

PAPER • OPEN ACCESS

Comparative LCA of a concrete and steel apartment building and a cross laminated timber apartment building

To cite this article: A R Eliassen *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **323** 012017

View the [article online](#) for updates and enhancements.

Comparative LCA of a concrete and steel apartment building and a cross laminated timber apartment building

Eliassen A R^a, Faanes S^b, Bohne R A^a

^aDepartment of Civil and Environmental Engineering, NTNU, Høgskoleringen 7A, 7491 Trondheim, Norway

^bVeidekke Entreprenør AS, Postbox 506 Skøyen, 0214 Oslo, Norway

alexander.roy.eliassen@gmail.com

Abstract. In this paper an LCA is carried out on a concrete and steel apartment building and a cross laminated timber apartment building to compare the greenhouse gas (GHG) emissions from the two buildings. The buildings are built by Veidekke Entreprenør AS and they are almost identical except for the structural system and the number of floors. They are connected by an underground car park of reinforced concrete. The product stage (A1-A3), transport to the building site (A4) and operational energy use (B6) is examined. Results show that the cross laminated timber building has 25% lower GHG emission compared to the concrete and steel building when looking at the production stage, and 13% lower emissions when looking at all stages. The results also show that the material that contributes to the most GHG emissions is reinforced concrete, and that the underground car park has a high GHG emission because it consists of a lot of concrete. What is new in this paper is that there are two real buildings close together that can be compared to find out which has the lowest environmental impact. The paper is valuable for people designing environmentally friendly buildings with a low carbon footprint.

1. Introduction

Climate change is an enormous problem for the world today, and if global warming is not limited it will have huge negative consequences. Therefore, it is urgent to reduce the greenhouse gas emissions to reach the 1,5° C goal stated in the Paris agreement [1]. The building sector is responsible for a large share of the world's total greenhouse gas emissions. In 2010, buildings stood for 32% of the total global energy use, and 19% of energy related greenhouse gas emissions [2]. Therefore, reducing the greenhouse gas emissions from the building sector can be an important measure to reach the goals of reducing global warming as much as possible.

Concrete is one of the most widely used construction materials in the world today, but one problem with using concrete as a building material is that it contributes to a huge amount of greenhouse gas emissions globally. It is especially cement, which is an important ingredient in concrete, that contributes to a large amount of greenhouse gas emissions. In 2017 cement clinker production stood for around 4% of the global CO₂-emissions [3].

One way to reduce the greenhouse gas emissions from buildings can be to use cross laminated timber-elements (CLT) as a construction material instead of concrete. More and more large buildings are constructed with CLT-elements today instead of more traditional materials like concrete and steel.



Mjøstårnet in Brumunddal is an 85,4 m tall apartment- and hotel building which was completed in March 2019, and is an example of a new building that uses CLT and glulam for the structure [4].

In this paper it will be investigated whether or not it is possible to save greenhouse gas emissions by using CLT elements to construct apartment buildings instead of concrete. The case which will be examined is Maskinparken 2 and TRE, which are two new apartment buildings constructed by Veidekke AS in Trondheim, Norway. Maskinparken 2 is a five-story apartment building which is constructed in concrete and steel, while Maskinparken TRE is an eight-story apartment building constructed using CLT-elements. What makes the two buildings comparable is that they are constructed side by side and they are almost identical except for the number of floors and the structural system. An LCA of the two buildings looking at the impact category climate change will be carried out to compare the greenhouse gas emissions from the buildings.

1.1. Previous research on greenhouse gas emissions of concrete and wood buildings

Skullestad et al. [5] investigated the climate change impact of reinforced concrete structures and timber structures in buildings with heights between 3 and 21 storeys. The study only examined materials in the load bearing structures and foundations. When attributional LCA was applied, the timber structures caused a climate change impact that was 34-84% lower than the reinforced concrete structures. The results of the study showed that the timber structures had a lower climate change impact than the reinforced concrete structures for all scenarios. Kaspersen et al. [6] looked at greenhouse gas emissions from technical systems for buildings of different heights. The scope of the study was cradle-to-gate. The results showed that the change in GHG emissions from the technical systems for increased building height was small.

