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Assessing the Climate Impact of Building Demolition

A study of module C (end-of-life) impacts from two Swedish demolition projects.

Master's thesis in Industrial Ecology

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MASTER’S THESIS ACEX30

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Master’s Thesis in the Master’s Programme Industrial Ecology

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ABSTRACT

As the construction sector aims to reduce its climate impact, including all lifecycle stages in assessments becomes increasingly important. In Sweden, Boverket proposes to extend the current climate declaration regulation to include modules B – use and C- end-of-life by 2027. However, there is currently a lack of research around climate impacts of module C. This thesis assesses the scale, drivers and distribution of climate impacts associated with building demolition, through calculating the climate impacts of module C – end-of-life for two demolished buildings in Sweden.

Project specific data on the two case studies was collected in terms of demolished quantities, waste management strategies and transported distanced. By applying generic climate data, the climate impact was calculated for sub-modules C1-C4 as per EN 15978. The total climate impact of module C was estimated to 25-29 kg CO_2e/m^2 GFA for project A and 20 – 25 kg CO_2e/m^2 GFA for project B, indicating that the climate impact of end-of-life processes is small but not negligible. Sub-modules C3-C4 - waste processing and disposal – were the largest contributors, while C2 – transport of waste – was the smallest but most actionable in terms of mitigation. The results indicate a dependency on material as concrete was identified as the main driver of climate impacts across all sub-modules. Additionally, the results are sensitive to the distance of transport, which can be affected by the choice of waste management strategy.

The study is subject to several uncertainties due to lack of data and identifies the largest data gap regarding required on-site machinery for calculation of sub-module C1- demolition and deconstruction. The results demonstrate that, regardless of uncertainties, it is possible to estimate the climate impact of module C post demolition. However, the appropriate allocation of these impacts remains an open question, particularly in cases where demolition is undertaken as part of a broader building replacement project.

Key words: Life cycle assessment (LCA); end-of-life (EoL); demolition; module C; climate impact

Bedömning av klimatpåverkan vid rivning av byggnader

En studie av klimatpåverkan från modul C (slutskedet) i två svenska rivningsprojekt

Examensarbete inom masterprogrammet Industriell Ekologi

SOFIA FREDRIKSSON

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SAMMANFATTNING

I takt med att byggnadssektorn strävar efter att minska sin klimatpåverkan, blir det allt viktigare att inkludera hela byggnadens livscykel i klimatpåverkansbedömningar. I Sverige föreslår Boverket att den nuvarande lagstiftningen kring klimatdeklarationer utökas för att även omfatta modul B (användning) och C (slutskede) år 2028. För närvarande saknas forskning kring klimatpåverkan från modul C. Syftet med den här uppsatsen är att bedöma omfattningen och drivkrafterna kopplade till rivning av byggnader, genom att beräkna klimatpåverkan från modul C – slutskede – för två genomförda rivningsprojekt i Sverige.

Projektspecifik data samlades in avseende rivna mängder, avfallshanteringsstrategier och transportavstånd. Genom att tillämpa generiska klimatdata beräknades sedan klimatpåverkan för delmodulerna C1-C4 enligt EN 15978. Den totala klimatpåverkan från modul C uppskattades till 25-29 kg CO_2e/m^2 BTA för projekt A och 20-25 kg CO_2e/m^2 BTA för projekt B. Resultatet indikerar att även om klimatpåverkan från modul C är liten i förhållande till hela livscykeln, så är den inte försumbar. Delmodulerna C3-C4 – avfallsbehandling och deponering – stod för de största bidragen, medan C2 – transport av avfall – var det minsta bidraget men det med störst potential att minska. Resultaten indikerar även ett beroende av byggnadsmaterial då betong identifierades som den huvudsakliga drivkraften bakom klimatpåverkan i samtliga delmoduler. Dessutom är resultaten känsliga för transportavstånd, som bland annat påverkas av valet av avfallshanteringsstrategi.

Studien präglas av flera osäkerheter till följd av bristande data och den största dataluckan identifierades avseende information kring maskiner på plats för beräkning av delmodul C1- rivning och demontering. Denna studie visar att det, trots osäkerheter, är möjligt att uppskatta klimatpåverkan från modul C efter rivning då datan är tillgänglig. Frågan om hur denna klimatpåverkan ska allokeras förblir dock öppen, särskilt i de fall då rivning genomförs som en del av ett större byggnadsersättningsprojekt.

Nyckelord: Livscykelanalys (LCA); slutskede (EoL); rivning; modul C; klimatpåverkan

Contents

List of tables

List of figures

Acronyms

A_{temp} – The heated area of a building, including all floors.

GFA – Gross floor area, the total area of the building, including all floors.

BTA – Brutto total area, the Swedish term for GFA.

Building footprint – The area covered by the ground floor of the building.

CO_2e – Carbon dioxide equivalents.

IVL – The Swedish environment research institute

LCA – Life Cycle Assesment

EoL – End-of-life

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SOFIA FREDRIKSSON, Gothenburg, June 2026

1 Introduction

The construction sector is the largest contributor to climate change, producing 34% of total emissions of CO_2 globally (United Nations Environment Programme, 2025). Additionally, the sector is one of the largest producers of material waste. Annually, the sector generates two billion tons of construction and demolition waste (CDW) which amounts to 30% of all global waste. In Sweden, the construction and real estate sector accounts for emissions of 9,8 million tons of CO_2e, corresponding to 21% of the total emissions in Sweden each year (Boverket, 2023).

The common practice to assess the climate impact of buildings is to use the life cycle assessment (LCA) methodology. As per EN 15987, a building's lifecycle is divided into three modules (CEN, 2026). Module A covers the extraction of raw materials, production of components and the construction of the building. Module B covers the operational phase of the building, including operational energy, maintenance and repairs. Module C covers the building's end-of-life, including deconstruction, demolition, transport of waste and waste management. The climate impact of each module is expressed as global warming potential (GWP) and quantified in carbon dioxide equivalents (CO_2e).

In January 2022, the Swedish government enacted the Act on Climate Declarations for Buildings (2021:787) to promote reduced climate impact from the construction sector by requiring climate declarations for new buildings. The climate declaration is to include the calculated climate impact of the planned building in CO_2e/m^2 GFA. The framework is administered by the Swedish national board of housing, building and planning (Boverket), which provides methodological guidelines and a national climate database to support the calculations. As of the regulation's implementation, the climate declaration is only required to account for the construction phase, module A as per EN 15978, of a building's lifecycle. Boverket is continuously developing the framework for climate calculations on buildings and proposes to implement limit values by 2025 and aims to expand the scope of the climate declaration to include modules B and C for new buildings over 1 000m^2 in 2028 and all new buildings in 2030 (Boverket, 2026b).

The climate impact of a building is often calculated at early stages where demolition activities are far into the future. Therefore, the calculation of module C is oftentimes scenario-based in accordance with EN 15978, and the results are not verifiable which causes uncertainty (Balouktsi & Birgisdottir, 2023). Due to the current lack of incentive, assessments of the climate impact of module C (end-of-life) are limited. This thesis strives to fill this research gap through the following aim.

1.1 Aim and objectives

The aim of this thesis is to assess the scale, drivers and distribution of climate impacts associated with building demolition activities and how these impacts are allocated within current LCA frameworks.

To fulfill this aim, the following objectives have been identified:

1. Develop a comprehensive understanding of the end-of-life phase and the current data landscape by reviewing relevant literature and databases as well as by gathering practical knowledge on demolition activities.
2. Calculate the climate impact from the end-of-life phase of two buildings and derive a key figure (in kg CO_2e/m^2 GFA) that can be applied in future assessments of demolition projects.
3. Examine the allocation of climate impacts from end-of-life activities within current building LCA frameworks in comparison with construction industry practice.

The two buildings used as case studies in this thesis were provided by Akademiska Hus. Akademiska Hus is one of Sweden's largest property owners, managing majority of the country's higher education and research facilities. This thesis is conducted in collaboration with Akademiska Hus to provide insight into the climate impact of their demolition projects.

2 Background

The following chapter provides the background for this thesis, presents relevant theory and describes the case studies. The scope of a building's end-of-life phase (C) is described alongside common demolition practices and previous research on the subject.

2.1 Module C – end-of-life

As per EN 15978, module C includes all impacts associated with a building's end-of-life. This phase begins when a building has been decommissioned and is not intended to be further of use and ends when all produced demolition waste has been cleared from the site and the site is ready for future use. The default scenario for calculations of this module is full deconstruction and demolition. Furthermore, activities concerning waste management are included until all waste has reached a state of end-of-waste. End-of-waste is defined in the European Waste Framework Directive (WFD) as the state when waste transforms from waste into a product or secondary material (European parliament, 2008) .This status is achieved when materials, after recovery, have a defined purpose and market and comply with technical requirements. Module C is further divided into four sub-modules, as seen in Figure 1, which are further described below.

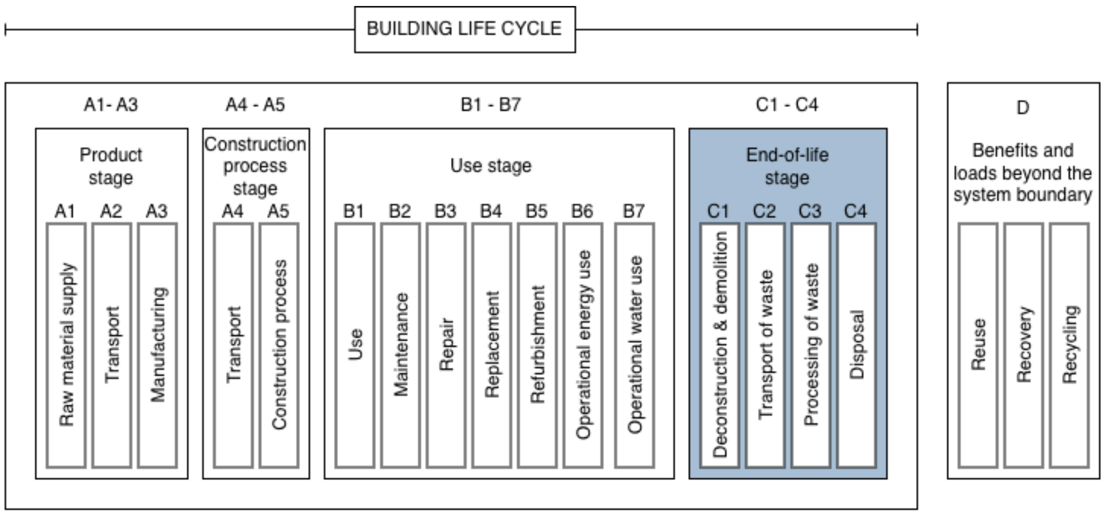


Figure 1: Stages of a building's lifecycle, as per EN 15978

C1 – Deconstruction & demolition

Module C1 includes impacts from the on-site processes of building deconstruction and demolition. Common included activities are sanitation of hazardous materials, dismantling and deconstruction of building components as well as demolition of structures. Initial on-site crushing, separation and sorting of material fractions is also included in this module. The climate impact from this module depends on the demolition practices on-site and the main driver is emissions from machinery.

C2 – Transport

Module C2 includes impacts from the transportation of waste. The scope of this module covers the transport of materials and waste from the demolition site until they have reached their end-of-waste or final disposal site. Through this definition, all transports between intermediate processing or storage facilities are to be included.

C3 – Waste processing
Module C3 includes impacts from the preparation and preprocessing of materials which are to be reused, recycled or incinerated with energy recovery. These processes can include but are not limited to sorting, crushing or aggregating materials at the waste management site.

C4 – Disposal
Module C4 includes impacts associated with the final disposal of materials, including preparation for these processes. Included materials are all which are not reused or recycled and are instead disposed of through neutralization, landfill or incineration without energy recovery.

2.1.1 Allocation of climate impacts from module C

Boverket has proposed an expansion of the climate declaration regulation to include modules B and C from 2028, assigning these climate impacts to new buildings (Boverket, 2026b). The regulation will demand contractors to report the climate impact of modules A, B and C before the start of construction. Due to the nature of modules B and C, the calculation of impacts from these modules are to be scenario-based.

As per EN 15978, all impacts from modules C1-C4 are allocated to the demolished building. The standard is aligned with the "polluter pays principle", meaning that the environmental impacts associated with demolition, transport of waste and waste processing are allocated to the demolished building. Only in cases when waste management and disposal processes generate outputs which may be of use in future products, such as heat or energy, are the impacts assigned to module D outside of the system boundary.

However, the nature of buildings can make them difficult to assess with conventional LCA frameworks (Eberhardt, 2020). Buildings are complex products with long lifespans, often exceeding 50-80 years before being deconstructed or demolished. The calculation of impacts from module C, when allocated to new buildings, therefore requires long-term assumptions on future demolition methods, transport distances and available fuel. As a result, these calculations are oftentimes uncertain rather than directly measurable or verifiable (Balouktsi & Birgisdottir, 2023).

2.2 Common demolition practices

Building demolition can be conducted in different ways and the choice of method depends on several factors. A common differentiation is to define conventional demolition and selective demolition. In conventional demolition, buildings are demolished with little regards to the management of waste, material is oftentimes crushed on-site and not always sorted (Andersen et al., 2022) . In contrast, selective demolition involves sorting of material fractions to facilitate recycling to a larger extent. Selective demolition also involves strategic removal of elements which can be reused. Commonly, selective demolition approaches are applied firsthand, followed by conventional demolition of elements which are difficult to reuse or recycle. However, the extent of selective demolition often differs in accordance with the project's aim to reuse and recover building elements or materials. The choice of demolition method can also in itself affect the environmental impact due to differences in on-site machinery and chosen waste management strategies.

The on-site demolition process is also affected by building characteristics. For instance, the demolition method and required machinery depend largely on building height. The common practice of building demolition is mechanical demolition, by crane or excavator (Yuzbasi, 2025). For low buildings, common excavators and cranes are oftentimes sufficient. However, slightly taller mid-rise building require heavier machinery and the use of high-reach excavators.

