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Life cycle analysis of concrete floors with

varying VCT

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Summary

The aim of the study is to assess and compare the climate impact of two different concrete floors. One with a water-cement ratio (VCT)=0.4 and one with VCT=0.5. This is done to determine which concrete floor has the least climate impact. The floors have been ordered by the University of Borås

and they are manufactured by the concrete factory Thomas Betong. The cement is manufactured by the cement factory Kunda Nordic Tsement As, the reinforcement for the floor is manufactured by the company BE Group and the macadam for the concrete is manufactured by Skanska.

The climate impact of the concrete floor is assessed through a life cycle assessment. Life cycle assessment (LCA) is a method for calculating how a product affects the environment throughout its entire life cycle. The LCA study calculates the product's environmental impact from the extraction of natural resources until the product is no longer used and must be taken care of.

This LCA study does not study the entire life cycle of the concrete floor, but only the production and transport of the component materials, as well as the production and transport of the floor from the manufacturer to the client.

Results of the LCA study showed that the concrete floor with VCT=0.5 has the least climate impact. Production of the sub-materials for the concrete floor is the process in the floor's life cycle that contributes the most climate impact. The sub-process that has the greatest impact on the climate is the production of cement.

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1 Introduction

Swedish buildings account for a total of just over a fifth of greenhouse gas emissions in Sweden, seen from a life cycle perspective (Naturvårdsverket, 2020). An important factor leading to climate impact in construction is building materials. The use of natural resources, manufacturing, transport, use, recycling and disposal of building materials affect the external environment in many different ways. This can include, for example, the use of finite resources, emissions of CO_2 and other climate-affecting gases, acidification and toxicity (Burström, 2021).

In order to choose environmentally friendly materials, the climate impact of the materials must be determined. The environmental impact caused by building materials can be determined using various methods, and life cycle analysis is one such method. Life cycle analysis (LCA) calculates how a product affects the environment throughout its entire life cycle (Palm, 2019). Within the LCA study, the environmental impact of the product is calculated from the extraction of natural resources until the product is no longer used and must be taken care of.

1.1 Previous studies

Previous studies that have been done are by the Swedish National Board of Housing, Building and Planning. The study has been carried out according to the standard (SS-EN ISO 14040, 2006). There they have calculated the climate impact of a solid floor (Boverket, 2021) and a solid floor, climate-improved (Boverket, 2021). The result that the LCA study shows will be compared with the result of the Swedish National Board of Housing, Building and Planning's study.

2 Method

To calculate the environmental impact of the concrete floor, the life cycle assessment method has been used. The analysis has been carried out according to the standard (SS-EN ISO 14040, 2006). It consists of four parts. Definition of objectives and scope is the first part. This includes a description of the objective, determination of the functional unit, simplified flow chart and system boundary, data quality, allocation and assumption.

The second part is inventory analysis. It contains detailed flow charts, short descriptions of the sub-processes, data collection, calculation of reference flow for all inflows and outflows, and compilation of emissions from sub-processes where EPDs are not available.

The third part is climate impact assessment. Here, classification and characterization are performed for the unit processes where EPDs are not available. Then the results for the unit processes, modules and the total are presented. Finally, the results of the study are compared with the results of the Swedish National Board of Housing, Building and Planning's study. The fourth part is interpretation of the results.

3 Product description

A concrete floor consists of concrete and reinforcement. The concrete consists of cement, aggregate, water and additives. The reinforcement consists of steel. The concrete floor has a thickness of 220mm and a reinforcement ratio of 1.5‰. Concrete with VCT 0.4 has a density of 2359kg/m^3 and the compressive strength class is C55/67. Concrete with VCT 0.5 has a density of 2345kg/m^3 and the compressive strength class is C40/50.

3.1Concrete recipe

VCT=0.4:

Table 1 shows the density, weight and volume of the component materials included in 1m3concrete with VCT=0.4.

