Into the Outdoors

Educational Partners:

HOW HEALTHY MARKETS SUSTAIN FORESTS

High School Lesson –

Life Cycle Analysis – Greenhouse Gas Emissions

HOW HEALTHY MARKETS SUSTAIN FORESTS

Life Cycle Analysis – Greenhouse Gas Emissions

Developed By: Gina Smith, LEAF – Wisconsin's K-12 Forestry Education Program

Target Grade Level: 9-12

Appropriate for 6-8 with support (interpreting text & calculations)

Science Categories

Forestry, Climate Change, Sustainability, Economics

Time Frame 1.5-2 hours

- Introduction: 30 minutes
- Activity 1: 45 minutes
- Activity 2: 15
- Conclusion: 5 minutes
- Extension: 45 minutes (optional)

Materials

- How Healthy Markets Sustain Forests episode
- Student Sheet: Life Cycle Assessment_Information Sheet_Activity 1
- Student Sheet: Life Cycle Assessment_Data Sheet_Activity 1
- Student Sheet: Life Cycle Assessment_Summary_Activity 2
- Student Sheet: Examining the Future of Cross Laminate Timber in Wisconsin Buildings _ Extension (optional)

Key Words

- Greenhouse gas emissions, climate change, cross laminated timber, life cycle assessment, raw material, environmental product declaration

Learning Objectives

Students will be able to:

- Explain what a Life Cycle Assessment is, the steps involved in the process and how it helps people make decisions

- Examine information from a completed life cycle on greenhouse gas emissions and summarize ways to reduce greenhouse gas emissions based on findings from the life cycle assessment
- Identify factors (in addition to greenhouse gas emissions) that producers must consider when creating products

Activity Summary

Students will view an Into the Outdoors episode and discuss the different things producers/ manufacturers need to think about when producing a product. Students will examine a comparative life cycle analysis of two buildings – one made from steel and concrete and the other made from cross laminated timber – with a focus on greenhouse gas emissions. Students will summarize the results of the life cycle analysis and suggest other factors that influence the decisions producers make. An optional extension activity allows students to examine if cross laminated timber is a building solution for Wisconsin.

Vocabulary

- Greenhouse Gas (GHG) emissions: the release of carbon dioxide, methane and nitrous oxide into the Earth's atmosphere; the gases trap heat and contribute to the greenhouse effect; GHG emissions are primarily generated by human activities like burning fossil fuels for energy
- Climate change: long-term shifts in temperatures and weather patterns; largely from increased greenhouse gas emissions from the burning of fossil fuels
- Cross laminated timber: a wood product made by gluing layers of lumber together at right angles to create a strong, lightweight building material
- Life cycle assessment: process that maps the flow of materials and energy required by a product from the extraction of the raw materials used to make it to the manufacturing and use of the product to the disposal (or recycling) of the product
- Raw materials: materials used to produce goods or services; these materials are unprocessed or minimally processed
- Environmental product declaration: reports that document the environmental impact of a product through its life cycle

Background Information

The student texts provide the background information needed to complete the activities within this lesson.

Learning Procedure

Introduction: *How Healthy Markets Sustain Forests* – Into the Outdoors episode

Show students the Into the Outdoors episode, *How Healthy Markets Sustain Forests.* Prompt students to listen for all the decisions the people producing forest products must make to provide the product to consumers.

- After the episode, ask students to share the different decisions that are involved in producing forest products.

Activity 1: Comparative Life Cycle Assessment of Greenhouse Gas Emissions

Pass out a copy of the Life Cycle Assessment – Greenhouse Gas Emissions – Information Sheet and Life Cycle Assessment Greenhouse Gas Emissions Data Sheet to each student. Tell students they will be reviewing a Comparative Life Cycle Assessment that was conducted on two apartment buildings in Norway (Maskinparken 2 and Maskinparken TRE). Tell students that this is real data and information that was gathered and reviewed by multiple scientists. Explain that a **Life Cycle Assessment** (LCA) is a process that maps the flow of materials and energy required by a product from the extraction of the raw materials used to make it to the manufacturing and use of the product (or in this case a building) to the disposal (or recycling) of the product (building). Tell students that while complete life cycle assessments look at all the impacts of material and energy use during the complete life cycle of a product (affects on water, land, etc.), during this activity they will only investigate the **greenhouse gas (GHG) emissions** of the two buildings.

Remind students that greenhouse gas emissions include carbon dioxide, methane and nitrous oxide. Explain that greenhouse gases trap heat and contribute to the greenhouse effect which warms the planet. Remind students that while there are natural processes that produce GHGs, human activities like burning fossil fuels for energy have caused a rapid increase in GHG emissions over the past two centuries which is contributing to **climate change (**long-term shifts in temperatures and weather patterns). Explain to students that their task is to examine LCA data to learn about the GHG emissions of both buildings to determine which building produces fewer GHG emissions over its lifetime. Explain that processes like these help builders make sustainable decisions about the design and construction of their buildings.

Students should work in groups (3-5 students per group) to complete the table on their Data Sheet (page 1). Outline the following step for students.

1. Read through the Life Cycle Assessment – Greenhouse Gas Emissions Information sheet. Don't make any notes or record any information on the Data Sheet during this first reading. Focus on understanding what the text says.
2. Read the Life Cycle Assessment – Greenhouse Gas Emissions Data Sheet to determine what data needs to be gathered from the Life Cycle Assessment.
3. Reread, the Life Cycle Assessment. This time, record information on the Data Sheet as you read. Note – some data/information comes directly from the text while other data/information comes from the tables and figures. All members of the group should record information on their data sheet.
4. Tell students not to move on to page 2 or complete any calculations yet.

