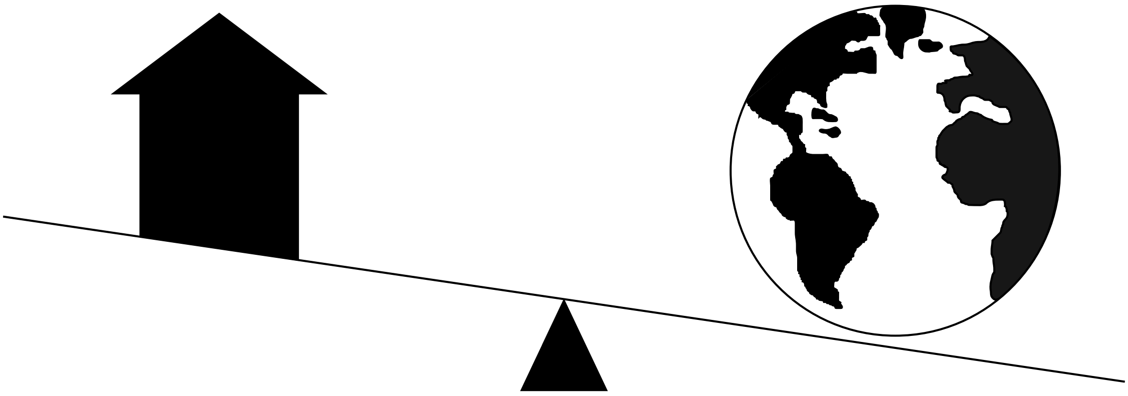

The advancement towards climate neutrality within the Swedish construction industry

- Identification of improvement potentials in relevant disciplines at a consultancy firm

Master's thesis in Design and Construction Project Management

Celine Hagman & Linn Stolt

DEPARTMENT ARCHITECTURE AND CIVIL ENGINEERING

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Cover: An illustration of how the climate impact caused by a building is valued in relation to global warming.

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Abstract

In accordance with the Paris Agreement and Sweden's national climate action plan, the construction industry is to achieve climate neutrality by year 2045. To succeed, all disciplines within the sector need to take responsibility and make considerable actions to reduce their climate impact. Through identifying climate impact reducing measures within the structural, electrical and HVAC engineering disciplines that are suitable for residential building projects, this thesis aims to contribute to the advancement towards a climate neutral construction industry.

The study consists of a literature review, an interview study and a life cycle assessment (LCA). The literature review resulted in suggestions of several measures of reducing climate impact. The measures were discussed and evaluated both through an interview study and an LCA. The interview study encompassed interviews with two environmental coordinators and one representative from each of the studied disciplines. Findings indicated a willingness and need to learn more about climate impact reducing measure and the LCA-methodology.

The LCA was conducted according to the SS-EN 15978:2011 standard, encompassed a time period of 60 years and the system boundary A1-A3, A4, B4-B7, and C1-C4. Through a multiple scenario analysis, the suggested measures were evaluated both individually and collectively. The combined scenario, where green concrete, cellulose insulation, photovoltaic cells, and smart ventilation were incorporated, achieved a reduction of 7.91% in global warming potential (GWP) which corresponds to 80 000 kg CO_2-eq or nine Swedes' annual climate impact.

Results indicate that LCA can induce pro-environmental decision making through comparing different scenarios and identification of environmental impact reduction opportunities throughout a building's life cycle. It was also identified that although widespread implementation of current technologies can contribute to substantial reductions in climate impact, extensive actions of climate compensation are still required to achieve climate neutrality. Thus, mainstreaming of best practices needs to occur in parallel with development of disruptive technologies and innovations to achieve climate neutrality.

Keywords: construction industry, innovation, climate impact, life cycle assessment, knowledge management, measures of reducing climate impact

Den svenska byggsektorns utveckling mot klimatneutralitet
- Identifiering av förbättringsområden med avseende på relevanta discipliner inom ett konsultbolag
Celine Hagman & Linn Stolt
Institutionen för Arkitektur och Samhällsbyggnadsteknik
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Sammanfattning

Enligt Parisavtalet och Sveriges klimatpolitiska handlingsplan ska byggbranschen uppnå klimatneutralitet senast år 2045. För att lyckas måste alla aktörer inom bygg- och fastighetssektorn ta sitt ansvar och vidta omfattande åtgärder för att minska sin klimatpåverkan. Genom att identifiera klimatpåverkansreducerande åtgärder med avseende på disciplinerna Konstruktion, El och VVS, inom det studerade konsultföretaget, vid nyproduktion av bostadsprojekt ämnar det här examensarbetet bidra till utvecklingen mot en klimatneutral byggbransch.

Studien har omfattat litteraturstudie, intervjustudie samt en livscykelanalys (LCA). Litteraturstudien resulterade i ett flertal förslag på åtgärder för att minska klimatpåverkan. Åtgärderna diskuterades och utvärderades både genom en intervjustudie och en LCA. Intervjustudien genomfördes med representanter från de respektive disciplinerna samt två miljösamordnare på det studerade konsultföretaget. Resultaten indikerar att det finns en önskan och ett behov av att lära sig mer om både åtgärder med syfte att minska klimatpåverkan och LCA-metoden.

Livscykelanalysen har genomförts enligt standarden SS-EN 15978:2011 och innefattade en tidsperiod på 60 år samt systemgränserna A1-A3, A4, B4-B7 och C1-C4. Genom en analys av flera scenarier utvärderades de föreslagna åtgärderna både individuellt och i kombination. Det kombinerade scenariot där grön betong, cellulosaisolering, solceller och behovsstyrd ventilation modellerades, uppnådde en minskning på 7,91 % i GWP vilket motsvarar 80 000 kg CO_2-ekv eller nio svenskars årliga klimatpåverkan.

Resultaten indikerar att LCA kan understödja beslutsfattande genom jämförelser av scenarion och identifiering av möjligheter att minska miljöpåverkan under en byggnads livscykel. Det konstaterades att även om storskalig implementering av nuvarande teknik kan bidra till minskad klimatpåverkan, krävs det fortfarande omfattande klimatkompensationsåtgärder för att nå klimatneutralitet. Således måste integrering av bästa praxis ske jämsides med utveckling av disruptiva teknologier och innovationer.

Nyckelord: byggsektorn, innovation, klimatpåverkan, livscykelanalys, kunskapsåterföring, klimatpåverkansreducerande åtgärder

Preface

This Master's thesis was carried out in cooperation with the consultancy firm AFRY and the department of Architecture and Civil Engineering at Chalmers University of Technology during the spring semester of 2021. The initial thesis proposal was created by AFRY and further developed throughout the collaboration. The work corresponds to 30 higher education credits and was supervised by Karin Andersson in support of AFRY, and both supervised and examined by Holger Wallbaum, Full Professor in sustainable building at the Division of Building Technology, on behalf of Chalmers University of technology.
The entirety of the process has been both educational and rewarding, and all the help we received along the way has been invaluable. Therefore, we would like to thank the following, in alphabetical order:

- AFRY - The company in general, and the *Sustainable Building* discipline in particular. A special thanks to Karin Andersson, Kaia Eichler and Jesper Åberg for help, given trust and confidence, and a warm welcome.
- All interview respondents for dedicated time and valuable insights
- Sofie Hammer and Joline Kraemer - For great feedback, and mental support during the process
- Holger Wallbaum - For guidance, support, patience, and unparalleled wisdom

This thesis marks the end of five years of studies, and we would like to express our gratitude towards all our friends and family who have supported and encouraged us throughout.

Celine Hagman & Linn Stolt, Gothenburg, 2021/06/11

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Glossary

AP Acidification Potential, indicator of the potential acidification of soils and water due to emissions of gases such as nitrogen oxides and sulphur oxides. 44, 47, 49

Atemp A Swedish term for the internal area for each floor, attic and basement heated to at least 10 °C. 41, 45

BBR Boverkets Byggregler, the Swedish National Board of Housing Building and Planning's building regulations. 10, 26

BIM Building Information Modelling is a 3D-model-based process that enables architects, engineers and designers to plan, design, construct, and manage buildings and infrastructure projects more efficiently. 36

Bio-CO_2 Biogenic Carbon, the carbon that is stored in biological materials, such as plants or soil. When a bio-based material is used for a building product instead of being incinerated, the absorbed carbon will slowly be re-released to the atmosphere. 44, 45, 47, 48

Carbon Designer A tool in One Click LCA where the software generates a generic building. 37, 43, 52

CAV Constant Air Volume. 25

CML-IA 2012 A method for the life cycle impact assessment which regulates quantitative modelling to the early stages to limit uncertainties. Results are grouped in midpoint categories. 14, 44, 51, 85

DCV Demand Controlled Ventilation. 25, 42, 61, 88, 90

DOI Diffusion of Innovation. 31, 33, 38, 39, 63, 79, 85

EP Eutrophication Potential, indicator of the enrichment of the aquatic ecosystem with nutritional elements due to emissions of nitrogen or phosphor. 14, 44, 45, 47–49

EPD Environmental Product Declaration, commonly have a validity of five years and are produced on life cycle assessment calculations. 7, 10, 15, 37, 44, 51, 52, 54, 62, 68, 69, 74, 82, 84, 85, 89, 91, 92

FTX Exhaust and supply air ventilation with heat recovery. 25, 42, 61, 71, 88, 90, 91

GHG Green House Gas, any gas that has the property of absorbing infrared radiation emitted from the Earth's surface and reradiating it back to the surface of the Earth, thus contributing to the greenhouse effect.. 5, 6, 10, 16, 17

GWP Global Warming Potential, indicator of global warming potential due to emissions of greenhouse gases. v, vi, 14, 15, 44–47, 49, 54, 68, 70

HVAC Heating, ventilation, and air conditioning. v, 2, 3, 24, 27, 35, 39, 53, 54, 59–64, 71–73, 77, 84, 89

HWD Hot Water Distribution. 26, 61, 71, 88, 90, 91

KJ-analysis A method used to categorise large quantities of data also known as affinity mapping devised by Jiro Kawakita in the 1960s. 13, 39, 54, 85

LCA Life Cycle Assessment or Life Cycle Analysis. v, vi, 2, 7, 10, 13–17, 27, 35–38, 40, 41, 43, 48–52, 54, 60–62, 67–75, 77, 78, 82, 84, 88, 90–92

LCCA Life Cycle Cost Assessment. 54, 92

LCI Life Cycle Inventory. 14

LCIA Life Cycle Impact Assessment. 14, 85

NHWD Non-hazardous Waste Disposed, the amount of waste disposed that stems from raw material extraction, manufacturing, supply processes, and end of life-processing. 44, 45, 47–49, 70

ODP Ozone layer Depletion Potential, indicator of emissions that cause the destruction of the stratospheric ozone layer. 44, 47–49

One Click LCA A software used for life cycle assessments of buildings and infrastructure projects. 37, 43, 44, 50–52, 69, 85

Paris Agreement A legally binding international treaty on climate change adopted by 196 parties during the UN Climate Conference in 2015 in Paris. v, 1, 82

POCP Photochemical Ozone Creation Potential, indicator of emissions that affect the creation of photochemical ozone in the lower atmosphere (smog) catalysed by sunlight. 44, 47, 49

ReCiPe A method for the life cycle impact assessment. ReCiPe assesses environmental impact based on 18 midpoint indicators which are then grouped into three endpoint indicators. 14, 51, 85

SGBC Sweden Green Building Council. 6

SLCA Social Life Cycle Assessment. 92

Solibri A software used for model checking, clash detection and information takeoff. 36, 43, 52

VAV Variable Air Volume. 25, 42, 61, 88, 90

1 Introduction

In 2015, 196 parties signed an international treaty now known as the Paris Agreement (United Nations, 2016). This legally binding agreement spurred the occurrence of many climate actions plans on both national- and industry levels. Sweden introduced a new climate statute in 2018 and The Swedish Building and Construction Industry (2018) released their plan for a climate neutral construction industry by year 2045 with the support of many key actors in the industry (Miljödepartementet, 2017) (Löfven & Lövin, 2019). Furthermore, the new law on climate impact declaration commences in 2022, and in 2027 limit values will be introduced (Boverket, 2020b).

The construction industry is known for its traditional way of work and complexity (Dubois & Gadde, 2002). Global warming affects every country on every continent, it disrupts national economies and affects lives (United Nations Environment Programme, 2019). Urgent actions are required to address the climate crisis. Thus, it is no longer acceptable to consider the long-established ways of working in the construction industry as an excuse for not improving. It has already been confirmed that the 1.5 °C pledge is likely to be overrun if immediate actions are not taken. Furthermore, it was reported by the UN (2019) that we are well on our way to a 3.2 °C temperature increase by the end of the century, which would result in mass extinction and make large parts of the planet uninhabitable.

The construction industry needs to take responsibility as one of the largest contributors to climate change worldwide (World Green Building Council, 2017). Trials and testing of alternative methods and materials has been going on ever since the environmental movement of the 1960's, but no major changes have been made in the way we design or build today (Coma Bassas, Patterson, & Jones, 2020). This phenomenon demonstrates both the stubbornness of the industry as well as the difficulties in diffusing an innovation from the innovator to the masses mentioned in Rogers (1962) law of diffusion of innovation. Furthermore, it is equally important to diffuse knowledge between actors as it is to spread lessons learnt within the organisation.

Hence, this thesis investigated how a consulting company can better align their operations to their vision and mission *"Making future - We accelerate the transition towards a sustainable society"* (AFRY, 2021a). As the second largest consultancy company within the Swedish construction industry, the studied organisation has a lot of influence over the Swedish market, putting them in a position to act as an active change agent towards a sustainable society (Alla Bolag, 2021). Therefore, this thesis also investigated improvement areas for the studied consultancy firm's advancement towards their vision. In particular, the Sustainable Building section accompanied with the three disciplines: Structural Engineering, Electrical Engineering, HVAC Engineering were examined.

According to a study by the International Energy Agency (2020), which included indirect emissions from upstream power generation, buildings were responsible for 28% of global energy-related CO_2 emissions in 2019. To reduce this impact, new measures need to be identified and their efficiency evaluated. Life cycle assessment (LCA) is a common methodology for calculation of the total climate impact caused by the product, process, or building.

Furthermore, Boverket (2018a) highlighted the importance of research concerning measures of reducing climate impact. Thus, an LCA of a conventional residential building in Sweden was performed with the aim of comparing the potential of different climate impact reducing measures within the structural engineering, electrical engineering, and HVAC engineering disciplines.

1.1 Purpose and aim

The purpose of this thesis is to contribute to the advancement towards a climate neutral construction industry. The aim of the study is both to identify climate impact reducing measures within the structural engineering, electrical engineering, and HVAC engineering disciplines, that are suited to be recommended by the studied firm's consultants in residential building projects, and to shed light on the underlying obstacles that hinder this from transpiring.

1.2 Research questions

To fulfil the aim and purpose of this study the following research questions were formulated:

- *What are the current methods used within the structural engineering, electrical engineering, and HVAC engineering disciplines to reduce environmental impact with a focus on global warming potential?*
- *Which solutions, actions, and methods of reducing climate impact does the studied consultancy firm have the potential to implement in the design process of residential buildings?*
- *What competence and expertise regarding climate impact reducing measures currently exists within the respective disciplines at the studied consultancy firm, and what needs to be strengthened?*
- *How can a life cycle assessment induce pro-environmental decision making during the design process?*

1.3 Delimitations

The following topics have not been covered by the study:

- disciplines other than structural engineering, electrical engineering, and HVAC engineering
- projects where the environmental coordinators collaborate with engineers from external organisations
- interviews with representatives from actors other than the consultants
- construction project stages other than the design phase
- life cycle stages A5, and B1-B3 in the life cycle assessment (see figure 3.2)
- interpretation analyses: decision-maker analysis, variation analysis, and sensitivity analysis in the life cycle assessment (see section 3.1.2)
- monetary costs or expenses

1.4 Contributions

There is a pressing need for further research on how the construction industry can reduce its climate impact. Furthermore, findings need to be evaluated and enforced in practice. Through identifying solutions that are suited to be recommended by the studied firm's consultants in residential building projects, this thesis aspires to contribute to both their operations and the industry at large.

Previous research has mainly focused on isolated systems, materials, or atomistic life cycle assessment system boundaries. Since this thesis investigates the effects from a holistic life cycle perspective, it both complements said previous research and contributes to the development towards a climate neutral construction industry.

1.5 Disposition of the thesis

Chapter two comprises the background for the thesis while chapter three contains the theoretical framework. The fourth chapter describes the methodology, the fifth chapter presents the life cycle assessment, and chapter six comprises of the interview study. The succeeding chapter contains the discussion. Finally, the eighth, and last, chapter presents the conclusions. Future research is suggested in section 8.1.

Reading guidelines

Henceforth the general fields of study within structural engineering, electrical engineering, and HVAC engineering will be named as structural engineering discipline, electrical engineering discipline, and HVAC engineering discipline. The specific organisational groups that were studied will be named as *Structural Engineering* discipline, *Electrical Engineering* discipline, and *HVAC Engineering* discipline.

2

Background

The chapter describes key themes within the Swedish construction industry, and acts as a precursor to the literature review.

2.1 Definition of climate neutrality

Several researchers have recognized issues related to the extensive terminology within the field of sustainable construction. Rheude, Kondrasch, Röder, and Fröhling (2021) express that the increasing research upon sustainability in the construction industry over the last decade has not only generated a progression towards a more climate neutral sector, it has also led to the emergence of several specific terms and concepts. Some of which are interrelated which induces misunderstandings and confusion in both the scientific community and the industry.

The definition for climate neutrality used in this report is derived from The Swedish Building and Construction Industry (2018). The definition reads:

> *"Climate neutrality means that all emissions that occur must be able to be absorbed by the ecological cycle or with technical solutions, thus not contributing to the greenhouse effect. In the same sense carbon neutrality is defined as a balance between emission and absorption of GHG however only regarding the emission and absorption carbon"*(European Parliament, 2019).

Finkbeiner and Bach (2021) use the term carbon neutrality as a synonym for climate neutrality. The concepts are based on reducing emissions and sometimes the term net zero GHG emissions to the atmosphere is also used in the same context. Satola, Balouktsi, Lützkendorf, Wiberg, and Gustavsen (2021) interpret this concept as a design target, ambition level, benchmark, or budget for buildings. They also argue that the vision is to reach a state in which buildings throughout their entire life cycle cause minimal contribution to GHG emissions in the atmosphere and, by extension, global warming. They refer to this vision as nearly climate neutral.

Climate compensation

The Swedish Building and Construction Industry (2018) state that the primary strategy is to reduce emissions, but that climate neutrality can also be achieved through using compensatory measures. As some emissions are unavoidable, compensation strategies are crucial to achieve climate neutrality (Finkbeiner & Bach, 2021). Satola et al. (2021) states that there are different perceptions of which compensatory measures are acceptable when aiming for net zero GHG-emission in building projects. Kellner (2020) agrees that determination of acceptable climate compensation measures is often ambiguous but defines a climate compensation as an operation that permanently retains emissions from the atmosphere. According to Finkbeiner and Bach (2021) a life cycle perspective is necessary to fully comprehend the effects of climate compensation measures. Otherwise, there is risk for double-counting, problem-shifting or green-washing.

Urge-Vorsatz et al. (2020) claims that it is possible to achieve net- or nearly-zero energy building outcomes in most building types and climates with current knowledge and technologies. Carbon-negative technologies are currently being explored by the scientific community (Erlandsson, Malmqvist, Francart, & Kellner, 2018). The technologies are mostly based on carbon storage, but knowledge and calculation methods need to be further developed. Erlandsson (2019b) predicts that it will become relevant for material manufacturers to change their manufacturing processes and apply both carbon capture and storage technologies to achieve climate neutral production.

2.2 Environmental certifications in Sweden

To reach climate neutrality within the construction industry, SGBC developed a new environmental certification system called NollCO_2. NollCO_2 considers the entire life cycle of a building and is based on a net zero-balance, meaning that measures of climate compensation are included in the assessment (SGBC, 2021b). Climate impact should be compensated through one or a combination of the following three actions:

- installation of renewable electricity production
- energy efficiency measures in existing buildings
- climate compensation that meets NollCO_2's criteria for environmental integrity

As the manufacturing processes of building components are typically not fossil-free, it is currently impossible to build without any climate impact (SGBC, 2021b). Satola et al. (2021) argues that one precondition in the NollCO_2 certification is that the electricity mix will be carbon-neutral by 2050. Furthermore, the assessment is based on the assumption that the impact of the end-of-life modules C1 and C2 is equal to zero, see figure 3.2 (SGBC, 2021b).

The intention of the NollCO_2 certification is to complement Miljöbyggnad, BREEAM, LEED and Svanen which are the most used certification systems in Sweden (SGBC, 2021b) (Boverket, 2018a). Each certification system has its own characteristics and different assessment categories (Freitas & Zhang, 2018).

Forsberg and de Souza (2021) declare that environmental certifications have been actively developed and used during the past ten years, and that this trend will continue. In figure 2.1 the number of environmental certifications conducted in Sweden for residential buildings per year is presented.

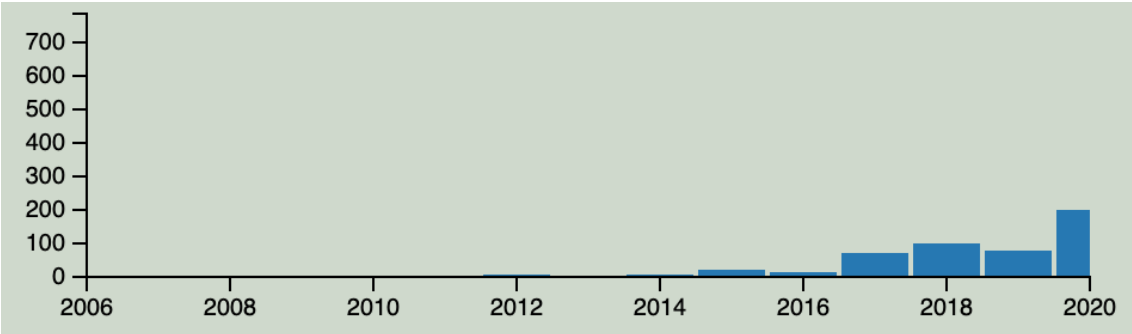


Figure 2.1: Number of environmental certifications conducted in Sweden for residential buildings (SGBC, 2021a). The y-axis describes the number of residential buildings in Sweden that received an environmental certification for each year between 2006 and 2020. The respective years are displayed on the x-axis.

Environmental certifications are considered effective tools that facilitate practitioners to position their products on the market, aiding the choice of sustainable design and construction principles as well as creating a unified understanding concerning quality control for design solutions (Forsberg & de Souza, 2021). Miljöbyggnad, BREEAM, and LEED all require life cycle assessment (LCA) calculations, but with different scopes and criteria (Boverket, 2019).

LCA calculations for buildings are based on either generic data or specific data such as environmental product declarations (EPD) (Erlandsson, 2019b). EPDs are based on product LCAs, which have been produced using third-party reviewed information and developed in accordance with the ISO 14025: 2008 standard (Thrysin, Andersson, & Ejlertsson, 2020). EPDs are available in various databases and have the potential to guide material selection in favour of product suppliers whose products cause lower environmental impact (The Swedish Building and Construction Industry, 2018) (Boverket, 2018b) (Och, 2021).

2.3 Circle of blame and the influence of each actor on environmental impact

It has previously been observed that due to the project-based nature of the construction industry, further characterized by interdependence and complexity, the pace of innovation and change is slower than in most other industries (Gambatese & Hallowell, 2011) (Dubois & Gadde, 2002). Additionally, disputes as to which actor is responsible for driving change and pushing innovation complicates the process of achieving climate neutrality (The Swedish Building and Construction Industry, 2018). Erlandsson (2019b) reveals that industry actors, the client, consultant, architect, and contractor, request clarifications of how they can influence the caused climate impact within a project.

Lützkendorf (2011) and Andelin, Sarasoja, Ventovuori, and Junnila (2015) highlight the debate concerning why sustainability has not yet infiltrated the real estate market and construction industry. However, design principles, technologies and construction products for energy efficient and sustainable buildings have been available for decades (Lützkendorf, 2011). Both Lützkendorf (2011) and Andelin et al. (2015) argue that this is the result of a "vicious circle of blame". The notion is that a tendency to blame on other stakeholders rather than realizing and fulfilling one's own responsibility. According to Andelin et al. (2015), this mentality creates a never-ending circle and the consequences is a slow progression towards a sustainable construction industry.

2.3.1 The client's responsibility and influence

As the end customer of the project, the client possesses considerable power to affect the outcome of the project (Kwok, Lai, Cheung, & Li, 2020). Customer requirements are frequently identified as determining factors for both the overall goal and attitude of the project, as well as the main driver for any innovations within the industry (The Swedish Building and Construction Industry, 2018) (Gambatese & Hallowell, 2011). On the other hand, research by Ivory (2005) showed that client influence can hamper innovation.

Both The Swedish Building and Construction Industry (2018) claims that decisions made in the early stages of the project process heavily influence the building's climate impact. Likewise, Erlandsson (2019b) agrees and has further identified four different ambition levels amongst clients:

- Pursuant to legislation and regulations
- Pursuant to industry customs
- Exceed legislation, regulations, and industry customs
- Set market-leading requirements

Furthermore, the client also decides whether or not an environmental certification will be pursued (Erlandsson, 2019b).

Developers are a type of client that intends to sell the building to a facility manager after construction (Erlandsson, 2019b). Boverket (2018a) highlights the issue that the developers do not consider all long-term ownership aspects which could result in operating costs over time and sustainability not being prioritized.

2.3.2 The contractors responsibility and influence

The contractor is employed by the client and resides over the execution of the project. Subsequently, the contractor has influence over sub-contractors, suppliers, and consultants, and can urge them to innovate and improve the environmental performance of their products and services (The Swedish Building and Construction Industry, 2018). However, the argument of the contractor being unable to act without the client's support or direction was highlighted in a study by Gambatese and Hallowell (2011).