Dodoo et al. [7] looked at carbon emissions from the entire life cycle of three different building systems in wood. The building systems that were investigated were CLT elements, beam and column system and prefabricated modules. They looked at both conventional and low-energy versions of the building. The results from the study showed that the low-energy version of the CLT building had the lowest carbon emissions, while the conventional version of the beam-and-column building gave the highest emission. The reason for this was because the beam-and-column system used more concrete and steel in the foundations and elevator shaft compared to the CLT building.

Dodoo et al. [8] also examined the effects of management of materials after use on the life cycle carbon balance of buildings. They found that carbonation of crushed concrete gave a significant uptake of CO₂, but that the emissions of CO₂ from fossil fuels that are used to crush the concrete reduced the CO₂ benefit of the carbonation. They also found that recycling of rebar and energy recovery of wood was more important and gave larger CO₂ benefit compared to the carbonation of concrete.

In a Swedish report from 2018 [9] an LCA of five different construction systems (cast-in-place concrete frame, cast-in-place concrete frame with light wooden and steel walls, prefabricated concrete frame, volume elements of wood and CLT frame) was carried out. The reference building is a 6-story apartment building in Stockholm which was completed in 2010. In this study the CLT frame building had a 40% lower greenhouse gas emission compared to the concrete frame building in the product stage. The CLT frame building had a higher emission in transport than the concrete frame building.

1.2. LCA of buildings

Life Cycle Assessment (LCA) is a method to assess the environmental effects of a product through the whole life cycle of the product, from extraction of resources to disposal. LCA is used to evaluate all types of products and product systems. NS-EN-ISO 14040 is a standard that describes principles and framework of an LCA, while NS-EN-ISO 14044 gives detailed requirements for the implementation of an LCA [10, 11].

NS-EN 15978 gives calculation principles to assess the environmental performance of new and existing buildings [12]. In this standard, system boundaries are defined for LCA of buildings. The system boundaries defined in NS-EN 15978 are A1-A3 (product stage), A4-A5 (construction process stage), B1-B7 (use stage), C1-C4 (end of life stage) and D (benefits and loads beyond the system boundary).

Environmental product declarations (EPDs) are built on an LCA of a product, and gives verifiable, accurate, non-misleading environmental information for products. NS-EN 15804 gives core product category rules for all construction products and services [13].

2. Method

2.1. System boundaries and functional unit

The goal of this study is to compare greenhouse gas emissions from a concrete and steel apartment building and a CLT apartment building. Therefore, the impact category which is investigated is climate change.

In this study the product stage (A1-A3), transportation to the building site (A4) and the operational energy use (B6) is examined. It is chosen to look at these stages because it is assumed that these are the stages with the highest greenhouse gas emissions [9], and because there is a lack of data on the other stages. The end of life phase (C1-C4) is not included in this study because there is a lack of data in many EPDs when it comes to end of life. There is also a large amount of uncertainty with respect to how the materials will be treated when the building is demolished in 60-100 years.

The functional unit that is used is kg CO₂-eq per m² gross internal area. The lifetime of the building is set to 60 years in this study. All the materials that are in the actual buildings, and that are assumed to contribute to the greenhouse gas emissions, are included in the calculations. The materials that are not included are assumed to be less than 1% of the total mass as stated in NS-EN 15804 [13]. Any materials used outside the buildings or foundation are not included in the calculation.

A detailed calculation of the technical systems has not been done in this study, because the main goal of the study is not to look at the technical systems, but rather to compare the two building structures. The technical systems are assumed to be very similar in the two buildings, and therefore it will not have any effect on the results that the technical systems are omitted from this study. [6] showed that there was not a large increase in GHG emissions from technical systems for increased building height.

Biogenic carbon is not included in the greenhouse gas emission calculations because the end of life phase is not included. The approach within the ZEB Research Centre is to exclude biogenic carbon if the end of life phase is not included [14]. This is because the biogenic carbon that is absorbed in the trees in the product phase will be released in the end of life phase when the wood is burned, or it decomposes.