Once all groups have completed the table, ask students if they can tell which building produces less GHG emissions over its lifetime? Have students explain why they think so. Tell students that information is often easier to understand when looking at percentage increase or decrease or percentage of whole versus just raw numbers. Tell them they are going to complete a series of calculations that will help them analyze and understand their data better.
Review the process for calculating percentage change (decrease or increase) with students. Tell students that they have already recorded all the information/numbers needed to complete the calculations on their student sheets.

Calculating a percentage increase or decrease (Questions 1-4)

Use the following formula to calculate percentage decrease or increase:

(MTRE Value – M2 Value) ÷ M2 Value x 100%

Negative value = percent decrease in GHG emissions using CLT elements

Positive value = percent increase in GHG emissions using CLT elements

***Example:** If GHG emissions from Production (A1-A3) for M2 is 104.8 and GHG emissions from Production (A1-A3) for MTRE is 62.4 then…*

(MTRE Value – M2 Value) ÷ M2 Value x 100% =

(62.4 – 104.8) ÷ 104.8 x 100% = (-42.4) ÷ 104.8 x 100% = -0.4045 x 100% = -40.45%

This is a 40% decrease in GHG emissions using CLT elements.

Calculate a percentage of the whole (Questions 5-8)

GHG Emissions of part ÷ total GHG emissions of whole x 100% =

***Example:** If GHG emissions of the bathrooms were 12.2 and total greenhouse gas emissions were 248.8*

12.2 ÷ 248.8 x 100% = 0.049 x 100% = 4.90%

The bathrooms contribute almost 5% of the GHG emissions in this example.

Allow groups time to perform the calculations. After all groups have finished, discuss the answers as a class.
Have students do the final part of the activity – a written summary of the results of the Comparative Life Cycle Assessment for Greenhouse Gas Emissions – independently. Review the process and expectations with students as outlined on their data sheet:

Complete a written summary of the results of the Comparative Life Cycle Assessment for greenhouse gas emissions of the steel and concrete Maskinparken 2 and cross laminated timber Maskinparken TRE apartment buildings. Your summary should include the following information:

For each building:

- Overall greenhouse gas emissions for the lifetime of the building
- Largest stage contributing to greenhouse gas emissions
- Largest materials contributing to greenhouse gas emissions
- At least one way to reduce greenhouse gas emissions for the building

Overall Review:

- Which apartment building produces the lowest greenhouse gas emissions over its lifetime?

Support statements in your summaries with evidence from the text, tables, figures, and your calculations. Use complete sentences, proper grammar and correct spelling.
Tell students to submit their work to you when they have completed it. Once all students have completed their summaries, move on to Activity 2.

Activity 2: Life Cycle Assessment – Greenhouse Gas Emissions - Summary

Pass out a copy of the Life Cycle Assessment – Greenhouse Gas Emissions – Summary sheet to each student. Have students return to working in their group. Instruct them to read the summary together to learn what the conclusion of the original Comparative Life Cycle Analysis of Maskinparken 2 and Maskinparken TRE. Tell students to discuss the following questions with their group when they are done reading:

- Does the information from the conclusion of the LCA support what you wrote in your summary?
- Did you come to the same conclusion as the authors of the Comparative Life Cycle Assessment of apartment buildings Maskinparken 2 and Maskinparken TRE?
- What things besides GHG emissions do builders need to think about when constructing a building? How might that affect the decisions builders make?

Conclusion: Class Discussion

After groups have had time to complete the reading and their own discussion ask groups to share their thoughts with the class.

Extending the Lesson

High School: Economics Focus – Have students participate in the Extension activity *Examining the Future of Cross Laminated Timber in the Forest Marketplace*

Educational Partners:

Elementary School Recommendations

Use the K-5 lesson from this Into the Outdoors episode, *How Healthy Markets Sustain Forests – Cost-Benefit Analysis,* with students in grades 2-5.

The following LEAF lessons may be used for early elementary learners:

LEAF K-1st Grade Forestry Lesson Guide, Lesson 4: Forest Products Time Machine

- Students learn about historical uses of forest resources. Students begin by sharing ways we use the forest while playing a game of Hot Pine Cone. Next, the class explores forest resources used to create products of the past, while relating them to present-day goods. To conclude, students examine forest products and draw a picture of one they use every day. https://www.uwsp.edu/wp-content/uploads/2023/11/leaf-k-1-lesson-4-forest-product-time-machine.pdf

LEAF K-1st Grade Forestry Lesson Guide, Lesson 5: Animals Need Forests Too

- Students explore what the forest provides for its animal residents. Cooperatively, students create a forest ecosystem with their classmates, and enter the forest as animals in search of food, water, shelter, and space.

LEAF 2nd-3rd Grade Forestry Lesson Guide, Lesson 4: Forests Are Important to Me!

- Students explore and graph their personal forest values. Using a checklist, they discover how many of the forest products they use are made right here in Wisconsin and map them. As a conclusion, students create a collage and write about why they value forests. https://www.uwsp.edu/wp-content/uploads/2023/11/leaf-2-3-lesson-4-forests-are-important-to-me.pdf

LEAF 2nd-3rd Grade Forestry Lesson Guide, Lesson 5: Decisions, Decisions

Students learn about forest management by making a plan for a schoolyard. Using a card game similar to Old Maid, students learn about some of the people involved in managing forests. As a conclusion, they act out the roles of people involved in forest management and sing a song about what forests can be managed for. https://www.uwsp.edu/wp-content/uploads/2023/11/leaf-2-3-lesson-5-decisions-decisions.pdf

Middle School Recommendations:

Middle school students should complete the 6-8 lesson from this Into the Outdoors episode, *How Healthy Markets Sustain Forests*.

