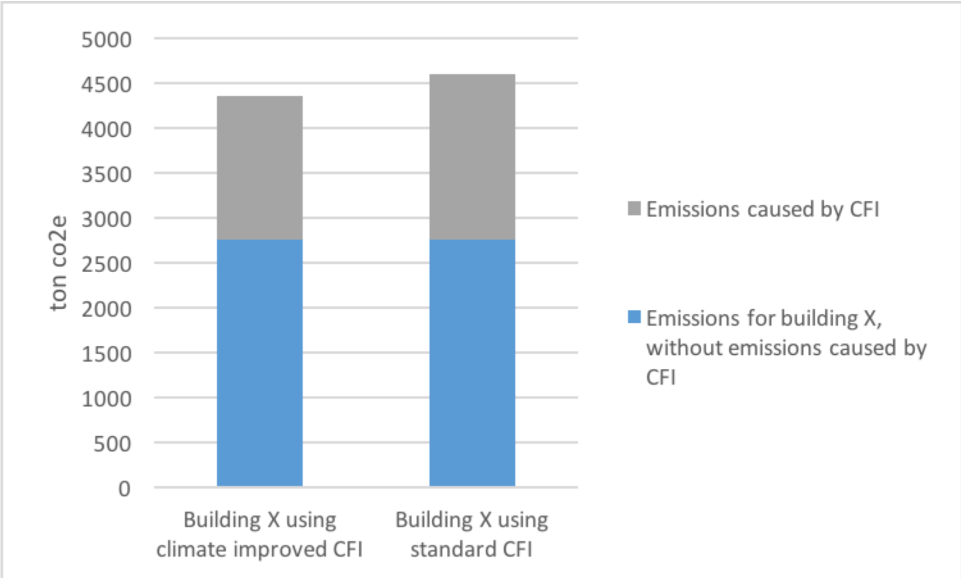

Figure 5. The total CO_2e emissions for building X when using standard concrete for the flooring indoor, and the total CO_2e emissions when using climate improved concrete for the flooring indoor instead.

4.3 Sensitivity analysis

In this part of the section of the results, a sensitivity analysis will be done on the computed results, in order to analyze them and other possible outcomes. Firstly, the scenarios will be studied for the base-scenario 2050, instead of the high-scenario. In the second part, the scenarios for year 2050 will be regarded again, but in this case include the garage and LOA for Strandparken and building X.

4.4.1 High- and base-scenarios

In this section, the emissions for the different scenarios are recalculated with the estimated population growth for the base-scenario 2050. In the base-scenario 2050, the input parameter regarding the population growth for people living in multi- and single-family houses until year 2050 are changed. They are presented in *table 12*.

Table 12. The increase of people living in multi- and single-family houses in year 2050 for the base-scenario until year 2050.

BASE 2050		Source
$PG_{MFH2050}$	61 056	Sweco, 2013
$PG_{SFH2050}$	24 637	Sweco, 2013

The emissions for the base-scenario are based on the case without garages and LOA for Strandparken and building X, as in result 1. In order to compare the difference in emissions, both the high- and base-scenario are presented in *figure 6*. The emissions for the single-family houses are included in the calculations.