Erlandsson (2019b) states that the contractor can influence the construction project's climate impact in aspects such as avoiding materials or products with unnecessarily high climate impact, choice of suppliers, reducing waste, minimizing transportation, and minimizing environmental impact caused by the construction processes. Erlandsson et al. (2018) suggests using energy efficient establishments and substituting conventional machinery for equipment powered by either electricity or renewable fuels.

2.3.3 The architect's and consultant's responsibility and influence

Contrarily to the notion the client needs to set requirements that encourages and promotes innovative solutions, The Swedish Building and Construction Industry (2018) argues that the architects and consultants need to be the ones to suggest solutions as the client might lack the knowledge needed to set appropriate requirements.The architect has a prominent role to suggest placement of the building, the design and floor plan solutions, all of which have significant impact on the building's environmental performance (Erlandsson, 2019b).

Likewise, the consultant can advise the client regarding design choices and suggest measure to reduce climate impact (Erlandsson, 2019a). However, depending on customer requirements and regulations, the ability to leave such suggestions varies.

The environmental coordinator

According to Gangemi, Malanga, and Ranzo (2000), it is unattainable for the architect to single-handedly manage the building's environmental impact. Instead, the architect should be able to rely on other experts and specialist regarding environmental performance.

Gangemi et al. (2000) claims that in some European countries, environmental consultancy is becoming increasingly important. In 2014, Gluch, Gustafsson, Thuvander, and Baumann (2014) predicted that a new market for specialist and experts within the environmental auditing field was emerging in Sweden.

The environmental coordinator supports the client in establishing requirements regarding environmental performance (Erlandsson, 2019b). The environmental coordinator can also assist with procedures concerning environmental certification and LCA calculations.

The environmental coordinator's influence depends on when they get involved in the project (Erlandsson, 2019b). Early involvement facilitates prioritization of environmental aspects throughout the project.

2.4 Outlook on the National Board of Housing Building and Planning's proposed law for climate impact declaration and limit values

The majority of GHG-emissions from a building's life cycle occur during the construction phase and from energy consumption during the use phase (Boverket, 2021b). Emissions from operating energy are regulated by the energy management requirements in the National Board of Housing, Building and Planning's building regulations (BBR). However, there are no regulations limiting GHG-emissions from the construction phase. The introduction of requirements for a climate impact declaration is a first step in reducing emissions during the construction phase which can contribute to reducing the total emissions during a building's life cycle.

In 2019 the Swedish government commissioned the National Board of House Building and Planning to initiate preparations for the introduction of regulations for climate impact declarations for new buildings (Boverket, 2020b). A part of the commission was to propose a plan for the proceeding expansion of regulation on climate declarations covering the entire life cycle as well as including limit values on climate impact. Regulations for climate declarations are planned to commence in 2022 while the regulations on limit values for climate emissions are to be introduced in 2027.

Earlier in 2021 the National Board of House Building and Planning released a trial version of their database for climate impact declarations (Boverket, 2021a). On June 1st, the final version of the database was introduced. The database uses generic data as it is currently impossible to impose requirements for specific data due to the lack of legal connection between EPDs under SS EN 15804 and the harmonised construction product standards, although generic data can be substituted with EPDs if available. (Boverket, 2020b) (European Commission, n.d.) (SIS, 2019). The National Board of House Building and Planning estimates that this obstacle will be vanquished and that by 2027, it will be possible to impose requirements on product specific data for climate impact declarations (Boverket, 2020b). This would also entail that manufacturers would be required to provide EPDs for all their products i.e., making EPDs a basic requirement for market entry into the Swedish market for construction products.

In addition to the proposal for a new law on climate impact declarations for buildings, amendments to the Planning and Building Act (2010:900) are also proposed (Boverket, 2020c) (Finansdepartementet SPN BB, 2010). The proposals were open for remittances up until the 12th of March earlier this year, after which the government sent them for legal consultation. The upcoming regulations on limit values for climate emissions denotes the maximum allowable climate emissions, thus facilitating the transition towards a climate neutral construction industry by 2045 (Boverket, 2020b). The National Board of House Building and Planning further proposes that the limit values will be gradually lowered in both 2035 and 2043. As the limit values will apply to all actors, regardless of size, within the industry and almost all new buildings, it is deemed reasonable to wait until 2027 to introduce the new requirements even though several major actors are expected to have gained experience and expertise in carrying out similar calculations beforehand.

3

Theoretical Framework

The theory described in this chapter are the results generated by the performed literature study as well as descriptions of the theory behind the research methods used.

3.1 Descriptions of methods and tools

This section contains theory behind the chosen methods as well as brief descriptions of software and tools used.

3.1.1 KJ-Analysis or affinity mapping

KJ-analysis, or affinity diagramming, is an inductive method of categorising large quantities of data which was devised by and named after Jiro Kawakita in the 1960s (Wikberg-Nilsson, Törnlind, & Ericson, 2015) (Spool, 2004). Quotes are extracted and those similar are grouped together. By doing so, connections and patterns of relevant issues or requirements can be identified. Furthermore, the method illustrates how many of the answers concern a certain issue, indicating the importance of that specific problem.

3.1.2 Life cycle assessment

Life cycle assessment (LCA) is a method used to evaluate the cumulative environmental impact associated with the entire life cycle of a product, system, process or service (ISO, 2006). The concept was introduced in the first edition of ISO 14040 created in 1997 where it was defined as:

> *"LCA studies the environmental aspects and potential impacts throughout a product's life (i.e., cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences."*(ISO, 2006).

In 2011, the European standard EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method, was given the status of a Swedish standard (Kommittén för Hållbarhet hos byggnadsverk, 2011).

There are two main types of LCA methods (Finnveden et al., 2009). The attributional method estimates what share of the global environmental burdens belongs to each component or product, while the consequential approach aims to describe how environmentally relevant flows will change in the future in response to possible decisions.

An LCA consists of four steps: goal and scope, inventory analysis (LCI), impact assessment (LCIA), and interpretation (ISO, 2006). These stages are showcased in figure 3.1. The first step defines the goal and scope of the assessment as well as the system boundaries and any assumptions made.

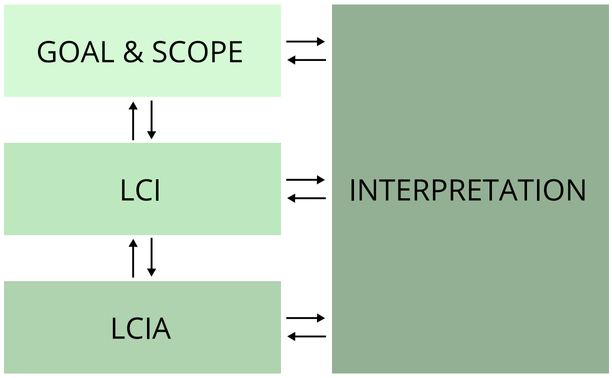


Figure 3.1: Illustration of the four stages of a life cycle assessment, adapted from ISO 14040: 2006 (ISO, 2006).

The inventory analysis, also known as LCI, involves identifying and quantifying all resources used including raw materials, water, and energy (Kommittén för Hållbarhet hos byggnadsverk, 2011). Additionally, all pollutants and substances released to the environment should be quantified. The data collection and quality of said data heavily influences the reliability and accuracy of the assessment, however, is a time consuming and costly task. The results from the LCI can be converted into impacts on different categories, such as global warming potential (GWP) and eutrophication potential (EP), during the third stage, the life cycle impact assessment (LCIA). The LCIA can be calculated using different methods such as either CML-IA 2012 or ReCiPe. Depending on which method is chosen different environmental impact is assessed for different impact categories.

The final stage of the LCA is interpretation (Kommittén för Hållbarhet hos byggnadsverk, 2011). The interpretation is based on the preceding stages and discusses the conclusions and potential recommendations or improvement opportunities in accordance with the goal and scope. The interpretation includes multiple checks and analyses to identify significant issues and test the robustness of the results.

A dominance analysis is performed to investigate which part the life cycle that has the dominant environmental impact, thus indicating which part to focus on when trying to improve the environmental performance (Kommittén för Hållbarhet hos byggnadsverk, 2011). The contribution analysis is similar to the dominance analysis; only the results are not divided according to process but environmental load. The break-even analysis investigates trade-offs of environmental impacts associated to the use of the studied products and systems. As a single company does not have full control over the entire value-chain, a decision-maker analysis examines which stakeholder is responsible for which activity and, by extension, any associated environmental impact.

All the previously mentioned analyses aim to identify significant issues to consider, the following six checks and analyses test the robustness of the results (Kommittén för Hållbarhet hos byggnadsverk, 2011). The purpose of a completeness check is to review any data gaps in the inventory analysis. The consistency check controls the appropriateness of the life cycle modelling and methodological choices made given the defined goal and scope. The data quality assessment evaluates the degree of data gaps, approximations, and appropriateness of data in terms of geographical, temporal, and technical correlation. A study of how each parameter contributes to overall model uncertainty is carried out during the sensitivity analysis. The sensitivity analysis is a type of uncertainty analysis; hence it checks the effect of uncertain data. However, other types of uncertainty analyses exist. The final analysis, the variation analysis, checks the effect of alternative scenarios and life cycle models.

3.1.2.1 System boundaries for construction projects in life cycle assessments

LCAs for buildings are generally based on EPDs and commonly focus on climate impact and GWP, and the life cycle is divided into five stages during the calculations (IVL, 2020) (Kommittén för Hållbarhet hos byggnadsverk, 2011).

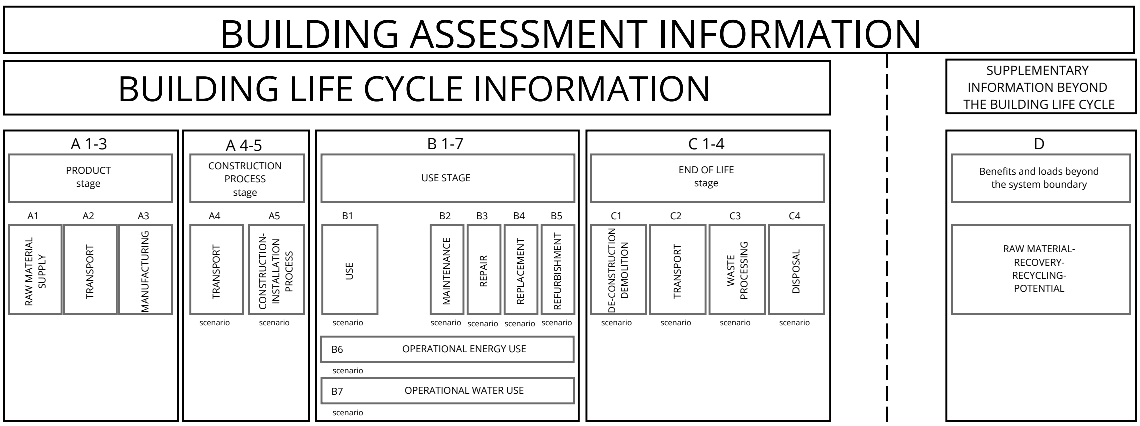


Figure 3.2: Life cycle stages for a building according to the standard SS-EN 15978 (Kommittén för Hållbarhet hos byggnadsverk, 2011).

Figure 3.2 illustrates the entire life cycle of a building, from raw materials to potential reuse, recycling or recovery beyond the system boundary. Stages A1-A3 concern the product phase where raw materials are refined and converted into finished goods (Kommittén för Hållbarhet hos byggnadsverk, 2011). A life cycle analysis which only includes these three stages is called a cradle-to-gate analysis. Stages A4-A5 account for the environmental impact caused during the construction phase. B1-B7 represent the use phase and includes impacts related to maintenance, refurbishment, and operational energy consumption etcetera. The remaining stages C1-C4, and D are generally based on estimations. Furthermore, it is not mandatory to include stage D when conducting an LCA.

3.2 Climate impact reducing measures within the structural engineering discipline

Similarly, Erlandsson and Malmqvist (2018) claims that attention should be directed to the construction and manufacture of building materials which accounts for a sizable climate impact. Further, they mention that although implementation of existing technology can contribute to significant reductions in climate impact, new innovative solutions are also necessary.

Many studies investigating a building's climate impact from a life cycle perspective have been conducted over the last decade (Erlandsson, Petersson, & Jönsson, 2020). The Swedish Building and Construction Industry (2018) requests more research comparing the climate impact caused by different design-, material-, or system choices from a life cycle perspective. However, Erlandsson et al. (2020) points out that it is important to keep in mind that the goal and scope as well as the system boundary of an LCA have significant impact on the results. Thus, a fair comparison of LCAs can be hard to realize.

3.2.1 Structural framework choices and their effect on the building's environmental performance

Ingelhag (2020) states that the foundation and the structural framework constitutes for a significant proportion of the building's total climate impact. A study by Erlandsson et al. (2018) compared the difference in climate impact from five types of structural frameworks. Results showed that the choice of structural framework heavily influences the outcome of a project's climate impact.

Currently, concrete is the primary material used for the framework in residential buildings (Boverket, 2018a). However, recently the use of timber frames has increased. Further, Boverket (2018a) implies that when considering all aspects, none of the framework types outperforms the others, but timber frames generate the lowest carbon emissions. The same conclusion was also reached in a study by Erlandsson et al. (2018).

Boverket (2018a) suggests using bio-based materials as an action for reducing the climate impact from construction materials. Wood is a bio-based, renewable resource which according to Boverket (2018a) does not generate an increase in GHG since wood binds and stores carbon. In a study conducted by Erlandsson et al. (2018) it was concluded that for a building with a lifetime of 100 years where carbon capture is accounted for, a solid timber structure could be considered climate positive. Ingerson (2009) on the other hand, claims that there are uncertainties regarding carbon storage and that wood is not as climate positive as often portrayed.

Erlandsson (2019a) concludes that negative emissions can be obtained by capturing and binding GHG through renewable resources. Erlandsson et al. (2018) defines wood as a temporary carbon capture and highlights its significance to avoid tipping points concerning carbon levels in the atmosphere. Other studies have highlighted the importance of preserving forests and that undisturbed forests have an important function in the carbon cycle (Ingerson, 2009) (Feist et al., 2005). Furthermore, Erlandsson et al. (2018) implies that wood products can have a detrimental effect on the climate and suggests that this issue should be considered from a wider perspective than that of a product, where forests' carbon storage and long-term dynamic effects are included. Leaving forests untouched can lead to more carbon being stored. However, from a societal perspective, the products that the forest provides must be replaced with other products which are often made from non-renewable resources.

Ingerson (2009) claims that increased use of timber products will have very little net effect on climate change. Currently the knowledge and methods for calculations of carbon capture and storage is limited and the generated effect on overall climate impact is therefore uncertain (Ingerson, 2009) (Erlandsson, 2019a) (Kurkinen, Norén, Peñaloza, Al-Ayish, & During, 2017). There is no admitted method for including neither emissions from demolition nor carbon storage in LCAs (Boverket, 2018a) (Kurkinen et al., 2017). Erlandsson (2019a) agrees, but also highlights that research is being made on the topic and that a few methods have recently been developed.

Apart from calculation difficulties regarding caused climate impact, resistance against implementing wood also originates around uncertainty concerning its durability as a construction material (Boverket, 2018a). In addition, Boverket (2018a) also points out that quantities and other attributes are affected when substituting a concrete structural framework with a timber frame. Soundproofing, fire-resistance, and solidity differ between the materials and to fulfil the same standard larger quantities of timber are needed. This thereby generates more material consumption which also has a significant impact on the environment. To fulfil the same requirements on functional performance, alternative design and construction solutions are often necessary (Erlandsson & Malmqvist, 2018) (Erlandsson et al., 2020) (Larsson, Erlandsson, Malmqvist, & Kellner, 2016).

As previously mentioned, concrete is the most used framework material in Sweden (Boverket, 2018b). Due to the emission emitted during the manufacturing process, concrete is classified as a carbon intensive material (Boverket, 2018a). Lippiatt, Ling, and Pan (2020) point out that concrete- and cement production account for 8% of the total global CO_2-emissions. Most emissions are generated during the cement production, to reduce climate impact new concrete recipes where cement clinker is replaced with alternative binders such as slag and fly ash have been developed (Boverket, 2018a). The Swedish Building and Construction Industry (2018) claim that with existing technology there is great potential for reducing climate impact related to concrete production. Between 40 % and 70 % reduction of emissions can be achieved through active selection of concrete recipes and formations.

Similar to wood, concrete has also material qualities which enable carbon storage (Erlandsson et al., 2018). This is achieved through a chemical reaction called carbonation, where the carbon dioxide in the air reacts with calcium hydroxide in the concrete to form calcium carbonate (Kurkinen et al., 2017). Few methods of calculating the effects of carbonation currently exist, but in a study by Kurkinen et al. (2017) it was calculated that the carbonation process corresponds to a reduction of the buildings' climate impact by 6% over 100 years or 10 kg CO_2-eq per square meter useable floor area.

According to Svensk Betong (2019) climate-neutral concrete will exist on the market by 2030 and by 2045 all concrete used in Sweden will be climate-neutral. Several green concrete recipes currently exist on the market and Erlandsson (2019a) showed that choosing green concrete over conventional concrete has a substantial effect for reducing climate impact given that the green concrete is developed to meet the same requirements for persistence, durability, strength.

In addition to implementing green concrete, Erlandsson (2019b) suggests choosing resource-efficient construction solutions, combining concrete with other materials, and choosing the best product supplier to further reduce climate impact. The importance of avoiding higher concrete qualities than necessary regarding durability and exposure class is also highlighted.

According to The Swedish Building and Construction Industry (2018), steel and concrete account for most of the climate impact caused during the construction phase. Emissions related to steel are mostly exhausted during the iron processing. In addition, steel production is also energy consuming. However, one benefit is that steel can be reused multiple times which is a very positive aspect when evaluating materials from a life cycle perspective (Boverket, 2018a).

Fahlén, Högberg, Ingelhag, Ljungstedt, and Lundström (2020) suggests using recycled steel as a climate impact reducing measure. Recycled materials are beneficial from a resource-perspective as it can replace virgin materials (Erlandsson et al., 2018) (Boverket, 2018b). However, the recycled product's climate impact must be compared with the climate impact caused by the corresponding product from a life cycle perspective to gauge if the substitution is beneficial or not. Urge-Vorsatz et al. (2020) argues that the most efficient measure is to decrease the usage of steel to begin with and instead replace it with other materials. Although timber is often suggested as a substitute for concrete and steel frames and considerable reductions in embodied emissions can attained, M. Andersson, Barkander, Kono, and Ostermeyer (2018) claims that wide-spread implementation is not possible on the Swedish construction market. Thus, it is implied that development of additional alternative solutions is needed.

3.2.2 Climate impact related to insulation material choices

Erlandsson et al. (2018) showed when using a timber frame, the insulation accounts for a relatively large share of the climate impact in the product phase. This is supported by Larsson et al. (2016) who concluded that the insulation in a reference project was responsible for 13% of the total climate impact. Nonetheless, Erlandsson et al. (2018) implies that the substitution of insulation material could still have a significant effect on climate impact even when a concrete frame is used.

Coma Bassas et al. (2020) declare that as buildings are designed to be more energy efficient the amount of insulation material also increases. This indicates that insulation will constitute for a large share of the building's climate impact. Therefore, Carcassi, Habert, Malighetti, and Pittau (2020) suggest designing for climate neutrality and using materials with low climate impact to avoid trade-offs such as increased embodied emissions as a consequence of energy saving actions.

According to Urge-Vorsatz et al. (2020) several studies investigating the embodied carbon and energy in insulation materials have been conducted. Dosch (2018) denotes that glass wool and stone wool, which are two of the most used insulation materials, have fairly high impact per kilogram compared to other material types, but also point out that insulation materials are generally used in small quantities.

Giama and Papadopoulos (2020) declare that the stone wool production process is both energy intensive and provokes considerable amounts of carbon emissions. Glass wool, on the other hand, can be produced with a large portion of recycled glass which saves a lot of energy. Correspondingly, Erlandsson et al. (2018) suggests exchanging stone wool for glass wool in concrete structures as a measure to reduce climate impact. Furthermore, it was concluded that the climate impact related to certain material types, such as reinforcement steel and glass wool insulation, vary considerably depending on the supplier. Therefore, it was suggested that material selection should be based on the supplier whose product generates the lowest climate impact.

Fahlén et al. (2020) predicts that glass wool insulation will be produced using recycled materials and fossil-free energy in the future, which will significantly reduce the material's climate impact. Implementation of reused materials is gaining more attention within the construction industry (The Swedish Building and Construction Industry, 2018). Similarly, Giama and Papadopoulos (2020) argue for a new mindset, where circular economy and a life cycle perspective is adopted in the material selection, and that it is not tenable to neglect the impact from resources exploited during the manufacturing processes. Thus, it is suggested to reduce the consumption of virgin materials and instead use reused materials and adopt a circular mindset. Similarly, Urge-Vorsatz et al. (2020) suggests that the selection of insulation materials should be based on a life cycle perspective.

Ingelhag (2020) suggested bio-based building materials as a measure to reduce climate impact in a preschool project. Another study of the previously mentioned preschool explored the possibilities of replacing mineral wool with hemp insulation and reached the conclusion that hemp insulation would have been preferred over mineral wool if it were produced in Sweden (K. Andersson & Björhagen, 2018). In yet another study concerning the same preschool, Fahlén et al. (2020) reached the conclusion that using glass wool would generate six times more climate impact compared to cellulose insulation, and that bio-based products can be used to achieve a fossil-free construction. However, due to the strict fire-protection requirements the preschool was not able to use cellulose insulation. The project investigates several alternative materials and designs that could reduce climate impact, and the municipality aims for this project to set an example for the entire construction industry on how to achieve fossil-free construction (Göteborgs Stad, 2017).

3.2.3 Optimization of design and material usage

The Swedish Building and Construction Industry (2018) states that the manufacturing of building materials has been shown to account for around 80% of the climate impact caused during the product- and construction stages, see figure 3.2. Erlandsson et al. (2018) highlights the importance of resource-efficient design solutions and material optimization to reduce climate impact. This argument was especially accentuated when discussing concrete; it is not enough to merely focus on the concrete recipe and improvements of the material's environmental performance, but that it is equally important to consider the amount of concrete used and optimize it as much as possible (Erlandsson & Malmqvist, 2018). Likewise, Svensk Betong (2019) argues that through resource-efficient design, material optimization and construction solutions that use the concrete more efficiently and which are optimized based on functionality there is potential to reduce climate impact. The potential varies depending on the project's preconditions; however, it is estimated that the amount of concrete can be reduced by up to 30%. Svensk Betong (2019) also reflects upon using the appropriate concrete quality and the tendency to use a higher quality concrete than necessary. This practice results in increased climate impact, and it is therefore recommended that the appropriate concrete quality is used.

Furthermore, Erlandsson et al. (2018) implies that material substitution affects the functional performance and that to fulfil certain functional requirements overall material consumption could increase, which in turn affects climate impact. The Swedish Building and Construction Industry (2018) on the other hand claims that it has been proven that the increased material consumption in a well-insulated buildings induces a relatively small rise in climate impact compared to poorly insulated buildings. Nevertheless, it is important to consider material consumption even when choosing more environmentally friendly materials.

Finally, Erlandsson et al. (2018) points out the importance of choosing materials with long durability to avoid the need of replacing it as that would generate considerable material consumption and climate impact.

3.3 Climate impact reducing measures within the electrical engineering discipline

Electricity consumption in the housing- and real estate sector is linked to the total energy use in the construction- and building sector (IVA, 2016). 40% of Sweden's energy use stems from residential buildings and other facilities (Energimyndigheten, 2020a). Therefore, electricity consumption needs to be discussed in the light of the sector's total energy demand.

In 2016 IVA estimated that 500 000 new dwellings are needed by 2050 to fulfil the housing demand as Sweden's population continues to grow. Population development and the extent of new construction are two out of many key factors influencing future electricity consumption. Other factors are regulations for energy performance, energy efficiency in existing buildings, outdoor climate, property owners' and developers' preferences, and political goals and instruments.

3.3.1 Renewable energy sources - Photovoltaic cells

Many energy-efficiency measures have involved replacing processes and products powered by fossil fuels with electricity (IVA, 2016). Hence, even though the total energy efficiency increases, future electrification could result in increased electricity demand (Teki, Maharana, & Panigrahi, 2020) (Selvefors, MariAnne Karlsson, & Rahe, 2015). Provided that the electricity is produced from renewable energy sources, further electrification could be the pathway to reduce emissions and transition to a carbon neutral society (IVA, 2016). Both technological innovations and legislation drive the development of increased energy efficiency. However, user-behaviour and disruptive technology trends may also influence the future electricity demand both negatively and positively. According to IVA (2016) the trend is leaning more towards households and companies no longer being just consumers but also producers, so-called prosumers, as they for example invest in photovoltaic cells.

Photovoltaic panels can be either detached or connected to the grid (Energimyndigheten, 2020c). Interest of connected solar panels has increased over the last years and in 2019, 18 000 new solar panel systems were connected to the grid, representing an increase of above 70 % in the number of connected systems compared to the previous year (Energimyndigheten, 2020b). According to Energimyndigheten (2020a) solar power currently amounts to less than 1 % of Sweden's total electricity production, but has the potential to add up to 5% of Sweden's total electricity production by 2040.

According to a study by Kharseh and Wallbaum (2020), photovoltaic systems installed on the roof can generate up to 31% more annual electricity compared to if they were installed on the facade. Furthermore, both the latitude in which the solar cells are placed and the slope of the roof affect energy production (Solcellskollen, 2020b). Panels facing south produce the most energy. East- or west facing roof only generates 80 % of the energy that would have been produced if the roof instead faced south. A roof facing north only produces about 50 %of the energy.