2.2. Calculation of quantities

The quantities of the building materials are extracted from the BIM-models of Maskinparken 2 and TRE. The program Solibri model checker v9.8 is used to extract the quantities, and the quantities are afterwards exported to Excel where they are organized. Drawings of the buildings have also been used to get information about quantities and to understand the structure of the building.

2.3. Calculation of emissions

Environmental product declarations (EPDs) for the different building materials have been used in this paper to calculate the emissions of greenhouse gases. For most products EPDs for the actual product used in the buildings are used, but for the products without EPD available, EPDs for similar products that could have been used in the building were used. The EPDs are obtained from the Norwegian EPD Foundation [15], the German Ökobaudat [16], the International EPD system [17], IBU [18] and manufacturers' websites.

Energy calculations performed by Ramboll [19, 20] are used in this study. The dynamic calculation program Simien 6.007 is used to calculate the energy use of the buildings.

The emission factor for district heating is 51,1 g CO₂-eq/kWh taken from Statkraft [21] which is based on data for Trondheim. For electricity an emission factor of 132 g CO₂-eq/kWh is used. This is the CO₂-factor used in the ZEB Research Centre, and it is the simulated average carbon intensity of the European electricity grid for the next 60 years [22].

The bathrooms used in the project are prefabricated bathroom cabins which are fabricated in Finland and transported to the building site. No EPD was available for the bathroom cabins, and to calculate the GHG emissions, the bathroom cabins are assumed to be made of concrete, reinforcement, steel and ceramic tiles. This is based on drawings of the bathroom cabins and the SINTEF certification [23]. EPDs of the different products have been used to calculate the GHG emissions of the bathroom cabins.

The GHG emissions from the concrete underground car park are allocated between the buildings by using the gross internal area of the buildings as a factor.

2.4. Calculation of emissions from transport

The emissions from the transportation to the building site (A4) is taken from the information in the EPDs for the different products. This means that the greenhouse gas emissions from transport is not accurate for this construction site, but it gives an indication of how large the greenhouse gas emissions from the transportation of materials could be for a typical building site.

For the materials that did not have any transport information (A4) in the EPD, a transport calculator developed by Østfoldforskning has been used [24]. This transport calculator is based on data from Ecoinvent version 3.1. In the calculator information about the weight of the material, distance and the means of transport is entered. Both direct and indirect environmental impacts are included in the total environmental impacts from the calculator.

3. Case buildings

Maskinparken 2 and TRE are two apartment buildings in an area called Lilleby in Trondheim, Norway. Maskinparken 2 was completed in August 2018 and Maskinparken TRE was completed in December 2018. The buildings are connected by an underground carpark made of reinforced concrete.