Another factor which can influence the demolition process is the presence of hazardous materials such as asbestos. Asbestos is a compound which, when disturbed, releases fibrous dust that causes adverse health concerns when inhaled. Therefore, the chosen method of demolition needs to be adapted if there is asbestos in the building to be demolished (Stevulova et al., 2020) . Prior to any conventional demolition work, the building must go through extensive sanitation work to remove all asbestos from the property. In Sweden, all work concerning construction or demolition where asbestos is involved must be permitted by the Swedish Work Environment Authority. Thereafter, all removal of asbestos must be notified and reported to the same authority.

2.3 Policies and frameworks for construction and demolition waste

The Waste Framework Directive 2008/98/EC (WFD) is the primary legislative framework governing waste management within the European Union (European Parliament, 2008) In regards to construction and demolition waste (CDW), the directive states that member states shall prioritize selective demolition as described in section 2.2 as it enables sorting of materials to a larger extent which facilitates material recycling. According to the WFD, construction and demolition waste must be sorted into at least six fractions which are wood, mineral fractions (concrete, bricks, tiles and ceramics, stones) metal, glass, plastic and plaster. The same six fractions are, by Swedish law, required to be sorted and stored separately at the site of demolition (Regeringskansliet, 2020).2.2

Furthermore, the directive introduces a waste hierarchy that defines a five step priority order of waste management strategies as illustrated in Figure 2. The waste hierarchy aims to encourage member states to prioritize prevention of waste, re-use and recycling over conventional waste recycling strategies such as landfill and incineration. The directive applies to all material waste that is produced within a member country. Therefore, the waste hierarchy should be implemented in the decision-making in the management of waste from any product, including buildings. In accordance with the waste hierarchy, building demolition is the worst-case scenario. However, the WFD also states that member states shall always take into account the overall environmental, human health, economic and social impacts when applying the waste hierarchy. From a systems perspective, this means that a multitude of factors need to be weighed when deciding to demolish a building.

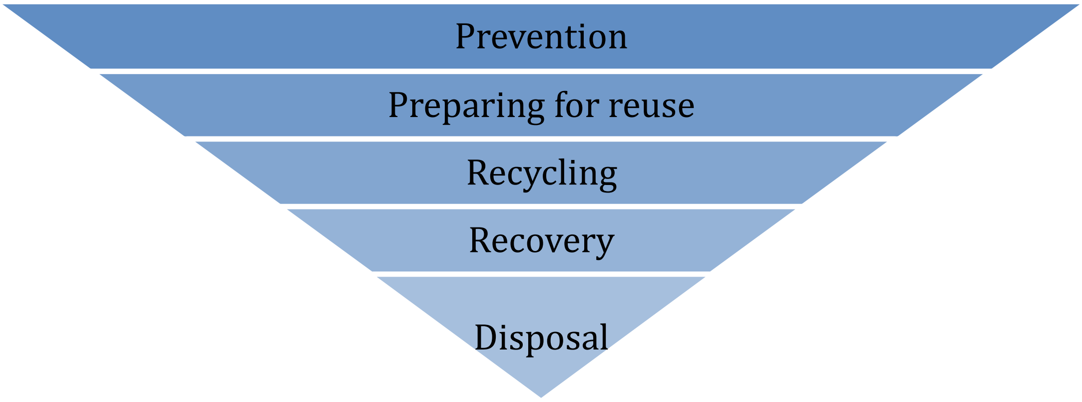


Figure 2: The waste hierarchy

Building's usually reach the end of their functional life when technical or structural elements are no longer operational. However, the end-of-life can also be reached when the building's function no longer meets the occupants needs. At Akademiska Hus, before deciding to demolish old or construct new buildings, an assessment framework called the "four step principle" is applied (Akademiska Hus, 2025) . The four step principle is mainly utilized to question the need for new buildings by assessing the potential of existing ones. The four principles are described Table 1, where construction of new buildings is the last resort. Similarly to the waste hierarchy, many factors weigh in on the decision to demolish and rebuild.

Table 1: The four step principle, translated from Akademiska Hus

Use existing – can we meet new demands with a change in maintenance and operation?
Can we optimize and increase efficiency?
Can we meet new demands through renovation or building extension?
If the above are not possible -> new building

2.4 Description of case studies

Two case studies were chosen for this thesis, referred to as project A and B. Both demolition projects were provided by Akademiska Hus and were demolished in recent years. In line with the nature of Akademiska Hus properties, both projects concerned demolition of buildings that housed facilities for higher education. Table 2 presents an overview of the two projects which are further described in this chapter.

Table 2: Overview of the two case studies

Project	Location	Building footprint [m^2]	Total demolished GFA [m^2]	Year of construction	Year of demolition	Number of floors
A	Gothenburg, Sweden	3 211	12 609	1934 / 1972	2023	3-5
B	Luleå, Sweden	10 904	16 113	1971 / 1997	2023 - 2024	3

2.4.1 Project A

Project A is located in central Gothenburg and consists of a main building and a parking garage. The main building consists of two conjoined structures which were built in 1934 and housed education facilities, Figure 3 shows the main building before demolition. One of the structures had five floors and the other four. The building underwent renovation work in 1992 before it was demolished in 2023. The parking garage was constructed in 1972 and consisted of three floors of parking spaces, the structure was demolished simultaneously as the main building.

Figure 3: Main building of project A, Photo: Per Hilmersson (Akademiska Hus), personal communication, 2026

The three objects were demolished at the same time and documented collectively. Since the three are not differentiable in the acquired data, they will in this thesis be regarded as one entity. The total demolished gross floor area (GFA) of project A was

12 609m^2, the method of GFA estimation for the main building and parking garage is presented in section 0.

Structural composition
The load bearing structure of the main building consists of concrete. The building has a brick façade which is insulated with mineral wool. The parking garage is constructed completely in concrete with an outer brick façade. The ground floor is paved with asphalt whilst the second and third floor are of concrete. The main structural materials are accounted for in Table 3.

Table 3: The main structural materials of project A

	Load bearing structure	Facade
Main building	Concrete	Brick
Parking garage	Concrete	Concrete / Brick

Demolition context
Project A was demolished to facilitate the development of the property and the construction of a modern replacement building. Due to the planning of the new construction being in place at the time of demolition, many materials were deconstructed with reuse in mind. However, the extent of reuse of the deconstructed materials is inconclusive in the provided project documentation. During demolition, asbestos was discovered which complicated the demolition work, demanding sanitation work. Majority of the structure was demolished conventionally, with a tall crane as seen in Figure 4.

Figure 4: Demolition of main building in project A, Photo: Per Hilmersson (Akademiska Hus), personal communication, 2026

2.4.2 Project B

Project B is located in Luleå in northern Sweden and also housed facilities for higher education. Project B consists of one building of two floors above ground and a cellar. The building was developed in phases, the first floors were built in 1971 and the last floor added in 1997. The total demolished area was estimated to 16 113m^2. A part of the building was not demolished, pictured in Figure 5 to showcase the characteristics of project B which has the same structural composition.

Figure 5: Part of the building in project B which was not demolished, to show the charasteristics, Photo: Per Hilmersson (Akademiska Hus), personal communication, 2026

Structural composition

The main material of the buildings load bearing structure is concrete, which is complemented with steel pillars. The outer façade of the building is composed of brick and sheet metal. Table 10 accounts for the main structural materials.

Table 4: The main structural materials for project B

	Load bearing structure	**Facade**
Project B	Concrete / Steel	Brick / Sheet metal

Demolition context

Similarly to project A, project B was demolished to facilitate the development of new buildings in the future. However, the main cause of demolition was building related health concerns. Consequently, several material fractions tested positive for contamination after demolition which limited the options for reuse and recycling. Similarly to project A, extensive sanitation of asbestos was performed during the demolition. Figure 6 pictures part of the demolition process, showcasing the structural steel components of the building.

Figure 6: The demolition process of project B, showcasing the steel elements, photo: Per Hilmersson (Akademiska Hus), personal communication, 2026

2.5 Current calculation methods & data landscape

Available climate databases
Climate data is needed to calculate the climate impact of any process, however current climate databases in Sweden exclude data concerning module C. In the construction sector in Sweden, the main climate database is provided by Boverket (Boverket, 2024). The database was developed to support the climate declaration regulation and contains generic data on the climate impact of building materials, components and activities. As current national directives focus on the calculation of module A, climate data for the calculation of modules B and C are excluded from the database. A similar climate database was developed by Trafikverket, Trafikverkets klimatkalkyl, focusing instead on data concerning infrastructure projects (Trafikverket, 2026). Similarly to Boverket, the database excludes activities during module B and C.

The most frequently cited climate database in module C calculations in Sweden is the Finnish National Emissions Database (CO2data.fi) developed by the Finnish Environmental Institute. Similarly to Boverket's climate database, CO2data.fi includes data on the climate impact of building products, processes and systems (Finnish Environment Institute, 2025b). CO2data.fi distinguishes itself from Boverket's climate database by including climate data for all stages of a building's lifecycle, including module C. The database includes generic values on the climate impact of complete sub-modules as well as included processes for an extensive number of material fractions.

Current calculation methods
As of today there is no national directive on how the climate impact of module C is to be calculated in Sweden, however suggested methodology can be found in existing publications on building LCA. The Swedish Environmental Institute (IVL) has developed directions on how to perform LCA on the full lifecycle of buildings (Swedish Environmental Research Institute, 2024). The report presents a methodology and data to be used when calculating the climate impact of module A in accordance with the climate declaration regulation. Furthermore, the report includes directions on how to calculate the climate impact of modules B and C. Due to the lack of national directives and data on modules B and C, these directions mainly concern the application of generic climate data from external databases.

2.6 Previous research

Previous research has assessed the climate impact of the end-of-life stage (module C), although reported results vary considerably. The variation is likely due to differences in building characteristics, system boundaries, assumptions and calculation methodology. All introduced studies and calculated values along with key assumptions are summarized in Appendix D, Table 21.

Larsson et al. (2016) assessed the complete module C1-C4 for both a concrete and a wooden building, following the directives of the Swedish environment research institute. The results showed a climate impact was 23 kg CO_2e/m^2 A_{temp} for the concrete building and 9 kg CO_2e/m^2 A_{temp} for the wooden building, highlighting a strong dependance on material composition (Larsson et al., 2016). A_{temp} refers to the heated floor area of a building and can be converted to gross floor area (GFA) by using a factor of 0,95 (Energimyndigheten, 2010). The estimated values correspond to 21,85 and 8,55 kg CO_2e/m^2 GFA, respectively.

For sub-module C1, reported values vary widely. Adalberth (2000) studied seven Swedish buildings and estimated the energy use for demolition to be 10kWh/m^2 GFA. The same value is utilized by Bozdag and Secer as well as Gustavsson to calculate a climate impact of 3 kg CO_2e/m^2 GFA (Finnish Environment Institute, 2025a; Gustavsson et al., 2010). Coelho & De Brito (2012) estimated a slightly lower value of 2.6 kg CO_2e/m^2 GFA by applying a "top-down" LCA approach and utilizing data from demolition contractors. In contrast, the Finnish environment institute database, CO2data.fi, present estimated values from the Finnish demolition company Delete Oy which range from 2-29 kg CO_2e/m^2 GFA but do not disclose applied methodologies (Finnish Environment Institute, 2025a). Lastly, Pettersson et al used a similar approach to Larsson et al. and calculated a value of 10.3 kg CO_2e/m^2 (Pettersson & Talback, 2026). However, in the study by Pettersson, the energy consumption of demolition is assumed equal to that of construction.

Research on sub-modules C2-C4 is more limited. Pettersson et al estimated C2 at 4,4 kg CO_2e/m^2 GFA for concrete structures and 0,6 kg CO_2e/m^2 GFA for wooden structures, again indicating a strong dependance on building material. Petrovic et al utilizes the software One Click LCA and examines a wooden building in Sweden (2024). Their results identified C3 as the largest contributor if C1 is excluded, with values of 3.3 kg CO_2e/m^2 GFA for C2, 8.2 kg CO_2e/m^2 GFA for C3 and 0.1 kg CO_2e/m^2 GFA for C4. Coelho & De Brito (2012), however, found that C2 was the main driver of climate impact, estimating transport-related emissions at 34.4 kg CO_2e/m^2 GFA. Their study also highlights the fact that an increased rate of recycling can increase the climate impact, since advanced recycling facilities are often scarce and therefore situated further from the demolition site.

Despite these variations, several authors agree that the climate impact of the end-of-life phase is small in relation to the rest of a building's lifecycle. In Sweden, the average climate impact of A1-A5 has been estimated to 263 kg CO_2e/m^2 GFA for all building types and approximately 300 kg CO_2e/m^2 GFA for concrete buildings (Boverket, 2023). Furthermore, in relation to the energy used for material production and construction (A1-A5), the energy required for demolition only accounts for approximately 1-3% (Gustavsson et al., 2010). Similarly, Ylmen assessed the full lifecycle of a building and concluded that end-of-life activities only account for 2-6% of the total environmental impact (2019).

However, as electricity and operational energy are increasingly decarbonized, the share of embodied carbon becomes larger. Embodied carbon includes emissions from the production and demolition of buildings, whilst emissions from the use-phase are defined as operational carbon. Currently, operational carbon accounts for 75% of building sector emissions but is reducing rapidly due to decarbonization and the development of more energy efficient buildings (OECD, 2025). On the contrary, embodied carbon is often a blind spot to legislation and is expected to increase in relation, accounting for half of the total carbon footprint of new buildings in 2050. This highlights the importance of assessing module C – end-of-life – impacts, to ensure that module embodied carbon is accurately represented which facilitates the implementation of effective mitigation strategies and legislation.

3 Methods

The following chapter describes the methodology applied in this thesis. First, a literature review was conducted to establish the theoretical background and identify existing methods and data for assessing the climate impact of end-of-life activities. The result of the literature review was presented in section 2 - Background. In parallel, quantitative and qualitative project-specific data was collected from two demolition case studies provided by Akademiska Hus. In addition, generic climate data for end-of-life activities was collected from climate databases. When datasets were complete, the climate impact for modules C1-C4 were calculated. Finally, the results were compared, analyzed and conclusions were drawn. An overview of the methodology is presented in Figure 7.