Student Pages

See additional documents that will need to be included:

- Student Sheet: Life Cycle Assessment_Information Sheet_Activity 1
- Student Sheet: Life Cycle Assessment_Data Sheet_Activity 1
- Student Sheet: Life Cycle Assessment_Summary_Activity 2
- Student Sheet: Examining the Future of Cross Laminate Timber in Wisconsin Buildings _ Extension (optional extension activity)

Standards

WISCONSIN STANDARDS FOR SCIENCE

- SCI.CC6.h Students model complex and microscopic structures and systems and visualize how their function depends on the shapes, composition, and relationships among their parts. They analyze many complex natural and designed structures and systems to determine how they function. They design structures to serve particular functions by taking into account properties of different materials and how materials can be shaped and used.
- SCI.PS1.A.h The fact that matter is composed of atoms and molecules can be used to explain the properties of substances, diversity of materials, states of matter, phase changes, and conservation of matter.
- SCI.ETS2.B.h All human activity draws on natural resources and has both short- and long-term consequences, positive as well as negative, for the health of people and the natural environment.

WISCONSIN STANDARDS FOR SOCIAL STUDIES

- SS.Econ1.a.h Perform a cost–benefit analysis on a real-world situation, using economic thinking to describe the marginal costs and benefits of a particular decision.
- SS.Econ2.a.h Connect the roles of consumers and producers in the product, labor, and financial markets, and the economy as a whole. Analyze the roles of the market for goods and services (product market) and the market for factors of production (factor market).
- SS.Econ2.b.h Differentiate between supply and demand and the resulting impact on equilibrium prices and quantities produced.
- SS.Econ3.a.h Assess how decisions about spending and production made by households, businesses, and governments determine the country's levels of income, employment, and prices.
- SS.Geog3.a.h Evaluate, in both current and historical context, how the prospect of gaining access to resources in contested zones creates competition among countries.
- SS.Geog5.a.h Analyze the intentional and unintentional spatial consequences of human actions on the environment at the local, state, tribal, regional, country, and world levels.
- SS.Geog5.b.h Hypothesize how changes in human behavior (e.g., organic agriculture, Genetically Modified Organisms, ecotourism) can result in changes that have effects on a global scale.

WISCONSIN STANDARDS FOR ENVIRONMENTAL LITERACY AND SUSTAINABILITY

- ELS.EX4.A.h Examine the role of renewable and nonrenewable resources in creating sustainable economies. Analyze how the movement of natural resources through acquisition, production, consumption, and disposal impact sustainability of local, regional, and global systems.

WISCONSIN STANDARDS FOR ENGLISH LANGUAGE ARTS

- ELA.R.9-12.1 Cite textual evidence that strongly supports an analysis of what the text says explicitly/implicitly and make logical inferences, develop questions for further exploration.
- ELA.R.9-12.2 Objectively and accurately summarize texts, from a variety of genres, to determine one or more themes or central ideas and analyze its development, including how it emerges and is shaped and refined by specific details.
- ELA.W.9-12.3 Create writing that utilizes organization: introduce a topic; organize complex ideas, concepts, analysis, information and claims to make important connections and distinctions. Establish and maintain a structure and conventions consistent with the mode of writing. Provide a concluding statement or section that follows from and supports the topic, themes, and experiences presented in the text.
- ELA.W.9-12.4 Produce clear and coherent writing in which the development, organization and style are culturally sustaining and rhetorically authentic to task, purpose and audience.
- ELA.W.9-12.7 Conduct short as well as more sustained research projects to answer a question or solve a problem that is rhetorically authentic and culturally sustaining; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating an understanding of the subject under investigation.
- ELA.W.9-12.8 Gather relevant information from multiple authoritative print and digital, academic and popular sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- ELA.W.9-12.9 Draw evidence from literary or informational texts to support analysis, reflection, and research.

Resources

- Listed and linked in lesson and student pages.

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HOW HEALTHY MARKETS SUSTAIN FORESTS

Life Cycle Assessment – Greenhouse Gas Emissions -
Information Sheet – Activity 1

COMPARATIVE LIFE CYCLE ASSESSMENT

Concrete and Steel Apartment Building and Cross Laminated Timber Apartment Building

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Excerpted from:
Comparative LCA of a concrete and steel apartment building and a cross laminated timber apartment building by A R Eliassen et al for the Sustainable Built Environment 2019 IOP Conference Series: Earth and Environmental Science

Comparative life cycle assessment of cross laminated timber building and concrete building with special focus on biogenic carbon by Julie Hansted Anderson, Nana Lin Rasmussen and Morten Walbech Ryberg for the 2020 Energy and Buildings journal, Volume 254.

Modified by Gina Smith from LEAF – Wisconsin's K-12 Forestry Education Program (28 Oct 2024) for use in this lesson. Where appropriate, original text and citations from original sources have been preserved.

Background Information:

The building and construction sector is responsible for about 39% of the World's process and energy related CO_2-emissions. The emissions related to this sector appear to increase each year [1]. This continuous increase in **greenhouse gas (GHG) emissions** makes it increasingly difficult to achieve commitments related to **climate change**, like those outlined in the Paris Agreement [2]. Construction is projected to increase through 2060 [1]. It is necessary to identify solutions to reduce the GHG emissions created during construction of buildings to reduce overall emissions in the building and construction sector.

Concrete is one of the most widely used construction materials in the world today. Cement, which is an important ingredient in concrete, contributes to a large amount of greenhouse gas emissions globally. In 2017 cement clinker (solid, lumps of material-made from limestone and other minerals- used to make cement) production created around 4% of global CO_2 emissions [3]

One suggested way to reduce greenhouse gas emissions from buildings is 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.

Educational Partners:

A common approach used to calculate environmental impact and evaluate options to reduce environmental impact of buildings is a **Life Cycle Assessment (LCA)** [3,4]. In LCA, the flows of material and energy pertaining to a building are mapped throughout its full life cycle. It starts with the extraction of raw materials to produce building materials, includes the construction and use of the building, and ends with the decommission of the building and final disposal and recycling of the building materials.