The optimal slope depends on the geographical location of the building (Solcellskollen, 2020b). In the southern parts of Sweden, the optimal slope is 35° while 45° is more suitable in the northern parts of the country. However, as long as the slope is within the range of 15° to 60°, the roof is considered suitable for photovoltaic panels.

The technological lifetime of a photovoltaic panel system is around 25 years (Solcellskollen, 2021). Although energy is required to manufacture solar panels, this amount of energy is very small compared to how much energy produces during its entire estimated 25-year lifespan (Solcellskollen, 2020a). In the norther parts of Europe, it takes about two and a half years for a solar panel to produce the amount of energy consumed during its manufacture. Most solar cells are made of silicon, which is the second most common substance in the earth's crust. However, it is not a renewable material.

If the photovoltaic system is connected to the grid, excess electricity is sold at a profit (Solcellskollen, 2021). Thus, solar panels are generally considered a method of climate compensation rather than a measure to reduce climate impact (SGBC, 2021b) (Satola et al., 2021). Excess electricity can also, to a certain degree, be stored in batteries for later use such as during night-time when no electricity is generated from solar power. Thus, resulting in the synergy of also reducing peak load demand on the grid.

3.3.2 Peak load demand management

Demand for electricity increases as the development of new technology progresses (Teki et al., 2020). An increase in demand is accompanied with further mismatch between supply and demand. Electricity generated through renewable sources cannot meet peak load demand, therefore electricity generated through fossil fuels or imported electricity are needed to cover the supply gap. To reduce climate impact a transition from fossil fuel to renewable energy sources is necessary, but it is accompanied by the challenge of integrating a more fluctuating energy supply. This motivates the introduction of demand-side management strategies to create more energy flexibility in buildings through load shifting, valley filling and peak shaving (see figure 3.3).

One method of peak load reduction is to use photovoltaic cells and batteries for storage of any excess energy (Danish et al., 2020) (Teki et al., 2020). Furthermore,

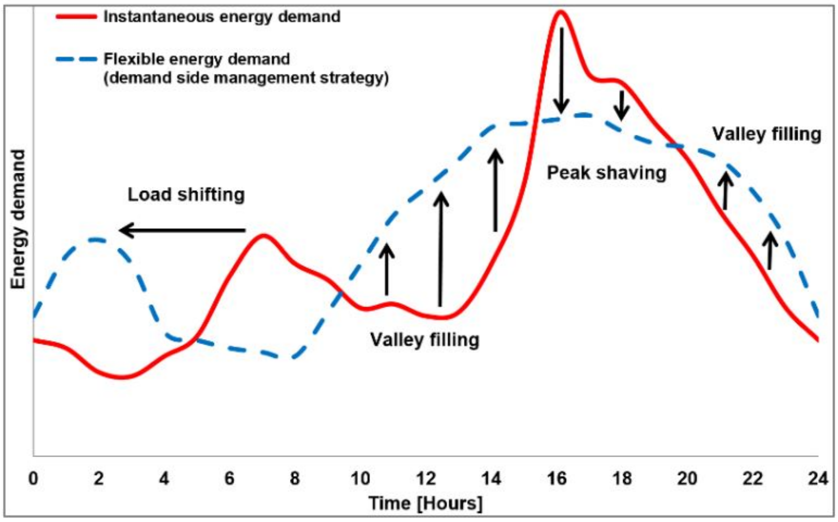


Figure 3.3: Example of demand side management /energy flexibility strategy with peak shaving, valley filling and load shifting (Andersen et al., 2019)

utilising the passive thermal energy storage in a building through its thermal inertia shifts heating energy use from high demand periods to periods when more renewable energy sources are available (Andersen et al., 2019) (Johra, Heiselberg, & Dréau, 2019).

Demand-side management also depends on the residents and their consumption. Previous research suggests that communication about upcoming load shifts can promote acceptance of indoor temperature variations to save energy amongst the occupants (Sweetnam, Spataru, Barrett, & Carter, 2019). A study by Hagejärd, Dokter, Rahe, and Femenías (2021) showed the opposite; significantly fewer participants in their study were inclined to accept temperature variations to conserve energy after the trial compared to before. Still, Hagejärd et al. (2021) agrees with the notion that communication with the residents about demand-side management can contribute to reduction of peak load demand.

3.3.3 Nudging and behavioural incentives for residential electricity conservation

Previous research has indicated that new technological innovations that improve energy efficiency of electronics and appliances may result in increased use and, by extension, raised energy consumption (Hertwich, 2005). On the other hand, Selvefors et al. (2015) suggests improving energy efficiency, functionality and usability of products and artifacts that facilitates both convenient and energy efficient interaction may enable people to use less energy when using the products. Actions to reduce energy consumption are not prioritized if they restrict people's everyday needs. Therefore, it is of high importance to consider people's everyday life and what conflicts they experience to understand why people do, or do not, prioritize energy conservation.

Recent studies of how individual feedback of one's energy consumption show that people reduce their usage, on average by 11.1 ± 3.1 % relative to what residents in a control group consumed during the same time period (Meinrenken et al., 2021). The two most efficient feedback types in Meinrenken et al.'s (2021) study were comparing their most recent usage with their own usage during the previous feedback-loop, and messages of high variety from one feedback-cycle to the next. Likewise, a similar study conducted by Buckley (2020) also showed that individual feedback of the households' own consumption, and personalised advice are found to be the most effective at lowering residential electricity consumption.

3.4 Climate impact reducing measures within the HVAC discipline

In 2018 a new European directive on buildings' energy performance was commenced, setting minimum requirements and a common framework for EU countries to calculate energy performance, while at the same time accounting for local environmental conditions (European Parliament Council of the European Union, 2018). Furthermore, the new directive stipulates that all new buildings, as well as all refurbishments, are required to be so-called near zero-energy buildings.

40% of Sweden's energy use stems from residential buildings and other facilities, whereof the majority is used for heating and water heating (Energimyndigheten, 2020a). The importance of adequate and well-functioning ventilation is becoming more and more crucial (Shin, Rhee, Lee, & Jung, 2018) (Svensk Ventilation, 2021). Svensk Ventilation (2021) denotes that many technological developments have been made within the HVAC field in the past two decades. It is also mentioned that Sweden has come far in the development of energy-efficient and innovative ventilation solutions compared to other European countries. Efficient ventilation systems have the potential of saving a substantial amount of energy which would have great impact on the progression towards a climate neutral construction industry.

Furthermore, adequate ventilation is necessary to prevent dampness and remove low quality air that could otherwise cause negative health effects (Svensk Ventilation, 2021). Likewise Guyot, Sherman, and Walker (2018) denote that people spend 60–90% of their life in indoor environments which makes the indoor air quality a major concern for public health. Johansson, Bagge, and Wahlström (2018) also point out that nowadays most buildings are constructed with air-tight building envelopes to save energy which makes it even more important to consider air-quality and adequate ventilation. The ventilation demand in a residential building is associated with the occupancy density in the building and constantly variate depending on factors such as the residents' activities, outside temperature, and sun exposure (Shin et al., 2018) (Khadra, Hugosson, Akander, & Myhren, 2020).

There are several different ventilation systems that can be used in apartment buildings. The systems can either be based on natural airflow or forced through a mechanical ventilation system. In a natural ventilation system fans are not used since temperature differences provoke air flow (Boverket, n.d.). However, in new buildings the most common ventilation system is the FTX-system (Swegon, n.d.). FTX-systems use heat recovery and 50-80% of the heat that otherwise would have been exhausted can be reused. Regardless of which ventilation system is applied, Svensk Ventilation (2021) points out that it is very important to prevent leakage to attain efficient ventilation. An airtight system is crucial to avoid leakage and to prevent energy from being wasted on transporting air which does not reach the endpoint.

In a report by HSB (2015) it was acknowledged that as buildings become more energy efficient, energy for hot water is becoming an area which accounts for a substantial part of the total energy consumption. Mannan and Al-Ghamdi (2020) also point out that by implementing sustainable water use practices in the building industry the industry's climate impact will diminish.

3.4.1 Energy savings through ventilation control strategies

Ventilation systems can be based on either constant air flow (CAV), variable air flow (VAV), or demand-controlled air flow (DCV) (Swegon, 2021a). CAV is regulated by natural air flows whereas VAV regulates air flow based on temperature or air quality, and DCV is a more advanced system which regulates air flow based on demand and occupancy.

Shin et al. (2018) argues that through smart ventilation, such as DCV, the accurate ventilation with regard to the demand can be achieved. Svensk Ventilation (2021) claims that DCV-systems can save a lot of energy. Another important aspect to consider is that through energy efficiency methods and ventilation control it is possible to reduce peak loads (Svensk Ventilation, 2021). Although Ma, Aviv, Guo, and Braham (2021) recognised that improperly controlled ventilation systems can cause unnecessary energy consumption and increased health risks, it is also pointed out that improved thermal- and air quality may result in increased energy consumption.

There are a number of methods of controlling DCV-systems such as occupancy sensors, occupant counting methods and scheduled number of occupants (Shin et al., 2018). However, the most common method is to measure CO_2 concentration. According to a meta-analysis by Guyot et al. (2018), it is possible to achieve energy savings up to 60% through smart ventilation. The results were accomplished without compromising indoor air quality and in some cases, it was even improved. Worth mentioning is that the analysis also included some cases where the outcome was not as favourable and where energy consumption instead increased. One of the case studies was based on an apartment building in Sweden and resulted in an annual heat demand saving of more than 50% when the control strategy was based on CO_2 or humidity, and 20% when occupancy control was used. Another residential building in Sweden where a DCV-system was compared to a CAV-system, reductions in heating/cooling energy and fan energy with 40% and 80% respectively were achieved (Swegon, 2017).

3.4.2 Potential improvements of water distribution losses

According to the regulations in BBR, properly tempered hot water must be obtained without inconvenient waiting time (Bebo, 2015). The general advice given is that hot water should be obtained within ten seconds at a flow of 0.2 liters/s. To reduce the time it takes to get hot water to a tap, hot water circulation is used (HWD).

Bebo (2015) claim that current systems can be improved with regards to insulation and leakage. HWD-losses in apartment buildings are often assumed to be of minor importance, however this tendency is considered unjustified and a need for more investigation into the topic is requested. In new buildings, HWD-losses are often approximated to 4 kWh/m^2 per year. However, in practice the HWD-losses can be more significant, in some cases they can be as great as the total energy demand for hot water. HWD-losses mainly occur in horizontal and lengthy pipes. To minimize HWD-losses it is therefore important to consider the placement of pipes and installations.

3.4.3 Heat recovery of wastewater and greywater, and greywater recycling

Through heat recovery from greywater, Hervás-Blasco, Navarro-Peris, and Corberán (2020) managed to utilize 80% of the available recovery heat. Likewise, Niewitecka (2018) agrees that substantial energy savings can be achieved with greywater heat recovery systems.

Malm (2015) claims that heat recovery can also be applied to wastewater and that this also has great potential for energy savings. Currently, there are products and systems available on the market, but further development is needed, especially regarding energy efficiency and life cycle cost.

Another measure to utilize the consumed water within a building is to purify and reuse greywater (Malm, 2015). Greywater can be collected from showers, washing machines, dishwashers, and sinks (Holm, 2021). Based on what purpose the reused water will be used for, different requirements are placed on the water quality which determines what purification technology is applied. 64% of a household's water consumption is used for non-potable functions, meaning non-drinking purposes. Greywater recovery has been explored at HSB Living Lab in Gothenburg since 2019 and results show that reusing greywater could save up to 40 liters of freshwater per person and day.

Greywater from showers and sinks can be purified and reused for the same purpose (Holm, 2021). The installation saves water, but a major driving force behind this type of system is energy saving. The purified water has a temperature of about 25 °C, in comparison with municipal water which is usually around 12 °C. Hence, substantial energy savings can be achieved.

3.4.4 Efficient design for optimization of installation systems and material consumption

A case study by Passer, Kreiner, and Maydl (2012) indicate that the technical installations contribute to the overall environmental performance of a building and that the optimization potential is high. Hence, it is recommended that technical building equipment is included in LCA-calculations going forward. Furthermore, an LCA-study by Nyman and Simonson (2005) showed that the energy consumption during the manufacturing processes of the ventilation units amounted to 0.5% of the energy consumed during the operational phase.

Ingelhag (2020) performed an LCA of the HVAC-system in the previously mentioned preschool with the system boundary A1-A5, see figure 3.2. Results indicate that pipes, followed by ventilation ducts, and valves cause the greatest climate impact. To minimize the impact of these products the preschool engaged in a collaboration with the project REPIPE-demo. REPIPE-demo is a project that aims to demonstrate the collection, sorting, material recycling and manufacture of new pipes and profiles on a larger scale (Göteborgs Stad, 2017). A similar approach was applied for the ventilation ducts.

According to Urge-Vorsatz et al. (2020) the high-quality components required for low-energy buildings often have a longer lifespan than conventional products. Thus, the need for replacement is diminished which, by extension, also results in reduced climate impact. Another strategy to reduce the climate impact caused by installation systems is to optimize the design (Ingelhag, 2020). By planning the location of installations and considering the operational need, ducts, pipes, and cabling in buildings can be minimized. Further, it is suggested that system solutions where several functions are combined could result in reduced material consumption.

Finally, material consumption can also be minimized during the construction phase through considering standard measurements for certain products and planning material flows to avoid unnecessary amounts of spillage (Ingelhag, 2020).

3.4.5 User-behaviour and active heating systems at a lower indoor ambient temperature

A recent study by Loy, Verbeeck, and Knapen (2020) investigated how adaptation of the heating system to the effective spatial use by only heating places where residents reside, could lead to more sufficient heating. The results showed that active heating elements such as heated blankets or personalized heating systems were able to increase the thermal comfort even though the ambient air temperature was lowered to by 2 °C. Previous research has mostly focused on lowering the ambient air temperature in office environments. Loy et al. (2020) however, concluded that active heating is suitable for residential buildings as the resident has the power to change their clothing if needed to maintain thermal comfort.

User-behaviour also affects a building's total energy consumption as the residents' activities, such as opening windows, may increase heating- and cooling demand (Gbolagade Oladokun & Ohis Aigbavboa, 2018). Similarly, the benefits of water-efficient taps may be revoked by improper user-behaviour (Holm, 2021). Both Dosch (2018) and Mannan and Al-Ghamdi (2020) denote that water consumption within households have considerable impact on the environment. Holm (2021) also points out that user-behaviour and technology have equal impact on water usage and that both need to promote sustainable water consumption. In 2006 Energimyndigheten suggested water-efficient taps as an action to reduce water consumption. This practice is still endorsed by researchers such as Holm (2021) who argues that installing water-efficient taps could generate savings of 15 liters per person and day.

3.5 Knowledge management and innovation management

Organisations exist to create value for their stakeholders (Eriksson, 2020). As society and technology evolves, so do customer requirements. If an organisation is to achieve business excellence, it must adapt to these changes and continuously improve all operations and knowledge- and innovation management are important factors to consider.

3.5.1 Importance of a knowledge management system for preservation of intellectual capital

The purpose of knowledge management is to diffuse competences and knowledge from a specific group or individual to an entire organisation, converting it into an organisation capability (Gambatese & Hallowell, 2011). An innovation in a single project does not equal to innovation within the entire organisation (Kadefors, 2020). Although knowledge preservation is considered crucial for many organisations to achieve long-term business excellence and to stay competitive in an ever-changing market, few companies have implemented formal strategies for this purpose (Liebowitz, 2011). Without a knowledge management system, an organisation risks losing intellectual capital and will thereby be deprived of the knowledge that the employees lent them if, or when, they choose to leave. This, how to capture years of experience in a few hours of an exit-interview, is one of the key barriers tied to knowledge management identified by Todericiu and Boanta (2019).

There are many different options to choose between when considering a knowledge-preservation system including reward schemes, mentoring, interviews and gathering knowledge from retired employees (Todericiu & Boanta, 2019). However, many barriers remain. Another hurdle mentioned by Todericiu and Boanta (2019) is that employees sometimes prefer to be knowledge-keepers rather than knowledge-sharers as they consider their own competence a competitive advantage compared to other employees. To circumvent this issue the knowledge-sharing company culture needs to be built on the paradigm that *knowledge-sharing is power* rather than *knowing is power* (Singh & Tripathi, 2017).

A third obstacle is referred to as the paradox generated by knowledge (Todericiu & Boanta, 2019). It proposes that the more competence an individual has, the more they gather and the more challenging it is to recover it from them. Additionally, many organisations have not successfully integrated their knowledge management system with their core business operations. Thus, crippling it from fulfilling its purpose and risking the loss of a competitive advantage.

A common thread in literature on knowledge management speak about how technology and IT can provide network links between geographically dispersed groups and enable knowledge-sharing (Swan, Newell, Scarbrough, & Hislop, 1999). However, this assumes that knowledge is a skill or ability that can be perfectly transferred through technological networks without any complications. A contrasting viewpoint is that knowledge is embedded in, and constructed from and through social relationships and interactions, differentiating knowledge from information. Additionally, it is highlighted that people management practises are often more fundamental to knowledge-sharing than the use of technology or IT. Similarly, Kraut, Fish, Root, and Chalfonte (2020) emphasize the need of informal communication to facilitate cooperation and build a company culture which promotes knowledge-sharing. On the other hand, Boh (2007) underlines that large and geographically dispersed organisations should consider institutionalizing knowledge-sharing routines rather than relying on informal mechanisms.

Furthermore, Swan et al. (1999) found that knowledge easily spreads in homogeneous groups and where innovation is localised, but that the opposite is true for heterogeneous groups and where innovation is interactive. Nonetheless, knowledge-sharing through cross- or interdisciplinary teams is identified as the key to effective use of knowledge for innovation purposes.

3.5.2 Innovation management in the construction industry

Innovations are divided into product- and process innovations (Egbu, 2004). A product innovation occurs when a new product is introduced to the market. It can either be a newly developed product or an adoption of an existing product from a different industry. As this new product innovation is exposed to new ideas, more efficient methods of production or utilization are often created, resulting in process innovation as well.

The construction industry is known for its traditional way of work and complexity

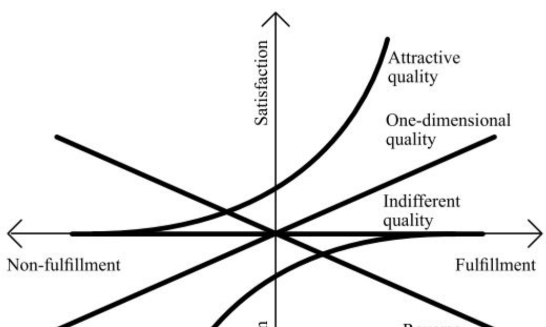
(Dubois & Gadde, 2002). In the report *The construction industry as a loosely coupled system: implications for productivity and innovation* (2002), Dubois and Gadde mentions that the construction industry is often considered to be ineffective and lacking of innovation. A self-reported survey undertaken by the European Business Awards in 2020 comprised of responses from 791 companies, spanning 21 industries, put the construction- and property industry, together with the retail industry, at the bottom for incorporating innovation culture in all actors' roles (RSM International, 2020). Furthermore, the construction- and property sector also ranked fourth from the bottom when investigating the quota of companies in each specific industry who thought that innovation was an important part of their business. The construction- and property industry ranked in the middle of the list when asked if they achieve their innovation aims, perhaps indicating unambitious goals to begin with. On the other hand, Pries and Janszen (1995) highlight that there is significant opportunity and tendency for new practices due to the uniqueness and project-based approach of the industry.

In 1995 Pries and Janszen studied innovations in the Dutch construction industry and concluded that 12.3% of innovations originated from the architect or consultant. Ten years later, in 2005, Pries and Dorée released updated statistics, then showing that architects and consultants were only responsible for 8.8% of innovations. However, both studies highlighted the supplier as the main source of innovations (Pries & Janszen, 1995) (Pries & Dorée, 2005). On the other hand, Tookey, Kulatunga, Kulatunga, Amaratunga, and Haigh (2011) identified the client as the key source of innovation within the construction industry. Though the client can stimulate team dynamics, actions, and increase efficiency which strengthen innovation, the client's possible lack of knowledge is recognized as a hindrance for innovation. Furthermore, other research by Ivory (2005) pinpoints the client as an inhibitor. It was found that many construction firms avoid the introduction of new processes due to conservative clients and that the client's desire to avoid risk is a decisive factor.

3.6 The Kano model

The Kano model first surfaced in 1984 and has since become one of the most well-recognised quality-measurement methods in quality management (Kano, Seraku, Takahashi, & Tsuji, 1984) (İpek Ek & Çıkış, 2015). The main objective of the model is to help businesses focus their attention and resources of the products or services, or elements of them, that contribute to customer satisfaction (Six Sigma Daily, 2020). It was the first model to introduce a two-dimensional perspective to quality: the degree of customer satisfaction and the degree of fulfilment of functional aspects of the product or service (İpek Ek & Çıkış, 2015). This relationship is presented figure 3.4.

There are five different categories of products or services (Kano et al., 1984). *Must-be qualities* are taken for granted when satisfied but when they are not,



customer dissatisfaction is unavoidable. These qualities are also often referred to as basic requirements. One example of a basic requirement is the existence of meal options for all dietary restrictions at a lunch restaurant. *One-dimensional qualities*, or performance attributes, are linear to the degree of fulfilment (Kano et al., 1984). Companies compete on these attributes and better performance directly corresponds to a higher degree of customer satisfaction. For example, the tastier the food, the more satisfied the customer (Veyrat, 2017). *Attractive qualities* are often unspoken as the customers generally do not expect them (Kano et al., 1984). Non-fulfilment does not cause dissatisfaction, but fulfilment can result in a significant increase in satisfaction and gain business compared to competitors, for instance if a restaurant offers free parking (Veyrat, 2017). *Reverse qualities* on the other hand have the opposite effect (Kano et al., 1984). If the exist, they lead to customer dissatisfaction, such as a restaurant having long queues (Veyrat, 2017). The last category is the *indifferent qualities*. These attributes do not have any impact on customer satisfaction (Kano et al., 1984). For instance, it does not matter to the customer what inventory management system a restaurant uses (Veyrat, 2017).

Important to note is that a product or service can switch category as time passes and the market evolves (Löfgren, Witell, & Gustafsson, 2011). Customers easily grow accustomed to a new level of fulfilment and a once attractive quality can easily become a one-dimensional attribute, and eventually a must-be quality. Customer expectations evolve, and to stay profitable companies need to develop their products and services accordingly.

3.7 Law of diffusion of innovation

The law of diffusion, DOI, was first introduced by Rogers (1962) and has since been viewed as a backbone of innovation management theory. The theory describes how an innovation, product, idea, or behaviour spreads through a specific social system, see figure 3.5. Based on the normal distribution curve, the leftmost 2.5% are considered *Innovators*; the ones that drive the development, are willing to take risks and are very easy to appeal to. The next 13.5% are called the *Early Adopters*. They represent opinion leaders, people who embrace change opportunities and already see the need for change. To win over this group, instructions for implementation and information sheets are necessary. The *Early Majority*, amounting to 34%, typically needs hard evidence and success stories to adopt a new concept although they are more willing to do so than the average individual. The next group: the *Late Ma-*

jority, also representing 34%, are sceptical and will only embrace an innovation if it has been thoroughly tested by the majority and often require numbers on how many others have successfully adopted the change in question. The last group is referred to as the *Laggards*. The *Laggards* consist of the remaining 16% and are very difficult to appeal to. They are highly sceptical and bound by tradition. To convince this group, fear appeals, statistics and pressure from the other groups are necessary.

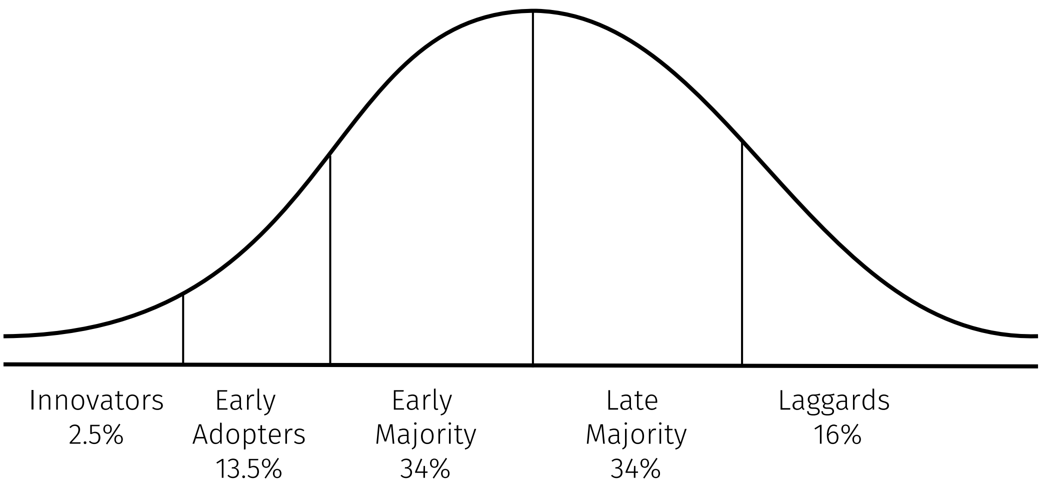


Figure 3.5: Illustration of the five groups that the law of diffusion of innovation divides the population of a specific system into, adapted from LaMorte (2019).

There are five key factors that influence the acceptance of an innovation: relative advantage, comparability, complexity, trialability, and observability (Rogers, 1962). Relative advantage is the degree to which the innovation is considered superior to the one it replaces. The innovation's alignment to the adopters' needs and values is measured as its comparability, likewise its complexity is defined as how difficult it is to understand and use. Trialability describes to what extent the innovation can be tested before a commitment of adoption is made. Finally, observability specifies the degree to which it generates tangible results.