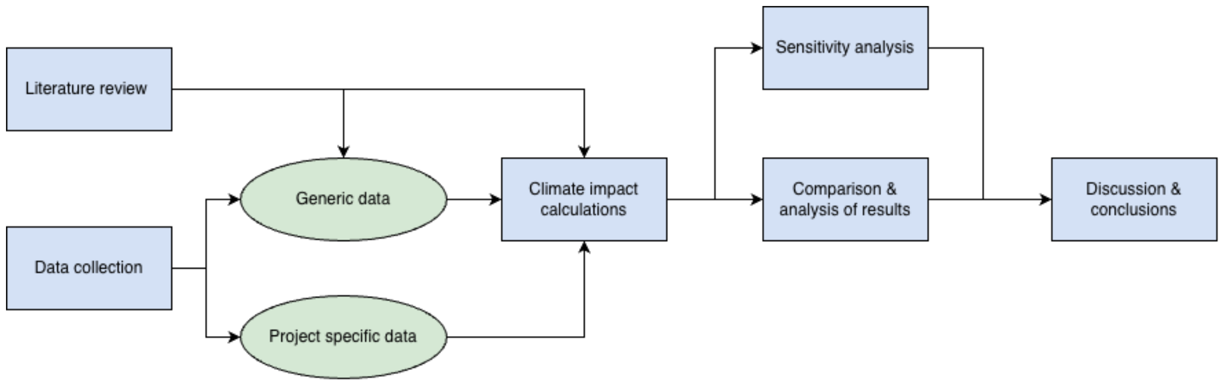


Figure 7: Diagram of the thesis research methodology

3.1 Method of literature review

The information derived from the literature review was included in section 2 – Background. The focus of the literature review was to identify current methodology for assessing the climate impact of module C, as well as scope previous research in the area and data which could be used for the calculations of climate impacts.
The literature review was conducted through databases and search engines Scopus, ScienceDirect and Google Scholar. Several AI tools were used in the literature review to effectively search for and scan the content of publications. Perplexity and ResearchRabbit were utilized to search for relevant articles and publications. Some articles were uploaded to NotebookLM in order to effectively identify relevant content and extract information.

3.2 Climate impact quantification: goal & scope

A goal of this thesis is to produce a key figure kg CO_2e/m^2 GFA on the climate impact of demolition projects, defined by the scope below.

Scope

This thesis focuses on the end-of-life phase (C1-C4) of buildings in Sweden as described in section 2.1. The study is based on two completed demolition projects carried out by Akademiska Hus, as described in section 2.4 (description of case studies), and is therefore limited to these two case studies. Due to the nature of Akademiska Hus properties, the scope is further limited to buildings used for higher education and research in Sweden. Consequently, findings may not be applicable to other building types or similar building types in other countries.

Within the construction sector, the main assessed environmental impact is the climate impact, oftentimes expressed as global warming potential (GWP) which is reported in emitted kilograms of carbon dioxide equivalents (CO_2e). In Sweden, the indicator utilized in Boverket's climate declaration regulation is kg CO_2e/m^2 GFA. Therefore, this study only assesses the climate impact of building demolition and does not include other environmental impacts.

3.3 Data collection and management

The following section describes the data collection and management of this thesis. It accounts for the required data, how it was acquired as well as in which way it was utilized. Acquired data from excel files, pdf's, transport receipts or other forms of project documentation was transcribed into a new excel file as to not overwrite original documentation. When transcribed, the data was anonymized by renaming the projects A and B. Per the request of the participating project managers, all original datafiles were deleted at the end of the thesis work. The names of participating project managers, contractors or other stakeholders are only included in this report when consent was obtained to do so. Below follows a detailed description on the data collection process, divided into project specific data and general data.

3.3.1 Collection of project specific data

Majority of the collected data was project specific, directly related to the two studied demolition projects described in section 2.4. The project specific data consisted of both qualitative data to understand each project as well as quantitative data to be used in calculations.

Quantities
Quantities of demolished materials are the base of all calculated climate impacts in this study. The data includes the weight of demolished material by material fraction. This data was obtained from project documentation provided by the project managers in-company at Akademiska Hus.

Transport data
To calculate the climate impact of C2, transport data was needed. This data includes which waste management sites that material waste was delivered to, the transported distance and the utilized fuel and truck type. The utilized waste management sites for each material fraction was included in the acquired project documentation. The transported distance was identified by regarding the distance, by car, from the demolition site to each waste management facility using Google Maps. Where the data lacked detail, the involved waste management actors were contacted to establish which facilities had been delivered to and with what fuels.

Contextual understanding
Contextual information was collected to accurately interpret the findings, their applicability and identify differences between the projects. This includes the

characteristics of each building such as gross floor area, year of construction and material composition. Each building's characteristics were acquired from in-company documentation and building plans. Furthermore, contextual understanding of each demolition project was collected through correspondence with involved project managers and stakeholders. This data includes project timelines, methods of demolition, project specific challenges or approaches as well as costs.

3.3.2 Collection of generic data

Generic data is data which was not related to a specific project, but utilized in calculations for both case studies to transform quantities into climate impacts.

Machinery
To calculate the climate impact of module C1, information regarding the machinery used on the demolition site was needed. This data was not included in the acquired project documentation. Instead, this data was collected through correspondence with demolition contractors and include an estimation of the utility of demolition machines.

Climate data and emission factors
To transform the project specific data into a climate impact, generic climate data was required. This data includes climate data regarding the emissions of co2e from machines, transport vehicles and waste management processes. This data was derived from Boverket's climate data base and the national Finnish database for construction works (CO2data.fi). Additionally, estimates for the climate impact of processes during C1, C3 and C4 were derived from the Swedish environmental research institute's directives for building LCA.

3.4 Method for calculation of climate impacts

In the following section, the method for the calculation of the climate impact of module C is described. Firstly, the functional unit is defined. Thereafter, the calculation method for each sub-module C1 through C4 is described. All calculations were performed separately for project A and B.

Functional unit
The functional unit is defined as $1m^2$ gross floor area (GFA) of a building, demolished at its end-of-life. The unit was chosen to produce a key figure of kg CO_2e/m^2 GFA, as is common practice in building LCA. This functional unit ensures the results are scalable and that the estimated climate impact can be applied to, and compared with, other buildings.

3.4.1 Calculation method for C1 – deconstruction & demolition

The climate impact of C1 was calculated using two approaches. First, the impact was calculated by applying climate data to the Tons of demolished material in accordance with the directives from the Swedish environment institute (Swedish environment research institute, 2024. Secondly, the impact was calculated through an estimation of the machine hours for demolition.

Approach 1 – IVL

The Swedish environment institute recommend to apply climate data for demolition processes directly to the tons of demolished material and GFA, as presented in Table 5 (Swedish environment research institute, 2024). The data is divided into initial demolition works, to be calculated with electricity or diesel, as well as additional factors for each material and the height of the building.

Table 5: Input data for the calculation of C1 - deconstruction and demolition with the IVL approach, translated from Swedish (Swedish environment research institute, 2024)

Demolition	**Energy carrier**	**kWh/m2BTA**	**Input data**
Preporatory demolition work	Electricity	0,1	Total GFA
	Diesel	1	Total GFA
Demolition (crushing) of structures, regardless of type	Electricity	8	Total GFA
	Diesel	10	Total GFA
Additional	**Energy carrier**	**kWh/Ton material**	**Input data**
Concrete	Diesel	10	Tons of concrete
Masonry	Diesel	5	Tons masonry tiles and bricks
Steel	Diesel	1,1	Tons reinforcement steel and other steel products
Wood and other materials	Diesel	1,1	Total Tons of materials excluding concrete, masonry and steel products
Additional crane required for structures over six meters above ground	**Energy carrier**	**kWh/Ton material**	**Input data**
Concrete	Diesel	4,1	(Number of floors above ground, excluding the first two floors)*Tons of concrete
Masonry	Diesel	4,1	(Number of floors above ground, excluding the first two floors)*Tons of masonry tiles and bricks
Steel	Diesel	2	(Number of floors above ground, excluding the first

			two floors)*Tons of steel

The data Table 5 was applied to equation 1 and 2 to calculate the total energy consumption of demolition. All material quantities for each project used for calculations are specified in appendix A.The energy consumption for initial demolition works was calculated through equation 1, with diesel as the fuel.

$$E_{on-site,initial} = \sum_i EI_i \times GFA \quad (1)$$

where;

- $E_{on-site,initial}$ = The on-site energy consumption for initial demolition work and crushing of material [kWh]
- EI_i = The energy intensity of a process [kWh/m^2]
- GFA = The demolished gross floor area [m^2]

The energy consumption of demolition of different material fractions was calculated through equation 2, with diesel as the fuel for all materials.

$$E_{on-site,material} = \sum_i EI_i \times M_i \quad (2)$$

Where;

- $E_{on-site,material}$ = The on-site energy consumption for material specific demolition [kWh]
- EI_i = The energy intensity of the demolition of a material fraction [kWh/Ton]
- M_i = The mass of demolished material [Tons]

Thereafter the total energy consumption was calculated through equation 3.

$$E_{on-site,total} = E_{on-site,initial} + E_{on-site,material} \quad (3)$$

The total on-site energy consumption was transformed into a climate impact through equation 4 and lastly divided with the gross floor area to produce a key figure of kgCO2e/m2 for each case study. The utilized emission factors for electricity and diesel are presented in Table 6.

$$Climate\ impact = E_{on-site,total} \times EF \quad (4)$$

Where;

- EF = The emission factor for the utilized fuel [$kgCO_2e/kWh$]

Table 6: Emission factors for diesel and electricity

	Emission factor [kg CO_2e/kWh]	**Source**
Electricity	0,059	(Nina Chi Johansson & Annamaria Sandgren, 2026)
Diesel	0,32	(Boverket, 2026a) (converted from kgCO2e/MJ)

Approach 2 – machine hours

Johan Engström from the demolition contractor NKR demolition provided an estimate of the utility of demolition machines. The company estimates that each demolition machine demolishes 9 tons of concrete each hour. This estimate was utilized to calculate the machine hours required for complete demolition in both projects, through equation 5. The values of the variables are presented in

$$MH = \frac{M_c}{U} \tag{5}$$

Where;

- MH = The machine hours for demolition on-site [h]
- M_c = The mass of demolished concrete [Tons]
- U = The utility of demolition machines on-site [Tons/h]

Table 7: Input data for calculation of C1 - deconstruction & demolition, Machine hours approach

	Value	**Unit**	**Source**
Fuel consumption	35	l/h	(Kuikka, 2012)
Utility	9	Demolished Tons/h	Personal correspondence with Johan Engström (NKR Demolition), 2026
Energy intensity (diesel)	9,94	kWh/l	(Boverket, 2026a) (Converted from MJ/l)
Emission factor (diesel)	0,32	kg CO_2e/kWh	(Boverket, 2026a) (Converted from kg CO_2e/MJ)

When the machine hours of a project are known. The total on-site energy consumption of C1 can be calculated through equation 6. Generic input data for this calculation is found in Table 7.

$$E_{on-site,total} = MH \times F \times EI_f \quad (6)$$

Where;

- MH = The machine hours for demolition on-site [h]
- F = The fuel consumption of a demolition machine [l/h]
- EI_f = The energy intensity of the utilized fuel [kWh/l]

Thereafter, the energy consumption can be translated into climate impact through equation 4, applying the emission factor in Table 7. Lastly, the total climate impact was divided with the gross-floor area to produce a key figure of $kgCO_2e/m^2$ for each case study.

3.4.2 Calculation method for C2 – transports

As per EN 15987, all intermediate process or storage facilities are to be included in C2. As the acquired project documentation lacks this detail, the scope of this calculation is from demolition site to first site of waste management, all further or intermediate locations are excluded. Following The Swedish Environmental Research Institute's guidelines for LCA calculations for buildings, the climate impact of C2 was calculated through equation 7. The utilized emission factors are presented in Table 8. Project specific data on demolished amounts of material and transported distances utilized for this calculation are included in Appendix A and B.

$$Climate\ impact = \sum_i M_i \times EF \times D_i \times T_{ec} \quad (7)$$

Where;

- M_i = The mass of demolished material i [Tons]
- EF = The emission factor of the utilized fuel [$kgCO_2e/MJ$]
- D_i = The transported distance of material i [km]
- T_{ec} = The transport energy consumption, 1.5 MJ/tkm

Table 8: Emission factors for calculation of C2 - transport of waste

Energy carrier	**Energy [MJ/ liter]**	**Emission factor [kg CO_2e / MJ]**	**Source**
Diesel	35,8	0,0899	(Boverket, 2026a)
HVO100	34,1	0,016	(Boverket, 2026a)

In the IVL guidelines, the calculation is performed with a standard distance of 50km. In this study the actual transported distance of each material in each project was applied. The calculation was performed with the assumption that all transports were fuelled by diesel to compute a baseline scenario. The transport energy consumption was set to 1.5 MJ/tkm in accordance with the IVL guidelines and includes empty return transports.

3.4.3 Calculation method for C3-C4 – waste processing & disposal

Sub-modules C3 – waste processing and C4 – disposal were calculated together as the waste management strategies differ between materials. Materials which are landfilled only produce climate impact for submodule C4 whilst materials which are incinerated or recycled produce climate impacts for C3. For these sub-modules, generic climate data from CO2data was applied to the amount (weight) of demolished materials. The climate impact was calculated through equation 8 and then divided with the building GFA to produce a key figure kg CO_2e/m^2 GFA. The utilized climate data is detailed in Table 9 and was applied in accordance with the waste management strategies for each material as described in section 4.2. The exact amounts of demolished materials for this calculation are specified in Appendix A.

$$Climate\ impact = \sum_i M_i \times EF_i \tag{8}$$

Where;

- M_i = The mass of demolished material i [kg]
- EF_i = The emission factor for the waste processing of material i [kgCO2e/kg]

Table 9: Emission factors for sub-modules C3 and C4, retrieved from CO2data.fi

Material fraction	**C3 (kg CO_2e/kg)**	**Definition in CO2data.fi**
Concrete	0,006	Waste processing, concrete materials
Metals	0,002	Waste processing, metal materials
Wood	0,02	Waste processing, wooden materials
Bricks	0,005	Waste processing, bricks, gypsum and lime sand bricks
Glass	0,02	Waste processing, glass
Gypsum	0,0046	Gypsum plasterboard
Other materials	0,02	Waste processing, wooden materials
Material	**C4 (kg CO_2e/kg)**	**Definition in CO2data.fi**
Gypsum	0,0017	C4 from EPD, scenario 100% landfill
Pure insulation	0,057	Glass wool insulation, stone wool insulation
Other landfilled materials	0,057	Waste disposal

3.5 Method of sensitivity analysis

A sensitivity analysis was performed to evaluate how changes in key parameters affect the results. The analysis included variations in fuel type for sub-module C1 and C2 as well as transport distances.