Life Cycle Assessments of Buildings

One of the Life Cycle Assessments that can be used to address the environmental performance of new and existing buildings is called NS-EN 15978 [4]. It includes examining the building in the following stages:

- **Production Stage (A1-A3)**
    - A1 = Raw Material Supply
    - A2 = Transport of Raw Materials
    - A3 = Manufacture of Raw Materials into Building Materials
- **Construction Process Stage (A4-A5)**
    - A4 = Transportation to Construction Site
    - A5 = Construction/Installation Process
- **Use Stage (B1-B7)**
    - B1 = Use
    - B2 = Maintenance
    - B3 = Repair
    - B4 = Replacement
    - B5 = Refurbishment
    - B6 = Operational Energy Use
    - B7 = Operational Water Use
- **End of Life Stage (C1-C4)**
    - C1 = Deconstruction/Demolition
    - C2 = Transport
    - C3 = Waste Processing
    - C4 = Disposal
- **Benefits and Loads Beyond the System Boundaries (D)**
    - Reuse / Recovery / Recycling Potential

Your Task:

You will use information from a NS-EN 15978 Life Cycle Assessment to compare greenhouse gas emissions from a concrete and steel apartment building to a cross laminated timber apartment building to investigate whether it is possible to reduce greenhouse gas emissions by using CLT elements to construct apartment buildings instead of concrete. The LCA was completed on two new apartment buildings constructed in Trondheim, Norway. One building, **Maskinparken 2** (M2), is a five-story apartment building constructed of concrete and steel. The other, **Maskinparken TRE** (MTRE), is an eight-story apartment building constructed using CLT elements. Both buildings were constructed by Veidekke AS. The two buildings are very comparable since they were constructed side by side and are almost identical except for the number of floors and the structural system.

Educational Partners:

You will examine data about GHG emissions during the **production stage** (A1-A3), **transportation to the building site** (A4) and the **operational energy use** (B6) because they are projected to have the highest greenhouse gas emissions [5] and there is a lot of data for these stages. You will not examine end of life stage (C1-C4) because that data is limited and there are a lot of questions about what will happen to the building materials when it is demolished in 60-100 years.

Use the information from the NS-EN 15978 Life Cycle Assessment of Maskinparken 2 (M2) and Maskinparken TRE (MTRE) that follows to help you complete your Comparative LCA Data Sheet.

LCA measurements and calculations:

Unit of Measurement: GHG emissions were measured using kg CO_2-eq per m^2 gross internal area. The lifetime of the building is set to 60 years. All the materials that are in the actual buildings and foundations were included in the calculations.

Calculating quantities: The quantities of building materials used in M2 and MTRE were determined using 3D models and drawings of the buildings. **Environmental product declarations (EPDs)** (reports that document the environmental impact of a product throughout its life cycle) for different building materials were used to calculate the emissions of greenhouse gases. If materials that were used in the building did not have an EPD, EPDs from similar materials were used.

Calculating emissions: The emission factor for district heating is 51.1 g CO_2-eq/kWh based on data from Trondheim, Norway [7]. For electricity an emission factor of 132 g CO_2-eq/kWh was used. It is based on the simulated average carbon intensity of the European electricity grid for the next 60 years [8].
All bathrooms in the apartments were prefabricated in Finland and transported to the building site. No EPDs were available for the bathrooms so it was assumed they were made of concrete, reinforcement, steel and ceramic tiles. EPDs for these products were used to calculate the GHG emissions of the bathrooms.
The GHG emissions from the underground carport that is shared by the buildings were calculated using the internal area of each building.

Calculating emissions from transport: The emissions from the transportation of building materials to the building site (A4) were taken from the information in the EPDs for the different products. The are representative of GHG emissions from the transportation of materials for a typical building site and not specific to the location of these buildings. For materials that did not have any transport information in the EPD, a transport calculator was used. Information about the weight of the material, distance and the means of transport was entered into the calculator resulting in an estimated value of GHG emissions. [9]

LCA Buildings

Maskinparken 2 (M2) and MaskinparkenTRE (MTRE) are both located in an area called Lilleby in Trondheim, Norway. M2 was completed in August 2018 and MTRE was completed in December 2018. The buildings are connected by an underground car park made of reinforced concrete.

Maskinparken 2 (M2): M2 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 vapor barrier with gypsum board, and the facade of M2 is an aired plaster system. The concrete quality used in the slabs and walls of M2, and the underground car park is a heavy-duty concrete mix, C35.

Maskinparken TRE (MTRE): MTRE 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 [10]. 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. Facade is wooden panels. MTRE has a technical room underneath the building in the underground car park.