During a TED conference Sinek (2009) spoke about how great leaders inspire action and used the law of diffusion of innovation to further illustrate this argument. Sinek's (2009) research shows that to get mass market success, 15-18% market penetration is required, after which the system tips over and full market acceptance is reached. The first 15-18% consist of both the *Innovators*' and the *Early Adopters*' groups. These groups are more motivated by the beliefs and visions of a company than what products or services the company produces, "*People don't buy what you do, they buy why you do it. And what you do is simply the proof of what you believe.*" (Sinek, 2009). Thus, the best way of convincing these groups is to speak to their beliefs. A comparison is made between the computer companies Dell and Apple. Both companies are well equipped to make laptops and computers. Both companies have the competence needed to make great smartphones, but only one of them has launched this product type successfully.

DOI has been utilized in many industries such as public health, agriculture, social work, and marketing (LaMorte, 2019). However, there are limitations to the theory. These limitations include omitting an individual's resources or social support to embrace the specific innovation or behaviour. Additionally, the theory is not equally applicable to prevention of behaviour as it is promoting new practices, ideas, and innovations.

3.8 Diffusion of responsibility and Social loafing

According to the individual responsibility principle, actors are only responsible for their own actions, regardless of their relation to the other actors (Nollkaemper, 2018). Shared responsibility is often instigated to mend shortcomings of individual responsibility. Nonetheless, shared responsibility can result in diffusion of responsibility. Thereby, crippling the intended effect and instead causing new responsibility gaps to appear.

Diffusion of responsibility is the phenomenon of diminished individual sense of responsibility when belonging to a group or social collective (American Psychological Association, 2020a). A common consequence of diffusion of responsibility is social loafing, which is defined as when an individual puts in less effort when working in a group compared to if they were to work alone (American Psychological Association, 2020b).

4
Methodology

This chapter present the methodologies applied in the work of this thesis.

4.1 Research approach and process

The initial thesis proposal was based on the case project where the environmental coordinators, structural engineering, electrical engineering and HVAC engineering disciplines from the consultancy firm were involved in the design phase. As such, the scope was limited to the design phase and what the individual consultants could influence. Figure 4.1 illustrates how the individual consultant is a subset of the construction industry at large.

Bell, Bryman, and Harley (2019) presents three different researches methods that could be applied to a research project. The described methods are quantitative research, qualitative research and a mixed methods research. Through a mixed research method, the strengths from both the qualitative and qualitative approach can be taken advantage of and outweigh the respective weaknesses. When combining a quantitative and qualitative research the latter can be used to obtain a perspective of the studied individuals whereas the quantitative data allows investigation of specific issues within the research area. A mixed methods approach was deemed most suitable for addressing the research objective of this thesis. The qualitative approach consisted of an interview study while the quantitative approach used was an LCA.

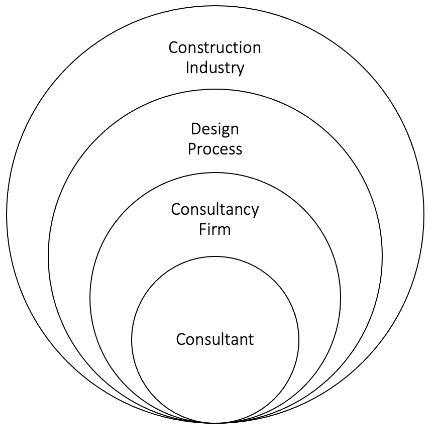


Figure 4.1: The consultant as a subset of the construction industry. The figure illustrates the design process is a subset of the many processes that make up the entire industry. Furthermore, the studied consultancy firm is but one of many actors within the design process, and the consultant is an individual member within that group.

An abductive process was applied. In an abductive process data collection and analysis occur in parallel and the process moves back and forth between the two

(Master Program Design and Construction Project Management, 2021). As the methods proceeded, each progression guided the next step in the continuing of the research as illustrated in figure 4.2.

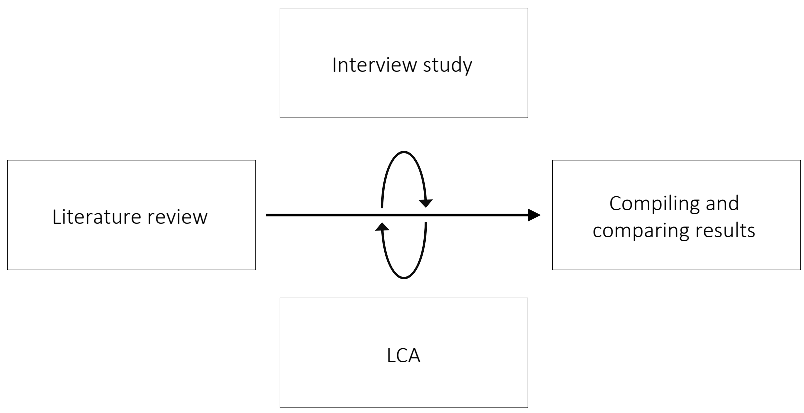


Figure 4.2: The applied research process. The figure illustrates how each of the chosen methods interacted and influenced each other.

4.2 Literature study methodology

The literature review includes a study of journal articles, books, reports, case studies, web pages, legislation, and frameworks. Literature was collected using databases and search engines such as Chalmers library and Google Scholar. Studies and reports were also found using the backward searching method presented by Bell et al.(2019). Backward searching entails using reference lists of relevant journal articles to guide the selection of further literature.

Initially, a wide range of literature and data was collected to obtain a general overview of the studied topic. As the study proceeded data was continuously reevaluated and narrowed down. Information regarding measures of reducing climate impact within each of the three disciplines, and knowledge- and innovation management theory was gathered. All references were critically reviewed and chosen based on relevance, both in terms of research field and date of publication.

4.3 Life cycle assessment methodology

An LCA was conducted with the aim of exploring the effects of different climate impact reducing measures on a conventional residential building. The full LCA is presented in chapter 5 Life cycle assessment and case study.

Data was extracted using the BIM software Solibri. Solibri can be used for clash detection, model checking, and information takeoff (Solibri, 2021). Provided that the dimensions, classifications, and other attributes of each component has been added correctly, cumulative quantities can easily be extracted using the information take-off tool.

The LCA was performed in the One Click LCA software which was created by Bionova for LCAs for buildings and infrastructure projects (One Click LCA, 2021). The data available within the software is first gathered from free and readily accessible databases after which it is reviewed before inclusion. Rapidly growing LCA databases are reviewed bi-weekly to ensure high quality, and reliable data. Both generic data and EPDs are available and clearly marked for the benefit of the user. However, the appropriateness and accuracy of the input data is left to the user as the database is limited and approximations sometimes must be made.

One Click LCA gives the option of basing the calculation on several different certification systems such as BREEAM and NollCO_2. The software also has a tool called Carbon Designer which generates a model of a generic building.

The LCA-results, see chapter 5, were used during the second interview phase to generate discussion concerning the chosen climate impact reducing measures and the LCA-methodology itself. The LCA-model was quality checked by an employee at the studied consultancy firm to ensure the same standard as they generally supply.

4.4 Interview study methodology

The interview study was divided into two phases. The first interview phase included interviews with two environmental coordinators at the studied consultancy firm and generated both a general understanding of the environmental coordinator role, and an overview of what has previously been accomplished within the field of climate neutral construction. This interview phase also resulted in further identification of possible solutions for improvement of environmental performance in construction projects.

The second interview phase distinguished what knowledge and competence exist within the studied consultancy firm and how the respective interview respondents view their own ability to influence a project's climate impact. Therefore, interviews were held with one representative from each of the three chosen disciplines as well as the previously interviewed environmental coordinators.

Bell et al. (2019) categorizes interviews as unstructured, semi-structured or structured. A semi-structured interview method gives a general guideline but also enables discussion and follow-up questions. This approach was chosen partly due to the comprehensiveness and complexity of the LCA-results thus requiring in-depth discussions, and partly due to the possibility of uncovering underlying thoughts concerning the organisation itself and the institutionalized routines for knowledge-sharing and innovation.

4.4.1 Interview guide

When composing questions for a semi-structured interview Bell et al. (2019) suggests that questions should be formed and organized in a series that could guide the interview. However, it should be composed in a way that enables flexibility and the possibility to change the sequence of questions and ask further questions in response.

The assembly of the interview questions was partly based on a structure where the questions were categorized in the following groups: general, innovation, organisation, the individual, and hardware. The same structure was also used during the second interview phase which enabled a viable comparison as well as facilitated the discussion of the findings. Semi-structured interview often includes some closed questions which can provide a background (Bell et al., 2019). This approach was used for the general questions while the remaining categories consisted of open-ended questions.

When composing the questions, a purpose to each question was also formulated. During this process, some questions were found to be too vague or not well-formulated enough to ensure answers compliant with the purpose of the interview. Such questions were thereby erased or reformulated. The questions were reviewed multiple times and peer reviewed by one representative from the consultancy firm and one representative from Chalmers University of Technology.

The interviewees received the questions (see appendix A.1, A.2, and A.3) a few days in advance to give them the possibility to read through the questions and prepare themselves for the interview. The interviews were recorded with the permission from the interviewees which made it possible to go back and listen to the interviews in retrospect.

The second interview phase contained interactive discussions regarding DOI, the Kano model, and the LCA-results. The LCA-results were used to generate discussion about the chosen environmental impact reducing measures, previous experiences using them, their respective significance, and further thoughts. The Base Line scenario was shown to all respondents after which they were asked to discuss the respective scenario for their own discipline.

The interactive assessments regarding DOI was designed to let the respondents choose which category they thought that they belonged to, and later which one they wanted to be part of, without them knowing the names of each category. It was suspected that the names of the different groups could prevent the respondents from being honest about their categorisation, for example *Lagger* or *Late Majority* both have a negative intonation to them indicating that one should not belong in either of those groups. Thus, it was deemed best to omit them and instead focus on the descriptions. The descriptions of the first group were displayed, after which the following descriptions were added on. Descriptions were initially kept hidden and displayed one by one. Thus, hindering the respondents from knowing how many choices existed and consciously avoiding the less favourable groups. The respondents were instructed to speak up whenever they felt they had enough information to test or recommend the imagined innovation to a client.

While the DOI discussion was conducted with all interview respondents, the Kano model discussion was excursively held with the environmental coordinators as it specifically investigated the perceived customer satisfaction of the environmental coordination service. The model and different categories were explained with examples from the restaurant industry to give an objective case for the discussion. The respondents were then asked to place the environmental coordination service in the appropriate category.

4.4.2 Interview respondents

To answer the research questions in section 1.2, interviews were conducted with two environmental coordinators, one structural engineer, one electrical engineer, and one HVAC engineer. Interviewees were chosen based on suggestions from the supervisor at the consultancy firm. Due to time constraints, only one interview per engineering discipline could be conducted. Short profiles for each of the interview respondents are presented below.

- Environmental coordinator A
  - nine years' experience within the field
  - five years' experience as an environmental coordinator
  - has been employed at the studied consultancy firm for three years
- Environmental coordinator B
  - 1.5 years' experience within the field
  - 25 years' experience as an HVAC engineer
  - has been employed at the studied consultancy firm for 20 years
- Group manager at the *Structural Engineering* discipline
  - 15 years' experience within the field
  - approximately nine years' experience as group manager
  - has been employed at the studied consultancy firm for four years
- Head of the *Electrical Engineering* discipline
  - 27 years' experience within the field
  - four years' experience as head of section
  - has been employed at the studied consultancy firm for 16 years
- Group manager at the *HVAC Engineering* discipline
  - 13 years' experience within the field
  - approximately 7 years' experience as group manager
  - has been employed at the studied consultancy firm for 13 years

4.4.3 Interview analysis using KJ-analysis method

Quotes were derived from the interviews and grouped together in different categories to gain an overview of the collected data, see appendix A.5 and A.6. The KJ-analysis showcased which categories were the largest and hence also provided a hierarchy amongst the groups, indicating each group's specific importance. Common threads were identified in the results from the first interview phase, from which focus areas to dive deeper into during the second interview were derived.

4.4.4 Ethical considerations

This thesis studies the practices and organisation of a consultancy firm. As such information exclusively intended for internal use was observed. This information has not been disclosed in the report or shared in any way. The LCA was based on a case project which entailed sensitive information concerning both the project and the client which is why the client was asked for their consent beforehand. To avoid spreading sensitive information representatives from the studied organisation reviewed and approved the thesis before publishing.

When the interviews were conducted, the interviewees were informed how the gathered data would be handled and presented to ensure that the respondents were comfortable and conscious with the situation before answering the questions. When answers had been complied chapter 6 Interview Study was sent to the interviewees to give them the opportunity to review the material before giving their approval. With the permission of the interviewees the interviews were recorded and later deleted at the end of the study.

Apart from the interview questions concerning the specific project studied in the LCA, no additional interview responses relate to that particular project or client. All other statements or thoughts are therefore to be considered general. Furthermore, any opinions or remarks are specific to the interview respondent and do not necessarily apply to other employees or the company at large.

By reason of anonymity concerning the interview respondents participating in this study, it was important to consider whether it would be possible to trace back which answers was given by which interviewee. As a short description of each respondent is presented, it could be possible to identify the interviewees by those already familiar with the organisation or the respondents themselves. However, the interviewees were informed and gave their consent.

5
Life cycle assessment and case study

To answer the research questions in section 1.2 an LCA was carried out to later be used as background material during the interview study.

At the time of the thesis, construction of the reference project had not yet begun. The residential building has an Atemp of 1899 m^2 and will be equipped with FTX-ventilation and heated through geothermal heat. The roof truss will be constructed in timber while the remaining parts of the structural framework will consist of both concrete and steel components. A combination of prefabricated and cast-on-site concrete will be used for the foundation and structural framework. Curtain wall will be used for the exterior wall, and thermowood will be used for the facade. Furthermore, each building is designed to have both a lift and a stairwell and each flat with its own balcony or terrace. The main part of the roof has a slope of 30° and face southwest-northeast.

5.1 Goal and scope

The scope was limited to one of the four residential buildings in the construction project. However, as one of the remaining houses is identical the results from this study are applicable to that building as well. Furthermore, the system boundaries are limited to include exclusively stages A1-A3, A4, B4-B7, and C1-C4 (see figure 3.2).

Climate neutrality is linked to the impact category climate change. However, to avoid neglection of any other aspects that could have a considerable effect on the total environmental impact, other impact categories were also considered. Therefore, the functional unit used was percentage increase or decrease per BREEAM environmental impact indicator per scenario in relation to the base line model for Building B.

Given the goal of comparing the original design of the case project to alternative variants where environmental impact reducing measures have been implemented the following scenarios were modelled and analysed:

- Base Line: a base model of the original building design used for reference

- Scenario S: green concrete and cellulose insulation, showcased both separately and collectively
- Scenario E: photovoltaic cells
- Scenario HVAC: smart ventilation
- Scenario T (Combined): green concrete, cellulose insulation, photovoltaic cells, and smart ventilation

5.1.1 Scenario S

Scenario S constitutes of two alternative design solutions: green concrete, and cellulose insulation. As the case project has a concrete frame, it was not applicable to model a timber frame due to the extensive redesigning that would follow. However, according to both Ingelhag (2020) and Lippiatt et al. (2020) the structural frame is one of the main contributors to climate impact and substituting conventional concrete with green concrete could therefore result in considerable reductions in climate impact.

As buildings become more and more energy efficient more insulation material is required (Coma Bassas et al., 2020). To avoid trade-offs, it is therefore important to use insulation materials with low climate impact. It was chosen to model cellulose insulation in the analysis to investigate both how large reductions in climate impact such measure could achieve and why it has not been implemented to a larger extent.

5.1.2 Scenario E

Renewable energy sources and in particular solar panels have progressively become focus areas within several certification systems (Sweden Green Building Council, 2017). In the certification system NollCO_2, which achieves climate neutrality through both impact reductions and climate compensation, photovoltaic cells or implementation of renewable energy is considered a method of compensation and thus balances out the climate impact caused by the upbringing and operation of a building (Sweden Green Building Council, 2020).

Halicioglu (2020) views solar panels as an eco-innovation and claims that the application can significantly reduce a building's annual energy consumption and environmental impact. In addition, the studied consultancy firm has considerable competence within the field of photovoltaic cells and implementation of the technology in this specific case project was therefore deemed feasible.

5.1.3 Scenario HVAC

Currently most residential buildings are designed with FTX-systems. However, improving such systems with DCV or VAV could save a considerable amount of energy and at the same time ensure good indoor air quality (Shin et al., 2018). Smart ventilation have been widely implemented in commercial buildings with good results and has shown potential of being implemented in residential buildings as well (Swegon, 2017) (Swegon, 2021b).

5.1.4 Delimitation for the life cycle assessment

Due to the goal and scope, and the scenario-based nature of the analysis, the following interpretation analyses were deemed irrelevant:

- Decision-maker analysis
- Variation analysis
- Sensitivity analysis

5.2 Inventory analysis

This section records the relevant materials used, the motivation behind decisions made along the way, and explains the process of the modelling in One Click LCA.

5.2.1 Quantity take off using Solibri and blueprints

The initial method of choice for gathering data was to use the information take-off tool in Solibri. However, due to incomplete models, complementary data had to be extracted manually from blueprints.

One Click LCA offers the tool Carbon Designer where the software generates a generic building. This model was used as a guide for assumptions made for the reference project. For example, the amount of steel studs and plates estimated in the interior walls was derived from the generic model. Other estimations and simplifications, such as approximating 100kg reinforcement steel per cubic meter concrete, were made in accordance with the consultancy firm's customary assumptions.
As the goal of the LCA was to compare different scenarios, exclusions were made of railings and all interior furnishing since they are irrelevant for the scenario analysis.

5.2.2 Quantification of water- and household electricity consumption

Water consumption was based on the daily average in Sweden of 140 liter/d per person (Svenskt Vatten, 2019). The number of residents were estimated according to table 5.1. Thus, amounting to 2606.1 m^3 potable water per year.

Number of rooms in each apartment	1	3	3/4	5
Number of apartments	1	9	8	2
Number of residents	1	2	3	4
Total number of residents:	51			

Table 5.1: Estimation of number of residents.

Energy calculations were provided by the client and from them an approximation of household electricity was derived. The calculations estimate household electricity to 30 kWh/m^2 heated floor space which is slightly higher than E:on's (2021) assessment of averaging 2500 kWh per apartment and year.

5.2.3 Modelling in One Click LCA

One Click LCA gives the option of basing the calculation on several different certification systems. In this case, the BREEAM-certification was chosen due to there being a bigger database of EPDs available. Many simplifications were made during the modelling due to the limited amount of available data in the software. For instance, instead of seven different types of wooden interior doors only one type was used in the model. Similar simplification approaches were applied to all other building components.

Modelling of Scenario S

During the modelling of Scenario S, all ready-mix concrete was replaced with green concrete. All mineral wool was substituted with the corresponding quantity of a generic cellulose insulation resource.

Modelling of Scenario E

Photovoltaic cells were modelled using five different online simulation tools to estimate the achievable annual electricity production (see appendix A.4). In total, $140\,m^2$ of solar panels were modelled on the south-west facing part of the roof with a slope of 30°. The results spanned from 17 190 kWh to 28 500 kWh, of which the mean value (24 359.6 kWh) was used in the scenario. Since solar energy fluctuates, discrepancies in demand and production are inevitable. Therefore, 55% of the generated electricity is expected to be sold to the grid.

Modelling of Scenario HVAC

To simulate smart ventilation, heating/cooling energy and fan electricity were reduced by 40% and 80% respectively in accordance with another residential building project carried out in 2017 in Kalmar, Sweden (Swegon, 2017).

5.3 Impact assessment

The CML-IA 2012 methodology was used for the impact assessment as it is both the required method by the European standard EN 15978:2011 and the default method in One Click LCA (Kommittén för Hållbarhet hos byggnadsverk, 2011). The BREEAM-certification framework was chosen due to it having the most extensive data base of EPDs within the software.

Focused was given to the indicator GWP although other relevant impact categories such as acidification potential (AP), eutrophication potential (EP), ozone depletion potential (ODP), and photo-chemical ozone creation potential (POCP), non-hazardous waste disposal (NHWD), and biogenic carbon (Bio-CO_2) were considered.

As shown in figure 5.1 and table 5.2, GWP was reduced by 7.91% when implementing all suggested measures, Scenario T, compared to the Base line scenario. Furthermore, both AP, EP, and ODP were reduced by 2.29%, 5.15% and 9.16% respectively. While POCP also decreased with 4.53%, NHWD and Bio-CO_2 increased with 11.51% and 20.51% each. Boosts in Bio-CO_2 stem from the inclusion on both cellulose insulation and green concrete as shown in figure 5.4.

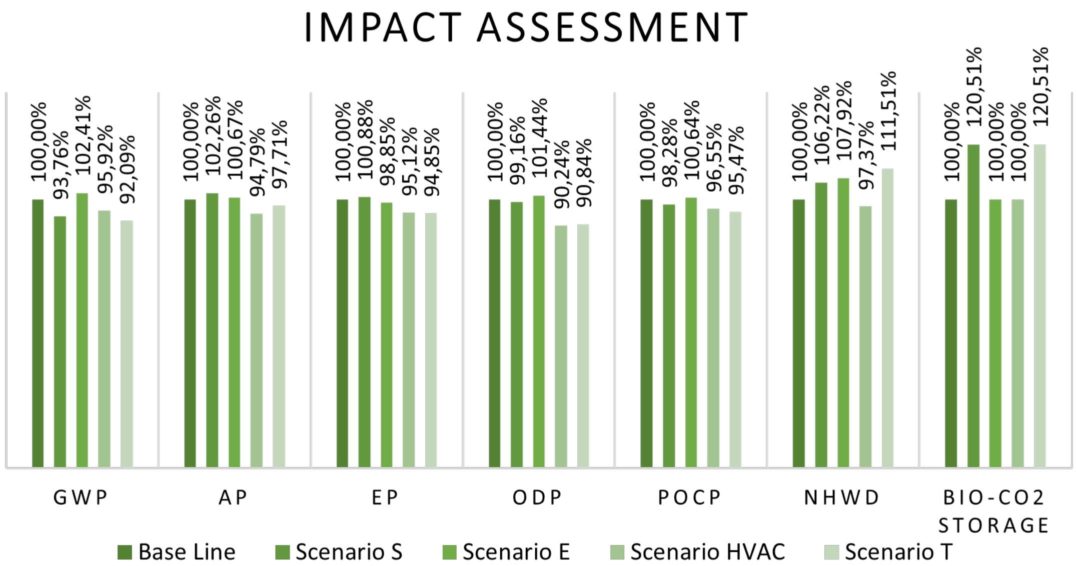


Figure 5.1: Life cycle impact assessment for all scenarios in relation to the Base line model for the case project using BREEAM indicators.

	GWP kg CO_2-eq	Shift in GWP∗	kg CO_2-eq/Atemp
Base Line	1 020 781	-	537.5
Green Concrete	959 914	-5.96%	505.5
Cellulose Insulation	1 014 094	-0.65%	534.0
Scenario S	957 096	-6.24%	504.0
Scenario E	1 045 365	+2.41%	550.5
Scenario HVAC	979 135	-4.08%	515.6
Scenario T	940 034	-7.91%	495.0

Table 5.2: LCA for BREEAM Int'l/ES/NOR/SE. This table displays more in-depth information concerning the left-most category (GWP) in figure 5.1. GWP is displayed in kg CO_2-eq. The sift in GWP (∗) is calculated in comparison to the Base Line scenario. The last column describes the caused GWP in kg CO_2-eq per square meter Atemp.

A rise in Bio-CO_2 signifies the re-release of carbon which was previously part of the biogenic carbon cycle thus resulting in CO_2 emissions. Similarly, an increase in NHWD reveals a damaging environmental impact. Due to increased material usage in the form of photovoltaic panels, and higher quantities of non-hazardous waste within the green concrete compared to the conventional resource, favourable effects of cellulose insulation and smart ventilation were revoked.

In summary, the inclusion of cellulose insulation, green concrete, photovoltaic cells, and smart ventilation generate beneficial results on all impact categories except NHWD and Bio-CO_2 where trade-offs, caused by the green concrete, cellulose insulation, and photovoltaic panels, were generated. However, solely implementing photovoltaic cells result in negative effect on all categories but EP, and Bio-CO_2.

In fact, the solar panels cause GWP to increases by 2.41%. The implementation of cellulose insulation and green concrete, and smart ventilation result in reduced GWP with 6.24% and 4.08% respectively, and the combination of all four suggested measures amount to a 7.91% reduction which corresponds to 80 747 kg CO_2-eq or nine Swedes' annual climate impact (Naturvårdsverket, 2020).

5.4 Interpretation

The interpretation is based on the preceding stages and discusses the conclusions and potential recommendations or improvement opportunities in accordance with the goal and scope. The section includes multiple checks and analyses to identify significant issues and test the robustness of the results.

5.4.1 Dominance analysis

The dominance analysis allowed for evaluation of which components contribute the most to GWP. As shown in figure 5.2, in the Base Line scenario energy consumption account for 42.0% of GWP, and concrete for 27.0%. The imminent majority in impact caused by the two resource types support the choice to make the specific efforts suggested in section 5.1. The dominance analysis also displays how the distribution of the components' climate impact vary when alternative designs are incorporated.