Transport distance
To assess the influence of estimated transport distances, similar material amounts with differing transport distances in the projects were regarded.

Fuel type
To assess the influence of fuel type during C2 – transport of waste, the climate impact was calculated for the three scenarios presented in Table 10.

Table 10: Fuel scenarios for C2 - transport of waste

C2 Scenario	Fuel division	Diesel fraction	HVO fraction	Combined emission factor [$kgCO_2e/MJ$]
1	100% Diesel	1	0	0,0899
2	50/50	0,5	0,5	0,0530
3	100% HVO	0	1	0,0160

The emission factor presented in Table 10 is the total emission factor for each scenario, calculated through equation 9 by applying emission factors for diesel and HVO100 from Table 8.

$$EF = (EF_{diesel} \times Diesel\ fraction) + (EF_{HVO} \times HVO\ fraction) \quad (9)$$

To assess the impact of substituting a fraction of diesel on-site to electricity, the climate impact of C1 was calculated using the values for initial demolition works with electricity from Table 7. Lastly, the fuel transport scenarios were compiled with the calculations of C1 to assess the combined impact on the total climate impact of module C in accordance with Table 11

Table 11: Scenarios for combined sensitivity analysis

Combined C1/C2 scenario	C1	C2
Baseline	IVL approach 100% diesel	100% Diesel
1	IVL approach 100% diesel	50% HVO100
2	IVL approach, electricity for initial demolition works	100% Diesel
3	IVL approach, electricity for initial demolition works	50% HVO100

4 Results & analysis

The following chapter presents and analyses the results of this thesis. First, the collected project specific data is presented in regards to material inventory as well as information on the waste management and transportation distances of each project. Thereafter, the calculated climate impact for each sub-module is presented. Lastly, all climate impacts are compiled for both projects in order to review the total climate impact of module C. All calculations follow the methodology presented in section 3.4, where input data on emission factors and machinery is also included. A detailed account of the material quantitates for each project, used for the calculations, is included in appendix A – material quantities.

4.1 Material inventory

The shares of the various demolished materials of project A and B are presented in Figure 8. The largest material fraction in both case studies is concrete, accounting for approximately 90% of all demolished material for project A and 71% for project B. A full account of the exact weight of each material share in project A and B is included in Appendix A.

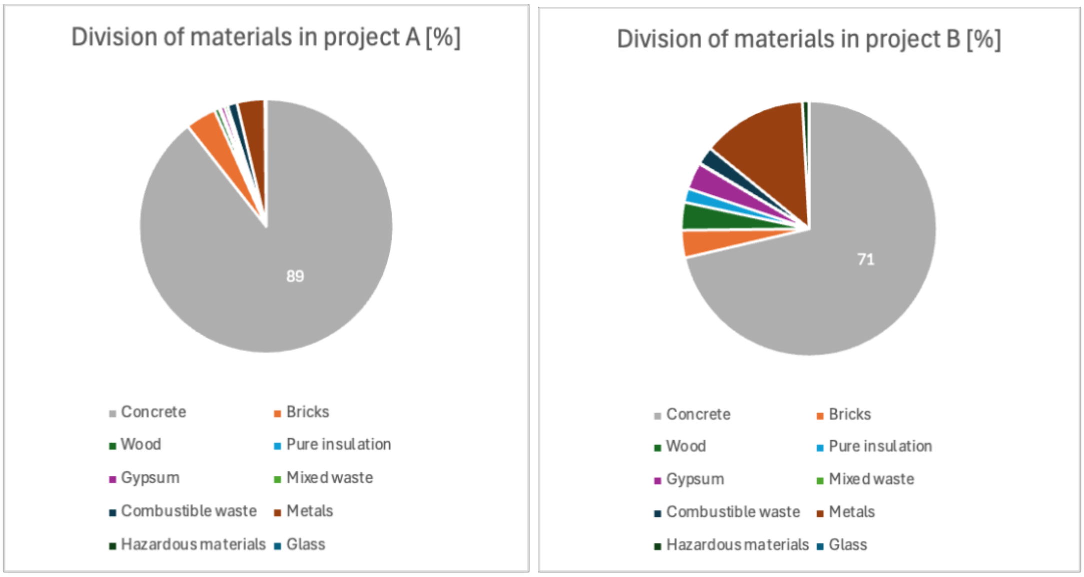
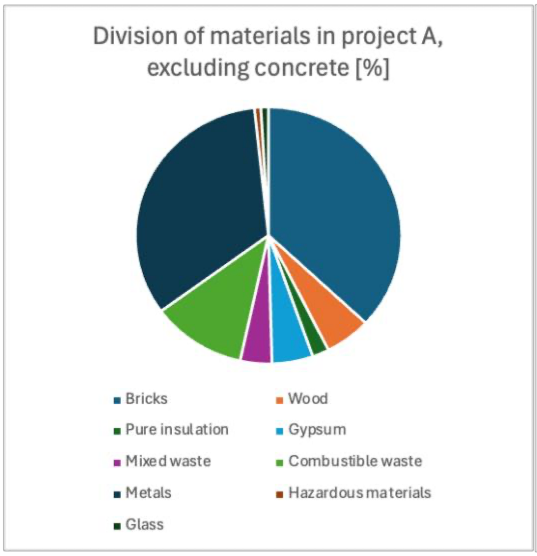


Figure 8: Share of demolished materials for both projects.

When concrete is excluded, the main material fractions differ between the two projects. As seen in Figure 9, the two largest fractions without concrete are bricks and metals for both projects. For project A, the amount of bricks and metals are similar. Project B however, has a significantly larger fraction of metals which accounts for almost half of the demolished materials when concrete is excluded.



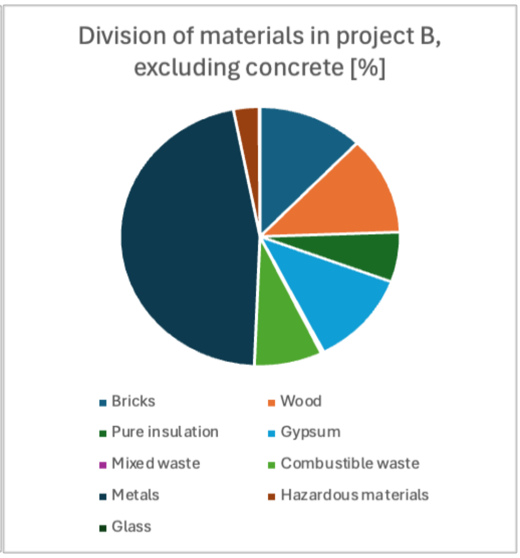


Figure 9: Share of demolished materials for both projects, excluding concrete

4.2 Waste management strategies

The waste management strategies applied for each material fraction in project A are presented in Table 12. Conventional strategies were applied to majority of the materials. For some materials, conventional waste management was substituted for more circular strategies such as recycling or reuse. A fraction of the demolished concrete was recycled and bricks were deconstructed for reuse.

Table 12: Waste management strategies for the documented material fractions of project A

Material fraction	Waste management strategy	Comment
Concrete	A fraction of the demolished concrete was sent to material recycling, the waste management for the rest of the concrete was not specified.	
Bricks	A fraction of the demolished bricks were saved and sent for reuse, the waste management for the rest of the bricks was not specified.	
Wood	Incineration with energy recovery	
Pure insulation	Deposition into or onto land	
Gypsum	Deposition into or onto land, storage of wastes pending further waste management operations	
Mixed waste	Exchange of wastes pending further waste management operations.	
Combustible waste	Incineration with energy recovery	
Metals	Material recycling	
Hazardous materials	Electronic waste and cables were sent to material recycling, other hazardous waste was sent to storage pending further waste management operations	Excluding asbestos

Asbestos	Hazardous waste landfill	
Glass	Material recycling	

A similar pattern is observed for project B, where conventional waste management practices are applied to most materials as seen in Table 13. Similarly to project A, bricks were deconstructed for reuse. However, all concrete was stored on-site, awaiting assessment for possible reuse as backfilling materials. An important observation is that in project B, all demolished gypsum was recycled instead of landfilled. Project B also utilized waste management facilities in other cities.

Table 13: Waste management strategies for the documented material fractions of project B

Material fraction	**Waste management strategy**	**Comment**
Concrete	The concrete was crushed and stored on-site for evaluation and testing of contamination. Expected to be used as backfilling material in future projects.	For calculation of C2, a distance of 10 km was assumed for future local transportation.
Bricks	Some bricks were saved to be reused in local construction projects, the waste management for the rest of the bricks was not specified.	For calculation of C2, a distance of 10 km was assumed for future local transportation of reused bricks.
Wood	Not specified	
Pure insulation	Deposition into or onto land	
Gypsum	Material recycling	Some gypsum was transported to nearby facilities, a large fraction was transported to the main facility of effective gypsum recycling, located in central Sweden.
Mixed waste	Deposition into or onto land	
Combustible waste	Incineration with energy recovery	
Metals	Material recycling	Some metal waste was transported to local facilities, some metal waste was transported to a facility in a neighboring city.
Hazardous materials	Not specified	Excluding asbestos.
Asbestos	Hazardous waste landfill	
Glass	Material recycling	

4.3 Transported distances

The transported distances to waste management sites for project A are presented in Figure 10. Some material shares appear several times in the diagram. This is because the diagram illustrates all transported distances and some material fractions were transported to several waste management sites. For concrete, the two different transportation distances are due to differences in waste management. However insulation and hazardous materials were transported to several sites regardless of waste management strategy. The majority of the waste was driven to local waste management sites within 10km of the demolition site. The longest distances were recorded for concrete and asbestos. The fraction of concrete sent to recycling was transported 67 km, further than the concrete for conventional waste management. Asbestos was transported furthest, 98 km, due to the fact that asbestos requires specific waste management of hazardous waste.

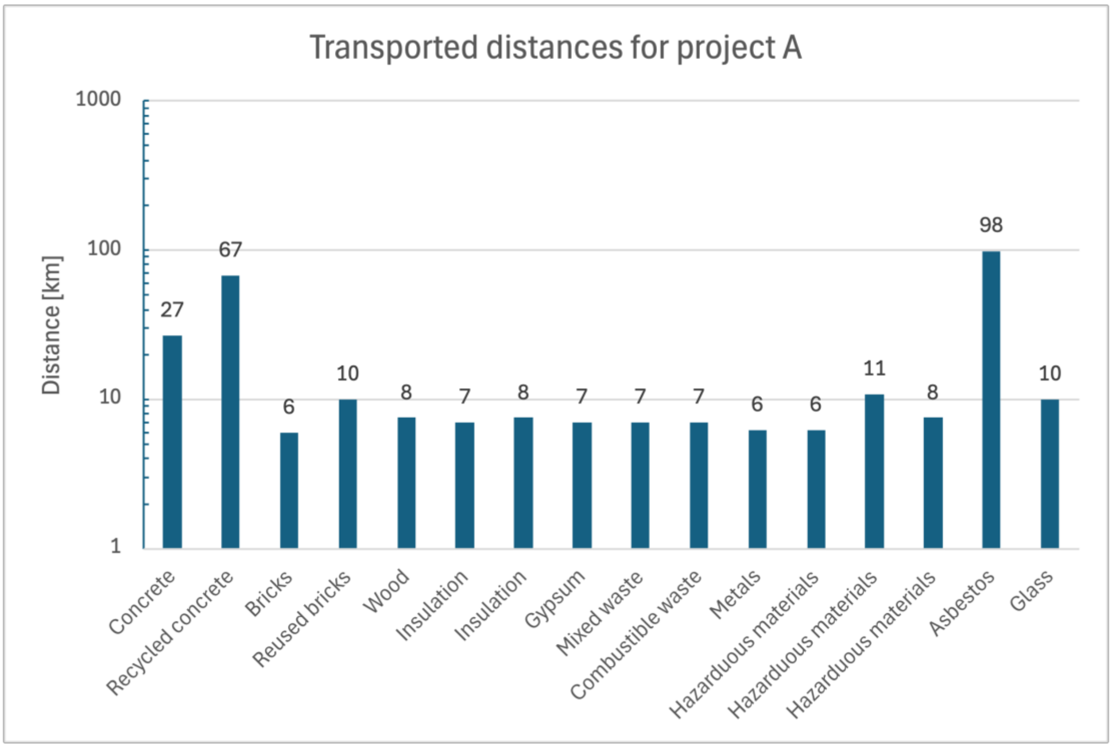


Figure 10: Transported distances for project A

Figure 11 illustrates the distances of transportation for project B. Similarly to project A, most transports were within a range of 10km from the demolition site. Again, some material fractions appear several times due to the material being delivered to several waste management sites. Noticeably, gypsum was transported 882 km, compared to only 7km in project A. The longer transportation distance for gypsum in project B is due to a different waste management strategy. As seen in Table 13, the gypsum from project B was recycled instead of landfilled which results in longer transportation distance due to a lack of local gypsum recycling facilities. Higher transportation distances were also recorded for metal waste which was transported to a facility in a neighboring city, 54 km away. Similarly to project A, asbestos waste is also transported further from the demolition site (37 km) than most other materials.