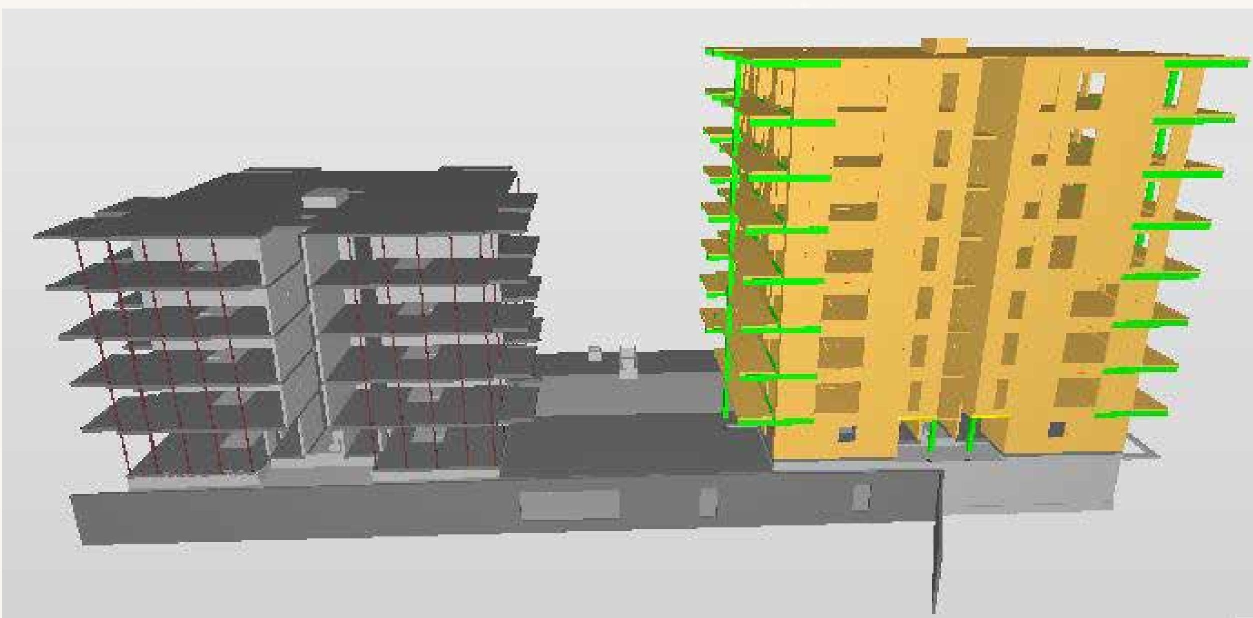

Figure 1. M2 (left) and MTRE (right) with the concrete underground parking underneath. The picture is taken from the Solibri model of the buildings.

Educational Partners:

LCA Data:

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
Facade	Aired plaster	Wood paneling
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 (weight) of M2 and MTRE						
	Maskinparken 2	[ton]	[%]	**Maskinparken TRE**	[ton]	[%]
Cast-in-lace 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	3.1		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
Bathrooms		62	1.3		102	2.1
Façade panel & 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

LCA Results (, is equivalent to .)

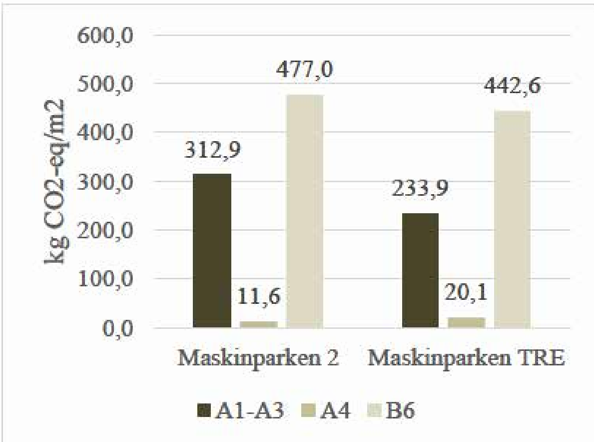

Figure 2: GHG emissions from Maskinparken 2 and TRE for the production stage (A1-A3), transport (A4) and operational energy use (B6).

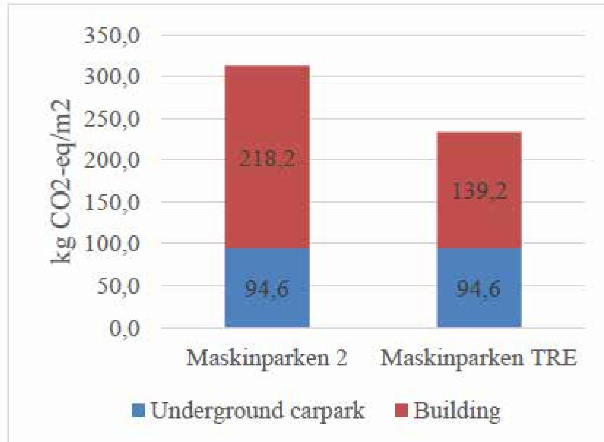

Figure 3: GHG emissions from the underground car park and the building (A1-A3).

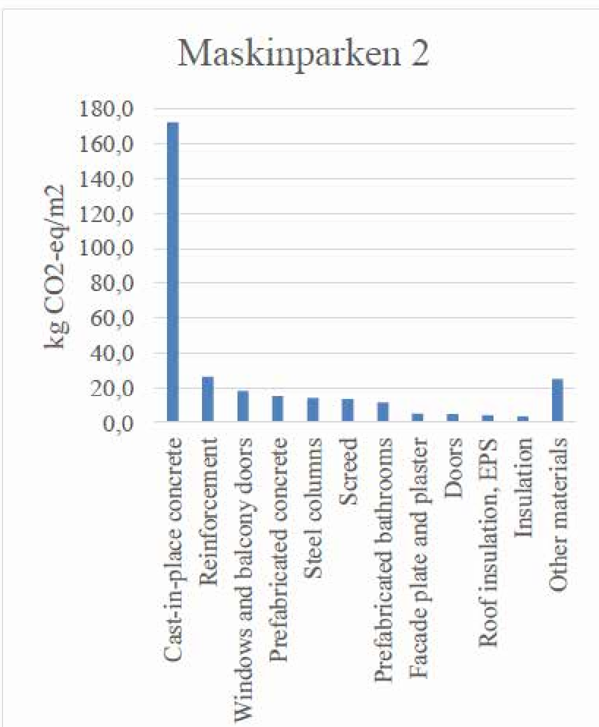

Figure 4: GHG emissions from the materials that emit the most greenhouse gases in Maskinparken 2 for the production stage (A1-A3).