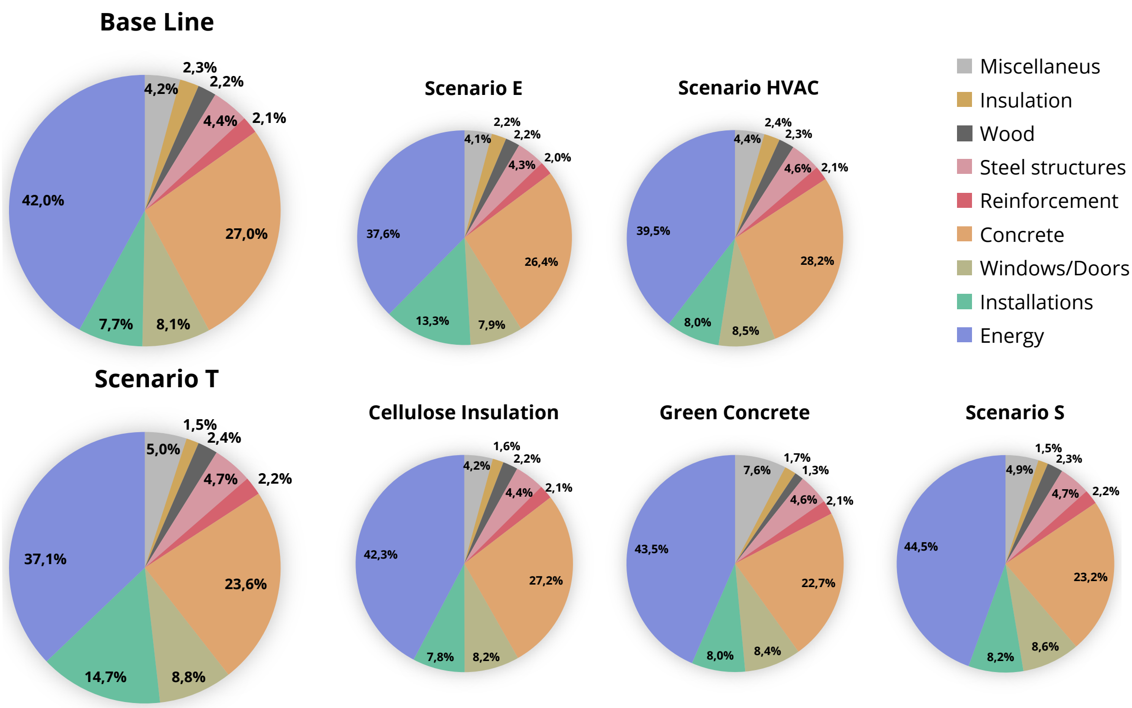


Figure 5.2: Dominance analysis for all scenarios. The dominance analysis showcases which components that contributes the most to GWP for each scenario. The miscellaneous category includes components such as coatings, gravel, and internal finishes.

Even though the implementation of solar panels cause an increase of the installations' contribution; energy consumption and concrete remain as the two main contributors to GWP even after all measures have been implemented.

5.4.2 Contribution analysis

As seen in figure 5.3, the indicator that contributes most to carbon dioxide emissions is GWP in all scenarios. Similarly, NHWD is the second largest contributor, and Bio-CO_2 the third while contributions from AP, EP, ODP, and POCP are marginal in comparison.

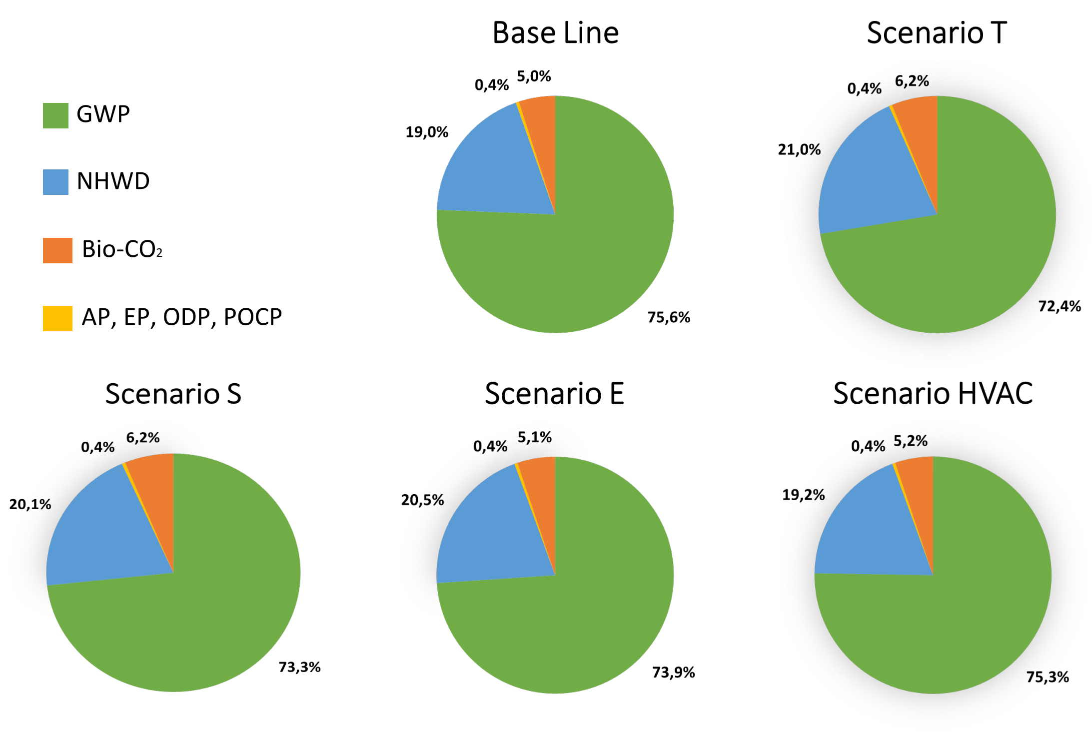


Figure 5.3: Contribution analysis for all scenarios. Impact has been converted to carbon dioxide emission for all indicators. Base Line represents the reference project, Scenario S includes substitutions of all ready-mix concrete to green concrete and all mineral wool to cellulose insulation. Scenario E contains photovoltaic cells, and Scenario HVAC simulates smart ventilation. Scenario T combines all suggested measures.

5.4.3 Break-even analysis

As previously stated, trade-offs resulting in increased NHWD and Bio-CO_2 are provoked through integrating green concrete and photovoltaic panels in Scenario T, see figure 5.1.

Trade-offs specifically concerning Scenario S, shown in figure 5.4, include AP, EP, ODP, NHWD, and Bio-CO_2. Increases in both AP and EP stem from the substitution of conventional concrete with green concrete, while the rise in and Bio-CO_2 is a consequence of the insulation substitution. The escalation in NHWD follows both the suggested measures, but the rise in ODP caused by the inclusion of cellulose insulation is mitigated by the positive effects from the green concrete.

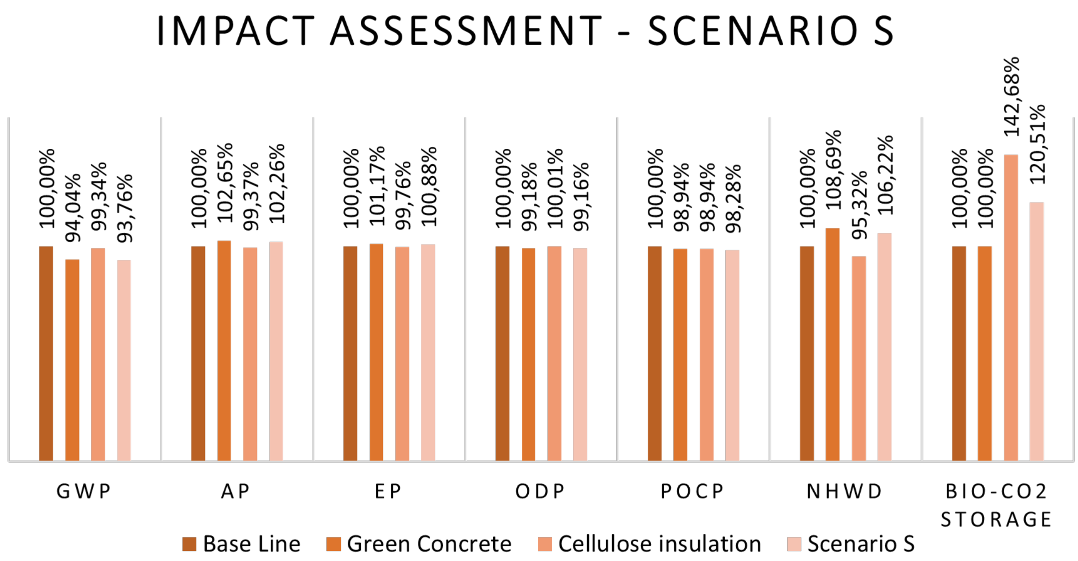


Figure 5.4: Life cycle impact assessment for scenarios within the structural engineering discipline using BREEAM indicators.

In Scenario E 55% of the generated solar electricity is sold to the grid and figure 5.5 illustrates the subsequent trade-offs in all categories but EP. As sold electricity belongs to life cycle stage D, it falls outside the system boundary and is therefore not accounted for in this scenario. Thus, the benefits from 55% of the generated solar electricity are not visible in the LCA. Therefore, a second scenario, Scenario E (100% Electricity) was solely created to visualize these benefits.

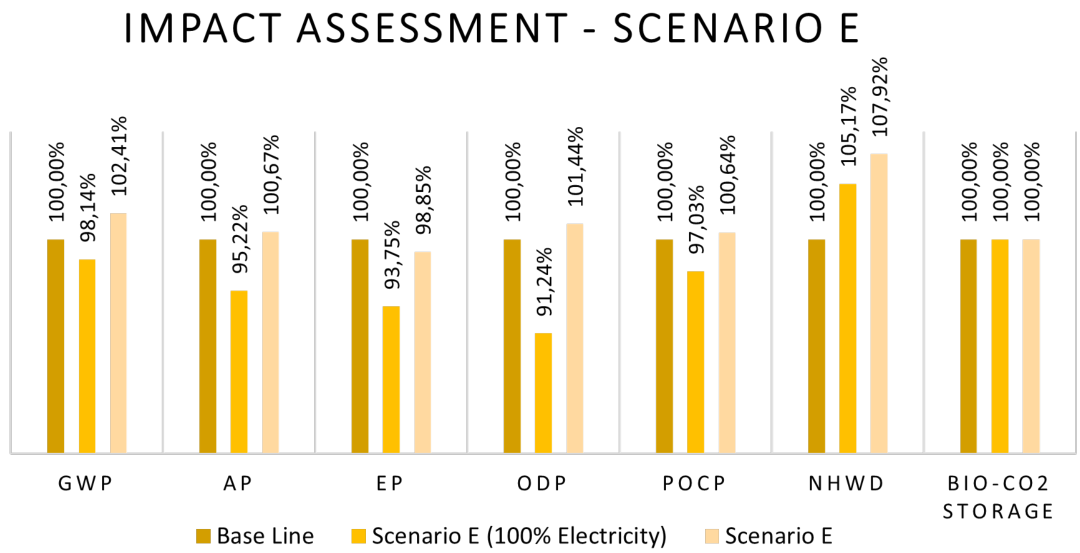


Figure 5.5: Life cycle impact assessment comparing the Base line scenario, Scenario E (100% electricity), and Scenario E using BREEAM indicators. Scenario E simulates that 55% of generated electricity is sold to the grid while Scenario E (100% Electricity) simulates the case where sold electricity is instead considered as a reduction in electricity consumption.

In Scenario E (100% Electricity) the 55% of generated electricity that is sold to the grid has instead been modelled as a reduction in electricity consumption. From a more societal perspective this is a more representative view of the effect implementation of photovoltaic cells can achieve as the sold electricity will replace other types of electricity productions which could have stemmed from non-renewable energy sources. Assuming that is the case, then the application of solar panels would decrease impact on GWP, AP, EP, ODP, and POCP as shown in figure 5.5. Trade-offs on NHWD will still remain. However, as the scope of the LCA is limited to the building's life cycle, sold electricity thus lies outside the system boundary of the study.

Scenario HVAC does not spawn any trade-offs, as shown in figure 5.6.

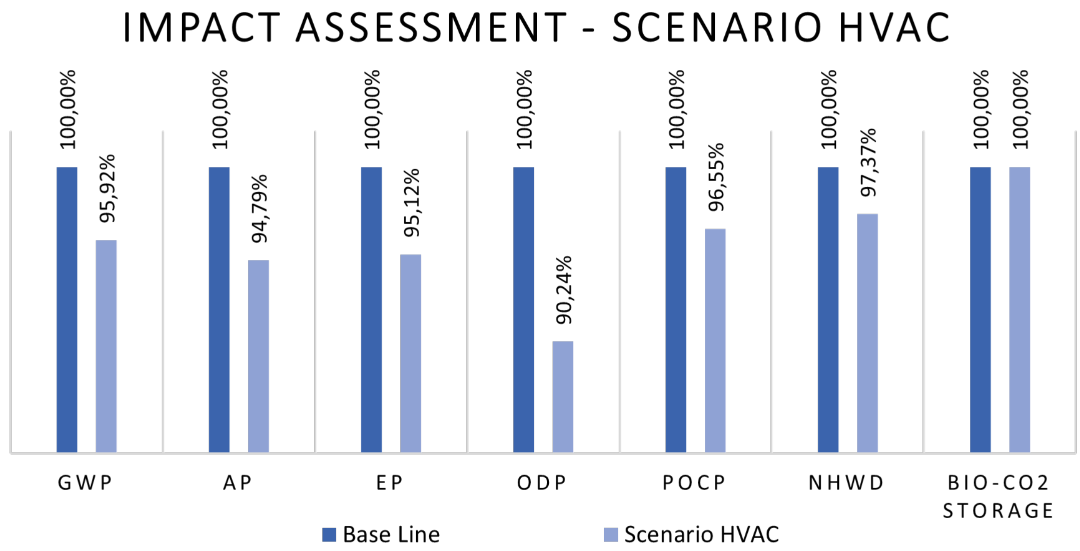


Figure 5.6: Life cycle impact assessment comparing the Base line scenario and Scenario HVAC using BREEAM indicators.

5.4.4 Completeness check

Simplifications such as excluding interior furnishings could to some extent be considered data gaps. However, this detail level was considered unnecessary according to the goal of the LCA being to analyse different scenarios and not to provide a climate impact declaration of the building.

Energy calculations for the specific project had been performed by another consultancy firm and were provided by the client. Approximations of household electricity were derived from these calculations. Water consumption was based on the daily average in Sweden and estimations of the number of residents, see table 5.1 (Svenskt Vatten, 2017).

Completeness has been verified using a verification tool available within the One Click LCA software. Each resource type is measured in weight or volume and the amount is then compared to a threshold value provided by the software based on a generic building of the same size and the same type of frame. All scenarios achieved the highest grade from the completeness check, with all resources except two lying within the range of threshold values. The exceptions were roofing bitumen and glass. The mass of roofing bitumen was slightly lower than the threshold value, but still within the allowed variation span. No materials were allocated to the glass mass category, hence the deviation. However, it is believed that all glass has been allocated to a different category called glass and openings mass, which is well within the allowed spectrum. Therefore, both deviations in the completeness check were considered negligible.

5.4.5 Consistency check

The system boundaries are limited to include the stages A1-A3, A4, B4-B7, and C1-C4 (see figure 3.2). These stages generate a more comprehensive analysis of the buildings climate impact than encountered in most other research (Erlandsson, 2019a). Still, it would have been interesting to include the entire life cycle as literature has shown that life cycle stage A5, construction installation process, also affects the potential to achieve climate neutrality (Ingelhag, 2020). However, the excluded stages were omitted partly due to lack of adequate data and the time constraint of the thesis.

Four different measures of reducing environmental impact were modelled in the respective scenarios. Had both more time and suitable data been available, scenarios would have been created for recycled steel and rebar, optimized material usage for piping and ventilation ducting, and grey-water heat recovery or recycling. For example, the generic data available for recycled steel and rebar in One Click LCA contributed to more CO_2-emissions than the chosen EPDs for conventional steel and rebar. Thus, it was not possible to simulate that substitution.

While the individual scenarios allowed for evaluation of each individual measure, scenario T made it possible to evaluate the combined potential. Thus, giving an estimate of the climate impact reduction achievable through implementation of existing technology.

The BREEAM-certification framework was chosen due to it having the most extensive data base of EPDs within the One Click LCA software. Initially the NollCO_2-certification framework was chosen. If NollCO_2-certification framework had been chosen another result would have been given. However, since this framework was only available as a BETA version it was disregarded due to risk for invalid results.

CML-IA 2012 is the required method by the European standard EN 15978:2011 and the default method in One Click LCA (Kommittén för Hållbarhet hos byggnadsverk, 2011). If a different methodology, for example ReCiPe, had been chosen it would have been possible to calculate caused environmental impact for additional impact categories such as land use and human toxicity. However, that would have required a different software.

Decision-maker, sensitivity and variation analysis were excluded in the LCA. The reason being that the decision-maker analysis investigates which stakeholder is responsible for different activities in the life cycle and the associated environmental impact. As this thesis aims to investigate measures that could be suggested by the consultants, measures were chosen on the basis that they were under the influence of a consultant. Therefore, it was considered redundant to perform a decision-maker analysis. The sensitivity analysis identifies and checks the effect of critical data by studying how each parameter contributes to overall model uncertainty. This analysis was deemed unnecessary as data was either extracted from 3D-models or the blueprints and any assumptions were made in accordance with the consultancy firm's customary estimates. A variation analysis was also considered redundant since the LCA in itself consists of multiple scenarios.

5.4.6 Data quality assessment

Data was extracted both manually from blueprints and by using the information take-off tool in Solibri. However, if the models contained inaccurate data this could potentially affect the data quality. Similarly, there is risk for miscalculations or overlooking of data when extracting data manually. To mitigate the risk of data inaccuracies, the verification tool in One Click LCA was used as a guide to compare if the data inputs were credible. Installations were modelled using the Carbon Designer tool as quantities were not readily available in the blueprints or the 3D-model.

To ensure high quality data, no EPDs older than five years were used in the LCA. EPDs and data was chosen based on accuracy. If possible, data from the original suppliers was chosen, the second-best option was to choose a similar product from another local supplier, and third choice national generic data, and lastly international generic data. In the instances where data was exclusively available in certain set dimension, manual calculations were made to convert the quantities which could have an impact on the results. The LCA-model was quality checked by an employee at the consultancy firm to ensure the same standard as they generally supply.

6
Interview study

To answer the research questions in section 1.2, interviews were conducted with five consultants at the studied consultancy firm. The studied firm is a global company offering engineering, design, and advisory services (AFRY, 2021a). The company consists of 16 000 consultants within infrastructure, industry, energy, and digitalisation with an aim to create *“sustainable solutions for generations to come”*. Furthermore, the company has five divisions: Infrastructure, Industrial Digital Solutions, Process Industries, Energy and Management Consulting. The divisions offer engineering, design and advisory services across three main sectors: infrastructure, industry and energy.

In 2019 after ÅF and Pöyry merged and a new vision and mission was created: *"Making future - We accelerate the transition towards a sustainable society"* (AFRY, 2021a). Today, AFRY has offices in 40 countries and projects in over 100 countries. Recently the firm also consolidation with another structural engineering firm which specialized in timber construction (AFRY, 2021b).

Within the infrastructure sector, the company offers consultancy services within Transportation, Buildings, Project Management, Architecture and design, Environment and Water (AFRY, 2021c). Furthermore, business area “Buildings” is divided into the following market areas:

- Sustainable building
- Structural engineering
- Electrical engineering
- HVAC engineering
- Buildings automation
- Safety
- Fire sprinkler
- Inspection and management
- Energy management and renewable energy

The engineers in the market area of Sustainable Building work with both environmental coordination and energy coordination for both new and existing buildings at all stages, from early idea sketches to implementation and management. They act as requirement makers, advisors and boards to find the best and most profitable solution for the project together with the customer. They are responsible for ensuring that the set requirements and goals are achieved through coordination in all project phases coordinate the work with different certification systems such as

Miljöbyggnad, BREEAM, LEED, Svanen and NollCO_2. Besides environmental and energy coordination, there are engineers specialised in energy calculations, indoor and daylight calculations, climate calculations, LCA and LCCA.

All interview guides are disclosed in the appendix A.1, A.2 and A.3. The interviewees work at different offices across the country, and short profiles of each of the respondents are presented in subsection 4.4.2 Interview respondents. The interview respondents consisted of two environmental coordinators, one structural engineer, one electrical engineer, and one HVAC engineer.

The first interview phase aimed to highlight problem areas to explore during the second interview phase. This was achieved through a KJ-analysis, of which a visualisation is shown in appendix A.5. The identified categories were:

- Certification systems, EPDs, and LCA
- View of the climate issue in the industry at large and legislation
- The client /developer
- The studied consultancy firm's organisational structure
- Collaboration within the studied consultancy firm
- Measures of reducing climate impact within each of the three disciplines

The largest categories were the client/developer and collaboration with the engineers. Results from the second interview phase were grouped accordingly to the categories first identified during the first interview phase (see appendix A.6). However, as the second interview phase used interactive assessments, those findings are disclosed as separate categories: *Law of diffusion of innovation,* and *The Kano-model.*

Disclaimer

Apart from the discussion concerning the specific project studied in the LCA, no additional answers relate to that particular project or client. All other statements or discussions are therefore to be considered general. Furthermore, any opinions or remarks are specific to the interview respondent and do not necessarily apply to other employees or the company at large.

The second interview phase discussed preliminary results from the LCA-study. Afterwards, modifications were made which resulted in decreased effect on several impact categories. The respondents were solely asked to comment on achieved reduction in GWP which at the time amounted to 9.47% but has since diminished to 7.91%.

6.1 The client: influence, responsibility, knowledge, and relationship

The relationship to the client and developer was recognized by all respondents as one of the main focus areas. This due to the influence the client has on the project team and what goals and ambitions are set for each individual construction project. Each respondent recognized that the client often sets the tone, for better or worse. On the positive, if the client is motivated to reduce climate impact, extensive efforts can be achieved. But on the negative, if the client is not interested, the climate issue is easily forgotten or not given the needed attention. This often results in the environmental coordinators being called in to the project later than ideal. Ideally, they would like to be brought in as early on as possible, or at least in time for the beginning of the project planning document process. This issue was also recognized by the engineers. In their opinion the earlier they are involved, the more they can influence the outcome and achieve a satisfactory collaboration with the architect.

Both environmental coordinators and all three engineers highlighted the client as the actor within the construction industry with the most responsibility to reduce climate impact. For example, the structural engineers mentioned *"The client must request certain solutions in order for us to prescribe them"* (*Structural Engineer*, 2021). Moreover, the client's lack of knowledge was recognized by all interview respondents from their own past experience working in the industry. However, when questioned about their own responsibility to inform, suggest actions, and educate as an appointed climate consultant in a project, neither environmental coordinator refutes it. The engineers, on the other hand, were less reflective about their responsibility as consultants. Furthermore, other barriers against reducing climate impact such as cost, time, and the clients' unwillingness to incorporate new, and seemingly uncertain, innovations were commonly mentioned by all interview respondents as additional reasons as to why the construction industry has not reach further in its pursuit to reduce climate impact.

It was also pointed out by one of the engineers that depending on the type of project, clients are either more or less willing to invest in climate impact reducing measures. They expressed that in general, there is more focus on climate impact in hospitals and preschool projects. However, a prevailing inclination to be associated with certain certifications and using them as an advertising strategy is common amongst clients regardless of project type. However, if the clients are also facility managers or future owners, they often see more advantages to investing in climate impact reducing measures.

6.2 Perceived attitude within the construction industry

Although the client is assigned most of the responsibility for driving the advancement towards climate neutrality, the government and need for formal legislation was not forgotten by either interview respondent. It was discussed that clients often need the extra push that legislation enforces upon them. When asked about whose responsibility it is to request and highlight the need for such legislation, the environmental coordinators dis not avert their own obligation, the engineers were less inclined to recognize their own responsibility and possibility to put pressure on the government.

The engineers were asked if it is possible to reach the goal of climate neutrality within the construction industry by 2045, upon which one respondent expressed that it is an ambitious goal, but that it is necessary to instigate such goals since the industry will not change by itself. Another respondent was a bit more optimistic and thought it possible, but also acknowledged that the industry needs to be forced through requirements from authorities and legislation *"/.../as long as it is profitable to build whilst neglecting climate aspects, it will occur."* (*Structural Engineer*, 2021). In addition, it was mentioned that regulations should become more and more strict each year.

Between the first and the second interview phase the climate impact declaration-tool from the National Board of Housing Building and Planning was released. During that time, one of the environmental coordinators had had the chance to glance over it but not yet to used it. Both interview respondent A and B showed support for the new law on climate impact declaration but hinted that a transition time of five years before limit values are to be implemented is too long. On the other hand, environmental coordinator A acknowledged the obligation to include all sizes of companies within the industry and give them time to adjust and avoid oligopoly.

Furthermore, impact caused by product manufacturers was mentioned by one of the engineers as a part of the value chain that also needs to be included by such legislation, and that all manufacturers should supply data on CO_2-emissions caused by their products and components. If that were the case, then it would be easier for engineers to compare different products and choose the one with the least climate impact. Additionally, the structural engineer mentioned that it is currently too cheap to be environmentally unfriendly. The price difference between different types of concrete is too low, making it more beneficial to use fewer trucks and overdimensioned concrete than optimizing the design and use more types of concrete and more trucks.

One of the engineers suggested that if engineers were procured before the entrepreneur, more focus could be given to climate impact and possible measures of reduction. Furthermore, the structural engineer mentioned that they try to promote the consultancy firm's environmental coordination service in all their projects, both to bring in more business to the company and to ensure each project pursues measures to reduce climate impact.

Another viewpoint brought up during the second interview phase with the engineers was that of the end-user. Theoretically, the end-user could request certain requirements or certifications, incentivising developers into producing buildings with lower climate impact. However, due to housing shortage, this is unlikely to occur. Environmental coordinator A, on the other hand, mentioned that they have seen tenants and residents request certain certifications, for example the silver level of Miljöbyggnad. That being said, the respondent still believed that there are better ways to reduce climate impact than environmental certifications as they are limited in what areas they cover.