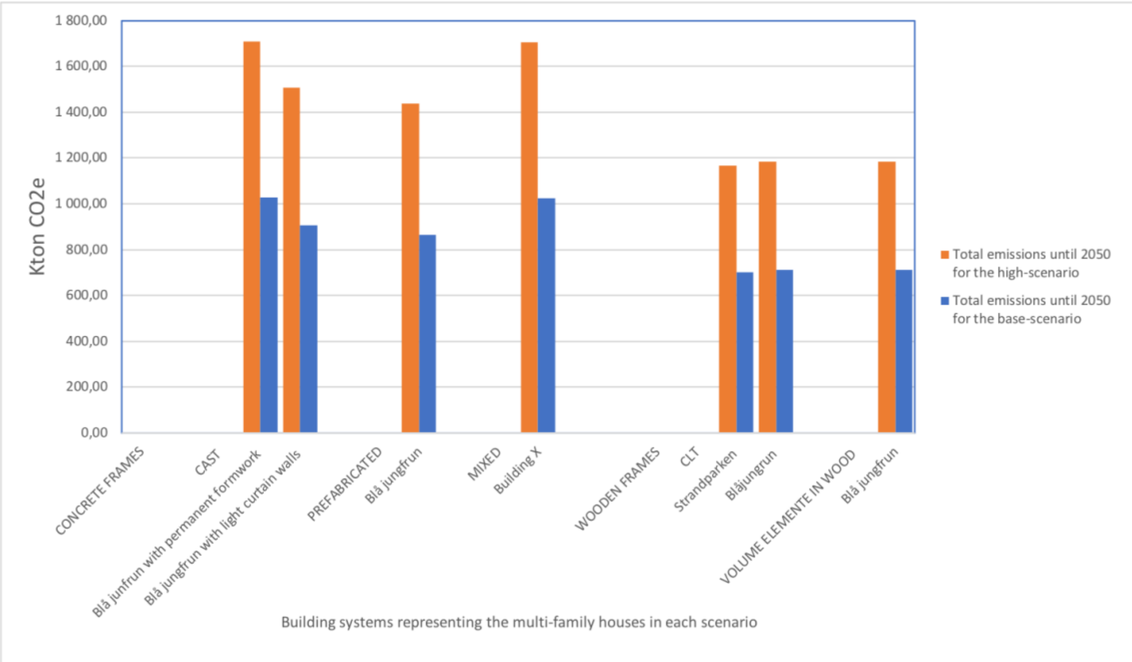

Figure 6. The CO_2e emissions for the different scenarios with multi-and single-family houses in Uppsala until year 2050, where a comparison between the growth scenarios "base" and "high" are presented.

For the base-scenario 2050, the ratio between the different building scenarios is the same in the high-scenario, result 1. However, it is clear that for the base-scenario, the emissions for each scenario are much lower, around 40% less.

4.4.2 Building systems with garage and LOA

Regarding the scenarios brought forward in the section result 1, the emissions for Strandparken and building X were recalculated, since these included garages and other premises of LOA. If, according to how they are built in reality, one would include the garage and LOA, the emission would become higher. In *figure 7*, the total CO_2e emissions for the different scenarios with the original values for Strandparken and building X are compiled and compared with the values from result 1, which did not include the garage and LOA.