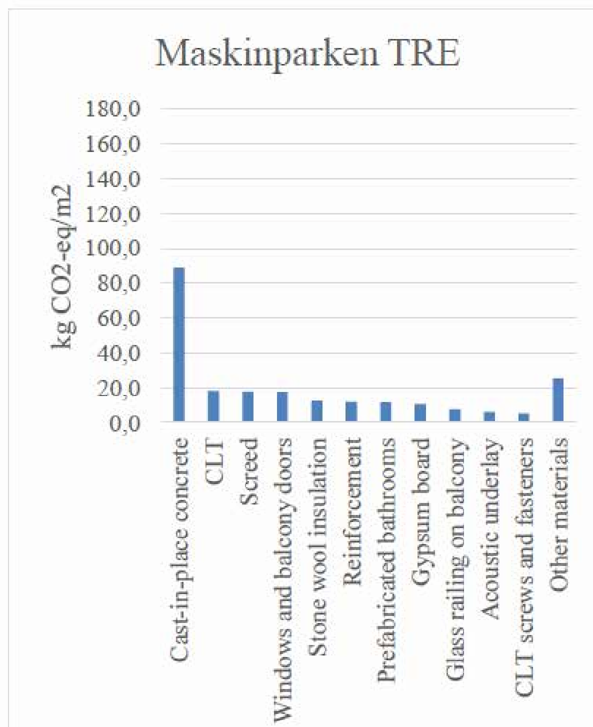

Figure 5: GHG emissions from the materials that emit the most greenhouse gases in Maskinparken TRE for the production stage (A1-A3).

Educational Partners:

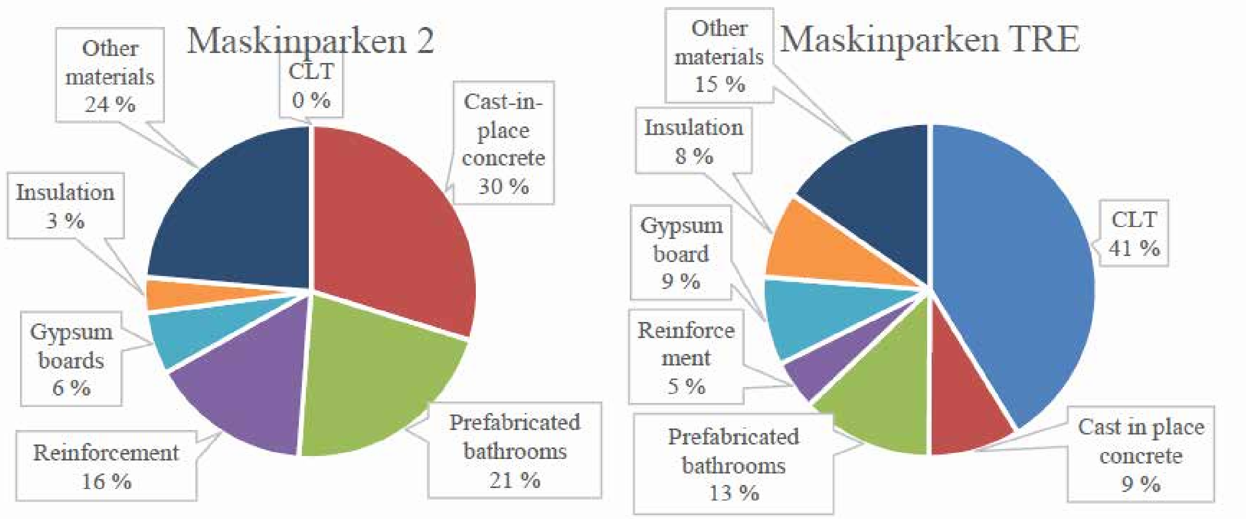

Figure 6: Greenhouse gas emissions from transport in percentage of the total emissions from transport for the products used in Maskinparken 2 and TRE.

Acknowledgements

Text modified from:

A R Eliassen et al. 2019. ***Comparative LCA of a concrete and steel apartment building and a cross laminated timber apartment building.*** IOP Conf. Ser.: Earth Environ. Sci. 323 012017 doi: 10.1088/1755-1315/323/1/012017 https://iopscience.iop.org/article/10.1088/1755-1315/323/1/012017

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J Hansted Anderson, et al. 19 Oct 2021. ***Comparative life cycle assessment of cross laminated timber building and concrete building with special focus on biogenic carbon.*** Energy and Buildings 254 (2022) 111604. doi.org/10.1016/j.enbuild.2021.111604.

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[2] UNFCCC, Decision 1/CP.21 Adoption of the Paris Agreement. FCCC/CP/2015/10/Add.1, (2015).

[3] Olivier JGJ, Peters JAHW. *Trends in global CO2 and total greenhouse gas emissions: 2018 report.* The Hague: Netherlands Environmental Assessment Agency; 2018.

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HOW HEALTHY MARKETS SUSTAIN FORESTS

Life Cycle Assessment – Greenhouse Gas Emissions - Data Sheet – Activity 1

INSTRUCTIONS:

Use this form to gather information from the Comparative Life Cycle Assessment of greenhouse gas emissions of the Maskinparken 2 and Maskinparken TRE apartment buildings.

Comparative Life Cycle Assessment of Greenhouse Gas Emissions for Maskinparken 2 and Maskinparken TRE		
	Maskinparken 2	**Maskinparken TRE**
Gross internal area		
Number of stories		
Number of apartments		
Raw materials used		
Building Materials used		
GHG emissions - Production (A1-A3)		
GHG emissions - Transportation in Construction Process (A4)		
GHG emissions - Operational Energy Use (B6)		
Total GHG emissions (A1-A3) + (A4) + (B6)		
GHG emissions - Production (A1-A3) **of Building** (Figure 3)		
GHG emissions - Production (A1-A3) of Underground car park (Figure 3)		

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GHG emissions from the (5) materials emitting most GHGs during Production stage (A1-A3)				
	Maskinparken 2		**Maskinparken TRE**	
#1 GHGs / Amount				
#2 GHGs / Amount				
#3 GHGs / Amount				
#4 GHGs / Amount				
#5 GHGs / Amount				

INSTRUCTIONS: Use the date you compiled in the table from Activity 1 to perform calculations and answer questions about GHG emissions from the M2 and MTRE buildings.