6.3 The organisational structure and implications on efforts made to reduce climate impact

One of the discussed topics during the interviews was responsibility and how the respondents view their own responsibility in their professional role. The interview respondents highlighted that they have policies within the company to reduce their own climate impact, for example to reduce traveling. However, the company also aspires to influence the climate impact caused by the projects they are involved in. They interviewees reasoned that this was part of why the environmental coordinator role was created; to take responsibility and support the engineers in questions concerning environmental impact. Although the client has a lot of influence on the project and the project team, the internal organisation at the studied consultancy firm also contributes to the overall ambition and mindset of a project. The in-house cooperation between disciplines also has the potential to facilitate or inhibit efforts made to reduce climate impact. Unfortunately, this cooperation does not work as smoothly as hoped for. The environmental coordinators have had to get backed by the developer to convince designers of the need to improve climate performance, even though they already have the formal authority to do so. They think that it comes down to that the engineers do not listen or respect the mandate given to the environmental coordinator by the developer. As the role of the environmental coordinator is a fairly new one, few engineers have previous experience working with one. It was contemplated that this could be a reason as to why they sometimes meet resistance from other disciplines. However, when all disciplines work at the studied consultancy firm this is less commonly experienced.

During the second interview phase when the engineers were asked about their experience working with environmental coordinators in project where all disciplines are from the studied consultancy firm, all three engineers expressed that they think that the cooperation runs very smoothly. The environmental coordinators did not share this viewpoint. While it seems cooperation within the firm runs more smoothly compared to working with external actors, it is by no means unproblematic. The environmental coordinators believed that top management needs to put more pressure on the engineers to work with sustainability issues and climate impact reducing measures.

Moreover, it was sometimes experienced by the environmental coordinators that the engineers put in insufficient time and effort in evaluating and designing systems with improved climate performance. Time in particular is mentioned as a substantial hinder, and the suggested solution is for the consultancy firm to allow their consultants to spend more billable hours on researching and assessing alternative solutions, systems and product to implement in a project. It was implied by the environmental coordinators that responsibility for climate aspects should be put on all disciplines and not only on the *Sustainable Building* discipline. Since they have the formal responsibility for ensuring compliance with climate goals, other team members seem to have renounced theirs. This diffusion of responsibility is followed by the consequence of not using lessons learned in previous projects but instead falling back to old habits as soon as the environmental coordinator is not there to remind them of the importance of climate performance.

During the first interview phase, the environmental coordinators mentioned that the engineers need to keep record of all building components and check that they are available in Sundahus or Byggvarubedömningen, both of which are databases which assesses construction-related products based on their chemical content and environmental impact during the life cycle. When inquiring about the engineers' own experience using those lists, it became apparent that this is an uncommon occurrence as these lists are only filled out upon request from the client. Furthermore, each discipline appeared to have tasked one or two employees with this specific task, meaning that it is not an organisational capability, rather it is a competence held by a single individual.

6.4 Organisational efforts made for acquisition of new competences and routines for preservation of intellectual capital

When asked about what initiatives the studied consultancy firm has made to educate their personnel, the respondents were unable to think of any concrete examples, but during the interview information about knowledge retention practices surfaced. Furthermore, if an employee expresses a wish to further educate themselves or apply for a course it is encouraged. The environmental coordinators were asked if they believe this is the correct strategy; to leave the responsibility of education and skills development up to the individual, upon which environmental coordinator A completely agreed. Environmental coordinator B (2021) contemplated that certain educations are very expensive and that the discipline manager needs to decide what competences are needed within the group and ensure that the company does not spend money on an employee that might choose to quit soon. Furthermore, environmental coordinator A mentioned that they have a limited number of licensed coordinators within each certification system and that they therefore often cooperate across the regional offices.

Both environmental coordinators mentioned monthly networking-meetings with all other employees with similar positions. They both appreciate the event and believe that it promotes cooperation and knowledge-sharing. While the documentation process is streamlined within the organisation, there does not exist a joint database for the corresponding disciplines to upload their documentation to and environmental coordinator A mentioned this as an improvement opportunity.

However, during the first interview phase both environmental coordinators indicated that the engineers could benefit from a general briefing in sustainable building as inadequate knowledge and lack of understanding of the climate goals put on a project is often encountered from those parts of the organisation. The engineers expressed that rather than receiving any education from the company, they learn when working in different projects.

The engineers were asked about their perception of their responsibility to reduce climate impact as discipline- or group managers. The electrical engineer declared that: *"My responsibility as discipline manager is to educate my employees, ensure that we work and think the right way"* (*Electrical Engineer*, 2021). The structural engineer, who is a group manager at the *Structural Engineering* discipline, expressed that they do not believe they have any such obligation as group manager, but rather that it is in the project teams as an engineer that they have a responsibility to diminish climate impact.

Furthermore, it was mentioned that the engineering disciplines and environmental coordinators are stationed at different floors at the office. Several interviewees experienced that this inhibits knowledge-sharing as people are less prone to ask simple, seemingly trivial, questions over email compared to in person. The "water-cooler" chats lower the bar, promotes informal conversation and stimulates a knowledge-sharing culture.

6.5 Influence of individual interest and motivation on work performance

The environmental coordinators experienced that the internal motivation affects the work of the employees and the outcome of a project's climate impact. The level of internal motivation is mirrored in the processional environment. This is perceived as applying to themselves, other environmental coordinators, and the engineers.

Both environmental coordinators expressed a passion for the climate both in their private and professional life. Interview respondent B, who had previously worked as head of the HVAC Engineering discipline actively applied for a transfer because of their enthusiasm for the climate. Environmental coordinator A also mentioned a similar occurrence, not regarding themselves but a colleague who transferred from the HVAC and Energy department to the *Sustainable Building* discipline.

Regarding the interest and motivation of the employees the electrical engineer conveyed that people are different, and that younger employees generally seems to be more motivated and interested in climate aspects. This view was echoed by the structural engineer. The HVAC engineer believed that almost everyone in their group was rather motivated. They thought that it is often a part of wanting to make technical solutions that are as good as possible and to see it from a more comprehensive perspective, beyond the first investment. They believed that most of the employees have picked up on that way of thinking. In addition, a wish to encourage motivated employees and to specifically look for applicants with a passion for the climate when recruiting is expressed, particularly from interview respondent B (2021).

6.6 Life cycle assessment: methodology and applications

During the second interview phase all respondents were shown the results from the LCA. While the environmental coordinators were only shown the impact assessment results (see figure 5.1), the engineers were also shown the dominance analysis for the scenarios that explored their specific focus area. All respondents, apart from the electrical engineer, thought the achieved climate impact reduction was surprisingly low. The electrical engineer reasoned that it probably corresponds to a large amount of CO_2 and thus also has a big impact even if the percentage is low. Although half of the respondents thought the results motivated them to do more and work harder to reduce climate impact in their upcoming projects, the remaining interviewees felt dejected.

While environmental coordinator A was familiar with the LCA methodology, that was not the case for environmental coordinator B or either of the engineers. Although they have seen LCAs before, they have not worked with them themselves before, and in most cases, they have only seen isolated systems such as the structural frame for life cycle stages A1-A3 and not a holistic analysis. All respondents still believed LCAs could be used a as basis for decision-making. The structural engineer had previously worked with a project where they used LCA to compare different types of structural frameworks and ultimately chose a timber frame. The electrical engineer expressed that it would have been useful to see these types of calculations when comparing different components, and the HVAC engineer (2021) added that *"Usually, only energy use is presented, very rarely is material impact shown as well. I think it gives an extra dimension to see this"*.

Environmental coordinator A was the most familiar with LCA and voiced unease over that there currently does not exist any regulations or guidelines for how to conduct an LCA. It is possible to isolate systems or limit the analysis to certain life cycle stages, which could mislead those who are not familiar with the methodology.

All engineers expressed a wish to see more LCA-calculations for different systems, materials and components. Specifically, the structural engineer mentioned fossil-free steel and rebar, while the electrical engineer would rather see comparisons between the same type of product from different producers. On the other hand, they recognized that not all clients are willing to pay extra for this service, or that they would simply not be interested in the results if they do not have the ambition to reduce climate impact to begin with. Although, the engineers themselves were interested in seeing more LCAs to gain more knowledge and potentially use to promote certain products to customers, it is not expected to always be enough to persuade a client into making a more environmentally friendly choice.

6.7 Outlook on climate impact reducing measures and improvement opportunities

The structural engineer had no previous experience working with cellulose insulation, and although they were not unfamiliar with green concrete or other types of concrete with reduced climate impact, it was not commonly used in projects. After seeing the achieved impact reduction through substituting conventional concrete with green concrete, the engineer expressed surprise over how little effect it had. However, they also added that it would be interesting to see the effects of optimizing the design and diminish the amount of concrete.

The HVAC engineer mentioned that they always look at ways to diminish energy consumption and design systems that are well below the regulations set by the National Board of Housing Building and Planning. Concerning residential buildings, they mentioned that there are limited options on what systems are feasible to implement. Other than FTX-ventilation, geothermal heating, and photovoltaic cells there are few other alternatives. VAV- or DCV-systems are rarely used in residential buildings due to air-flow requirements. If that type of system were to be used, it will require separate aggregates for each individual apartment, which few clients are willing to invest in. Furthermore, it would result in increased material usage which could be a potential trade-off to reduced energy consumption. But in offices or other types of commercial buildings these are common solutions that they always prescribe.

Measure to recover grey water or to recover heat from warm water were fairly unfamiliar to the HVAC engineer. Though they have seen different types of analyses on the subject, all saying it is less effective that commonly perceived, it is not something they have previously worked with themselves. Instead, they have prescribed solutions to reduce water consumption through using water-efficient taps. On the other hand, it is admitted that it could result in sub-optimization if the resident does not understand the purpose of the tap and chooses to let the water run for longer to achieve the desired temperature. In general, the HVAC engineer declares that the most feasible options, other than the one simulated in the LCA, is to further investigate reducing HWD-losses, optimizing material usage, and to combine different systems. The HVAC engineer elaborated that in the specific case project later discussed in relation to the LCA-study, extra focus has been assigned to reduce HWD-losses which resulted in energy savings.

While the electrical engineer was very familiar with photovoltaic panels, those projects are handed to a group that specifically works with such systems. At Buildings West the Solar Energy Systems group is part of the Energy Management discipline which lies under the Sustainable HVAC and Energy department, but it differs from region to region.

Upon seeing the effect solar panels had on the case project, the electrical engineer observed that the technology still has a long way to go and needs to become even better. It was admitted that seeing the impact caused from the materials and manufacturing of the cells adds a new perspective to the achieved reduction in energy consumption. All interviewees mentioned photovoltaic systems as convenient measures to reduce climate impact as solar electricity can replace electricity generated by non-renewable energy sources. While most respondents also asked about the size of the simulated photovoltaic system neither of them asked about the placement or further reflected upon other possible placements such as on the facade or off-site solutions.

Other than photovoltaic panels, the electrical engineer also had experience with reusing electrical installations in retrofit projects. Although reuse is cheaper, there are also downsides to it, including safety risks and that there is no warranty for reused installations which could prevent clients from choosing that option. Similar reasoning was made by the structural engineer regarding the client's attitude towards implementing alternative construction materials.

Software and access to relevant data was mentioned as a commonly occurring barrier within the industry, but the environmental coordinators believe that the new law from the National Board of Housing Building and Planning on climate impact declaration and limit values will have a positive effect and incentivise more manufacturers to create EPDs for their products.

Another identified improvement opportunity, that lies within the studied consultancy firm's influence, is to improve the work routines regarding digital models and BIM to better facilitate LCA-calculations and climate impact declarations. Moreover, LCA-calculations should be carried out earlier on in projects and used as a basis for decision making.

6.8 Innovation management and routines at the studied consultancy firm

At the HVAC and Energy discipline where the HVAC engineer works, they have weekly group gatherings where they discuss new technologies, interesting solutions, and share experiences with each other. Overall, the engineer perceived their coworkers as interested and curios individuals who are eager to learn and want to contribute to reducing climate impact. Unfortunately, they are steered by customer requirements and budget. Neither the *Structural Engineering* discipline nor the *Electrical Engineering* discipline have similar group gatherings, at least not as a formal routine, to facilitate discussion on innovations. They do, however, have their own presentations after every completed project where the respective groups share experiences and lessons learned from that specific project. Furthermore, the electrical engineer admitted that these gatherings easily end up focusing on how to solve certain installation difficulties rather than how to reduce climate impact. They also mentioned that they mainly get information regarding innovations and new technologies from sales pitches from different manufacturers. The structural engineer, who used to work at a different consultancy company, recalled that that company had a group who was specifically tasked with inventing, exploring, and testing innovations and new technologies, but they were not aware if any similar group or discipline exists at the studied consultancy firm.

Due to the strict requirements set on the structural framework, and since it is such a fundamental part of any building, the structural engineer found it risky to experiment with alternative materials. Similarly, the HVAC engineer mentioned that they would never prescribe anything they do not believe would work, thus making it more difficult to try new solutions. Overall, they all agreed on that the client has the last say, and if they are not interested in implementing new solutions that decision must be respected. However, in those instances where a client wants to reach a certain environmental certification or expresses interest in reducing climate impact, all engineers are pleased to discuss all possibilities.

6.9 Interactive assessment regarding Law of Diffusion of Innovation

Interview respondents were not allowed to see the DOI-curve to avoid negative bias towards less favourable groups, instead they were shown descriptions of each group and got to choose which one they thought they themselves, the discipline they work at, and the studied consultancy firm belong to. In addition, they were also asked to choose which group they think the discipline and the consultancy firm should belong to. Results from the assessments are shown in figure 6.1.

All but one respondent, environmental coordinator B, considered themselves to be somewhat ahead of their colleagues when it comes to adopting, or at least suggesting to clients, new innovations and placed themselves in the same category as they later also chose as the tier where their own discipline and the studied consultancy firm ideally should be.

All three engineers independently chose the same categories as each other for all questions. On the other hand, the environmental coordinators diverged, both from the engineers and from each other. Environmental coordinator A perceived themselves as being generally very quick to adapt new innovations and mentioned several examples of where they had cooperated with clients in trying alternative solutions in pilot projects, positioning themselves between the first and second category. Environmental coordinator B who was more sceptical in general, placed themselves, their discipline, and the studied consultancy firm in the third group. Overall, the common notion is that the consultancy firm, to achieve the vision and mission *"Making future - We accelerate the transition towards a sustainable society"*, should act as an *Early Adopter*. Meaning that they should strive to be the first company to implement new innovations in real projects and not just in trials or pilot projects.

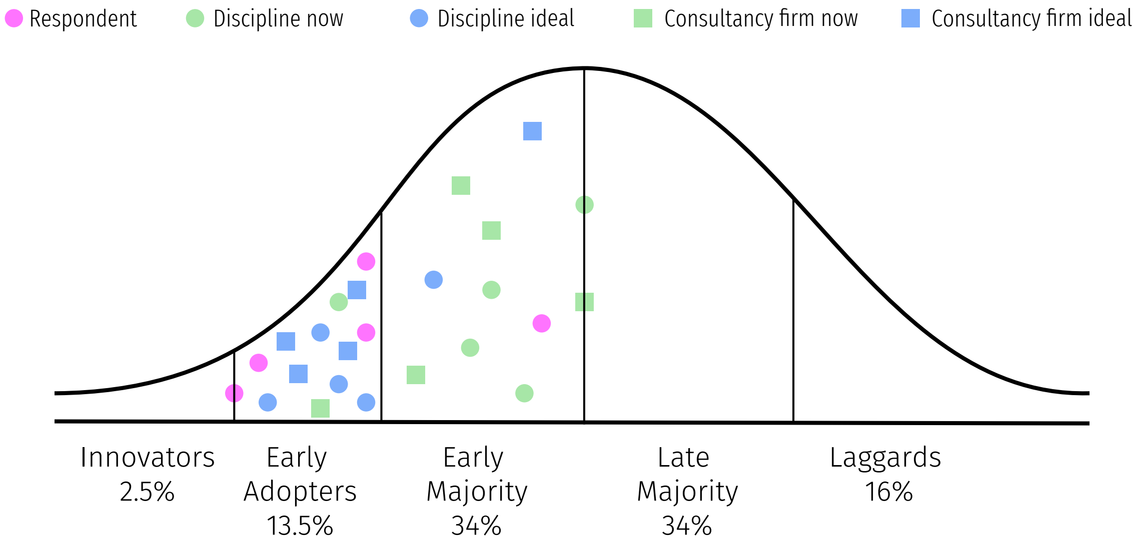


Figure 6.1: Interactive assessment regarding Law of Diffusion of Innovation. Pink circles represent the self-assessment of which group the respondent belongs to. Green circles illustrate where the respondent's discipline or group lies, while the blue circles demonstrate where the respondent thinks their discipline should be. Similarly, the green squares exhibit where the respondents' think the studied consultancy firm currently lies, and blue squares where the company should be situated. Note that there is no additional gradation of the symbols other than the already separated categories. Any scattering or distribution in each group is solely due to limited space within the diagram.

6.10 Interactive assessment regarding the Kano-model and customer satisfaction

Neither environmental coordinator was familiar with the Kano-model therefore, examples of the different categories were given. The respondents were asked to choose which category they thought that their customers viewed the environmental coordination service as. Environmental coordinator A had experience of clients both viewing it as a *One-dimensional quality* and as an *Attractive quality*. Generally, if an opportunity to suggest a solution or measure that has the potential to increase customer satisfaction, environmental coordinator A jumps at it and feels encouraged by the studied consultancy firm to do so. Interview respondent B said that due to the client's lack of knowledge on the area, it is easier to surprise a customer as an environmental coordinator compared to as an HVAC engineer. As such, it is also easier to bring an *Attractive quality* to the table. However, overall, it viewed as a one-dimensional quality. It is also recognized that many projects and clients do not have any ambition to reduce climate impact and would therefore not be amenable to suggestions.

7 Discussion

In this section the results of this thesis will be discussed with the prospect to answer the research questions the study is based on. In addition, a section reflecting on delimitations, ethical issues as well as the influence of the chosen methods and what alternative methods would induce will be presented.

7.1 Suggested environmental impact reducing measure and their potential to be implemented within the studied consultancy firm

Both the literature review and the empirical study shows that to achieve climate neutrality within the construction industry new materials, products and methods need to be developed and implemented at a larger scale. However, according to Erlandsson and Malmqvist (2018) significant reductions can be achieved by implementing existing technology. In chapter 3 Theoretical Framework several potential solutions for reducing the climate impact in the respective disciplines were identified of which some have already been implemented in practice with satisfying results. Others were developed more recently and have yet to be tested in practice. However, theory indicates that they have potential to reduce climate impact.

The potential climate impact reductions for each suggested measure were calculated through an LCA, see chapter 5. The results from the LCA were later discussed during the interview study.

In the following subsections the findings from the literature study will be reviewed with respect to the empirical findings to evaluate the suggested solutions and their potential to be implemented within the respective disciplines.

7.1.1 Suggested measures within the structural engineering discipline

As presented in chapter 3 Theoretical Framework, there is no universal solution applicable to all projects with the purpose of reducing the climate impact constituted by the construction of a building. Instead, literature indicate that each individual project should be assessed regarding its specific preconditions and limitations. Since the purpose of the LCA was to evaluate alternative solutions that would be applicable to a specific reference project some measures were excluded.

Green concrete was chosen based on both literature findings and the dominance analysis of the Base Line scenario (see figure 5.2) indicating that the structural framework constitutes the largest climate impact compared to other building components. Literature suggests several alternative structural framework types with less climate impact than the conventional concrete prescribed in the reference project. As substitution to green concrete does not require extensive redesigns or calculations this was considered a feasible option. Recently, research focusing on improving concrete has gained more and more attention. According to several researchers improving concrete could be one of the most efficient approaches to reduce the climate impact caused during the construction phase as conventional concrete is the most used material for structural frameworks in residential buildings. This opinion was shared by the structural engineer who had previous experience working with green concrete.

The LCA showed that implementation of this measure generated a reduction of 5.95% in GWP compared to the Base Line scenario. This result was discussed during the interviews and several respondents were somewhat disappointed and had expected a greater return. However, it became evident that most interviewees were unfamiliar with system boundaries beyond A1-A5, and that the comprehensive system boundary applied in this study gave a new perspective to their understanding of LCA-calculations as well as the potential climate impact reductions of green concrete. EPDs for green concrete typically only include life cycle stages A1-A3 which contributes to misleading marketing as the entire life cycle impact is not disclosed. Furthermore, green concrete partly consists of fly ash or slag which are waste products. From a climate impact perspective, it is beneficial to utilize and reuse waste materials. However, there is no standardized method of allocating climate impact caused by waste materials, meaning that there is risk for misconception and misleading results.

On a positive note, green concrete has managed to infiltrate the market and several projects have implemented it as an alternative to conventional concrete. The industry appears be open for implementing new concrete recipes, thereby, further focus on improving concrete mixtures could result in substantial reductions in climate impact going forward.

On the other hand, there is also the argument to disregard concrete in favour for timber-based construction (Boverket, 2018a). A considerable number of studies have shown that timber is the most effective solution to reduce the climate impact constituted by the building structure (Erlandsson et al., 2018) (Fahlén et al., 2020). However, according to Ingerson (2009) timber is not as climate friendly as portrayed and there are still ambiguities regarding the associated climate impact. Furthermore, the choice of structural framework material is often made before the design process which is why this measure was not included in the LCA.

Boverket (2018a) suggests increasing the amount of bio-based building materials, which motivated the decision of modelling a scenario using bio-based insulation materials. In a study by Fahlén et al. (2020) it was proven that implementing cellulose could reduce climate impact substantially, however, due to strict fire-protection requirements in that particular area they had to dismiss this option. In the LCA mineral wool was exchanged to the corresponding quantity of cellulose insulation. Results showed that the exchange would generate a reduction in climate impact, however, a rather modest one.

Substitution of materials with alternative materials affects the technical and functional properties, to fulfil the same functional performance more material often needs to be used which in turn influences the climate impact (Erlandsson et al., 2018). The choice of insulation materials should therefore be considered in the light of material consumption and potential trade-offs between the increased climate burden associated with the production of insulation materials and the energy saving benefits it would generate. In this case study the same requirements for heat resistance were attained with only a small increase in material consumption.

Furthermore, implementation of reused materials and a circular mindset was encountered several times in the literature review. In the interview study this was portrayed as difficult to realize due to restrictions and regulations. An attempt was made to model such action to display what effect recycled steel would generate. However, with the only current data accessible in One Click LCA being generic this measure was shown to generate a higher climate impact. The Base Line scenario was based on specific data which had a better performance than the generic data despite it being recycled steel. This thereby indicates that the lack of EPDs may to some extent prevent the implementation of alternative materials and recycled materials as it is not possible to showcase the achieved reductions in climate impact when using generic data. Even though a fair simulation of recycled steel was not possible to include in the LCA, implementation of recycled steel was discussed during the interview study. The structural engineer was positive towards this suggestion and would be open to implement recycled steel in future projects.

Another measure identified both in literature and the interview study was optimization of material consumption through resource efficient design, however, due to lack of applicable data it was not possible to model this measure. There is a tendency within the industry to use concrete with a higher performance than necessary which generates more climate impact (Svensk Betong, 2019). The structural engineer identified the same tendency and expressed that using the right concrete quality and reducing the amount of concrete might have a greater reduction on climate impact than exchanging conventional concrete to green concrete. This practice often entails more complex logistics and increased costs for the client which could contribute to difficulties for consultants to suggest this measure. Furthermore, even though the structural engineer had previously prescribed resource efficient designs in projects, it was recognized that this was not always adhered to by the contractor during the construction phase.

7.1.2 Renewable energy sources, photovoltaic cells, and other suggested measures within the electrical engineering discipline

Increased electrification could result in increased electricity demand (Teki et al., 2020) (Selvefors et al., 2015). However, provided that the electricity is produced by renewable energy sources, further electrification could be the pathway to reduce emissions and transition towards a carbon neutral society (IVA, 2016).

Interest in photovoltaic cells has grown during the most recent years, this is noticed in the increasing numbers of connected solar panels (Energimyndigheten, 2020b). According to Energimyndigheten (2020c) interest will continue to increase and solar power could add up to 5% of Sweden's total electricity production by 2040. Literature indicates that to reduce climate impact a transition from fossil fuel to renewable energy sources, such as solar power, is necessary. Additionally, using photovoltaic cells and batteries for storage of any excess energy could also help reduce peak loads (Danish et al., 2020) (Teki et al., 2020). Furthermore, as the consultancy firm has a group which specifically works with photovoltaic cells the adoption of this technology was deemed to lie well within the consultancy firm's organisational capabilities.

The generated electricity from photovoltaic cells can either be used in the building or sold to the grid. Due to asymmetries between power- generation and consumption a combination is inevitable. During the LCA, all sold electricity is considered part of stage D which lies beyond of the system boundary (see figure 3.2). From a life-cycle perspective it therefore looks as if the implementation of photovoltaic cells causes increased climate impact. From a societal perspective that is not the case as the generated solar power can replace other types of electricity.

Implementation of photovoltaic cells was suggested by interviewees from other disciplines than electrical engineering. There seems to be a common opinion that implementation of solar panels is the preferable measure to reduce climate impact. However, the interviewees did not deliberate over the fact that it is a method of climate compensation rather than a measure to reduce climate impact (SGBC, 2021b) (Satola et al., 2021). The specific scenario explored in the LCA only included photovoltaic cells as part of the roof as that placement generates more electricity compared to if they had been installed on the facade (Kharseh & Wallbaum, 2020). The resources and materials used combined with the waste-treatment processes of photovoltaic cells also contributes to impact in categories such as GWP and NHWD. The electrical engineer was surprised by the climate impact caused by the materials used in electrical installations themselves, and specifically that of photovoltaic cells, and expressed that manufacturers need to improve their products. It is thought-provoking how photovoltaic cells, as there are still ambiguities regarding whether it is beneficial or not from a life-cycle perspective, has managed to infiltrate the market when the adoption of other innovations has been notoriously slow (Gambatese

& Hallowell, 2011) (Dubois & Gadde, 2002). Investigation of the success factors behind this could perhaps serve as guidance for how other alternative solutions and climate impact reducing measures could gain more acceptance in the construction industry.

The electrical engineer mentioned reuse of electrical installations in refurbishment projects as a measure of diminishing climate impact which also saves the client money. However, they also recognized that the client may still choose to invest in new installations due to safety risks and lack of warranties for reused components.