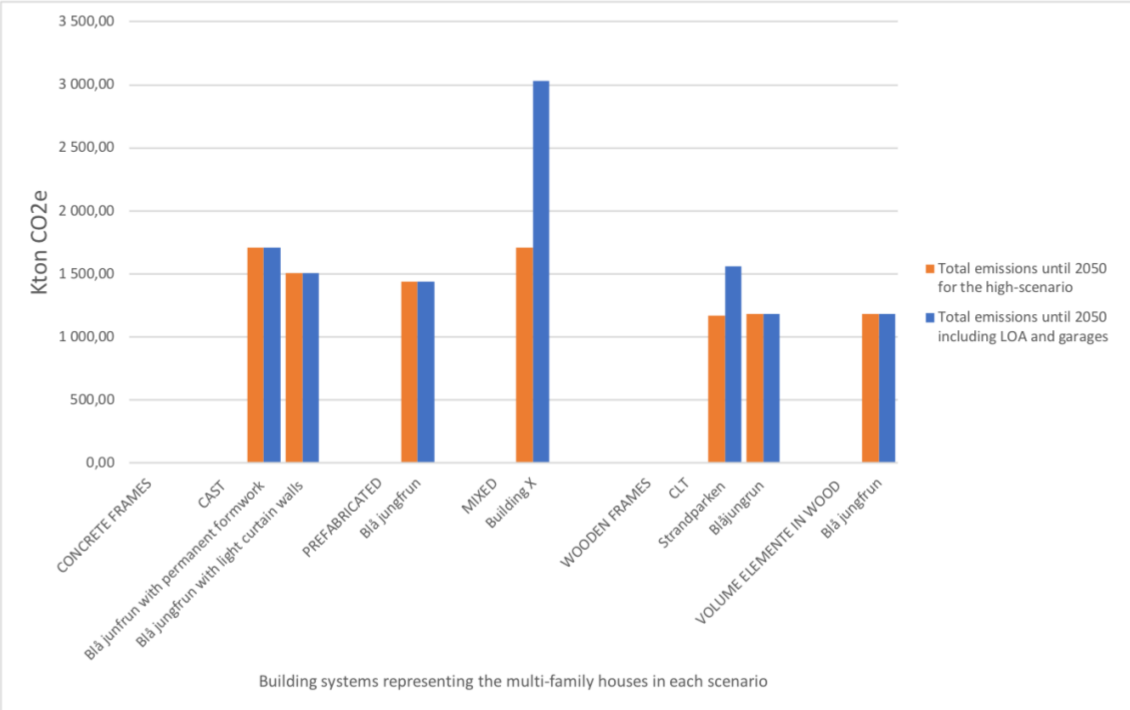

Figure 7. The emissions from the different scenarios with multi-and single-family houses in Uppsala until year 2050, where a comparison between the scenarios with and without LOA and garages are presented.

In this case, building X had the highest amount of CO_2e emission of the multi-family houses, while the two building systems of Blå jungfrun with wooden frame, had the least CO_2e emission. Again, the emission from the building systems with a wooden frame is in general lower than for the concrete ones.

However, the emission from Strandparken, consisting of CLT, is higher than the scenarios with the cast concrete with light curtain walls and prefabricated concrete frame. Between the building systems with concrete frame, Blå jungfrun with a frame of prefabricated concrete, still has the lowest CO_2e emissions during the construction phase.

5. Discussion

First of all, it is important to once again highlight that the scenarios that are compared in the report are based on some specific building systems and building projects, not general building systems. The results are therefore not necessarily valid for the general case but can be regarded more as conclusions based on some case studies.

5.1 Building systems

To be able to investigate how the CO_2e emissions differ between building systems during the construction phase of the LCA for residential buildings, the different systems need to be compared.

From result 1, it can be seen that constructions containing wooden frames in general seem to cause less emissions during the construction phase than constructions containing concrete frames. This is mainly due to the production of the material, where the cement in concrete represents a big part of its climate impact.

When comparing the scenarios including building systems with wooden frames with each other, they differ slightly. This may be because of the fact that one of them, Strandparken, is recalculated from the original value of the construction with a garage, implying that the values are not completely accurate. However, there are no extraordinary differences between the scenarios including CLT and volume elements. This means that, according to this study, there are not any big differences between the emissions during the construction phase when using CLT or volume element of wood for the frame. However, to get a more accurate result, further studies can be done with more collected data.

Regarding the scenarios including the building systems with a concrete frame, it is clear that the use of prefabricated concrete causes less emissions than the use of other materials in the other building systems. This may be due to the emissions during the manufacturing of prefabricated concrete being less compared to the other building systems corresponding manufacturing. Another reason can be the use of different kind of formworks when using prefabricated concrete. In addition, the building system with permanent formwork may have higher CO_2e emissions as the formwork stays in the building, which makes it impossible to reuse during the building’s lifetime. If one has to create a new formwork for each building, the emissions would naturally increase.

Further on, when generally comparing the different projects and discussing the prevailing differences for the emissions, there could be aspects that result in the differences other than the ones being mentioned earlier in this section. In the report, the emissions from the constructions include all materials used in the buildings signifying that there are other materials than wood and concrete that contribute to the climate impact.

For instance, reinforcement is necessary when building with concrete and may make the scenarios differ regarding the emissions. However, the building system with the lowest amount of emissions, prefabricated concrete, has the largest proportion of reinforcement but also the lowest proportion of concrete and the lowest amount of emission caused by the production of the material. This indicates that the amount of concrete is the most crucial factor in terms of emissions for concrete building systems. The reinforcement might eventually even help to reduce the amount of proportion of concrete according to the results, although it is of course important to take more aspects such as transport of the steel into account in order to make these sorts of conclusions.

5.2 The climate goals

With the aforementioned regarding the differences in emissions between the projects in mind, another aspect to discuss is the climate goals set by the municipality and whether they can be achieved or not.

One of the goals regards the usage of wood and that half of the completed building volume in urban construction projects produced by the municipality shall consist of wood in the end of year 2030. Therefore, the municipality wants to use more wood in future constructions. Based on result 1, it can be seen that constructions with a frame of wood tend to release less emissions, 272 kton CO_2e to be precise, than it would have done with a construction of concrete. This indicates that the usage of wood in the frame of the constructions increases the chances for Uppsala municipality of becoming climate neutral.