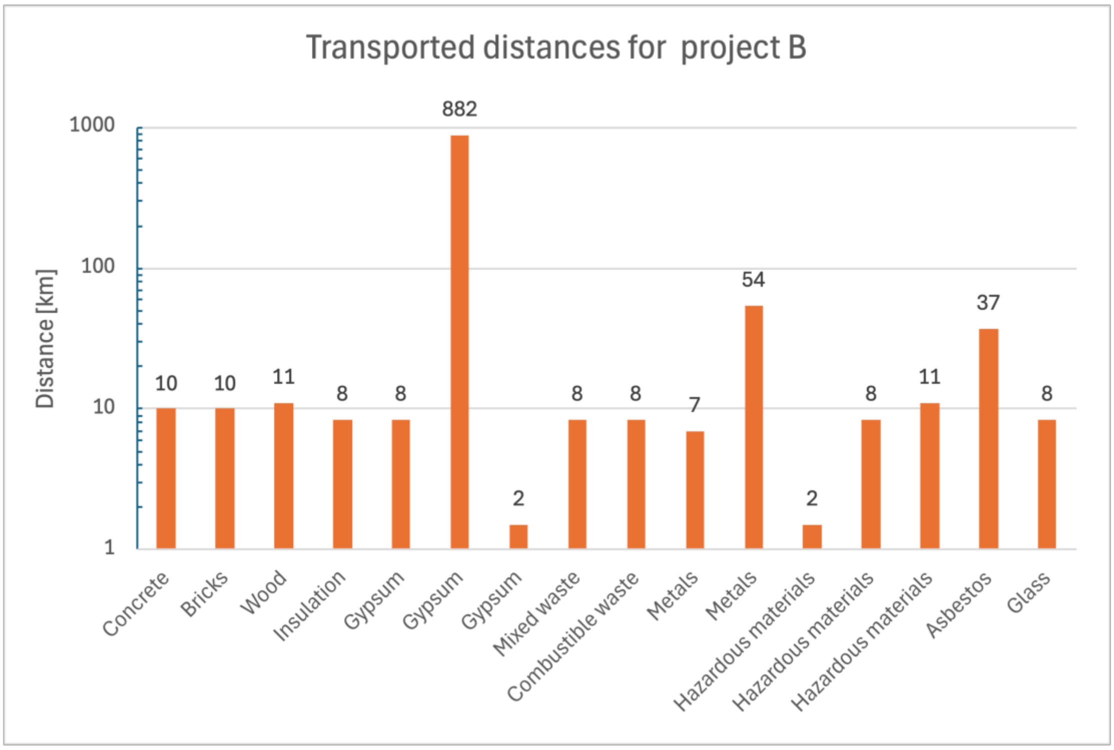


Figure 11: Transported distances for project B

4.4 Results of C1 – deconstruction and demolition

The climate impact of C1 was calculated with two approaches as described in section 3.4.1. The first step in the calculation was to calculate the energy consumption, when all on site activities are fuelled by diesel. The calculated energy consumption is illustrated in Figure 12. The calculation approach with an estimate of machine hours result in a higher energy consumption for both projects. Additionally, the difference between the two projects is larger when calculating the impact according to IVL guidelines. Notably, the calculated energy consumption is significantly higher than it has been estimated in previous research. For instance, Adalberth (2000) estimates the energy required for demolition to only 10 kWh/m^2.

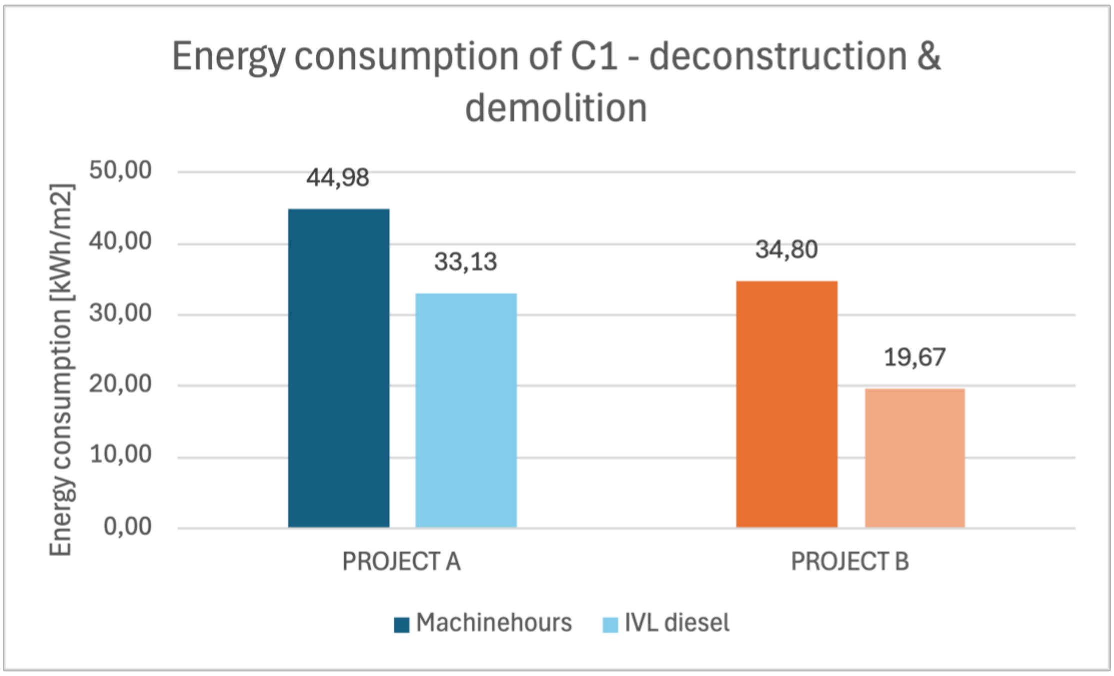


Figure 12: The calculated nergy consumption of C1 - deconstruction & demolition, calculated using two different approaches.

The same trend is observed in regards to climate impact, as seen in Figure 13. The calculated climate impact is higher through the machine hours approach. The difference between the two approaches is slightly larger for project B, and the difference between the two projects is larger with the IVL approach. The results imply that the climate impact of C1 is highly sensitive to assumptions regarding the demolition method and machinery. As project A consists of 4-5 floors, in the IVL approach additional climate impacts for each material fraction is included due to the need for additional cranes to demolish higher floors. As project B is only two floors, these impacts are not added. The impact of building height is not regarded in the machine hours approach, causing a smaller difference between the projects.

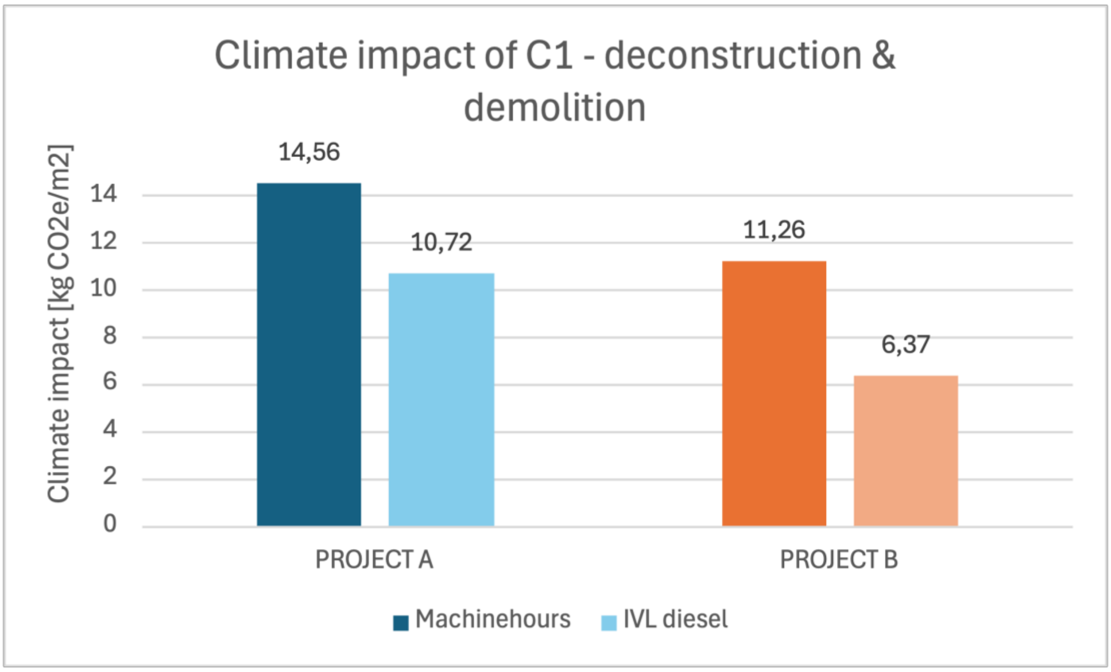


Figure 13: The calculated climate impact of C1-deconstruction & demolition, calculated using two different approaches.

4.5 Results of C2 – transport of waste

The climate impact of C2 – transport of waste was calculated in accordance with the method described in 3.4.2. The calculated climate impact of module C2 for both projects is presented in Figure 14. The calculated climate impact is larger for project A than project B.

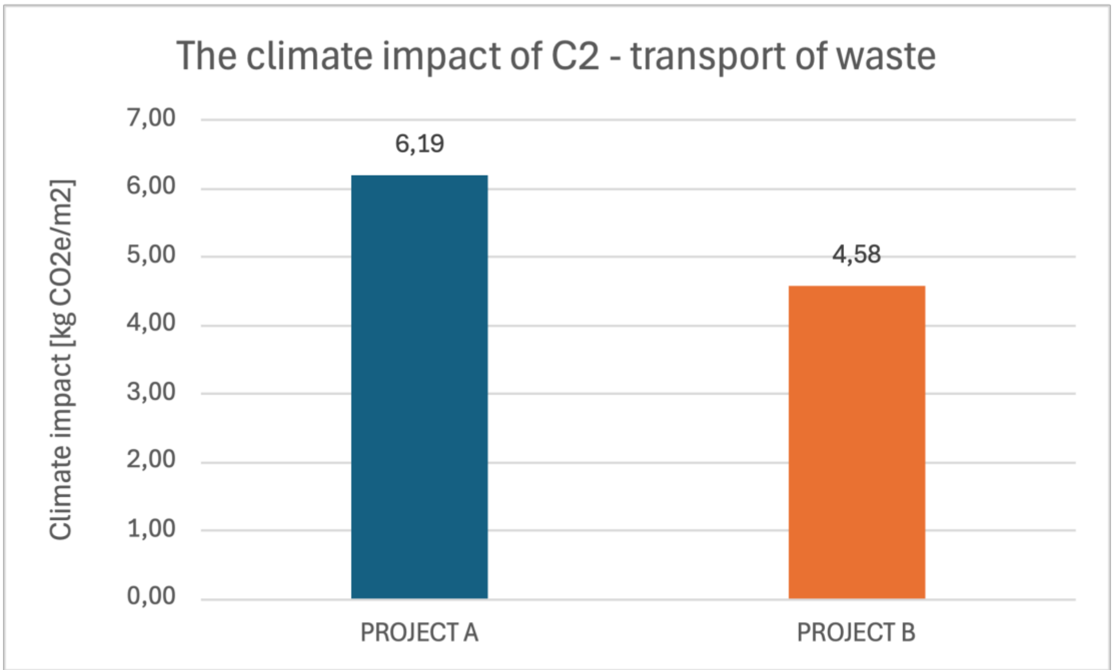


Figure 14: The calculated climate impact of module C2- transport of waste

Module C2 is impacted by weight of demolished material and transported distance. A detailed account of the distances and weights used for this calculation is given in Appendix B – Distances of transports and waste management. The difference between the two projects in this module is mostly due to a large difference in transported distances for some materials as aforementioned. Figure 15 illustrates the total climate impact of each material fraction in both projects, all transports included. Similar trends are observed for both projects, however there are some outliers. As previously stated, the total transported distance of gypsum is significantly larger in project B, thereby accounting for majority of the climate impact of C2. Similarly, concrete was transported further in project A than project B, resulting in a large difference in the impact of concrete on module C2.

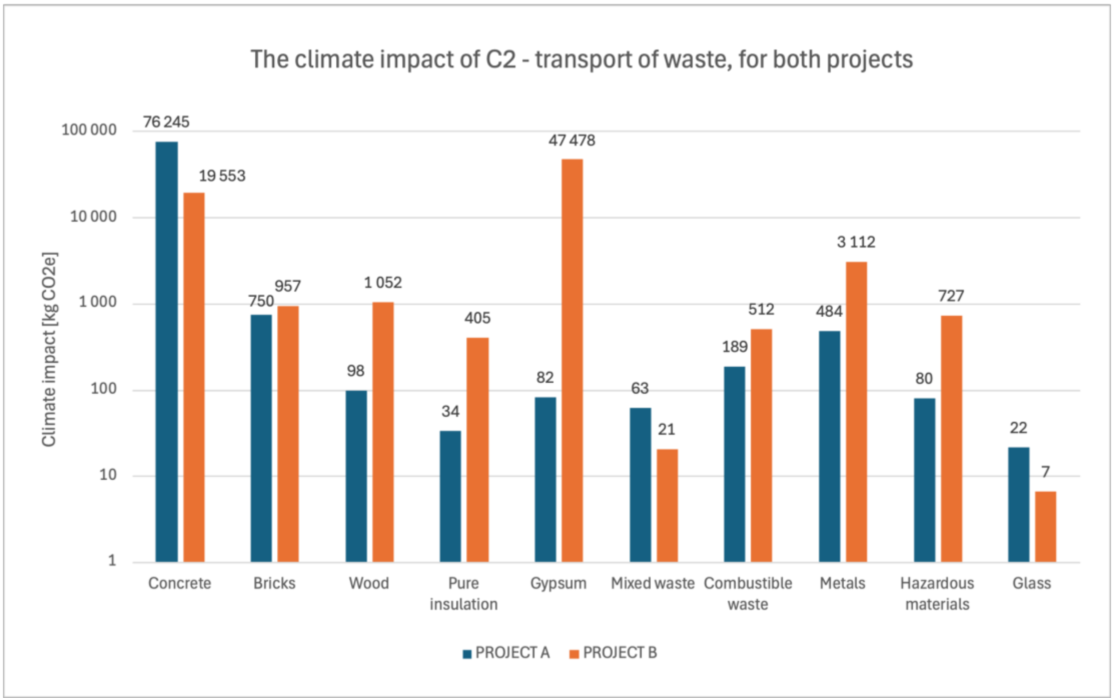


Figure 15: The calculated climate impact of C2 - transport of waste, by material fraction for both projects

4.6 Results of C3-C4 – waste processing and disposal

The climate impact of C3-C4 was calculated according to the method described in section 3.4.3. As seen in Figure 16, the calculated climate impact of modules C3-C4 is slightly higher for project B. The difference is partly due to project B consisting of larger amounts of other material fractions than concrete, which have higher emission factors in terms of waste processing.