Table 1 Concrete recipe for concrete with VCT=0.4

Part material (VCT=0.4)	Density [kg/m3]	weight [kg]	volume [m]3]
Cement	3100	462.5	0.15
Water	1000	185	0.19
Air		0	0.02
Ballast	2650	1711	0.65
Amount		2359	1

Ballast= 52% natural gravel and 48% macadam.

Table 2 shows the density, weight and volume of the aggregate components included in 1m3of concrete with VCT=0.4.

Table 2 Aggregate recipe for aggregate in concrete with VCT=0.4

Part material	Density [kg/m3]	weight [kg]	volume [m]3]
Gravel	2650	890	0.34
Macadam	2650	821	0.31
Total (ballast)		1711	0.65

Macadam shape: Cubic (+5% water)

Reinforcement proportion= 1.5‰ => 2.59kg/m2

VCT=0.5:

Table 3 shows the density, weight and volume of the component materials included in 1m3concrete with VCT=0.5.

Table 3 Concrete recipe for concrete with VCT=0.5

Part material (VCT=0.5)	Density [kg/m3]	weight [kg]	volume [m]3]
Cement	3100	370	0.12
Water	1000	185	0.19
Air		0	0.02
Ballast	2650	1790	0.68
Amount		2345	1

Ballast= 52% natural gravel and 48% macadam

Table 4 shows the density, weight and volume of the aggregate components included in 1m^3concrete with VCT=0.5.

Table 4 Aggregate recipe for aggregate in concrete with VCT=0.5

Part material	Density [kg/m^3]	weight [kg]	volume [m^3]
Gravel	2650	931	0.35
Macadam	2650	859	0.33
Total (ballast)		1790	0.68

Macadam shape: Cubic (+5% water)

Reinforcement proportion= 1.5‰ => 2.69kg/m^2

4 Definition of objectives and scope

The goal of the LCA study is to determine the climate impact of two different concrete floors, from production of its raw material to delivery of the finished concrete floor to the client. Within the study, two concrete floors, one with VCT=0.4 and one with VCT=0.5, will be studied and their climate impact will be compared. The goal is also to determine which of the sub-processes within the production of the concrete floor contributes the most to the climate impact.

The functional unit 1m^2has been chosen because the surface area of the floor is important to take into account when calculating carbon dioxide emissions when producing a concrete floor.

4.1Simplified flowchart and system boundary

Figure 1 shows a simplified flow chart of a concrete floor, from the production of the concrete floor component materials to the production of the floor itself. The flow chart also shows the life cycle of the floor after it is produced. Note that associated transport has been excluded from the simplified flow chart.