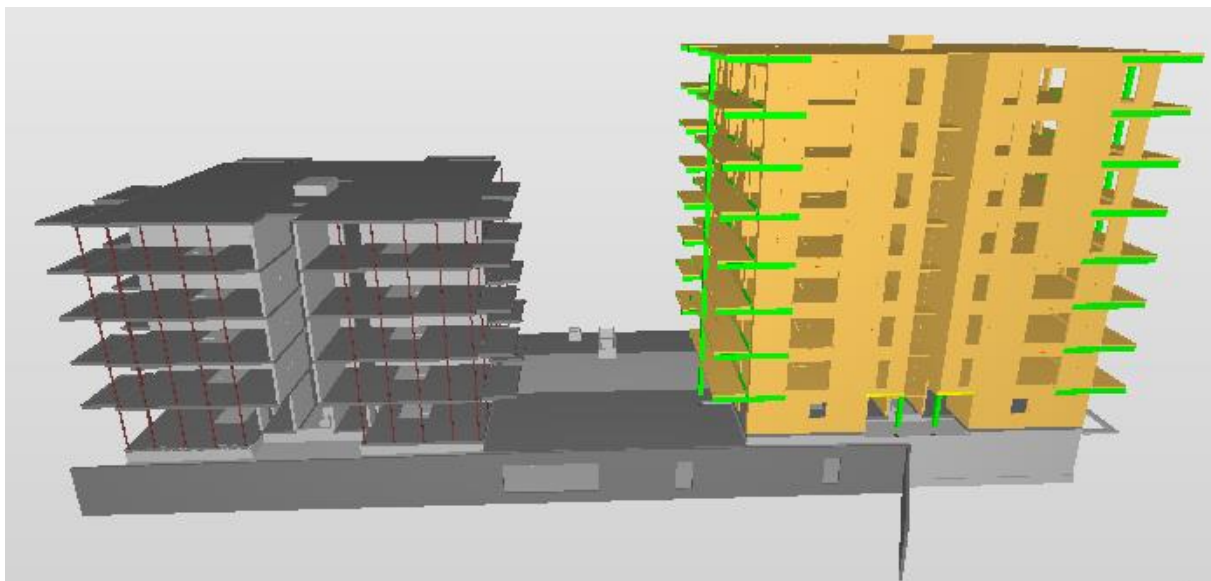


Figure 1. Maskinparken TRE to the right and Maskinparken 2 to the left with the concrete underground car park underneath. The picture is taken from the Solibri model of the buildings.

3.1. Maskinparken 2

Maskinparken 2 is a 5-story concrete and steel building with 31 apartments. It is built according to the Norwegian TEK10 standard energy demands. Slabs and walls in the building are made of reinforced concrete, with steel columns around the edges of the slabs. The slabs are reinforced with prestressing steel. The main staircase in the building is made of prefabricated concrete elements, and the elevator shaft is cast-in-place concrete. There is a technical room on the roof of the building. The outer walls are

built as isolated timber frames with outer wind barrier and inner vapour barrier with gypsum board, and the façade of Maskinparken 2 is an aired plaster system. The concrete quality used in the slabs and walls of Maskinparken 2 and the underground car park is C35.

3.2. Maskinparken TRE

Maskinparken TRE is an 8-story wooden apartment building with a total of 47 apartments. The building is built to meet the passive house standard NS 3700 [25]. The walls, slabs, main staircase and the elevator shaft are made of CLT-elements. Outer and inner load bearing walls and the ceilings are lined and covered with gypsum board. The façade cladding is wooden panels. Maskinparken TRE has a technical room underneath the building in the underground car park.

Table 1: Differences between the two buildings

	Maskinparken 2	Maskinparken TRE
Gross internal area	2376,1 m ²	3784,8 m ²
Number of stories	5	8
Number of apartments	31	47
Construction system	Reinforced concrete and steel	CLT
Foundation	Concrete underground car park	Concrete underground car park
Façade	Aired plaster	Wood panelling
Balconies	Prefabricated concrete	CLT
Outer walls	Insulated stud work	Lined CLT walls

Table 2: Delivered energy

	Maskinparken 2 [kWh/m ²]	Maskinparken TRE [kWh/m ²]
Direct electricity	34,0	36,4
District heating	63,9	49,9

Table 3: Material quantities of the two buildings

	Maskinparken 2 [ton]	[%]	Maskinparken TRE [ton]	[%]
Cast-in-place concrete	3874	82,8	3185	65,6
Prefabricated concrete	227	4,9	66	1,4
Steel	20	0,4	23	0,5
Screed	196	4,2	417	8,6
Reinforcement	151	3,2	125	2,6
Cross laminated timber	4	0,1	540	11,1
Wood	34	0,7	51	1,1
EPS	2	0,1	0	0,0
Bathroom cabins	62	1,3	102	2,1
Façade panel and plaster	13	0,3	0	0,0
Gypsum board	51	1,1	207	4,3
Stone wool insulation	8	0,2	71	1,5
Windows and balcony doors	16	0,3	25	0,5
Doors	11	0,2	16	0,3
Glass railing	0	0,0	17	0,3
Other materials	10	0,2	10	0,2

4. Results

The results from the LCA are shown in figure 2 below. The total GHG emissions for the production stage (A1-A3), transport (A4) and operational energy use (B6) is 801,5 kg CO₂-eq/m² for Maskinparken 2 and 696,6 kg CO₂-eq/m² for Maskinparken TRE for a building lifetime of 60 years. When looking at the production stage alone, Maskinparken 2 has a greenhouse gas emission of 312,9 kg CO₂-eq/m², while Maskinparken TRE has an emission of 233,9 kg CO₂-eq/m².