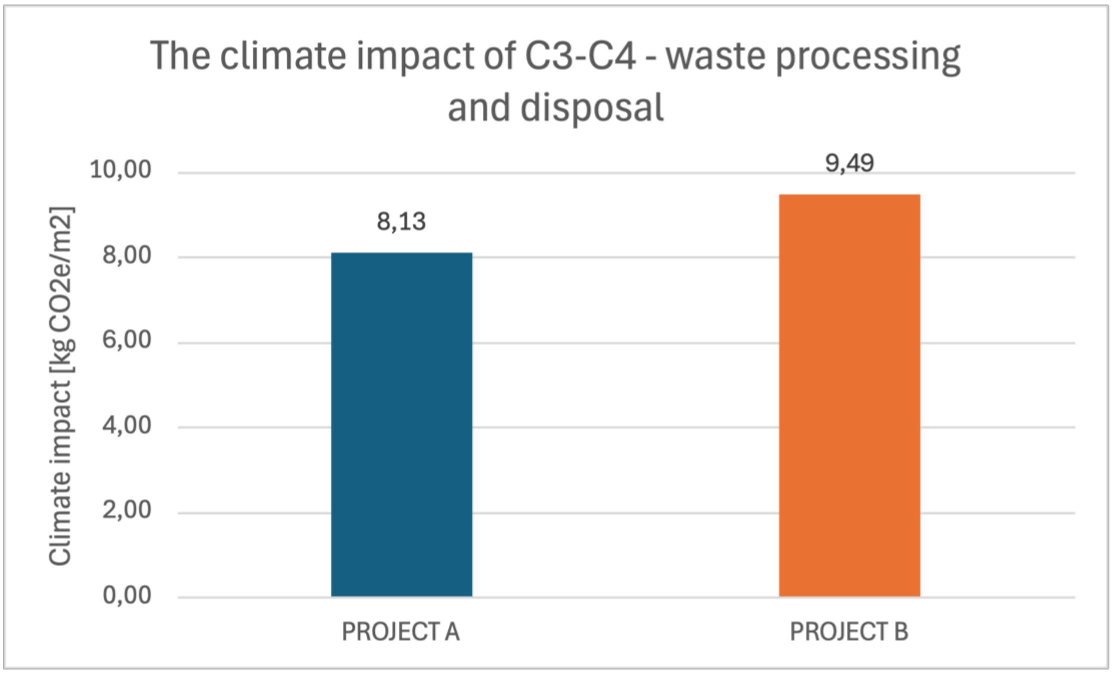


Figure 16: The calculated climate impact of module C3-C4

Furthermore, climate impacts of sub-modules C3-C4 for both projects are impacted by the generic data applied to the demolished material, which depend on waste management strategy. The applied generic data is specified in the method for calculation in section 3.4.3. The calculated impact is illustrated per material fraction in Figure 17. The same emission factors were applied to most material fractions in both projects, causing the projects to differ mostly due to a difference in material composition. The only difference in calculation with regards to waste management is gypsum, which was landfilled in project A but recycled in project B. As recycling of gypsum has a higher emission factor, the climate impact of Project B is higher for gypsum.

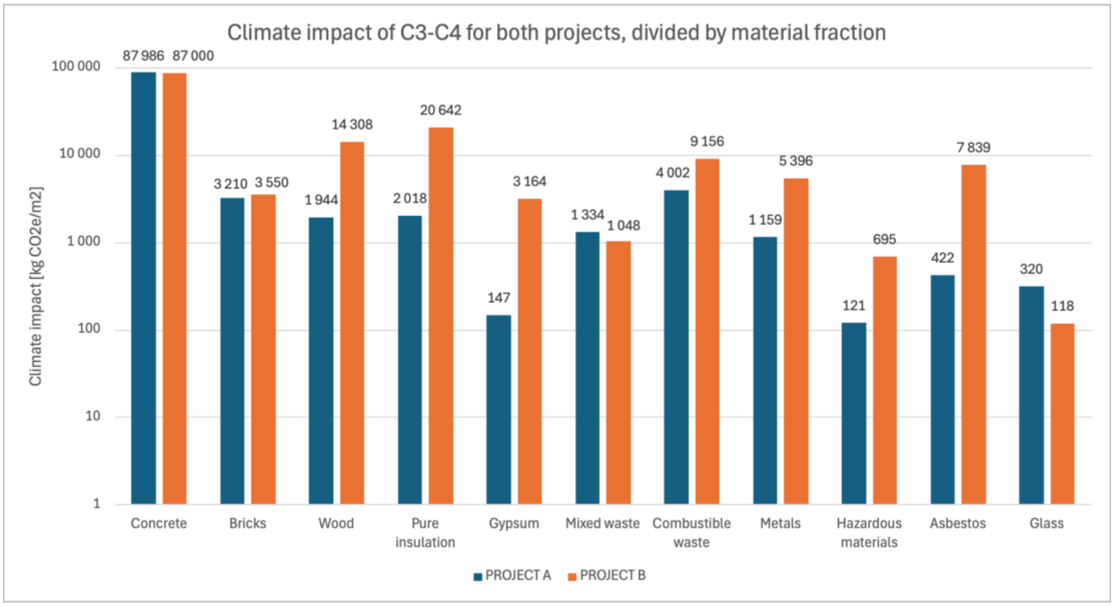


Figure 17: The climate impact of C3-C4 for both projects, in regards to material fraction

4.7 Comparison of results C1-C4

The total climate impact of module C for both projects is illustrated in Figure 18. Since the impact of C1 was calculated through two approaches, two totals are presented for each project. As aforementioned, the impact calculated with the machine hours approach is higher and therefore increases the total impact of module C. For project A, the total climate impact was calculated to 25,04 – 28,88 kg CO_2e/m^2 GFA whilst the impact of project B is slightly lower at 20,44 – 25,33 kg CO_2e/m^2 GFA.

Furthermore, the relationship between the submodules differs slightly between the two projects. In project A, sub-module C1 accounts for the largest impact regardless of calculation approach, followed by C3-C4. In contrast, sub-module C1 only accounts for the largest share of impact in project B when the machine hours approach is used. If the IVL approach is applied for C1 in project B, the impact is so low that C3-C4 instead is the largest share. For both projects, sub-module C2 accounts for the smallest share of climate impact.

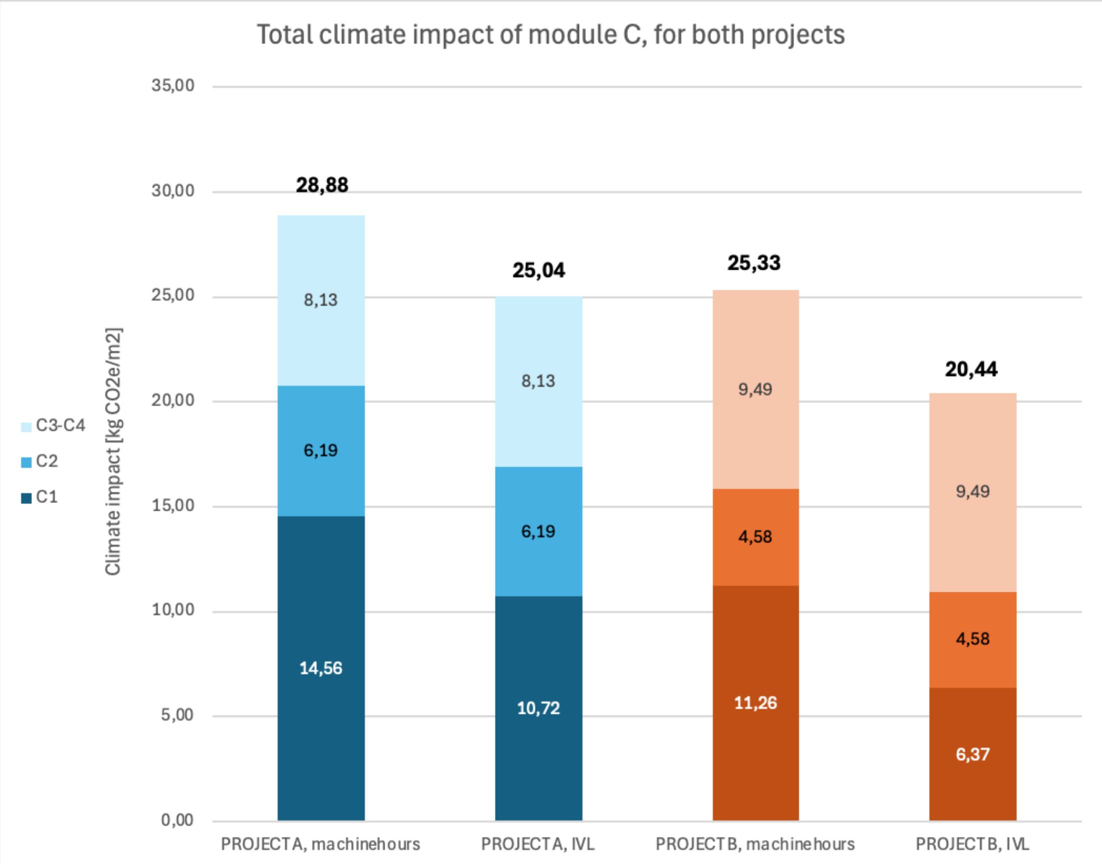


Figure 18: Climate impact of the whole module C (C1-C4), for both projects. Results are presented with C1 according to the IVL approach as well as the machine hours approach.

4.8 Sensitivity analysis

Transported distance

Project A and B have almost identical amounts of demolished concrete, 14 664,31 and 14 500 tons respectively, however the emissions from the transport of concrete waste differ significantly. As seen in Figure 19, the climate impact of transports of concrete from project B is approximately a fourth of the impact in project A.

The difference between the projects lies in the transported distances. In project A, concrete waste was sent to two different facilities 27 and 67 kilometers from the demolition site. On the contrary, the concrete waste from project B was stored on-site, awaiting further use and the estimated distance of future transport was set to 10 kilometers. Figure 19 illustrates how the distance of transports impact the results. It can also be seen that the impact of the two transported distances in project A is almost the same, even though the transported weights differ. Only a third of the total amount of concrete from project A is transported the longer distance of 67 kilometers, but this material accounts for half of the climate impact. These results indicate that the climate impact of C2 is highly sensitive to the distance of transports. Thus, approximated distances can be a cause of uncertainty in the calculation of this module and the complete module C.

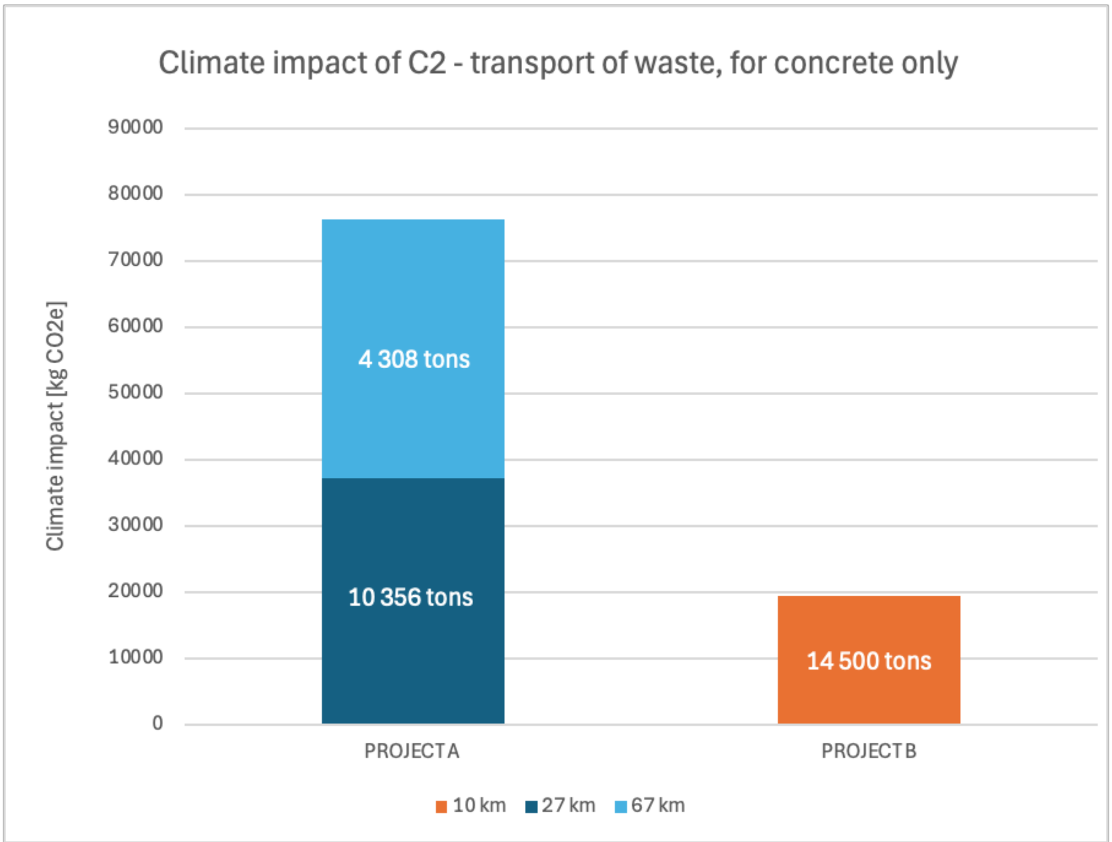


Figure 19: The calculated climate impact of C2 for concrete only, illustrated with transported distances and total weights.

Transport fuel type

In relation to fuel type, Figure 20 presents the climate impact of module C2 – transport of waste, computed for three scenarios of different fuel compositions. It can be observed that by exchanging diesel for HVO100 in half of all transports, the climate impact decreases by around 40% and if HVO100 is utilized in all transports the impact decreases by around 80%. These results imply that the climate impact of C2 is sensitive to the fuel utilized.