Note: *Some questions ask you to calculate the percentage change (decrease or increase) of greenhouse gas emissions from the MTRE building to greenhouse gas emissions from the M2 building for different stages of the life cycle. Use the following formula to calculate percentage decrease or increase:*

(MTRE Value – M2 Value) ÷ M2 Value x 100%

Negative value = percent decrease in GHG emissions using CLT elements
Positive value = percent increase in GHG emissions using CLT elements

Example: *If GHG emissions from Production (A1-A3) for M2 is 104.8 and GHG emissions from Production (A1-A3) for MTRE is 62.4 then...*

(MTRE Value – M2 Value) ÷ M2 Value x 100% =
(62.4 – 104.8) ÷ 104.8 x 100% = (-42.4) ÷ 104.8 x 100% = -0.4045 x 100% = -40.45%
This is a 40% decrease in GHG emissions using CLT elements.

QUESTIONS:

1. Calculate the percentage change in GHG emissions from the Production Stage (A1-A3) of the MTRE building compared to the M2 building. Identify it as a decrease or increase.

   Why do you think this change was observed?

2. Calculate the percentage change in GHG emissions from the Transport stage (A4) of the MTRE building compared to the M2 building. Identify it as a decrease or increase.

   Why do you think this change was observed?

3. Calculate the percentage change in GHG emissions from the Operational Energy Use stage (B6) of the MTRE building compared to the M2 building. Identify it as a decrease or increase.

   Why do you think this change was observed?

4. Calculate the percentage change in total GHG emissions of the MTRE building compared to the M2 building. Identify it as a decrease or increase.

   Why do you think this change was observed?

5. What percentage of GHG emissions during production can be attributed to the underground car park for the M2 building?

   GHG emissions from Underground carpark of M2 ÷ total GHG emissions of M2 x 100% =

6. What percentage of GHG emissions during production can be attributed to the M2 building?

   GHG emissions from M2 building ÷ total GHG emissions of M2 x 100% =

7. What percentage of GHG emissions during production can be attributed to the underground carpark for the MTRE building?

   GHG emissions from Underground car park of MTRE ÷ *total GHG emissions of M*TRE x 100% =

8. What percentage of GHG emissions during production can be attributed to the MTRE building?

   GHG emissions from MTRE building ÷ total GHG emissions of MTRE x 100% =

Complete a written summary of the results of the Comparative Life Cycle Assessment for greenhouse gas emissions of the steel and concrete Maskinparken 2 and cross laminated timber Maskinparken TRE apartment buildings. Your summary should include the following information:

For each building:

- Overall greenhouse gas emissions for the lifetime of the building
- Largest stage contributing to greenhouse gas emissions
- Largest materials contributing to greenhouse gas emissions
- At least one way to reduce greenhouse gas emissions for the building

Overall Review:

- Which apartment building produces the lowest greenhouse gas emissions over its lifetime?

Support statements in your summaries with evidence from the text, tables, figures, and your calculations. Use complete sentences, proper grammar and correct spelling.

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Examining the Future of Cross Laminated Timber in Wisconsin Buildings - Extension

You examined the Life Cycle Analysis of the Maskinparken 2 and Maskinparken TRE apartment buildings in Norway and learned that using cross laminated timber instead of steel and cement to construct buildings is effective at reducing greenhouse gas emissions over the life cycle of the building.

There are many economic factors involved in determining whether construction companies in Wisconsin will start using cross laminated timber instead of steel and cement. With your group, use the background information provided in this document and independent research to determine if you think Cross Laminated Timber is a building solution for Wisconsin.

Economic Evaluation of Cross Laminated Timber in Wisconsin	
Producers & Consumers	
Who **produces** cross laminated timber (CLT) in Wisconsin? (If nobody does, where is it produced?)	
Who **consumes** (uses) cross laminated timber in Wisconsin? (If nobody does, where in the US is it used?)	
What Factors of Production are required to produce cross laminated timber?	
Land	
Capital (including infrastructure)	
Labor	

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Does Wisconsin have the factors of production required to produce cross laminated timber? Explain.	
What is the supply and demand for cross laminated timber in Wisconsin? How does this relate to scarcity and opportunity cost?	
Describe the Market **(Supply and Demand)** for CLT in Wisconsin.	
How will supply and demand impact **cost** of using CLT in Wisconsin?	
How does supply and demand for CLT affect **scarcity**?	
What are the **opportunity costs** of choosing to build with CLT over steel and concrete?	

CONCLUSION: Write a paragraph explaining whether or not you think cross laminated timber is a building solution for Wisconsin. Use at least 3 pieces of evidence from your research to support your answer.

Background Information:

The following background information has been used and updated, with permission, from the LEAF Wisconsin K-12 Forestry Lesson Guide, 9-12 Unit, Lesson 4: The Forest Marketplace. https://www.uwsp.edu/wcee/wcee/leaf/leaf-curriculum/k-12-forestry-lesson-guides/

The Demand for Forest Resources

Demand for products, including forest resources, is most heavily related to population, income, and societal trends. As human populations grow, so does the demand for **goods** and **services**. As the average annual income increases, so does demand for goods and services. Yet, if the population of a given area grows but the total income remains stagnant, the demand will also remain stagnant in the long term. The demand for goods is also related to societal trends. Trends begin in many ways, including innovation, marketing, and endorsement. A variety of trends have influenced the forest products industry. One notable trend was an increase in demand for exotic woods like teak and mahogany. That demand decreased after the harmful effects of rainforest clearcuts were widely understood.