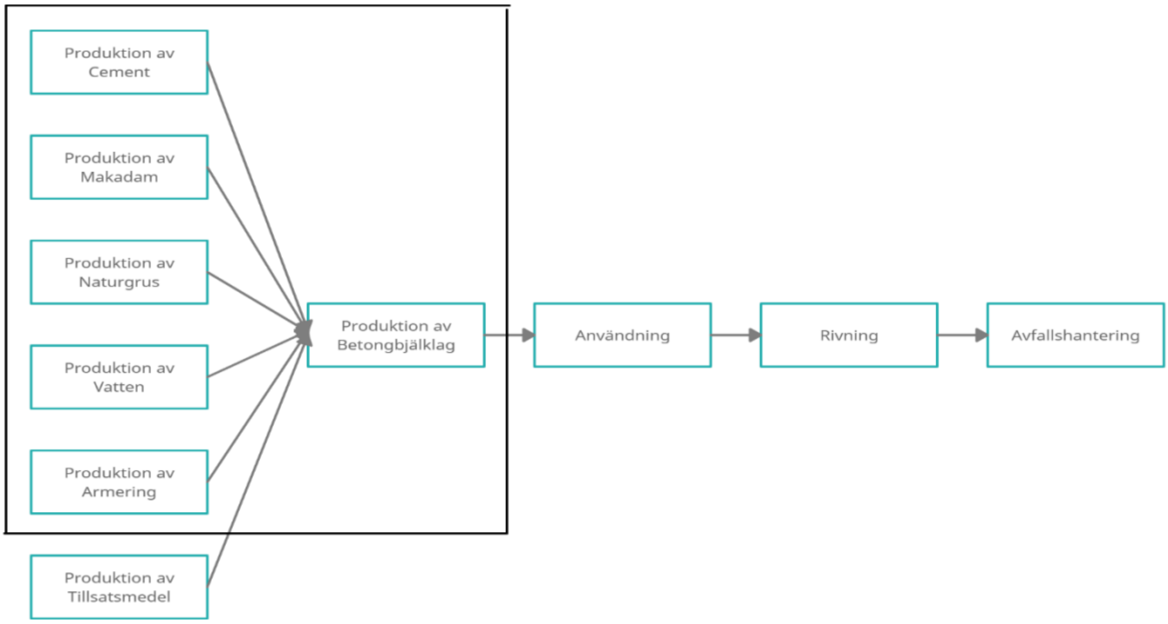

Figure 1 Simplified flow chart for the production of a concrete floor slab

The life cycle analysis is not done on the entire life cycle of the concrete floor, but only on the production of the materials for the concrete floor and the production of the floor itself and the associated transport. The LCA study also includes empty returns of the trucks. However, the production and transport of additives are excluded from the LCA study, since their climate impact is only a small proportion of the total climate impact of the concrete floor, and can be neglected.

4.2Data quality

Table 5 shows the data quality of EPDs for the sub-materials included in the concrete floor. The data quality is presented with respect to temporal coverage, where the publication date and validity date have been specified, and with respect to geographical coverage, the market area of the sub-materials has been specified.

Table 5 Data quality of the component materials' EPDs with respect to temporal and geographical coverage

EPD	Publication date	Validity date	Market area
Cement	2020-12-11	2025-12-10	Estonia
Rock crusher	2017-05-08	2022-05-08	Sweden
Reinforcement	2021-08-25	2026-07-26	Sweden

According to Table 5, all EPDs are valid. The crushed rock and reinforcement come from Sweden, however, the cement comes from Estonia, which leads to more climate impact, compared to the component materials delivered from Sweden.

4.3Allocation

When calculating emissions from empty returns of transports, allocation has been made to assign the total emissions to the amount of delivered material per animal. The allocation method used is:

$$\frac{\text{ä}\ (\ )}{\text{�}(\ )} \times \text{� ä} \ . \ (\ \frac{}{2})$$

Allocation made within the EPD of rock crushing is the distribution of environmental impact from rock crushing in accordance with EN 15804. In crushing, resource use has been distributed per crushing stage. Due to uncertain distribution of energy use between gravel and rock crushing, the calculation only includes those facilities that crush rock and do not simultaneously handle gravel, in order to avoid sources of error.

The allocation method used in the EPD of reinforcement is “allocation, delimitation by classification”. The allocation method is in accordance with the requirements of the EN 15804 standard. Allocation has only been used when certain material, energy and waste data cannot be measured separately for the product under investigation. Electricity consumption and diesel consumption for trucks used in transport have been allocated based on volume (mass).

4.4 Assumption

The assumption made in the study is that transport of the concrete floor from the factory to the client (Transport 7) is assumed to be done with a 40t Euro 6 truck.

5 Life Cycle Inventory Analysis

Figure 2 shows all the sub-processes and transports involved in the production of a concrete floor, as well as the life cycle of the concrete floor after it is produced.