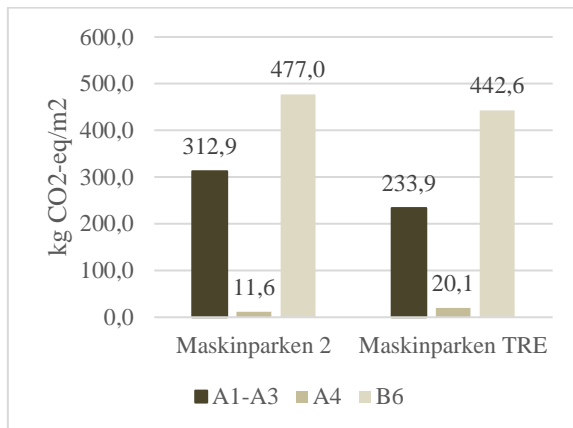


Figure 2: GHG emissions from Maskinparken 2 and TRE for the production stage (A1-A3), transport (A4) and operational energy use (B6).

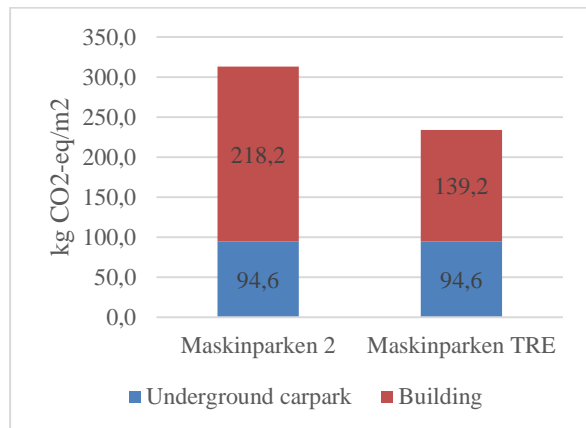


Figure 3: GHG emissions from the underground car park and the building (A1-A3).

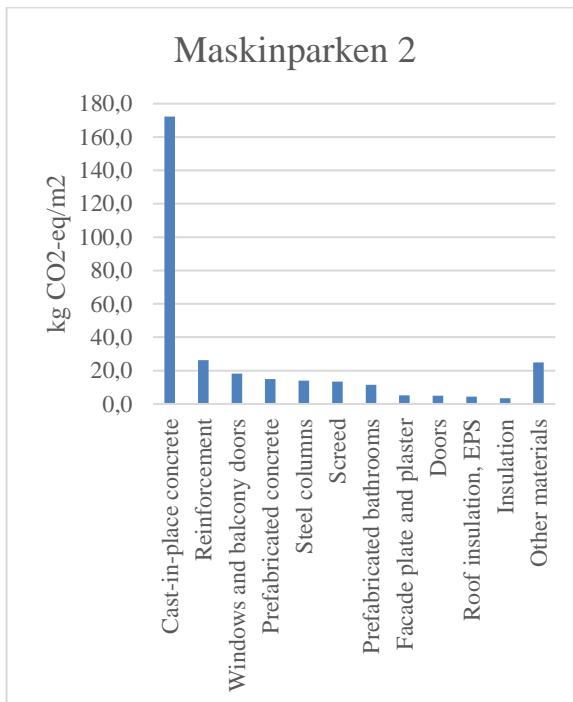


Figure 4: GHG emissions from the materials that emit the most greenhouse gases in Maskinparken 2 for the production stage (A1-A3).