7.1.3 Suggested measures within the HVAC engineering discipline

Concerning the HVAC discipline the detected measures to reduce the climate impact primarily revolved around three things; improving the efficiency of the systems, how the systems are regulated, and reducing the impact caused by the material through either design optimization to minimize material consumption or use reused materials. All these suggestions were difficult to model in the LCA. Both ventilation systems and water systems are related to specific building conditions such as, the size of the building, how it is operated and similar. Since it was difficult to find research on projects with similar conditions to the reference project, it was also difficult to find representative and adequate data for the suggested solutions.

The reference project already had an FTX-system, which is an efficient ventilation system. However, by reducing the fan electricity and heating/cooling demand an attempt to simulate smart ventilation was performed. It was assumed that smart ventilation would lower the ventilation demand in accordance with a similar residential project (Swegon, 2017). However, it is only possible to evaluate the effects of smart ventilation when the building is in use and there is also risk for increased ventilation demand. Thus, it is not certain that the implementation of smart ventilation would have beneficial effects on climate impact. The HVAC engineer expressed that the main hindrance for this solution is that it is very costly and would not be profitable enough for a residential building which could prevent the client from choosing this option.

Several technologies for water recycling and utilizing heat recovery of wastewater and greywater in residential buildings exist on the market (Malm, 2015) (Holm, 2021). Further it is presented that these technologies have great opportunities for energy savings and water savings which is important when considering environmental impact and not just climate impact. Despite this the HVAC engineer did not think these measures currently were profitable enough to implement and expressed concerns about regulations. Instead, the interviewee believed that reducing HWD-losses, optimizing material consumption and combining systems would be the most lucrative actions. In the reference project a lot of focus had already been addressed to HWD-losses and generated good results. It was evident that the interviewee had an economic- and risk avoiding approach to the measures. From the client's perspective these are important aspects which also makes them very prominent in the consultant's decision-making regarding which systems to prescribe.

None of the suggested measures for improvements of the water systems were possible to model in the LCA due to few comparable examples and studies, and lack of data in the software. Likewise, optimization of material usage and replacements of installation systems with alternative materials were not possible to model. Despite this, these measures were briefly discussed during the interview study and the HVAC engineer expressed a wish to learn more about the topic.

7.1.4 General barriers for implementation of climate impact reducing measures in the chosen disciplines

The result from the literature review as well as the empirical findings indicate that there are several prevalent reasons to why climate impact reducing measures are not implemented regardless of which discipline it concerns.

Several researchers as well as the interviewees point out the unwillingness within the industry to deviate from conventional methods and materials. For the construction industry to reach climate neutrality it is inevitable that new materials with a better environmental performance are developed and incorporated (The Swedish Building and Construction Industry, 2018). A common opinion among the interviewees was that they as consultants sometimes are restrained by the client. If the client has requested certain solutions, it is difficult to suggest alternatives. The client's lack of knowledge often mentioned in literature was recognized by all interview respondents from their own experience working in the industry (Ivory, 2005) (Tookey et al., 2011). In addition, barriers such as cost and time are identified as reasons for the clients' unwillingness to incorporate new, and seemingly uncertain, innovations. Several interviewees have experienced that clients rarely have a long-term perspective and thereby do not see the profitability in these measures as they do not intend to own and operate the building.

When reviewing the literature, it was distinguished that incorporating alternative solutions in a residential building project is restrained by technical barriers. Erlandsson et al. (2018) points out that introduction of new solutions cannot be to the expense of functional criteria. Technical barriers were also identified as part of the difficulties in deviating from conventional methods by all the interview respondents. Both the interviewees and literature highlight the need for more research and tests in pilot projects of climate impact reducing measures.

Similar to the interviewees, Holm (2021) highlights regulations as a hindrance for alternative solutions. Regarding water reuse, the current requirements and regulations strain the possibility to implement such measures. In this matter implementing such alternative solutions is restrained by the regulations despite willingness within the sector. Similar examples can be found within the structural engineering discipline were requirements related to soundproofing and fire protection occasionally inhibits the possibility to deviate from traditional practices.

As discussed in section 7.1.1 Discussion of suggested measures within the structural engineering discipline, the conditions and practices on site may also hamper implementation of alternative solutions. If other solutions are more favourable in terms of supply, cost, or time other solutions than those prescribed might be chosen by the contractor. Similarly, the consultant cannot influence how the end-users use the prescribed systems. This was mainly related to HVAC and electrical engineering disciplines. Advanced systems sometimes require knowledge and correct behaviour during the operational phase. If proper behaviour is not attained the benefits of implementing such systems could be cancelled out.

Both literature and the interview study recognize that climate issues are prioritized differently depending on which type of building is considered. For example, it was evident that improvements of HVAC-systems were given more focus in commercial properties, schools or hospitals than residential buildings. This in turn affects the technological development and the incentives for clients to request better systems for residential buildings. The same tendency can be seen regarding the recent focus on fossil-free construction within preschools. The intention is for preschool to work as a forerunner and that the successful initiatives would be spread to other building types (Göteborgs Stad, 2017).

Another interesting aspect regarding prioritization is how the discipline's respective climate impact is graded/judged in relation to each other. Previously a lot of focus was directed towards the energy and the operational phase of a building's life cycle, but Boverket (2018a) advocates that focus needs to be shifted to the product- and construction production stages. This raises the question, should each discipline focus on how they can reduce their impact, or should resources be directed to the disciplines that constitute the most impact? To reach climate neutrality, climate impact should influence all decisions. However, due to the urgency of climate the most critical challenges should be prioritized.

7.2 LCA-methodology and the possibilities to promote climate friendly construction

Increasing attention has recently been drawn to climate impact from a life cycle perspective within the construction industry. As an LCA considers the entire life cycle as well as numerous parameters, trade-offs are less likely to occur, and comprehensive result of the caused climate impact can be obtained. According to Finkbeiner and Bach (2021), a life cycle perspective is necessary to avoid risk for double-counting, problem-shifting or green-washing.

Currently there are obstacles that needs to be overcome for LCA to reach its full potential (Finkbeiner & Bach, 2021). One issue is that there currently does not exist a standardized method for conducting an LCA and that system boundaries thereby can be chosen to portray a certain result. Erlandsson et al. (2020) highlights that it is important to keep in mind that the system boundaries and purpose of an LCA have significant impact on the result. Thus, it is difficult to compare different LCAs with each other, making it even more difficult to generalize and draw universal conclusions based on LCA-results. Further, studies usually do not include all construction resources nor the entire life cycle. When reviewing previous studies, it was evident that several studies conducted based on LCA have a rather narrow perspective which neglects important aspects. This study aimed at a comprehensive perspective to avoid such risks.

Literature indicates that LCA is not merely useful in research purposes but that there is an aspiration within the industry to implement LCA to a greater extent and that it should facilitate decision making (Malabi Eberhardt, Rønholt, Birkved, & Birgisdottir, 2021). While some interviewees express that it would be useful in decision making and for motivating the client to go for alternative solutions or materials, others were more restricted and did not see these advantages. However, for LCA to facilitate decision making it is even more important that a standardized method for how an LCA is performed exists. Apart from misguiding system boundaries, Larsson et al. (2016) also highlights the issue of ambiguities regarding how different allocation methods affect the results.

Another issue hindering the calculations is access to data. Because of the low maturity within the sector there is currently few suppliers that provide EPDs for their products which obstructs LCA-calculation. Therefore, many LCAs are conducted based on assumptions and estimations. This issue was observed first-hand when conducting the LCA in chapter 5. This indicates that there are still major difficulties regarding technical development for calculations. Due to the prevailing uncertainties and results not being completely reliable it is difficult to base decisions on LCA-calculations and for it to facilitate decision making. However, as more accurate data and data from specific manufactures becomes available the results from LCAs will also become more reliable.

An interesting observation that was made was how the result of the LCA were perceived differently and how this appeared to be related to the respondents' knowledge and experience of similar calculations. It was encountered during the interviews that the engineers were unfamiliar with LCAs that showcased life cycle stages beyond A1-A5 (see figure 3.2). Perhaps that contributed to their surprise of the small effect the combination of all suggested measures had on the building's total climate impact. The environmental coordinators voiced unease over that there are no clear guidelines for how to conduct an LCA, and that it is possible to isolate systems or exclude certain life cycle stages, which could misinform those who are unfamiliar with the method. For example, a glance at the EPD for Skanska's green concrete gives the impression of having achieved up to 52% reduction in climate impact compared to conventional concrete (Skanska, 2020). However, as it is a product declaration it only contains life cycle stages A1-A3 which does not give a comprehensive view of the potential climate impact reduction when utilized in a building. Furthermore, if this type of information is distributed without the receivers being aware of the preconditions that the numbers are based on and how that translates to a full life cycle perspective, it has the potential of misguiding many actors within the industry into thinking that the industry is farther ahead than it is. It could give the false sense of security that climate neutrality is well within reach with current technology if it were to be widely implemented in all construction projects. The results from the conducted LCA disproves that notion. Mainstreaming of best practices needs to occur in parallel with development of disruptive technologies and innovations to achieve climate neutrality.

7.3 Division and diffusion of responsibility at the consultancy firm

One of the discussed topics during the interviews was responsibility and how the respondents view their own responsibility in their professional role. The interview respondents highlighted that they have policies within the company to reduce their own climate impact, for example to reduce traveling. However, the company also aspires to influence the climate impact caused by the projects they are involved in. They interviewees reasoned that this was part of why the environmental coordinator role was created; to take responsibility and support the engineers in questions concerning environmental impact. However, one of the environmental coordinators pointed out that everyone should reflect upon which climate impact their actions and proposals constitute in all decisions. Being a structural engineer should no longer merely concern constructing a durable structure but also how much climate impact it constitutes.

On the other hand, if responsibility was distributed amongst all employees there is a risk of diffusion of responsibility and social loafing. Diffusion of responsibility is the phenomenon where the individual feels a diminished sense of responsibility when belonging to a group (American Psychological Association, 2020a). A common consequence of this is social loafing, which occurs when an individual puts in less effort when working in a group compared to if they were to work alone (American Psychological Association, 2020b). According to Nollkaemper (2018) shared responsibility is often implemented to mend shortcomings of individual responsibility. However, it is also recognized that it often results in diffusion of responsibility and causes new responsibility-gaps to appear. Thus, if responsibility of reducing climate impact is spread out on between all the engineers instead of having an environmental coordinator, there is risk of no one taking any responsibility due to diffusion of responsibility and social loafing.

Collaboration between the disciplines

The perception of the collaboration between the disciplines and the environmental coordinator differs between the interview respondents and suggestions for joint activities is raised by both engineers and environmental coordinators. Furthermore, some sort of internal education was requested by several respondents. It was uncovered that the engineers wished to learn more about the work that environmental coordinators do and for clarification regarding which role is responsible for which tasks when it comes to diminishing climate impact.

As shown in figure 2.1, environmental certifications for buildings in Sweden have increased during the most recent years. While certification systems systematize the assessment of a building's energy- or environmental performance, each system also covers different aspects. Thus, depending on which, if any, certification is chosen, different assessments and tasks need to be carried out by the engineer and the environmental coordinator. One task mentioned during the interviews was that the engineers sometimes need to keep record of the materials and components they prescribe. While the record keeping seemed to work smoothly at some of the engineering disciplines, other's expressed dissatisfaction towards the tediousness of the task.

Even though it is uncommon for all disciplines to cooperate in a single project, it was recognized that cooperation between the different disciplines could either facilitate or inhibit the utilization of climate impact reducing measures. Since such measures often require adjustments on other design areas unsatisfactory collaboration between disciplines could hamper the implementation. Cooperation was experienced to run more smoothly when all disciplines are consultants from the studied consultancy firm compared to when external consultants are involved.

7.4 Competences and intellectual capital at the consultancy firm

Rheude et al. (2021) state that the extensive number of terms and concepts within the sustainability field in construction induce misunderstandings and confusion. Terms and concepts used in research have yet to fully penetrate the industry which contributes to misuse of terms in PR, i.e., green washing. This tendency was recognized by several interview respondents who all expressed dislike towards it.

There are many different environmental certifications, and they cover different areas. One of the services that the environmental coordinators offer is to help their clients choose the most appropriate one. Even though both environmental coordinators mentioned that there are better ways to reduce climate impact than to completely rely on environmental certifications, they still think that it is beneficial to use them as a frame of reference, especially when talking to a client.

The consultancy firm strives to have licensed employees in all the different environmental certification systems to be able to offer competence within all systems. Licenses with the different systems are distributed amongst the employees and across the regions. This is followed by cooperation across the regional offices when a certain certification is requested by a customer located in a district where the consultancy firm does not have a licensed coordinator in that specific system which also encourages additional exchanges of knowledge and competences across the regions.

While the HVAC engineer and the electrical engineer had extensive previous experience working with the suggested measures, the structural engineer had limited experience working with green concrete and no experience with cellulose insulation. Photovoltaic systems are commonly prescribed in the consultancy firm's projects and since they have a separate group specifically tasked with those projects, it can be considered an organisational capability. Furthermore, interviewees other than the electrical engineer suggested photovoltaic systems as convenient measures of reducing climate impact as solar electricity can replace electricity generated by non-renewable energy sources indicating well diffused knowledge within the organisation.

Although the HVAC engineer had extensive experience working with smart ventilation in commercial buildings, it was not commonly encountered in residential projects. However, as the technology remains the same it can still be regarded as intellectual capital held by the organisation. The structural engineer had previous experience working with timber frames and recently the consultancy firm acquired additional competence through consolidating with another firm which specialised in wood and timber construction (AFRY, 2021b).

While the environmental coordinators receive education in the LCA-methodology and consequently gain extensive competence within the field, the engineers had limited experience of LCAs. However, the engineers expressed interest in gaining more competence through seeing additional assessments of other types of materials and systems. One of the engineers mentioned wanting to see LCAs, or at least numbers on generated CO_2-equivalents, for all types of products and components and that such information would be valuable when deciding on what to prescribe.

7.5 Routines for knowledge-sharing and preservation of intellectual capital

According to all interview respondents, internal motivation and interest in the climate issue was noticeable in the professional environment and efforts made to reduce climate impact. This was especially noticeable amongst younger employees and was endorsed by all respondents. It was also mentioned that the consultancy firm encourages individual employees' wishes to further educate themselves or gain additional competences within a certain field.

During the interviews, several respondents mentioned reaching out to other regions for advice and to share experiences. While employees can contact each other through an internal network, it was expressed that knowledge-sharing could be improved, and expertise and experiences made more accessible. According to Swan et al. (1999), people management is more important than IT-systems to endorse knowledge-sharing, though it is recognized that technology can provide network links.

Todericiu and Boanta (2019) considered three main barriers of knowledge-sharing; that it is difficult to gain knowledge from an employee that has chosen to quit, that employees sometimes prefer to be knowledge keepers as it gives them a competitive advantage compared to their colleagues, and that the more competences an individual holds, the more difficult it is to recover any of it. If the interview respondents do not think the consultancy firm has sufficient knowledge-sharing practices, it could indicate that some of the mentioned barriers are experienced by the employees. One of the interview respondents especially reflected upon the first barrier and the potential consequences. According to Todericiu and Boanta (2019), the best way to prevent that from occurring is to have that employee teach the other team members, thus making it an organisational capability rather than an individual competence.

One barrier that was mentioned by several interview respondent was that the physical division of the different disciplines inhibited knowledge-sharing. One of the engineering disciplines is situated at a different floor and both the engineer from that discipline and one of the environmental coordinators recognized the situation of needing to ask a seemingly trivial question but opting not to because of the fear of appearing uneducated on the topic if they were to ask it via email. However, they would have asked that question in person if they had the opportunity to do so. If the consultancy firm decided to move all the disciplines to the same floor it would enable informal conversation and water-cooler chats which further facilitates cooperation and a knowledge-sharing culture (Kraut et al., 2020). According to Boh (2007), a large and geographically dispersed organisation should have both informal and institutionalized knowledge-sharing routines.

One formal routine is that the disciplines host presentations whenever they finish a project and share lessons learned with the other team members. Furthermore, they also upload a short summary on the internal network. During the interviews it was mentioned by the engineers that these presentations often focused on the technical aspects of how to implement a certain solution rather than climate impact. However, the corresponding presentations at the Sustainable Building discipline mainly focuses on climate impact and lessons learned.

7.6 Innovation management routines at the consultancy firm

From the results of the conducted LCA, it can be deduced that disruptive technologies and innovations are needed to achieve climate neutrality. One factor inhibiting adoption of innovations mentioned both in literature and by the interviewees is the client. Similarly, to Ivory (2005), the engineers perceived that their ability to reduce climate impact is governed by the client's own ambition, or lack thereof, to reduce climate impact. However, Tookey et al. (2011) identifies the client as key source of innovation within the construction industry. Environmental coordinator A recalled several projects where they have collaborated with clients in pilot projects, and where the client's ambition was what spurred on the project.

The engineers express a wish to more actively participate in finding and discussion new innovations than they currently do. Furthermore, the structural engineer mentioned that at their previous place of work, there was a group specifically tasked with inventing, exploring, and testing innovations and new technologies, but that they are not aware if any similar groups exist at the consultancy firm. Such a group does exist within the organisation which indicates that the communication regarding innovation initiatives could be improved.

There is a significant opportunity and tendency for new practices due to the uniqueness and project-based approach of the industry (Pries & Janszen, 1995). One interviewee expressed that new regulations generate new business opportunities for them as a consultancy firm, and that the consultancy service could also induce proposals of alternative solutions and accelerate the implementation of such innovations. Being the second largest consultancy company within the Swedish construction industry puts the studied consultancy firm in an opportune position of achieving their vision and mission *"Making future - We accelerate the transition towards a sustainable society"*. However, to do so, even more focus should be given to innovation management and to adopting innovations in their projects.

7.6.1 The law of diffusion applied to the adoption of climate impact reducing measures in the construction industry

To explore how the disciplines viewed themselves regarding adopting to alternative solutions and innovations an interactive exercise was conducted during the interviews. The respondents got to put themselves, their discipline, and the consultancy firm in the group where they thought they belonged in the DOI-curve (see figure 6.1) through choosing which description they thought most applicable.

The most common opinion amongst the respondents was that each respective discipline and the consultancy firm lied within the third category *Early Majority*, but that they wanted to belong to the second group *Early Adopters.* One respondent highlighted that the company rather was a combination of the first three categories and that it depends on the project and the client's ambition. If the client expressed high ambitions to reduce climate impact, the consultancy firm and the Sustainable Building discipline would gladly take part in developing the solutions, act as an *Innovator* and take part in pilot project or prestige projects. But if the client has no interest, it is easy to fall into the third category. As the second largest consultancy company in the Swedish construction industry, the studied firm is in an opportune position to drive innovation within the industry and achieve their vision and mission *"Making future - We accelerate the transition towards a sustainable society"*. However, interview findings suggest that while they aspire to be *Innovators* or *Early Adopters*, the company belongs to the *Early Majority.*

Sinek (2009) suggests that *Innovators* and *Early Adopters* do not buy into an innovation or idea simply because of what it does, they do it because of what they themselves believe and that the new product is simply proof of what they believe. People like to be first, to be viewed as front liners. Only after the first two groups have accepted an innovation will the masses follow. To act in accordance with the company vision and mission, the company should ideally operate as an *Innovator*, or at least as an *Early Adopter*. However, according to the interview respondents, that is not the case. On the other hand, none of the interview respondents actively work with innovation or research and development, and results could differ if employees from other disciplines had been interviewed.

According to Sinek (2009), 15-18% need to adopt the innovation for the system to tip over and eventually reach full market penetration. As the second largest consultancy company within the Swedish construction industry, the studied organisation has the opportunity to influence the market and raise the bar for other actors to follow.

7.6.2 The Kano model applied to the adoption of climate impact reducing measures in the construction industry

Boverket (2018a) argued that it is not currently beneficial enough for clients to request buildings with less climate impact nor for engineers to propose less climate-impacting building methods and building materials. The interviewed engineers shared this viewpoint, but the environmental coordinators believed their clients view the environmental coordination service as a *One-dimensional quality*, or in some cases even an *attractive quality*, see figure 3.4. It also became apparent during the interviews with the engineers that far from all projects hire an environmental coordinator to begin with. This indicates that the general view of the environmental coordination service within the industry is not that of a *One-dimensional quality*, and even less of an *attractive quality*. Rather it could imply that it is considered an *Indifferent*, or perhaps even a *Reverse*, *quality*.

Organisations should focus their attention and resources on the products and services, or elements of them, that contribute customer satisfaction (Six Sigma Daily, 2020). If measures of reducing climate impact do not generated that, then it is not surprising that the development of such innovations and solutions has not progressed further. Perhaps that is why no major changes have been made in the way we design or build today compared to in the 1960s despite that trials and testing of alternative methods have been going on ever since (Coma Bassas et al., 2020). It is evident that the natural transition from attractive to one-dimensional to *Must-be quality* that most innovations go through does not apply to climate impact reducing measures within the construction industry. That spurs the question of whether a service or product that was never considered to be an *Attractive quality* to begin with can ever become a *Must-be quality*. Instead of waiting for evolving customer requirements to guide the industry in the right direction, regulations can be used to accelerate the progression.

As the new law on climate impact declaration for buildings commences in 2022, the climate coordination service can be expected to take on the attributes of a basic requirement (Boverket, 2020b) (Kano et al., 1984). However, this only applies to the climate impact declaration part of the service. Suggestions of further measures to reduce climate impact could still be considered as an *Indifferent* or *Reverse quality*. On the other hand, it has the potential of becoming a one-dimensional or *Attractive quality* depending on the clients' ambitions of staying ahead of the upcoming limit values which are suggested to be introduced in 2027 and gradually become more and more strict. It could be an incentive for clients to request more measures, or at least be more susceptible towards suggestions of such measures.

7.7 Prevailing progress towards climate neutrality and outlook on the future

As one of the largest contributors to climate change worldwide, the construction industry needs to take responsibility and act to reduce the climate impact it constitutes (World Green Building Council, 2017). Reducing the climate impact has been on the agenda for several years and despite several initiatives results have been insufficient. In 2018 The Swedish Building and Construction Industry (2018) released their plan for a climate neutral construction industry by 2045. Both literature and the interview study reveal numerous aspects to why the progression towards a climate neutral construction industry have moved slowly.

Erlandsson and Malmqvist (2018) claim that by implementing existing technologies the sector can improve its climate impact substantially. However, from the interview study it was expressed that lack of efforts and an unwillingness to deviate from conventional practices exist among several stakeholders within the sector. These results confirm the notion of Coma Bassas et al. (2020) that trials and testing of alternative methods and materials has been going on ever since the environmental movement of the 1960's, but no major changes have been made in the way we design or build today. This phenomenon demonstrates both the stubbornness of the industry as well as the difficulties in diffusing innovations.

When reviewing the literature, ambiguities regarding theory as well as methods for calculating climate impact was acknowledged. Due to researchers contradicting one another it is not surprising that the industry has a hard time to navigate. An implication of this is associated to the theory behind carbon capture. One questionable aspect of these technologies is that they only storage carbon temporarily. Researchers claim that it is important to use these measures as a temporary carbon sink since it is important that measures are taken now to reduce climate change. However, what about the emissions exhausted when the timber is demolished? Is it sustainable to push these issues on future generations and leave them to deal with the repercussions of emissions caused today?

The current strategy to achieve climate neutrality by 2045 is to trust in technologies such as capture of carbon. Initiatives such as the recently developed NollCO_2 certification promote these measures. Furthermore, another questionable aspect of the current strategies is compensation measures. The NollCO_2 certification sanction climate compensations. Ambiguous of how to assess and weigh different parameters exist and whether it is a forceful enough strategy could be questioned. Is there a risk that more efforts are made to compensate for emission rather than reducing them in the first place?

Another issue hindering the climate impact calculation is access to data. Because of the low maturity within the sector there is currently few suppliers that provide EPDs for their products which impedes LCA-calculation. This was also experienced during the work of this thesis. Lack of EPDs obstructed the LCA and shows that it is currently difficult to perform adequate LCAs. This indicates that there are still major difficulties regarding technical development for calculations. The uncertainties within LCA therefore might be too large for it to facilitate decision making in the current state. Both literature and the interview findings highlight a need for more EPDs and request that product manufactures develop better products and decelerate its climate impact.

During the interviews, the respondents were asked if they thought it is possible to achieve climate neutrality by 2045. Several of the respondents thought it was possible but that drastic measures would be needed. It was expressed that there are currently too few economic incentives to build with better climate performance. Historically the economic gain of certifying a building has not been lucrative enough, however, according Boverket (2018a) this will not be the case in the future. As awareness of climate change increases in society prognoses indicate that citizens in the future will value how much climate impact the building they live or work in causes. If developers do not invest in these issues today, their building might not be attractive in the future. Therefore, to stay competitive developers hopefully soon realize that they should prioritize these matters.

7.7.1 Circle of blame and implications on the construction industry

Previous studies show that several actors neglect taking responsibility for their climate impact. A tendency among the actors to blame each other and not acknowledge their own responsibility prevails. This so-called circle of blame among stakeholders creates a never-ending circle and the consequence is a slow progression towards sustainable sector (Andelin et al., 2015). To adhere to the Paris Agreement all actors within the industry needs to take responsibility to advance towards climate neutrality.

The empirical findings mostly stress that the client should drive the progression which is also insinuated in the literature review. Customer requirements are frequently identified as determining factors for both the overall goal and attitude of the project, as well as the main driver for any innovations within the industry (The Swedish Building and Construction Industry, 2018). On the other hand, researchers also point out several areas in which all actors; clients, contractors, architects, and consultants can influence the outcome. Consultants have the ability to give advice on design choices and suggest measures for reducing climate impact to the client (Erlandsson, 2019b). However, if the client is not interested in reducing climate impact, they might not be susceptible for the consultant's suggestions.