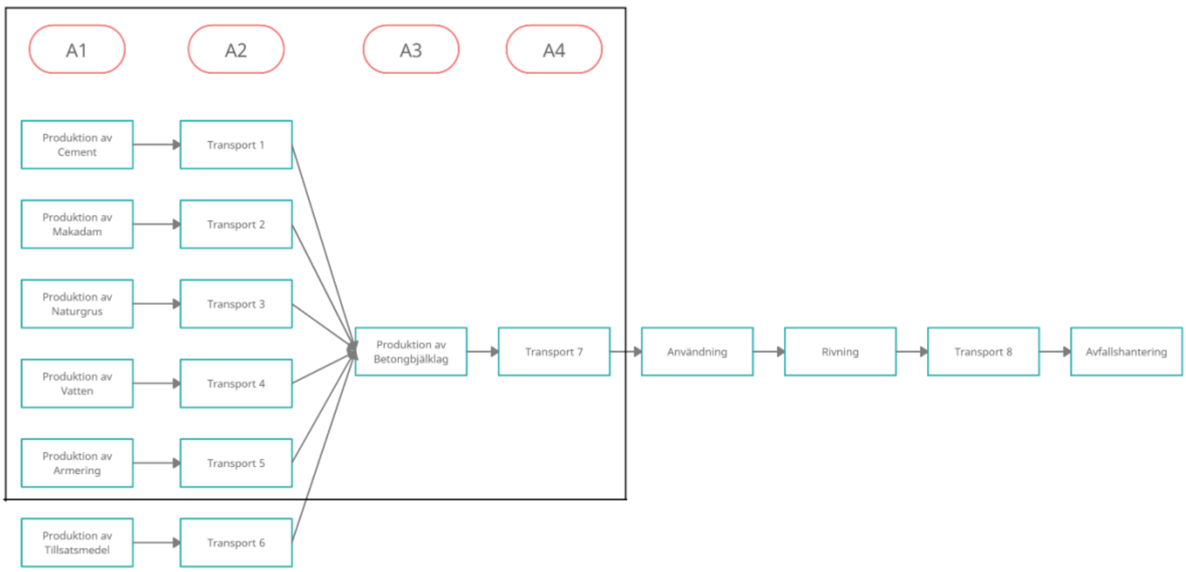

Figure 2 Detailed flow chart for the production of a concrete floor slab

- Production of Cement: Cement for the concrete floor is produced by the cement factory

Kunda Nordic Tsement, which is based in Estonia. The production takes place in three parts. The first part is the extraction of raw materials. The main raw material of cement is clinker. The second part is the transport of the raw materials to the cement factory. The third part is the manufacture of cement. Cement is produced by grinding clinker and other components, which after adding water becomes cement paste which is then hardened. (Kunda Nordic Tsement AS, 2020)

- Production of Macadam: The company Skanska Industrial Solutions AB produces macadam for concrete floors. The factory is located in Gothenburg, Angered. Production begins with the extraction of raw materials, which is done by blasting raw rock. The raw materials are later transported to the factory where the production takes place. During production, the raw materials are crushed into fractions of different sizes. (Erlandsson, 2017).

- Production of Natural Gravel: Natural gravel is soil sorted by nature that consists of sand, gravel and stones. Natural gravel for the concrete floor is produced by the company Stråkengrus Ab. The factory is located in Jönköping, Sweden.
- Water: The quality of the mixing water in the production of concrete can affect the setting time of the concrete, strength development and corrosion protection of the reinforcement. Mixing water for concrete is specified in the Swedish standard SS-EN 1008. Good quality drinking water is usually recommended (SS-EN ISO 14040, 2006)
- Production of Reinforcement: The reinforcement of the concrete floor is produced by the company BE Group. The factory is located in Malmö. BE Group does not manufacture reinforced steel itself, but purchases it from other suppliers. Reinforced steel is then transported to the factory in Malmö, where it is cut and bent into various shapes and sizes (BE Group, 2021).
- Admixtures: used to adjust the properties of fresh and hardened concrete. Almost all concrete produced today contains some type of admixture, which is usually classified according to the effects they have on the concrete (Burström, 2021).
- Transports 1–6: are the transport of all component materials from each factory to the concrete factory Thomas Betong. The transport is either by truck, or by boat and truck, depending on the distance between the factories.
- Production and transport (7) of the concrete floor: The concrete floor is produced by the company Thomas Betong. The factory is located in Alingsås. The concrete floor is then transported by truck from the factory to the University of Borås.

Table 6 shows all transports that are within the system boundary and are included in the LCA study. The table also shows the type of vehicle used and how far the materials are to be transported. However, the transport of water is excluded from the LCA study, as its climate impact is not large and can be neglected.