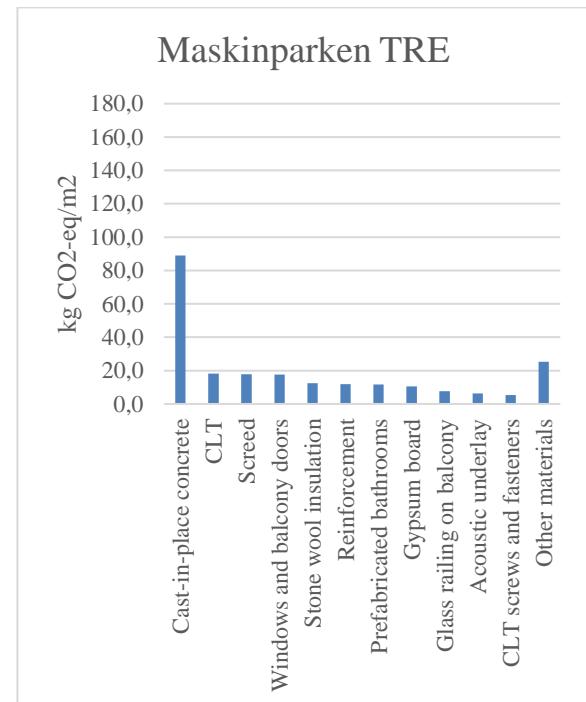


Figure 5: GHG emissions from the materials that emit the most greenhouse gases in Maskinparken TRE for the production stage (A1-A3).

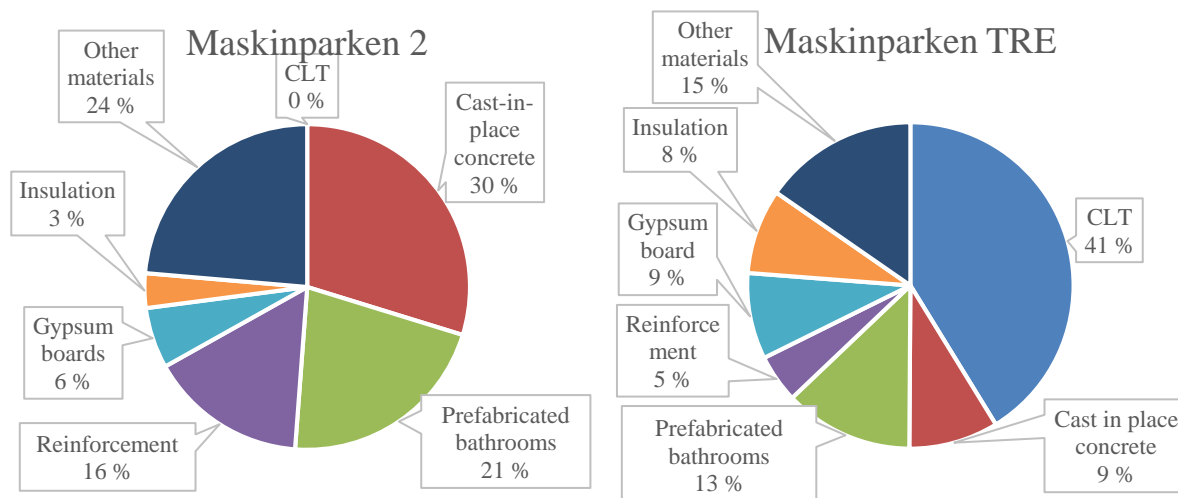


Figure 6: Greenhouse gas emissions from transport in percentage of the total emissions from transport for the products used in Maskinparken 2 and TRE.

5. Discussion and conclusion

The results in figure 2 show that in both the production phase and operational energy use, Maskinparken TRE has a lower emission of greenhouse gases than Maskinparken 2. The emissions per gross internal area (GIA) for the product phase are 25% lower for Maskinparken TRE compared to Maskinparken 2. The greenhouse gas emissions from operational energy use are 7% lower for Maskinparken TRE compared to Maskinparken 2. This was as expected, since Maskinparken TRE is built to the passive house standard NS 3700 and Maskinparken 2 is built to the Norwegian TEK10 standard, which is less strict when it comes to energy use than NS 3700. The results also show that for a 60-year lifetime of the buildings, the operational energy use is the phase that emits the most greenhouse gases. This would change if another lifetime than 60 years was chosen.

Figure 4 shows that for Maskinparken 2, cast-in-place concrete is the material that contributes with the most greenhouse gases, followed by the reinforcement used in the concrete. Cast-in-place concrete is also the material that emits the most greenhouse gases for Maskinparken TRE, see figure 5. This is because of the large amount of concrete in the underground car park. The third most emitting material for Maskinparken TRE is screed, which is used over the acoustic underlay. This means that choosing a material with low greenhouse gas emissions for screed can be important to lower the greenhouse gas emissions from CLT buildings.