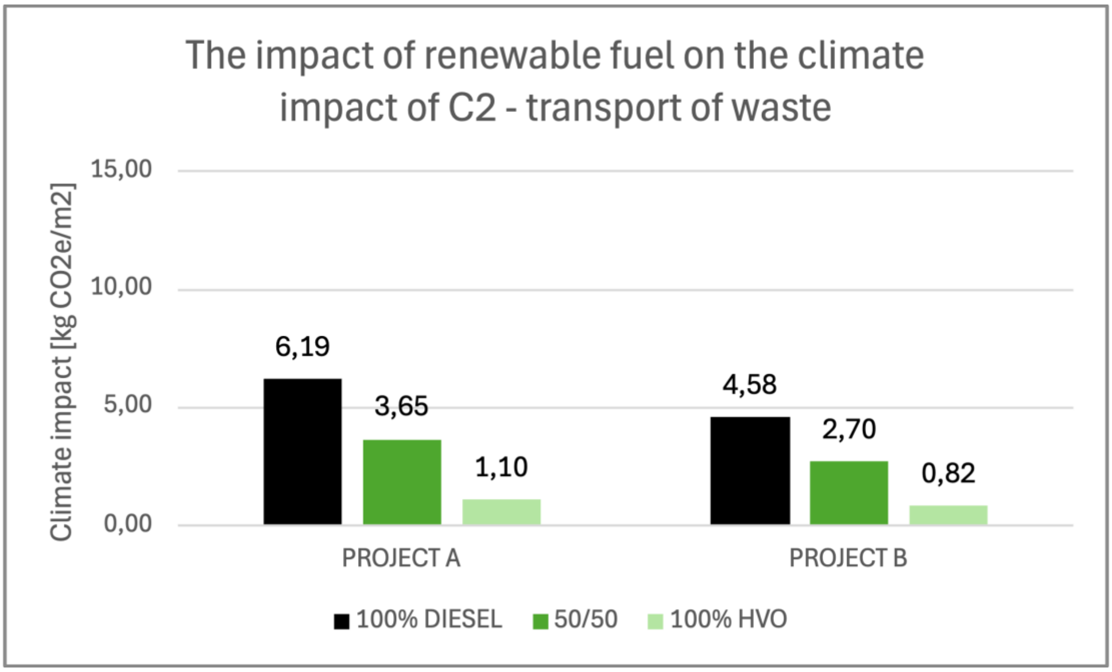


Figure 20: The climate impact of C2, depending on fuel type

Demolition energy carrier

The climate impact of C1- deconstruction and demolition was, through IVL approach, calculated through two scenarios. Firstly, with all processes run by diesel and secondly with initial demolition works run on electricity. As seen in Figure 21, replacing diesel with electricity decreases the climate impact by approximately 3 $kgCO_2e/m^2$ for each project. The results indicate that replacing some fuel on-site to electricity can have a significant impact on the climate impact.

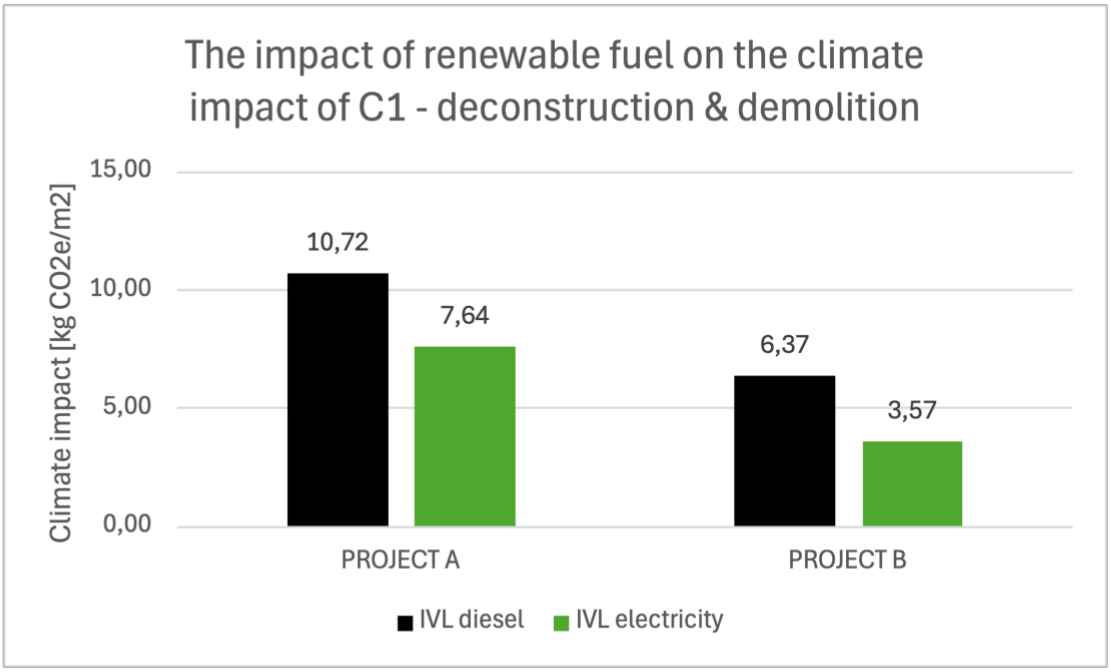


Figure 21: Climate impact of C1, in regards to energy carrier for on-site demolition works

Combined impact of fuel type for transport and on-site demolition

The above presented results indicate that a transition towards renewable fuels for transport of waste and on-site demolition can decrease the total climate impact of module C. The scenarios in Table 14 were computed to asses the implications of changing fuels in C1 and C2, C3-C4 values were baseline for all scenarios.

Table 14: Compiled scenarios for the complete module C

Scenario	C1	C2
Baseline	IVL approach 100% diesel	100% Diesel
1	IVL approach 100% diesel	50% HVO100
2	IVL approach, electricity for initial demolition works	100% Diesel
3	IVL approach, electricity for initial demolition works	50% HVO100

As seen in Figure 22, exchanging a fraction of diesel for greener alternatives in C1 or C2 has a similar impact on the overall climate impact. The impact of replacing diesel for electricity in C1 – deconstruction and demolition is slightly larger than replacing 50% of transports with HVO100. If greener fuels are utilized in both modules, the overall climate impact can be decreased by around 6 kg CO_2e/m^2 GFA for both projects. The decrease accounts for approximately 20% for project A and 30% for project B. If the computed scenarios, only 50% of transports are run by HVO100, if a larger fraction of diesel is replaced the impact would decrease even more.

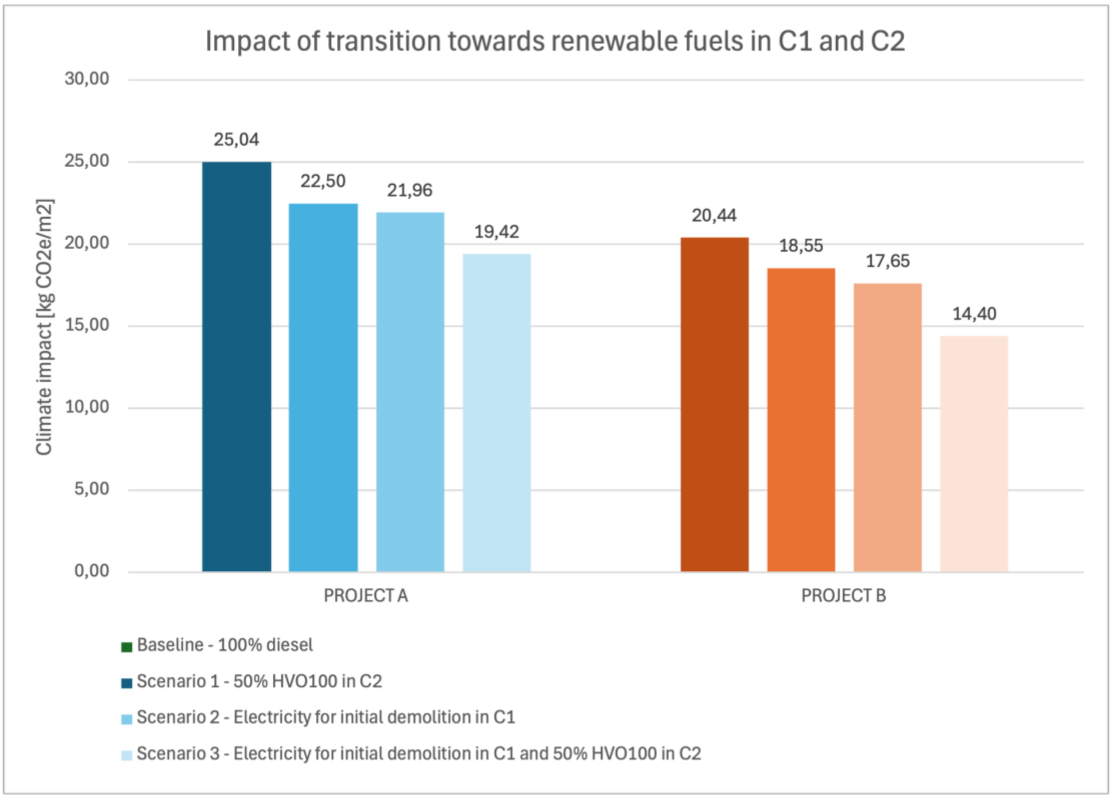


Figure 22: Computed scenarios with other fuels for C2 and C1

5 Discussion

The following chapter provides a discussion of the results. First, the results are put into the context of previous research. Thereafter, practical implications as well as uncertainties and limitations of the study are discussed. Lastly, recommendations for future research are presented.

5.1 Comparison of results to previous research

It is difficult to compare the results of this thesis with previous research as there is a lack of similar studies, particularly in Sweden. The total climate impact of module C was in this thesis estimated to the range 25 – 29 kg CO_2e/m^2 GFA for project A and 20 - 25 kg CO_2e/m^2 GFA for project B. The most relevant study for comparison was conducted by Larsson et al who utilized a similar method and concluded module C to account for a climate impact of 22 kg CO_2e/m^2 GFA for a concrete building.

There are few previous studies that report the climate impact of all submodules separately which inhibits accurate comparison. The Finnish database CO2data reports a default value of 10 kg CO_2e/m^2 GFA for module C1, which is within the range calculated in this study for C1. However, the same database reports values from other studies or demolition contractors ranging from 2,62 – 29 kg CO_2e/m^2 GFA. Furthermore, in this thesis, the energy consumption for building demolition was estimated to 30-40 kWh/m^2. On the contrary, a common estimate in Swedish studies regarding buildings is 10 kWh/m^2 for demolition (Adalberth, Kuikka, Gustavsson). This indicates large uncertainties in the calculation of sub-module C1.

For sub-module C2, a Swedish study estimated the climate impact of a concrete building to 4,37 kg CO_2e/m^2 GFA which is very close to the value estimated in this thesis for project B (4,58 kg CO_2e/m^2 GFA) (Pettersson). For C3-C4, previous research is even more limited. However, the calculated climate impact correlates to the estimation by Petrovic who also concludes C3-C4 to be the largest contributor with 8,3 kg CO_2e/m^2 GFA.

5.2 Practical implications

In relation to the climate impact of a building's complete lifecycle, the estimated climate impact of module C is small but not insignificant. A Swedish reference value for the climate impact of new construction is 263 kg CO_2e/m^2 GFA (Malmqvist et al., 2023). If put into this context, the climate impact of module C is approximately 10% of the impact of construction. The main driver of the climate impact of module C is the weight of demolished material, which cannot be affected. However, the results indicate that there are some factors during a building's end-of-life stage which can be changed to decrease the climate impact.

In this study, module C2 – transport of waste was identified as the smallest contributor to the climate impact of module C. However, it is also the module where it is easiest to apply effective mitigation strategies. Transitioning to HVO100 has the ability to decrease the climate impact of C2 by up to 80%, significantly impacting the overall climate impact. Furthermore, decreasing the transported distances for heavy material fractions can significantly decrease the climate impact of this module. As indicated, in project B the concrete was crushed on-site and the calculation performed with an estimate of 10km of possible future transports. Reusing concrete or utilizing it as backfilling material on-site has the potential to eliminate majority of the climate impact of C2- transport of waste.

Similarly to C2, the climate impact of sub-module C1 – deconstruction and demolition can be decreased by substituting fuels. However, the transition towards electric demolition machines is dependent on the availability and technological advancements. In contrast to C1 and C2, the climate impact of sub-modules C3-C4- waste processing and disposal are difficult to mitigate. The climate impact of this sub-module is dependent on processes at waste management facilities which are not subject to change. Furthermore, when assessing waste management processes there are oftentimes more environmental impacts which should be considered. For instance, the generic data for C3-C4 used in this study indicates that for gypsum, material recycling is a more emission intensive process than landfill. However, recycling gypsum will have positive implications in a future product system.

5.3 Uncertainties

This study is subject to several uncertainties which should be considered when interpreting the result. The main uncertainties are related to the use of generic emission factors, assumptions during calculations as well as data availability and data quality.

The lack of Swedish generic emission factors for processes during C1 and C3-C4 affects the accuracy of the results. The calculation of these modules was mainly done by applying data from the Finnish database CO2data. In some cases, especially concerning C3-C4, it is unclear how the data in the database was procured. This causes uncertainty especially in the results of C3-C4 as the waste management processes may differ between Sweden and Finland both in terms of activities and utilized fuels.

The results indicate that the climate impact is highly sensitive to the transported distances, however there is some uncertainty in the estimation of distances in this study. The transport distances were measured in Google Maps but it is possible that trucks may have driven other routes and the exactness of distances used in calculations is therefore uncertain. Furthermore, it is difficult to assess the accuracy of the acquired transport data in regards to the system boundary. According to EN 15987, all transports from the demolition site until end-of-waste are to be included, including intermediate locations. However, the provided project documentation only states the location that waste was driven from the demolition site. In some cases, this distance may be to the final waste management whilst in others material waste may be transported further after this point.