Table 6 Transport within the system boundary

Transport	With	Load capacity and emission standard	Distance (km)
1: Cement Customer	Boat + Truck	40ton Euro 6	1300 (boat) + 50 (truck)
2: Skanska Angered	Truck	40ton Euro 6	41.1
3: Scattered gravel	Truck	25ton Euro 6	112
4: Water	-	-	-
5: BE Group Malmö	Truck	25ton Euro 6	314

7: Thomas Concrete	Truck	40ton Euro 6	39.2

5.1 Calculation of reference flow

In order to determine the climate impact of the concrete floor, the mass of the concrete floor, concrete and reinforcement must be calculated in kg per fe (m^2).

The concrete floor:

The reinforcement proportion is 0.15% and this means:

0.15% reinforcement + 99.85% concrete = Concrete floor

- reinforcement density ρ_a: = 7850kg/m^3
- According to Table 1, the density of concrete ρ_{btg}:= 2359kg/m^3(VCT=0.4)

Density of the floor slab ρ_{blah}: = $(\frac{0{,}15}{100} \times \rho_a) + (\frac{99{,}85}{100} \times \rho_{btg})$ = 2367kg/m^3

The thickness of the floor slab = 0.22m, which means that the volume of the floor slab per m^2= 0.22m^3/m^2

Mass of the floor slab per foot (m^2) for VCT=0.4 is the density of the floor × the volume of the floor per m^2:

2367 × 0.22 = 520.8kg/m^2[3× 32= 2]

Mass of the floor slab per foot (m^2) for VCT=0.5 has been calculated in the same way as for VCT=0.4:

2353 × 0.22 = 517.7kg/m^2[3× 32= 2]

Concrete: Waste concrete = 1.5% => F_{waste}= $\frac{1}{1-0.015}$ = 1.01523

Wastewater = +100 liters/m^2

V_{blah}: volume of the floor slab per m^2: V_{btg}+ $V_{reinforcement}$= 0.22m^3

Reinforcement proportion = 0.15%

V_{btg}: 0.22 – $V_{reinforcement}$=> 0.22 – (0.0015×0.22) = 0.21967m^3 Example calculation 1:

ρ_{cem}: density of cement = 3100kg/m^3

According to Table 1 V_c: volume fraction of cement in 1m^3 for VCT=0.4 = 0.15m^3

V_c/m_2: volume of cement per $m_2 = V_c \times V_{btg}$=> 0.15 × 0.21967 = 0.0327m_3/m2 m_c: cement

mass per $m_2 = V_c/m_2 \times \rho_{cem}$=> 0.0327 × 3100 = 101.5kg/m_2 32× 3= 2

+ Spill: mc × F_{waste}=> 101.5 × 1.01523 = 103.01kg/m_2

For other sub-materials, the calculation is carried out in the same way as example calculation 1 and is presented in table 7.

Table 7 Mass of the component materials per fe for VCT=0.4 and VCT=0.5

Part material	Mass per animal (kg/m2) + spill	
	VCT=0.4	VCT=0.5
Cement	103.01	82.9
Macadam	183.2	195.04
Water	140.65	140.65
Natural gravel	201,015	206.9

Reinforcement

ρ_a: reinforcement density = 7850kg/m_3

Spill reinforcement = 2% => $F_{waste} = \frac{1}{1-0.02} = 1.0204$

V_{blah}: volume of the floor slab per m_2= 0.22m_3/m_2

Reinforcement part = 0.15% Reinforcement volume per m_2: $V_a = \frac{0{,}15}{100} \times 0.22 = 3.3 \times 10_{-4} m_3/m_2$

m_a: mass of reinforcement per $m_2 = \rho_a \times V_a$=> 7850 ×3.3 × 10_{-4}=2.59kg/m_2 32× 3= 2

+ Spill: $m_a \times F_{waste}$=> 2.59 × 1.0204 = 2.643kg/m_2

5.2 Compilation of emissions

Emissions from the production of cement, macadam and reinforcement are given by EPDs. Inflow and outflow from transport are given by (Lipasto, 2017). Emissions from the production of natural gravel are given by (Stripple, 2001).

Emissions of Natural Gravel

Table 8 shows the emissions that occur during the production of natural gravel that lead to climate impact (GWP100).