In order to further on achieve another of the goals which regards the municipality becoming a climate positive municipality, it will take that all sectors of the municipality will have to achieve this goal as well. It can be very difficult for the municipality to reach zero emissions when only examining the construction phase in the building sector. In order to get the best conditions for achieving the goals, it would at first sight be reasonable according to this study to use wood for the frame as those building systems contributes to the least emissions during the construction phase. However, other factors could affect the total climate impact and one should therefore not completely exclude concrete as a possible choice of material in the future development of Uppsala.

For instance, one difficulty of wooden materials in general regarding the emissions is the pursuit of a sustainable forestry behind the production of the material. Further on, due to the fact that wood is a quite light-weighted material it can be assumed that the transportation of the material is relatively easy compared to the transportation of more heavy-weighted materials such as concrete. A greater amount of the material could therefore be transported at once compared to a material that is not as light-weighted.

On the other hand, when transported for example cast concrete you do not transport actual concrete but its component. This implies that you do not have to transport for example all the water using when producing concrete, since this can be obtained at the building site, which makes the material easier to transport. However, in the result 1 it is shown that prefabricated concrete causes less emissions than cast concrete in this study anyway.

There is however another aspect to take in mind regarding the transportation of the material, which is the location of the gathering of the material. Although wood is a relatively light-weighted material that can be transported easily, the transport also regards the locations where the wood can be find. This implies that the transport could be a long or short one, depending on where the locations are situated. Longer transportations equal to more emissions and the same applies to concrete. Depending on where the concrete is gathered, it has an impact on the emissions. However, the location of the concrete source or factory can be perceived as more flexible than the location for forests. In Sweden forestry is a big industry, and long transportation for wood may not be an essential problem. Globally this might although be different depending of geographical conditions, which implies that this aspect should be considered more as a disadvantage for wood than for concrete.

Due to the aforementioned aspects regarding sustainable forestry as well as the original locations and the transportation of the materials, it is therefore important to have options and continue to develop different kinds of concrete in order to make them more sustainable.

Regarding the climate improved concrete, result 2 showed a decrease of emissions by approximately 5.2% by replacing the CFI. This indicates that it is possible to reduce the emissions but in order to achieve the climate goal of the emissions from concrete being reduced by 50% until year 2030, the continuous development would be justified. For example, the development of cement with for instance a lower proportion cement clinker is of interest.

However, it is important to have in mind that in this case study, it was only the concrete for the flooring indoors that was replaced. There are other parts of the building consisting of concrete, which could be replaced as well. By replacing all the concrete used the building, the emissions could have decreased even more.

5.3 Other general aspects

In addition, other positive and negative aspects outside the system boundaries could also affect the municipality’s ability of achieving their goals until year 2050 and are therefore important to illustrate.

One important aspect to have in mind is that the results in this report only regards the construction phase, i.e. phases A1 to A5. This implies that the results for the whole life cycle of a building could differ and lead to another building system having the least emission. Therefore, it is not valid to conclude from this study only that wooden frames would be the best option for the municipality. Anyhow, it is important to study the different parts separately and it is interesting to investigate the construction phase isolated from the other parts of an LCA.

Regarding the entire LCA, it is important to consider that both concrete and wood binds CO_2e during the whole LCA although the capacity of it can differ. After the construction phase, concrete absorbs CO_2e by carbonization and can reduce the emissions from the production phase with around 15 to 20%. Wooden houses, on the other hand, binds more CO_2e than it creates during the construction phase. Even though the binding of CO_2e regards the stage after the construction phase, it is still of interest because of the oversight of the overall emissions from the material, which is of importance in order to achieve the municipality's goal of becoming climate positive in year 2050.

Further on as mentioned, concrete has a long life span, normally more than 100 years. With a longer life span, the emissions caused by the construction phase in relation to the emissions in the long run, can become less significant. In general, wood is easy to recycle. This could imply that the amount of new material is less than it would have been if it had not been recyclable.

However, an aspect considering the emissions from for example CLT is that the adhesive being used in between the boards contains toxic chemicals. This has a negative impact on the surrounding environment as well as it complicates the process of recycling the building material. Trying to be more sustainable, the use of plugs or screws could be done instead of using adhesive to avoid that parts of the material cannot be recycled. The adhesive only represents 1% of the total weight in the building system, but it is still of importance for the discussion because of the existing improvement opportunities.