The Supply of Forest Resources

Forest resource supply in a region can be determined by looking at three characteristics:

- Availability of forest resources
- Production capacity of the forest industry
- Supportive infrastructure

The availability of forest resources in a region can be estimated using:

- Volume of standing timber (by species, size, and grade): to determine the total resource
- Net annual growth of trees: to determine productivity of the forest
- Forest ownership: to determine accessibility to the resource; landowners have different objectives; not all owners are willing to harvest trees

This information can be gathered from U.S. Forest Service surveys. The U.S. Forest Service conducts inventory and analysis in all the major forested states in the U.S. The statistics are published annually in some states and every five to 10 years in others. The surveys provide a variety of statistical information organized by tree species, size, ownership, region, and grade. The surveys are useful for determining timber supply and comparing the forest resources of the different states and regions of the U.S.

Production capacity of the forest industry in a region can be estimated using:

- Number of forest products establishments
- Type and size of the forest products establishments
- Availability of skilled workers

These three indicators help to define the size and diversity of the industry, the potential gaps and surpluses in production, and the availability of human resources. The U.S. Forest Service publishes assessments of the timber industry in all the major forested states in the U.S. The assessments provide statistics on industry status, the volume of production of primary wood products, production efficiency, and timber growth and removals. The assessments are useful for comparing states and regions in the U.S. and determining the status

and trends in the industry. Visit the Wisconsin DNR website (https://dnr.wisconsin.gov/topic/forestbusinesses/factsheets) for specific information on forestry and the Wisconsin economy.
Supportive **infrastructure** helps businesses produce and transport their products and includes:

- Transportation systems
- Availability of water
- Waste disposal
- Education system
- Security
- Other services

Infrastructure is usually provided by the government and funded through tax monies.

The Economics of Trade

CIRCULAR FLOW

The **circular flow** of economic activity describes the economic relationships that exist between households, businesses, and government. In the **product market**, households give money to businesses in exchange for goods and services and both households and businesses pay taxes to the government in exchange for the goods and services they supply. In the **resource market**, the government and businesses pay households for their productive resources (jobs they do) and the government pays businesses for goods and services the businesses supply to the government. This simplified economic model illustrates how the three players exchange goods, services, productive resources, and money.

COMPETITION

Competition for resources is the core concept around which modern economics is built. Prices, wages, production methods, type and quantity of production, size and organization of business firms, distribution of resources, levels of environmental regulation and compliance, outsourcing, and tax rates all result directly or indirectly from competitive processes.
Competition acts as both stick and carrot (it can threaten punishments or offer rewards). If a worker does not perform, or if the living wage in a region is relatively high, the employer can replace the worker or can move production to a region where wages are lower. If the employer does not treat the employee as well as other employers would, the employee can quit and go somewhere else if a job is available. If a company is not run efficiently or is too small to compete with large companies, customers can choose to go where they find better service at the same price or equal service at a lower price. All companies are subject to replacement by those that can do the job better or more cheaply. On the other hand, if the job is done well (better service at a cheaper price), the company is more likely to be rewarded.

SUPPLY AND DEMAND

In a capitalist economy, producers combine natural, human, and financial resources to provide goods and services that **consumers** are willing and able to purchase. The market price of a product or resource is determined by the interaction of **supply-and-demand**.

The costs and benefits of purchasing a good or service determine the amount of a product that a consumer will buy in a given time period. This is known as demand. As costs or benefits change, the demand for a product will also change. In general, as prices decrease, demand increases.

The amount of a good or service that producers are willing to sell during a certain period is determined by the amount of profit they can make. Producers intend to make the largest profit possible from their sales. Since profit is the difference between revenues and costs, anything that influences either can influence the amounts sellers want to sell. In general, the higher the price, the more producers will want to sell.

HOW HEALTHY MARKETS SUSTAIN FORESTS

Life Cycle Assessment – Greenhouse Gas Emissions - Summary – Activity 2

Comparative Life Cycle Assessment – Greenhouse Gas Emissions - Summary
Concrete and Steel Apartment Building and Cross Laminated Timber Apartment Building

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Excerpted from:
Comparative LCA of a concrete and steel apartment building and a cross laminated timber apartment building by A R Eliassen et al for the Sustainable Built Environment 2019 IOP Conference Series: Earth and Environmental Science
Comparative life cycle assessment of cross laminated timber building and concrete building with special focus on biogenic carbon by Julie Hansted Anderson, Nana Lin Rasmussen and Morten Walbech Ryberg for the 2020 Energy and Buildings journal, Volume 254.
Modified by Gina Smith from LEAF – Wisconsin's K-12 Forestry Education Program (28 Oct 2024) for use in this lesson. Where appropriate, original text and citations from original sources have been preserved.

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, 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 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, a thin layer of material which is used over the acoustic underlay in the flooring. 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 be avoided to reduce 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. 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 which is Norway's building code for energy efficiency. It is one of the strictest building regulations in the world. Maskinparken TRE is built to the passive house standard. The passive houses must be designed to use no more than 15 kWh of energy per square meter of living space to heat a home for the year. It also has limitations on the total energy that can be used for heating, cooling, hot water and electricity. Due to the different building designs-especially when it comes to heating and cooling, the energy used during the use stage for 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 though. For example, more insulation is needed in Maskinparken TRE to get lower u-value (level of insulation) on the outer walls. Even though material use should be higher in Maskinparken TRE than in Maskinparken 2, emissions were still 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.

Does this information support what you wrote in your summary?

Did you come to the same conclusion as the authors of the Comparative Life Cycle Assessment of apartment buildings Maskinparken 2 and Maskinparken TRE?

What things besides GHG emissions do builders need to think about when constructing a building? How might that affect the decisions builders make?

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