Table 8 Greenhouse gases that lead to GWP in the production of Natural Gravel

Greenhouse gas	Kg emissions per kg natural gravel
CO_2	7.28E-08
N_2O	2.30E-09
CH_4	3.76E-10

Emissions from Transport

Table 9 shows the emissions that lead to GWP during the transport of the component materials and empty return of trucks. The emissions are according to the Euro 6 emission standard.

Table 9 Greenhouse gases leading to GWP during transport

Greenhouse gas	Full 25t (g/tkm)	Full 40t (g/tkm)	Empty return 25t (g/km)	Empty return 40t (g/km)
CO_2	35	29	613	767
N_20	0.0019	0.0012	0.048	0.048
CH4	0.000028	0.00002	0.0006	0.0007

6 Climate impact assessment

The impact category studied is the climate impact GWP100. Greenhouse gases that lead to climate impact are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). In order to assess the climate impact of greenhouse gases, their emissions must be converted into carbon dioxide equivalents, by multiplying them by the associated characterization factor. The characterization factor is 1 for carbon dioxide, 310 for nitrous oxide and 21 for methane.

Carbon dioxide equivalent for natural gravel with values according to table 8:

$(7.28 \times 10^{-8} \times 1) + (2.3 \times 10^{-9} \times 310) + (3.76 \times 10^{-10} \times 21) = 7.937 \times 10^{-7} \quad _2 /$

Carbon dioxide equivalent for transport with values according to table 9:

At full load:

$25h: (35 \times 1) + (0.0019 \times 310) + (0.000028 \times 21) = 35.6 \quad _2 /$

40h: (29 × 1) + (0.0012 × 310) + (0.00002 × 21) = 29.4 $_2$ /

If empty return:

25h: (613 × 1) + (0.048 × 310) + (0.0006 × 21) = 627.9 $_2$ /

40h: (767 × 1) + (0.048 × 310) + (0.0007 × 21) = 781.9 $_2$ /

6.1 Results

Unit processes within A1 and A3

Example calculation 2

Production of cement VCT=0.4:

According to table 7, mass per unit area of cement = 103.01kg/m$_2$

According to the EPD for cement: carbon dioxide equivalent = 0.832kgCO$_2$e/kg Carbon dioxide equivalent per fe:

103.01 × 0.832 = 85.71kgCO$_2$m/f$_2$ [$_2$× $_2$ = $_{22}$]

For other unit processes, the calculation is done in the same way as example calculation 2 and is presented in Table 10.

Table 10 Carbon dioxide equivalents per fe for modules A1 and A3

Unit process	**Carbon dioxide equivalent from EPDs (kgCO$_2$(e/kg)**	**Carbon dioxide equivalent per fe (kgCO$_2$m/f$_2$)**	
		VCT=0.4	**VCT=0.5**
Production of Cement (A1)	0.832	85.71	68.97
Production of Macadam (A1)	0.00266	0.487	0.519
Production of Natural Gravel (A1)	7.937E-07	0.000159	0.000164
Water (A1)	0.000317	0.045	0.045
Production of Reinforcement (A1)	0.628	1.66	1.66
Production of the Flooring (A3)	0.0027733	1,444	1,436

Unit processes within A2 and A4

Example calculation 3

Transport 1 VCT=0.4:

According to table 6, the distance for transport 1 = 1300km by boat + 50km by truck 40t

According to table 7, mass per animal for transport 1 = 103.01kg/m^2

Carbon dioxide equivalents = 22g/tkm for boat + 29.4g/tkm for full load + 781.9g/km for empty return =>

$$\left(\frac{22}{1000} \times 103.01 \times 1300\right) + \left(\frac{29,4}{1000} \times 103.01 \times 50\right) + \left(\frac{781,9}{40000} \times 103.01 \times 50\right) = 3198.2 \quad {}_2 / {}_2$$

For other transports, the calculation is done in the same way as example calculation 3 and is presented in Table 11.