As can be seen in Figure 3, the underground car park contributes significantly to greenhouse gas emissions. The underground car park contains a large amount of concrete and steel reinforcement, and this means that if the buildings were built without the underground car park, this would reduce the GHG of the two buildings greatly. Where it is possible to have parking above ground, a concrete underground car park should therefore be avoided to reduce the GHG emissions.

It can be seen in Figure 2 that greenhouse gas emissions from the transport phase are small compared to the product stage and the operational energy use. Maskinparken TRE has a higher GHG emission from transport compared to Maskinparken 2. The products that contribute the most to emissions from transport are shown in Figure 6. The main reason Maskinparken TRE has a higher emission from transport is because of the CLT-elements which are transported from Ybbs in Austria to Trondheim. This means that the greenhouse gas emissions from transport could have been lowered if the CLT was produced in a factory nearer Trondheim. It is important to note that a detailed calculation of the GHG emissions from transport has not been carried out, and values from EPDs have been used for most products. This means that there is a large amount of uncertainty in the results with respect to transport.

Operational energy use (B6) is the phase that contributes the most to the greenhouse gas emissions for both buildings for a lifetime of 60 years. The results for the emissions from operational energy use are uncertain, because they are highly dependent on the emission factors for electricity and district heating. In this paper constant energy use and emission factors are assumed. There is a high level of uncertainty in the building's future energy use and the future emission factors, and therefore this phase should be examined further to gain more knowledge of the emissions in the operational phase.

There are some differences in the two buildings other than the structural system that makes comparison of the buildings more difficult. The most important differences are that the buildings are of different heights, have different cladding, and that they are built to different energy standards. A version of Maskinparken 2 with 8 stories has been made to compare the difference in GHG emissions in buildings of 5 and 8 stories. The results show that the version with 8 stories has 3-4% lower GHG emissions per square meter in the production phase compared to the version with 5 stories when the parking cellar is not included. The cladding on Maskinparken 2, aired plaster, has a higher GHG emission than the wood paneling used on Maskinparken TRE. Because the façade and other materials are different, maintenance during the lifetime could be different on the two buildings.

Maskinparken 2 is built to the TEK10 standard, and Maskinparken TRE built to the passive house standard, and this means energy use in Maskinparken 2 is expected to be higher than in Maskinparken TRE. Material use is expected to be higher in Maskinparken TRE compared to Maskinparken 2 because of the different energy standards. For example, more insulation will be used in Maskinparken TRE to get lower u-value on the outer walls. Even though material use should be higher in Maskinparken TRE than in Maskinparken 2, embodied emissions was found to be lower for Maskinparken TRE compared to Maskinparken 2. This confirms that CLT buildings have lower embodied emissions than comparable buildings in concrete and steel. However, maintenance emissions over the lifetime of the building needs to be confirmed.

Acknowledgements

The authors would like to thank Vidar Amundal for information about the buildings, and Liv Høijord Svare for help with the energy calculations.

References

- [1] IPCC. *Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Geneva, Switzerland: World Meteorological Organization; 2018.
- [2] Lucon O, Ürge-Vorsatz D, Ahmed AZ, Akbari H, Bertoldi P, Cabeza LF, et al. *Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press; 2014.
- [3] Olivier JGJ, Peters JAHW. *Trends in global CO₂ and total greenhouse gas emissions: 2018 report.* The Hague: Netherlands Environmental Assessment Agency; 2018.
- [4] Abrahamsen R. *Mjøstårnet - 18 storey timber building completed.* 24. Internationales Holzbau-Forum IHF 2018: Moelven Limtre AS; 2018.
- [5] Skullestad JL, Bohne RA, Lohne J. *High-rise timber buildings as a climate change mitigation measure—A comparative LCA of structural system alternatives.* Energy Procedia. 2016;96:112-23.
- [6] Kaspersen B, Lohne J, Bohne RA. *Exploring the CO₂-Impact for Building Height; A Study on Technical Building Installations.* Energy Procedia. 2016;96:5-16.
- [7] Dodoo A, Gustavsson L, Sathre R. Lifecycle carbon implications of conventional and low-energy multi-storey timber building systems. *Energy and Buildings.* 2014;**82**:194-210.
- [8] Dodoo A, Gustavsson L, Sathre R. Carbon implications of end-of-life management of building