The level of detail in the acquired data varied between both the projects, and the sub-modules C1-C4. Demolition contractors are required by Swedish law to report the amount of produced demolition waste. Therefore, the amount of demolished material was detailed in the provided project documentation. In terms of transport data, most documentation included the location of waste management sites but did not specify the exact transported distance. The largest data gap was identified concerning sub-module C1 – deconstruction and demolition. The provided project documentation did not include any information on the amount of machines at the demolition site or their utility. As the machinery on site is the main driver of the climate impact of C1, this lack of data greatly affects the calculated result.

5.4 Allocation of climate impacts in relation to practice

Current LCA frameworks imply that module C impacts belong to the demolished building, however this approach may not align with how climate impacts are handled in practice in the construction sector. Current regulation for declaring the climate impact of module C proposes scenario based estimations, which can be difficult to conduct and are based of off assumptions. The results of this thesis indicate that, regardless of uncertainties, the climate impact of module C is possible to estimate post demolition when project specific data becomes available. However, estimating the climate impact of module C post demolition raises the question on where the impact should be allocated.

In both case studies examined in this project, buildings were demolished to enable construction of new ones. Especially in project A, where the construction of the new building commenced closely after the demolition. In this case, module C may not only be regarded as the first buildings end-of-life but also the beginning of the new building. This raises the question of whether module C should be interpreted as an impact of the existing building or as part of a broader system of building replacement and material cycles. For property owners and developers undertaking replacement projects, it may be more reasonable to allocate the impact of module C to the new building. In contrast, in cases such as project B where demolition is the only activity occurring, it may be reasonable to report the climate impact constrained to that project. As these two case studies illustrate, the most reasonable approach to allocation may differ depending on the nature of the project, suggesting that a single allocation convention may not be sufficient for all situations. The choice of system boundary significantly influences the results of assessments and remains an area where clearer methodological guidance is needed.

5.5 Limitations and recommendations for future studies

The scope of this study was limited to module C of a building's lifecycle and therefore excluded any impacts which are commonly allocated to other modules. As per EN 15987, module D includes potential future environmental impacts or savings beyond the building's lifecycle. In both case studies reviewed in this thesis, many material fractions were recycled. Additionally, both projects applied selective demolition and deconstructed building components for reuse. Due to the scope of this thesis, the positive effects and potential savings from circular strategies was not regarded. It would therefore be of interest to expand the scope in future studies to examine the potential environmental savings of recycling and reusing these materials.

Especially concerning cases such as gypsum in this study, where recycling resulted in a higher climate impact in the regarded lifecycle modules.

Furthermore, this study only assessed two buildings and is therefore limited to these two. To facilitate the development of a general key figure, similar studies should be conducted for a larger number of buildings. It is essential that these studies also include and report all sub-modules separately in order to increase the comparability of results. Additionally, to facilitate accurate estimation of transport distances it would be of interest to map the available waste management facilities in Sweden to examine if there are significant differences geographically. Lastly, the main research and data gap identified concerns sub-module C1- deconstruction and demolition. To enable consistent future assessments of the climate impact of module C, it is essential that on-site activities are studied in detail. The development of more comprehensive estimates of machine hours and datasets for C1 would reduce uncertainties in future assessments.

6 Conclusions

The aim of this thesis was to assess the scale, drivers and distribution of climate impacts associated with building demolition activities and how these impacts are allocated within current LCA frameworks. The total climate impact of module C was estimated to 25-29 kg CO_2e/m^2 GFA for project A and 20-25 kg CO_2e/m^2 GFA for project B. If put into the context of previous reference values, the impact corresponds to approximately 10% of the climate impact of construction, indicating that end-of-life impacts are small but not negligible. Across both projects, sub-modules C3-C4 – waste processing and disposal were identified as the largest contributors, while C2 – transport of waste was the smallest. However, C2 was also identified as the sub-module where mitigation is the most feasible. Substituting only half of the fuel for HVO100 significantly decreases the climate impact of C2.

Concrete was identified as the main driver of climate impacts across all examined sub-modules C1-C4, indicating that the results are dominated by the largest, and heaviest material shares. Therefore, mitigation strategies should be focused on these material shares. Additionally, estimations on the climate impact of future demolition projects should focus on accurately estimating the impacts from these material shares as they will dominate the overall impact.

The results highlight several uncertainties, stemming from the use of generic emission factors, estimated transport distances and limited project documentation. The largest data-gap concerns on-site machinery during demolition, which is the main driver of the climate impact of C1- deconstruction and demolition but not documented in either case study. Other uncertainties concern assumptions made in calculations and lack of available, detailed data.

The question of how module C should be allocated and reported remains to be resolved. Under EN 15978, end-of-life impacts are allocated to the demolished buildings. However, given that demolition is often undertaken as part of a new construction project, this convention may not reflect how impacts are managed in practice. Whether it is more appropriate to allocate module C to the demolished building, the new building or separately is a question that warrant further consideration.

To improve the accuracy of future assessments, several factors should be further investigated in. Studies covering a larger number of buildings are needed to further validate the results of this study and establish representative key figures on the climate impact of module C-end-of-life. Furthermore, research and collection of data regarding on-site demolition activities are essential to reduce uncertainties in calculations of C1-deconstruction and demolition. Accurately accounting for the climate impact of building demolition remains a methodological challenge, and continued research into data availability, allocation principles and calculation methods is essential to enable consistent and reliable assessments in the future.

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Appendices

Appendix A – Material quantities

Table 15: Detailed Inventory of quantities of demolished materials for project A

Material fraction	Total weight [Ton]	Percentage of total documented weight [%]	Material intensity [Ton/m2]
Concrete	14 664,31	89,41	1,16
Bricks	642,00	3,91	0,05
Metals	579,41	3,53	0,05
Combustible waste	200,12	1,22	0,02
Wood	97,20	0,59	0,01
Gypsum	86,61	0,53	0,01
Mixed waste	66,72	0,41	0,01
Insulation	35,40	0,22	0,00
Glass	16,00	0,10	0,00
Hazardous materials	13,46	0,08	0,00
Total	16 401,23		

Table 16: Detailed Inventory of quantities of demolished materials for project B

Material fraction	Total weight [Ton]	Percentage of total documented weight [%]	Material intensity [Ton/m2]
Concrete	14 500,00	71,33	0,90
Metals	2 603,83	12,81	0,16
Wood	715,42	3,52	0,04
Bricks	710,00	3,49	0,04
Gypsum	687,90	3,38	0,04
Combustible waste	457,78	2,25	0,03
Insulation	362,14	1,78	0,02
Hazardous materials	172,27	0,85	0,01
Mixed waste	109,66	0,54	0,01
Glass	5,90	0,03	0,00

"Other waste"	2,98	0,01	0,00
Total	20 327,88		

Appendix B – Distances of transports and waste management

Transported distances for project A as well as applied waste management strategies are presented in Table 17. If not stated otherwise, all distances were measured in Google Maps from demolition site to waste management site as described in section 3.3.1.

Table 17: Detailed inventory of waste strategies and transported distances for project A:

Material fraction	Distance (km)	R&D code	Waste management strategy	Comment	Weight (tons)
Concrete	26,6		Not specified		10 356,37
Concrete	67,3	R5	Material recycling		4307,94
Bricks	6		Reuse		214
Bricks	10		Not specified		428
Wood	7,5	R1	Incineration with energy recovery		97,2
Pure insulation (mineral wool)	7	D1	Deposition into or onto land		31,86
Pure insulation (mineral wool)	7,5	D1	Deposition into or onto land		3,54
Gypsum	7	D1, R13	Deposition into or onto land, storage of wastes pending further waste management operations		86,61
Mixed waste	7	R12	Exchage of wastes pending further waste management operations		66,72
Combustible waste	7	R1	Incineration with energy recovery		200,12
Metals	6,2	R4	Material recycling		238,42
Metals	6,2	R4	Material recycling		340,99
Hazardous materials	6,2	R4	Material recycling		5,54
Hazardous materials (asbestos)	10,8	D1	Hazarduous waste landfill		1,95
Hazardous materials	7,5	R4, R13	Material recycling, storage of wastes pending further waste management operations		0,509
Hazardous materials (asbestos)	98	D1	Hazarduous waste landfill		5,46
Glass	10	R5	Material recycling		16

Transported distances for project B as well as applied waste management strategies are presented in Table 18. If not stated otherwise, all distances were measured in Google Maps from demolition site to waste management site as described in section 3.3.1.

Table 18: Detailed inventory of waste strategies and transported distances for project B

Material fraction	**Distance (km)**	**R&D code**	**Waste management strategy**	**Comment**	**Weight (tons)**
Concrete	10		Not specified	The concrete is stored on site, to possibly be used as backfilling material in future projects. 10km is an estimation of distance if/when transported.	14 500
Bricks	10		Reuse / not specified	The bricks were stored on site, some were reused in a local project. 10km is an estimated distance if/when transported.	710
Wood	10,9		Not specified		715,42
Pure insulation	8,3	D1	Deposition into or onto land		362,14
Gypsum	8,3	R5	Material recycling		84,48
Gypsum	882	R5	Material recycling	Transported to the main facility of effective gypsum recycling, located in central Sweden.	398,04
Gypsum	1,5	R5	Material recycling		205,38
Mixed waste	8,3	D1	Deposition into or onto land		18,38
Combustible waste	8,3	R1	Incineration with energy recovery		457,78
Metals	6,9	R4	Material recycling		2603,82
Metals	10,9	R4	Material recycling		0,178
Metals	54,3	R4	Material recycling	Transported to a facility in a different city in Northern Sweden.	2,8

Metals	54,3	R4	Material recycling	Transported to a facility in a different city in Northern Sweden.	91,28
Hazardous materials	1,5		Not specified		0,5
Hazardous materials	8,3		Not specified		33
Hazardous materials	10,9		Not specified		1,25
Hazardous materials (Asbestos)	37,1	D1	Hazarduous waste landfill		137,52
Glass	8,3	R5	Material recycling		5,9

Appendix C – Generic data

Table 19: Emission factors for energy carriers, utilized in C2 and C1

Energy carrier	Energy [MJ/ liter]	Emission factor [kg CO_2e / MJ]	Emission factor [g CO_2e/kWh]	Source
Diesel	35,8	0,0899	-	(Boverket, 2026a)
HVO100	34,1	0,016	-	(Boverket, 2026a)
Electricity	-	-	59	(Nina Chi Johansson & Annamaria Sandgren, 2026)

Table 20: Generic data on machinery used on-site for C1- deconstruction and demolition as well as transport energy consumption for C2

	Value	Unit	Source
Fuel consumption	35	l/h	(Kuikka, 2012)
Utility	9	Demolished Tons/h	Correspondance with NKR
Transport energy consumption	1.5	MJ/tkm	(Swedish Environmental Research Institute, 2024)

Appendix D – Calculated values from previous studies

Table 21 presents a summary of calculated values, units and some methodological assumptions identified in previous research which was presented in section 2.6 – Previous research.

Table 21: Calculated climate impacts of modules C1-C4 from previous research

Scope	Climate impact	Functional unit	Source	Comment
C1-C4	9	A_{temp}	(Larsson et al., 2016)	Swedish wooden house, calculated according IVL guidelines.
C1-C4	23	A_{temp}	(Liljenström et al., 2015)	Swedish concrete structure, calculated according to IVL guidelines.
C1	10,3	m^2 GFA	(Pettersson & Talback, 2026)	Swedish concrete structure and wooden structure. Assumes demolition to be equally as energy intensive as construction.
C2	4,3706	m^2 GFA	(Pettersson & Talback, 2026)	Swedish concrete structure
C2	0,5945	m^2 GFA	(Pettersson & Talback, 2026)	Swedish wooden structure
C1	3	m^2 GFA	CO2data.fi	A study by Bozdag and Secer
C1	2,62	m^2 GFA	(Coelho & De Brito, 2012)	Process based LCA, "top down" approach utilizing data from contractors.
C1	6	m^2 GFA	CO2data.fi	Calculated for concrete, using data from EPDs.
C1	10	m^2 GFA	CO2data.fi	Default value.
C1	15	m^2 GFA	Delete Oy, retrieved from CO2data.fi	Method and input data not specified.
C1	22	m^2 GFA	Delete Oy, retrieved from CO2data.fi	Method and input data not specified.
C1	29	m^2 GFA	Delete Oy, retrieved from CO2data.fi	Method and input data not specified.

C1	7	m^2 GFA	Delete Oy, retrieved from CO2data.fi	Method and input data not specified.
C1	11	m^2 GFA	Delete Oy, retrieved from CO2data.fi	Method and input data not specified.
C1	2	m^2 GFA	Delete Oy, retrieved from CO2data.fi	Method and input data not specified.
C2	3,3	m^2 GFA	(Petrović et al., 2024)	Swedish wooden house, calculated with OneClick LCA
C3	8,2	m^2 GFA	(Petrović et al., 2024)	Swedish wooden house, calculated with OneClick LCA
C4	0,1	m^2 GFA	(Petrović et al., 2024)	Swedish wooden house, calculated with OneClick LCA

Appendix E - Detailed method of gross floor area estimation

Project A
The main building of project A consists of two conjoined buildings. According to a material inventory report carried out before the demolition, the joint demolished building footprint was 1 860m^2. By looking at areal photos, an estimation was made that one of the building's footprint corresponded to 2/3 of the other one. This relationship was used to calculate each building's footprint. The footprint was thereafter multiplied with each building's number of floors to find the gross floor area (GFA), as per equation 10. The GFA of building A was estimated to 8 556m^2

$$GFA = building\ footprint \times number\ of\ floors \tag{10}$$

The footprint of the parking garage was not specified in the acquired project documentation. The parking garage GFA was therefore estimated by measuring the footprint using Google Earth and applying it, together with knowledge of the number of floors, to equation 10. The GFA was estimated to 4 053m^2.

	GFA [m^2]
Main building	8 556
Parking garage	4 053
Total	12 609

Project B
For project B, building plans were provided. To estimate the total GFA of the demolished building, the area of each demolished floor was measured on the building plans. The total demolished GFA was estimated to 16 113m^2.

	Floor area [m^2]
Floor 1	917
Floor 2	10 904
Floor 3	4 292
Total (GFA)	16 113

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