Table 11 Carbon dioxide equivalents for modules A2 and A4

Transport	Carbon dioxide equivalent per fe (gCO_2m/f_2)	
	VCT=0.4	**VCT=0.5**
1 (A2)	3198.2	2593.4
2 (A2)	368.3	382.6
3 (A2)	1366.7	1390.3
4 (A2)	0	0
5 (A2)	50.4	50.4
7 (A4)	998.7	995.2

Modules

Table 12 shows total carbon dioxide equivalents per fe for modules A1, A2, A3 and A4.

Table 12 Carbon dioxide equivalents for modules A1-A4

Modules	Carbon dioxide equivalent per fe ($kgCO_2m/f_2$)	
	VCT=0.4	**VCT=0.5**
A1	87.9	71.2
A2	4.9836	4.4167
A3	1,444	1,436
A4	0.9987	0.9952

Figure 3 shows the climate impact of modules A1, A2, A3 and A4 for VCT=0.4 and VCT=0.5.

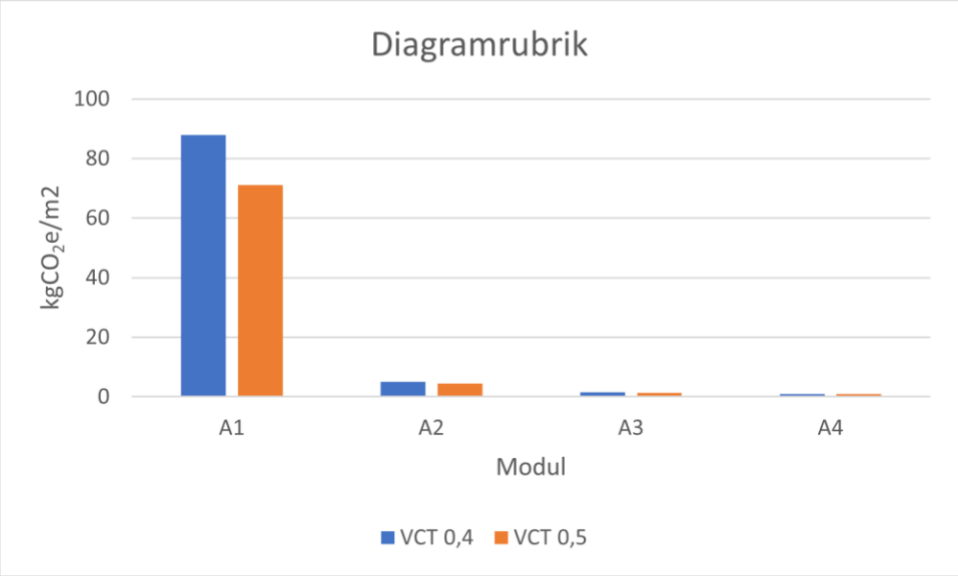

Figure 3 Climate impact of modules A1-A4 for VCT=0.4 and VCT=0.5

Total

Figure 6 shows the total climate impact of the concrete floor with VCT=0.4 and VCT=0.5