5.4 Sensitivity analysis

The original results show that the CO_2e emission for building X is relatively similar to the other concrete building systems. However, in the sensitivity analysis, the emissions for building nearly doubled when including garages and LOA, since the construction of these areas also contributes to emissions.

As for Strandparken, the garage stands for 27% of the emissions, which resulted in the scenario including Strandparken having higher emissions than some of the building systems with concrete frames. According to the sensitivity analysis, it becomes clear that garages as well as other LOA causes a high amount of emissions. The new values for the emissions without the LOA and garage are of course not 100% accurate but gives an estimation of how much the emissions would decrease. However, the fact that wood in general releases less emissions remains. If the motoring continues to require garage in the future, it would according to this be preferable to build these in wood over ground or in climate smart concrete underground.

In the first part of the sensitivity report, the emissions were calculated according to the population growth for the base-scenario, which resulted in around 40% less emissions. Naturally, building less houses will result in less emissions, which implies that the population growth impacts the climate. Another aspect is that the values for the expected growth of Uppsala used in result 1 were from 2010, which in the same way results in higher emissions, than if the emissions would be calculated from today.

6. Conclusions

Conclusions that can be done are that the scenarios including building systems with wood frames in general for the analyzed buildings releases less CO_2e emissions than the building systems with concrete frames. The main reason for this is that the emissions caused by the production of the materials differ. More specific, the system with prefabricated frame causes the least emissions of the ones made with concrete, while the one with permanent formwork causes the most emissions. Further on, one reason for this is that prefabricated concrete is produced in a factory where the waste becomes less and that the permanent formwork cannot be reused during the building's life span. Between the scenarios including the building systems with wooden frames, there were no extraordinary differences, however the usage of glue in CLT may also have an impact on the possibility to reach the municipality's climate goals in the long term.

Regarding Uppsala municipality's opportunity to achieve its climate goals for the residential development of Uppsala until year 2050, the fulfillment will depend on several aspects. Firstly, of course the building system with the lowest emissions, CLT, should considered to be used the most for residential buildings in the future. Although, the whole LCA should be analyzed before taking any decisions. Concrete should be developed further in order to reduce the climate impact when producing the material, since it will be difficult to exclude concrete completely when constructing residential buildings.

Replacing concrete for flooring indoor to climate improved concrete does not seem to affect the emissions substantially. Although, even more climate improved concrete would enable a decrease of the emissions and further on increase the chances for Uppsala municipality to reach the climate goals.

Anyhow, more equivalent research is requestable for a better overview of the field. The building sector represents a big part of the climate impact and it is therefore interesting and necessary to study this field further.

7. Occurring Terms and Abbreviations

A-temp = A-temp is the interior area for floor, garret and basement floor that is heated to more than 10 ° C.

BM = Building sector environmental calculation tool

BOA = Living area. “Boendearea” in Swedish.

CFI = Concrete for flooring indoor

CO_2-equivalent (CO_2e) = A measure of how much impact different greenhouse gases have on the greenhouse effect, converted to the corresponding amount of carbon dioxide.

CLT = Cross Laminated Timber

Emissions = Refers to the CO_2e

LCA = Life Cycle Assessment

LOA = Local area, which is not intended to use as living area. It includes for example garage and areas aimed for other activity than living. It is included in A-temp. “Lokalarea” in Swedish.

MFH = Multi-family house

SFH = Single-family house

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Appendix

Appendix A

Building system	MFH [Kg CO_2-e]	SFH [Kg CO_2-e]	TOTAL 2050 [Kg CO_2-e]
Cast concrete with permanent framework (Blå jungfrun)	1 602.5	107	1 709.5
Cast concrete with light curtain walls (Blå jungfrun)	1 400	107	1 507
Prefabricated concrete frame (Blå jungfrun)	1 332	107	1 439
Building X	1 598	107	1 705
Strandparken (CLT)	1 061	107	1 167
Massive frame of cross-laminated timber (Blå jungfrun)	1 076	107	1 183
Volume element in wood (Blå jungfrun)	1 076	107	1 183