- materials. *Resources, Conservation and Recycling*. 2009;**53**(5):276-86.
- [9] Erlandsson M, Malmqvist T, Francart N, Kellner J. *Minskad klimatpåverkan från nybyggda flerbostadshus. LCA av fem byggsystem. Underlagsrapport* Stockholm: Sveriges Byggindustrier; 2018 [cited 2019 07.03]. Available from: <https://www.ivl.se/sidor/publikationer/publikation.html?id=5658>.
- [10] Standard Norge. *NS-EN ISO 14040:2006 Environmental management, Life cycle assessment, Principles and framework (ISO 14040:2006)* [Standard]. Brussels: 2006 [Available from: <http://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=236802>].
- [11] Standard Norge. *NS-EN ISO 14044:2006 Environmental management, Life cycle assessment, Requirements and guidelines (ISO 14044:2006)* [Standard]. Brussels: 2006 [Available from: <http://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=236803>].
- [12] Standard Norge. *NS-EN 15978:2011 Sustainability of construction works, Assessment of environmental performance of buildings, Calculation method* [Standard]. Brussels: 2011 [Available from: <http://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=516244>].
- [13] Standard Norge. *NS-EN 15804:2002+A1:2013 Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products* [Standard]. Brussels: 2013 [Available from: <http://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=679924>].
- [14] Fufa SM, Schlanbusch RD, Sørnes K, Inman MR, Andresen I. *A Norwegian ZEB definition guideline. ZEB project report 29* Trondheim: SINTEF Academic Press; 2016 [cited 2019 23.01]. Available from: <https://www.zeb.no/index.php/en/news-and-events/256-a-norwegian-zeb-definition-guideline>.
- [15] The Norwegian EPD Foundation. *Byggevarer* 2019 [cited 2019 07.03]. Available from: <https://www.epd-norge.no/byggevarer/category315.html>.
- [16] Federal Ministry of the Interior BaC. *Database - Ökobaudat* 2019 [updated 27.02.2019; cited 2019 12.03]. Available from: <https://www.oekobaudat.de/en/database/database-oekobaudat.html>.
- [17] The International EPD System. *Search the EPD database* Stockholm: 2019 [cited 2019 12.03]. Available from: <https://www.environdec.com/EPD-Search/>.
- [18] Institut Bauen und Umwelt e.V. *EPD Programme* 2017 [cited 2019 11.03]. Available from: <https://ibu-epd.com/en/epd-programme/>.
- [19] Svare LH. *Maskinparken 2: Energikonsept*. Pers. com.: Rambøll; 2018.
- [20] Svare LH. *Maskinparken TRE: Energikonsept*. Pers. com.: Rambøll; 2018.
- [21] Statkraft Varmer AS. *Data til bruk i Breeam-sertifisering for kunder av Statkraft Varmer i Trondheim - 2018*. Trondheim; 2018.
- [22] Graabak I, Bakken BH, Feilberg N. Zero emission building and conversion factors between electricity consumption and emissions of greenhouse gases in a long term perspective. *Environmental and Climate Technologies*. 2014;**13**(1):12-9.
- [23] SINTEF Byggforsk. *Teknisk godkjenning Parmarine prefabrikkerte baderomsmoduler nr. 2453*. SINTEF; 2017.
- [24] Saxegård SA, Vold M, Edvardsen T, Brekke A, Iversen OMK. *Transportkalkulator: EPD-verktøy*. Kråkerøy: Østfoldforskning; 2016. Report No.: OR.08.16.
- [25] Standard Norge. *NS 3700:2013 Criteria for passive houses and low energy buildings - Residential buildings* [Standard]. Oslo: 2013 [Available from: <https://www.standard.no/no/Nettbutikk/produktkatalogen/Produktpresentasjon/?ProductID=636902>].