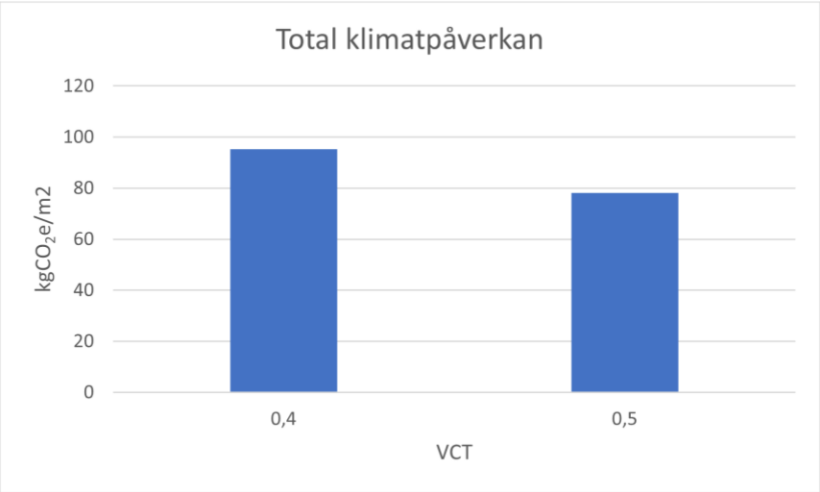

Figure 4 Total climate impact of concrete floors for VCT=0.4 and VCT=0.5

According to Tables 10 and 11, the unit process that contributes the greatest climate impact is “Cement Production”. According to Figure 3, the module that has the greatest climate impact is A1 for both VCT=0.4 and VCT=0.5. According to Figure 4, the concrete floor with VCT=0.5 has the least climate impact.

6.2 Comparison with the Swedish Board of Housing, Building and Planning's value

The results of the LCA study should be compared with generic values for the climate impact of a floor according to (Boverket, 2021). In order to be able to compare, the results of the study must be converted from carbon dioxide equivalent per fe to carbon dioxide equivalent per kg.

Example calculation 4

VCT 0.4: volume of the floor slab per $m^2 = 0.22 m^3/m^2$

Density of the floor = $2367 kg/m^3$

A1+ A2 + A3 = $94.3276 kgCO_2 m/f_2$

Convert to per kg:0 , 2294×,3272367= 0.1811 2 / 2 2× 3 [3 2 = 2]

Calculation of A4 for VCT=0.4, and A1-A3 and A4 for VCT=0.5 is done in the same way as example calculation 5 and is presented in Table 13. Table 13 also shows generic values for the climate impact of a floor according to (Boverket, 2021).

Table 13 The carbon dioxide equivalent per kg for concrete floors with VCT=0.4 and VCT=0.5, as well as generic values for a floor according to the Swedish National Board of Housing, Building and Planning.

	VCT=0.4	VCT=0.5	National Board of Housing, Building and Urban Development	
			Flooring	Climate-improved floor covering
A1-A3 ($kgCO_2(e/kg)$)	0.1811	0.1479	0.2288	0.1713
A4 ($kgCO_2(e/kg)$)	0.001918	0.001911	0.045	0.045

According to Table 13, the modules A1-A3 for VCT=0.4 have more climate impact than the Swedish Housing Agency's climate-improved floor, but less than its normal floor. The modules A1-A3 for VCT=0.5 have less climate impact than the Swedish Housing Agency's normal and climate-improved floor. The module A4 for both VCT=0.4 and VCT=0.5 has less impact than A4 for the Swedish Housing Agency.

7 Interpretation

The objectives of the study as defined in “Definition of objectives and scope” have been achieved by the results. Figure 4 shows the total greenhouse gas emissions in kg that occur during the manufacture and transport of $1 m^2$ of a concrete floor for VCT=0.4 and VCT=0.5. Comparison between VCT=0.4 and VCT=0.5 shows that a concrete floor with VCT=0.4 contributes to the most climate impact.

The different unit processes and modules within the concrete slab flow chart have been studied to identify which contribute to the greatest climate impact. Tables 10 and 11 and Table 12 show the amount of emissions of gases that contribute to the climate impact. Comparison between the different unit processes in Table 10 and 11 shows that the greatest climate impact occurs in the manufacture of cement. Comparison between the different modules in Table 12 shows that module A1 has the greatest impact on the climate.

As mentioned earlier, the production of cement is the process that contributes the most to the climate impact. This explains why the concrete floor with VCT=0.4 has a greater climate impact than the concrete floor with VCT=0.5, since VCT=0.4 has 92.5kg more cement per m^3concrete than VCT=0.5.

8 Conclusions and Recommendations

The conclusion can be drawn that more cement in a concrete floor leads to a greater climate impact, due to high emissions of greenhouse gases when cement is manufactured. It is recommended that a concrete floor with a higher water-cement ratio (VCT) is chosen, for a more environmentally friendly choice. Transportation of the sub-materials is also a significant part of the total emissions. It is recommended that the sub-materials for the concrete floor are ordered from factories that are closer to the concrete factory Thomas Betong. This is to minimize the distance that the sub-materials need to be transported.

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