During the interviews it was mentioned that legislation and regulations concerning climate impact need to become stricter to incentivise all actors within industry to focus more on environmental aspects. However, the interviewees also recognized their own potential to promote the question in the industry to guide authorities when establishing new regulations.

In summary, although the client is often mentioned as the main barrier it is important that all actors reflect on their own capabilities and responsibility to reduce climate impact. The construction industry is a loosely coupled system and each actor plays their own part. Thus, rather than blaming each other all actors should be more self-critical and, despite resistant from other actors, still pursue all possibilities within their own influence.

7.7.2 Outlook on how the new law for climate impact declaration and other regulations will affect the industry

Recently, stricter demands on energy efficiency have been defined, suppressing the possibilities to disregard the climate impact caused by energy consumption. This has had a positive effect and nowadays the construction and manufacture of building materials account for most climate impact rather than the energy consumption (Erlandsson & Malmqvist, 2018). The climate impact of materials and product has not been regulated until now. Several of the interviewees request stricter regulations that would restrict the ability to disregard climate impact.

In 2019 the Swedish government commissioned the National Board of House Building and Planning to initiate preparations for the introduction of regulations for climate impact declarations for new buildings along with the expansion of including the entire life cycle in the climate impact declarations, and limit values for climate impact (Boverket, 2020a). Regulations for climate impact declarations are planned to commence in 2022 while the regulations on limit values for climate emissions are suggested to be introduced in 2027.

Both interview respondent A and B showed support for the new law on climate impact declaration but insinuated that a transition time of five years before limit values are introduced is too long. As the industry adjusts to the new mindset authorities will introduce stricter regulations but enforcing limit values directly could have consequences. Environmental coordinator A acknowledges the obligation to not exclude anyone from the market and that smaller firms might need more time to adjust to the new regulations.

In addition, this slow transition enables for suppliers to adjust and produce EPDs to be used in LCA-calculations. One of the engineers outlined the importance of climate impact caused along the value chain and specifically mentioned the manufacturer's actions also should be regulated.

In general, the interview respondents had a positive attitude towards the new law on climate impact declarations for buildings. They expect it to be successful in its ambition to bring more awareness of climate impact to the industry. Furthermore, it was mentioned that it will bring about new business opportunities for the consultancy firm.

It is still uncertain whether the future climate impact limit values will be strict enough. Although it is extremely important to raise the lowest standard, it is also important to make it profitable to go above and beyond. This can be achieved through subsidies and green bonds. However, ideally the construction industry would be able to make this transition itself if the end-user viewed environmental performance as an *Attractive quality*, thus making it a competitive advantage within the industry.

7.8 Discussion of methodological choices

Given the initial thesis proposal created by the consultancy firm the choice of exploring measures of reducing environmental impact within the structural engineering, electrical engineering, and HVAC engineering disciplines was predetermined. Had focus instead been on one of the three disciplines perhaps more alternative measures could have been explored, but at the cost of the holistic perspective.

To fulfil the aim and purpose and answer the research questions a literature review, interview study and an LCA were conducted. The three main methods proceeded alongside one another through an abductive process. The interview study was divided into two phases due to the expectation of new information surfacing during the first phase that would be of interest to explore in the LCA and dive deeper into during the second interview phase. One topic that surfaced during the first interview phase was organisational barriers and improvement opportunities, had there not been two interview phases the opportunity to explore this theme would not have existed. Consequently, focus was given to both the suggested measures as well as organisational improvement opportunities.

When conducting an LCA there are several methodological choices to be made such as choosing the appropriate system boundary, what components to include and what impact categories to evaluate. To generate representative results a comprehensive system boundary was chosen and EPDs used when possible and only substituted with generic data when no specific data was available. As generic data generally is more conservative and therefore also has higher environmental impact than specific data, climate impact of the building for the chosen system boundary can be expected to be lower than calculated. On the other hand, life cycle stages A5, B1-B3 and D (see figure 3.2) were not included in the calculations, thus the total climate impact caused is likely higher than calculated.

The LCIA was calculated using the CML-IA 2012 methodology since it is both the required method by the European standard EN 15978:2011 and the default method in One Click LCA (Kommittén för Hållbarhet hos byggnadsverk, 2011). Had a different methodology been chosen, for example ReCiPe, it would have been possible to calculate caused environmental impact for additional impact categories such as land use, water depletion, and human toxicity. The BREEAM-certification framework was chosen due to it having the most extensive data base of EPDs within One Click LCA.

The interview respondents included one representative from each of the relevant engineering discipline as well as two environmental coordinators. In total there are around twenty environmental coordinators in Sweden, thus two representatives were considered a reasonable sample. However, during the interviews they were mainly asked about their own individual opinions and statements made are therefore considered specifically applicable to the individuals themselves and not the entirety of any of the two respective sections. The same is true for any statements made by the engineers. On the other hand, the engineering sections are considerably larger than the *Sustainable Building* disciplines and ideally more representatives from each engineering section should have been interviewed. Furthermore, a more comprehensive analysis of the underlying barriers towards implementing climate impact reducing measures could have been achieved through interviews with both clients and contractors. This was not possible due to time constraints.

The interviews were analysed using a method called KJ-analysis. The method was chosen due to having had previous experience working with it. Furthermore, KJ-analysis is an inductive method, common topics were identified through the interview responses rather than being preconceived. It is a time-consuming method and perhaps a deductive approach would have been more time efficient.

DOI is only one of many innovation theories, and Sinek only one of many authors and lecturers on the topic. A more comprehensive analysis of the consultancy firm's role in driving innovations within the industry could be achieved through including additional theories and perspectives from other research.

Similarly, the Kano-model is but one of many quality management concepts. Furthermore, the interview solely focused on the consultants' perception of their clients' attitude towards the environmental coordination service. Ideally, interviews should also have been conducted with clients that have previously worked with environmental coordinators at the consultancy firm to gain a first-hand perspective.

8
Conclusion

This chapter contains conclusions related to the research questions in subsection 1.2 Research questions. Recommendations for continued work and future research are also presented.

What are the current methods used within the structural engineering, electrical engineering, and HVAC engineering disciplines to reduce environmental impact with a focus on global warming potential?

In chapter 3 Theoretical Framework, several possibilities to reduce climate impact related to the studied disciplines are suggested.

The structural frameworks constitute a significant proportion of the building's total climate impact; hence, great improvement opportunities exist to reduce the contribution from this element. By using alternative materials instead of conventional concrete, a substantial reduction in climate impact can be achieved. In literature, timber is portrayed as the most advantages alternative as it is both a renewable resource and has carbon capture capabilities. However, it was also recognized that it is not always possible to substitute a concrete frame with a timber frame as it requires extensive redesigns and is a decision which needs to be made early on.

During the last decades green concrete has been developed with promising results. Conventional concrete can be exchanged with green concrete without the extensive redesigns that timber frames need. As concrete is the most used framework material in Sweden, the market is probably more recipient to green concrete than timber frames. As such, widespread implementation of green concrete could achieve substantial reductions in Sweden's total climate impact. To further reduce climate impact, efforts can be made to optimize the concrete quality. Both literature and the interview study identified a tendency to use a higher concrete quality than necessary. This practice results in increased climate impact, and it is therefore recommended that a sufficient concrete quality is used instead of over-dimensioning.

In addition to timber frames, literature suggests implementation of other bio-based materials such as hemp- or cellulose insulation. Given satisfaction of technical and functional requirements, material selection should be based on the best environmental performance as well as resource-efficient construction solutions. However, the product with the best environmental performance might contribute to increased material consumption. In such instances an LCA could be used performed to evaluate the effect of each measure and serve as a guide for decision making.

A circular mindset where recycled materials are incorporated is also highlighted by literature. Recycled materials are beneficial from a resource-perspective as it can replace virgin materials. However, it is not always possible to implement recycle materials due to technical and functional requirement. Furthermore, the recycled product's climate impact must be compared with the climate impact caused by the corresponding product from a life cycle perspective to gauge if the substitution is beneficial or not.

Design choices can be made with the aim of reducing energy consumption in the user phase. Energy efficient electrical installations and electronics should be favoured, and previous research has showed that individual feedback also has the potential to reduce electricity consumption. Another measure to reduce climate impact related to electricity consumption is to use renewable energy sources, such as solar power. Through implementation of photovoltaic cells solar electricity can be generated. Regardless of whether the generated electricity is used in the building or sold to the grid, it replaces the need for electricity generated by non-renewable sources which is beneficial from a societal perspective. If the photovoltaic system is integrated with batteries, electricity can be stored and used at another time which can contribute to reducing peak loads.

It is currently common practice to implement FTX-systems in new construction of residential buildings. This system saves a considerable amount of energy compared to ventilation systems based on natural airflow. FTX-systems are available in various levels of energy efficiency, from a climate impact perspective the most efficient system should be chosen. Further energy savings can be accomplished through adjusting ventilation in accordance with the demand. VAV- or DCV-systems could be incorporated to ensure that energy is not used for unnecessary ventilation. Another suggestion is to lower the indoor ambient temperature and instead utilize active heating systems which could result in energy savings.

Chapter 3 Theoretical Framework also presents several measures to reduce climate impact related to water systems. The design and placement of installations affects HWD-losses, which in turn influences energy demand and water consumption. Further water conservation can be achieved through implementing water-efficient taps. In addition, greywater can be purified and reused which diminishes freshwater consumption. Another possible solution is to apply heat recovery to grey- and wastewater which could result in energy saving as the recovered heat can be used for heating of incoming water.

Both ventilation- and water systems can be designed for optimization of material usage. By planning the placement of installations and evaluating the operational need; quantities of ducts, pipes and other installations can be minimized which results in both decreased climate impact and increasing relevance of embodied emissions associated with HVAC-systems.

In summary, there are many different measures of reducing climate impact within each of the three disciplines, all of which have their own set of benefits and disadvantages. All the suggested measures are listed in the table below.

Structural engineering	**Electrical engineering**	**HVAC engineering**
Resource efficient design		
Base material selection on EPDs		
Bio-based materials	Energy efficient electrical installations	Energy efficient systems
Green concrete	Renewable energy sources	Smart ventilation
	Resilience towards user-behaviour	Water conservation
		Placement of installations

Table 8.1: List of suggested measures within each of the studied disciplines. The measures are listed without any particular order.

Which solutions, actions, and methods of reducing climate impact does the studied consultancy firm have the potential to implement in the design process of residential buildings?

Only a selection of the previously mentioned measures can be implemented during the design process. Material choice for the structural frame is decided upon in the early stages therefore it might be difficult for the consultants to suggest an alternative design depending on when they get involved in the project. If the consultant is given the opportunity to advise the client on different types of structural frameworks, they can suggest a timber frame. However, if the client has already decided upon a concrete frame, the consultant can still suggest hybrid solutions or green concrete. Substitution to green concrete from conventional concrete does not require as extensive redesigning as when switching to a timber frame. Furthermore, as previously mentioned, efforts can be made to reduce climate impact by avoiding over dimensioning the concrete quality and instead use the appropriate concrete quality. Implementation of bio-based materials, such as cellulose, can be suggested during the design process and could potentially reduce the climate impact.

Component choices during the design process should be made with the aim to reduce energy consumption during the user phase. While energy efficient electrical installations and electronics should be favoured it is important to note that user behaviour affect the outcome. Inaccurate user behaviour can potentially cancel out the predicted benefits of the solution and this lies outside the consultant's area of influence. On the other hand, it can also be argued that the systems are not resilient enough to adapt to different user behaviours. Hence, user behaviour in an important factor to consider when comparing different components and electrical installations. Individual feedback also affects user behaviour and could potentially contribute to diminishing energy consumption. However, individual feedback lies out of the influence of the consultant.

During the design process the consultant has the possibility to suggest photovoltaic cells as a measure to reduce climate impact. Integration with batteries can also be suggested to fully exploit the generated solar electricity. However, if the client is not interested in installing batteries, excess electricity can be sold to the grid which still contributes to reduced climate impact from a societal perspective.

FTX-systems are nowadays common practice within the industry in new construction, nonetheless, attention could be focused to ensure that the system has a high efficiency rate. During the design process the consultant has the opportunity to suggest VAV- or DCV-systems instead of natural flow ventilation which could potentially reducing energy consumption.

Regarding water systems, design choices to reduce water consumption and achieve energy savings during the use phase could be made through optimal placement of the systems to reduce HWD-losses and implementation of water-efficient taps. Other measures could be to utilize grey- and wastewater by either implementing heat recovery systems that exploit energy from grey- and wastewater, or by purifying and reusing greywater.

Similarly, to how the performance of electrical installations is affected by the resident's activities, the success of water- and ventilation systems also depends on accurate user behaviour. Hence, the consultant should design systems that are resilient towards different user behaviour.

All disciplines should optimize material consumption, and if possible, recycled materials could be implemented to reduce consumption of virgin materials. To ensure optimal environmental performance for the entire building, material selection should be based on LCA-calculations.

What competence and expertise regarding climate impact reducing measures currently exists within the respective disciplines at the studied consultancy firm, and what needs to be strengthened?

The studied consultancy firm has knowledge and experience working with several of the previously mentioned measures. Both optimization of concrete usage and choosing the appropriate concrete quality are commonly practised at the consultancy firm's *Structural Engineering* discipline. Although green concrete has been used in previous projects it is not commonly prescribed and clients rarely request it. On the other hand, the consultancy firm has experience working with timber constructions and recently acquired additional expertise through consolidating with another company which specialized in this field.

The consultancy firm also has experience from incorporating renewable energy sources through prescribing photovoltaic cells in several projects. Since the organisation has a group which specifically works with photovoltaic cells the adoption of this technology lies well within the consultancy firm's organisational capabilities.

FTX-systems is commonly used within new construction of residential buildings and although previous experience from smart ventilation exists within commercial buildings it has not yet been applied to residential buildings. However, since the systems are still based on the same principle, the consultancy firm should be able to provide this service for residential buildings as well. While the consultancy firm also has previous experience working with reducing HWD-losses, they do not have previous experience of water recycling or heat recovery from waste- or greywater.

All engineering disciplines could become more aware of their material selection and choose the product or material with the lowest climate impact. This can be achieved either through comparing EPDs or by performing LCA-calculations. However, the interview findings indicate that expertise within the LCA-methodology needs to be strengthened. Although the environmental coordinators possess competence regarding the LCA-methodology, the engineers have limited experience working with the methodology and expressed interest in learning more to be able to interpret LCA-results without being misguided. This could either be achieved through formal education or by having the environmental coordinators share their expertise with the other disciplines.

The studied consultancy firm is a large and geographically dispersed organisation. Therefore, it is essential to maintain and follow up on their formal knowledge-sharing routines to fully utilize the benefits of their employees' intellectual capital. To offer a competitive service all consultancy firms need to continuously acquire new knowledge and competences. This is especially true for the environmental coordination service as measures of reducing climate impact are constantly being developed.

How can a life cycle assessment induce pro-environmental decision making during the design process?

Both the interview findings and literature support the notion that LCA can induce pro-environmental decision making through comparing different scenarios and identification of environmental impact reduction opportunities throughout a building's life cycle. However, for this to be possible, a standardized method on how LCAs for buildings should be performed needs to be developed to avoid misleading system boundaries which could misinform those unfamiliar with the methodology. Guidelines need to be standardized across the industry and preferably also internationally as a European Standard.

If LCA is to promote pro-environmental decision making the results need to be reliable. Generic data is more conservative than specific data which could generate misleading results. Therefore, it is important that more EPDs become accessible to ensure that calculations are based on specific data. In the early stages of a construction project generic data can be used in LCA-calculations to gain an estimate of different design solution which could potentially guide decisions regarding material selection. However, since the caused climate impact can vary within material groups depending on the supplier, it is important to compare EPDs for the final decision.

As the new law on climate impact declarations for buildings commences in 2022 and limit values are eventually introduced, LCA's potential of promoting pro-environmental decision making will most likely grow. Furthermore, as the transition progresses additional aspects of the LCA-methodology will eventually become expected customer requirements. For example, it is important to add social and monetary factors to the LCA in form of an SLCA and LCCA to fully grasp all perspectives that may affect decision making. Correspondingly, the need for competence within the methodology will also increase within the Swedish construction industry. As clients go to consultants for guidance on this matter many new business opportunities will surface.

8.1 Future works and recommendations

The results from the conducted LCA disproves the notion that climate neutrality is well within reach if current technology were to be widely implemented in all construction projects. Widespread implementation of current technologies can still contribute to substantial reductions in climate impact, but to achieve climate neutrality extensive actions of climate compensation are required. Thus, mainstreaming of best practices needs to occur in parallel with development of disruptive technologies and innovations to achieve climate neutrality. Due to the urgent need to diminish climate impact, further research and development of bio-based materials and carbon-storage technologies is needed. In particular, more LCAs that showcase a comprehensive system boundary is required to showcase the truly achieved climate impact reduction and guide the industry towards climate neutrality. Climate neutrality demands a large shift in the current practices in the construction industry. This includes all stakeholders.

To reach climate neutrality within the Swedish construction industry all actors need to reflect on their own capabilities and responsibility to reduce climate impact. The construction industry is a loosely coupled system and each actor plays their own part. Thus, rather than blaming each other all actors should be more self-critical and, despite resistant from other actors, still pursue all possibilities within their own influence. For consultancy firms this entails focusing on continuous improvement and institutionalizing routines that facilitate cooperation, knowledge-sharing, and innovation management.

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A
Appendix

A.1 Interview guide for the first interview with the Environmental coordinators

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Intervjuguide för intervjufas 1 med miljösamordnarna

Allmänt

- Kan du berätta om din roll och ditt arbete som miljösamordnare? Hur länge har du haft den?
- Hur många är ni på din sektion?
- Varför sökte du dig till den här tjänsten?
- Kan du kort berätta mer om hur projektprocessen fungerar, och när du brukar bli inkopplad i projekt?
- Vilka andra interna och externa aktörer har du kontakt med i ditt arbete?
  - Vilka av dessa har störst inflytande över projektet?
- Hur upplever du generellt att arbetet med miljöreducerande åtgärder har skett i projekten fram tills det att du kommer in i bilden?
- I de fall som inget arbete har skett, hur går du då vidare?
  - Hur bemöts ditt arbete sen när du presenterar dina förslag på miljöreducerande åtgärder? Och till vem/vilka presenterar du dina förslag?
  - Upplever du att det finns en drivkraft hos kunden att minska klimatpåverkan när väl lösningar presenteras?
- I de fall där det har skett ett bra förarbete, hur ser ditt arbete ut då?
  - Hur bemöts ditt arbete sen när du presenterar dina förslag? Och till vem/vilka presenterar du dina förslag?
  - Upplever du att det finns en drivkraft hos kunden att minska klimatpåverkan när väl lösningar presenteras?
- Vad tror du är anledningen till att det (inte) har skett något arbete innan? Vilka interna/externa incitament och drivkrafter är det som verkar?
  - Ligger det bara på miljösamordnaren att presentera förslag eller finns det andra som också bidrar med detta?

Innovation

- Sett enbart till pilotprojekt, vilka har vari de mest framgångsrika klimatreducerande åtgärder (material, system, verktyg och riktlinjer) som har prövats?
  - Finns det några som ni har tagit vidare till fler projekt och börjat använda i större skala?
  - De som ni inte har fortsatt med, tror du att dessa skulle gå att implementera i större skala?
  - Vilka hinder finns för storskalig implementering i de fallen?
- Vilka skulle du säga är de mest avgörande klimatreducerande åtgärder med avseende på disciplinerna VVS, EL och KV som i ett konventionellt projekt skulle kunna ge störst effekt? Nämn gärna ett eller två förslag per disciplin.
  - Vilka av dessa är implementerbara i stor skala?
- Är risk för att nya lösningar inte är byggtekniskt prövade och osäkerhet kring säkerhetsgaranti hinder för att implementera nya lösningar?
  - Vilka aktörer är det som har beslutsfattande roller i dessa frågor?

Organisation

- Vad känner du till om miljösamordnarrollens tillkomst och vad tror du att det grundade sig i?
- Vilka initiativ har AFRY gjort för att underlätta ditt arbete som miljösamordnare?
- Vi har fått se en mall för beslutsfattande ”Medvetet val”, är det något som du känner till och använder dig av i ditt arbete?
  - Om ja, tycker du att det är ett bra hjälpmedel för att utvärdera olika alternativ?

Intervjuguide för intervjufas 1 med miljösamordnarna

  - Om nej, hur brukar beslutfattningsprocessen se ut i de projekten du jobbar med?
  - Tror du att användandet av en sådan här mall hade gjort att bättre alternativ hade valts med avseende på miljön?
- Hur ser din arbetsrelation ut till projektörerna?
  - Hur ser din arbetsrelation ut till projektörerna?
  - Varför tror du att det inte projekteras bättre lösningar i konventionella projekt?
- Tycker du att ni (AFRY) har skapat en bra arbetsgång med rätt ansvarsfördelning i stort gällande samarbete med projektörerna och andra avdelningar?
  - Upplever du att arbetsgången ni följer har en positiv eller negativ inverkan på din egen motivation att driva klimatarbetet framåt?
  - Om du fick bestämma, hur hade den arbetsgången då sätt ut?

Individen

- Upplever du att dina medarbetare är motiverade och har en drivkraft att minska klimatpåverkan?
  - Tycker du att företagskulturen speglar den vision som AFRY satt upp (Att tillhandahålla de mest hållbara lösningarna)?
- Av din erfarenhet, räcker det att företaget har satt ambitiösa klimatmål eller krävs det att motivation även finns på individnivå?
  - Vad skulle företaget/organisation mer kunna göra för att säkerställa att deras vision når ut till sina medarbetare?

Hårdvara/Teknik

- Kan du kortfattat förklara om den utveckling som skett med programvara och datatillgänglighet inom miljösamordning och LCA?
  - Är den teknik som finns idag tillräcklig för att du ska kunna genomföra ditt jobb utan att behöva kompromissa på kvalitet?
- Vilka hinder finns det för att kunna utnyttja den teknik som finns till sin fulla potential?

Avslutning

- Vilka anser du är de största hindren till att man inte implementerar mer klimatreducerande åtgärder i större skala?
- Vad skulle behöva förändras för att byggindustrin ska kunna kringgå/lösa dessa hinder?
- Vems ansvar tycker du det är att driva den här utvecklingen?

A.2 Interview guide for the designers and engineers

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Intervjuguide för intervjufas 2 med projektörerna

Allmänt

- Kan du berätta om din roll och ditt arbete som sektionschef för projektörerna inom VVS/El/K? Hur länge har du haft den tjänsten?
- Hur många är ni på din sektion?
- När brukar projektörerna bli inkopplad i projekt? Och hur längre följer de projektet? Dvs, vilka stadier är ni inblandade i? (ex. förstudie, systemhandling osv)

Individen

- Vilken betydelse har miljöpåverkan i ditt arbetsliv och ditt privatliv?
    - Vilket ansvar tycker du att du har i din roll som projektör och sektionschef att bidra till att bygg- och fastighetssektorn minskar sin klimatpåverkan?
- Hur upplever du att drivkraften att minska klimatpåverkan ser ut hos dina medarbetare?

Organisation

- På vilka sätt tycker du att visionen (att tillhandahålla de mest hållbara lösningarna) märks av i företagskulturen? (tänker på den i ditt arbete?)
- Vad skulle AFRY mer kunna göra för att säkerställa att deras vision når ut till alla sina medarbetare?
- Vilka initiativ har AFRY gjort för att utbilda dig inom miljöpåverkansreducerande åtgärder som går att applicera inom din disciplin?
- En byggnad är ett system där alla discipliner påverkar varandra. Hur tycker du att samarbetet med de andra disciplinerna fungerar idag gällande miljöpåverkansåtgärder?
- Hur samarbetar din disciplin med miljösamordnarna?
    - Upplever du att de besitter tillräckligt med kunskap för att kunna komma med förslag på rimliga åtgärder och förstå de begränsningar som finns inom din disciplin?
- Vi förstått det som att miljöansvaret främst ligger på miljösamordnarna och inte projektörerna, vad tycker du om det?
    - Hur tycker du att den här ansvarsfördelningen hade kunnat förbättras för att främja klimatsmart byggande?

Teknik/Digitalisering

- Hur upplever du att arbetet med materialloggen fungerar (själv eller hos dina medarbetare)? Hur skulle det kunna förbättras?
- Tror du att det arbetet hade kunnat förenklas med hjälp av digitala medel, exempelvis BIM?

Innovation

- Har ni några rutiner inom disciplinen för hur man utvärderar och testar nya tekniker/processer/krav?
- Har du varit med i ett projekt där man tagit till åtgärder (ex. byte av material, produkter eller system) i syfte att minska klimatpåverkan? Vilka åtgärder implementerade man då?
    - Vilka av de åtgärderna togs vidare till fler projekt?
    - Och de som inte togs vidare, vad var anledningen till det?
- Tycker du att risk för att nya lösningar inte är byggtekniskt prövade och osäkerhet kring säkerhetsgaranti är hinder för att implementera nya lösningar?
    - Är detta något som hindrar dig från att frångå konventionella metoder?
- Utöver de som du tidigare nämnt, vad tror du mer skulle kunna vara framgångsrika klimatreducerande åtgärder inom din disciplin?

Intervjuguide för intervjufas 2 med projektörerna

- Vad tror du är anledningen, utöver det byggtekniska, till att man inte lyckas implementera fler/bättre åtgärder för att minska klimatpåverkan?

<u>Interaktivt moment on Diffusion of innovation</u>

<u>Disciplinsspecifika frågor om LCA för referensprojektet</u>

<u>LCA</u>

- Tycker du att livscykelanalyser är en bra metod för att utvärdera en byggnads miljöpåverkan och jämföra olika systemval inför beslut?
- Hur skulle livscykelanalyser kunna förbättras för att bättre stödja ert arbete?

<u>Branschen</u>

- Tror du att byggsektorn kommer kunna uppnå klimatneutralitet till 2045?
- Vad tror du är anledning till att man i dagsläget inte nått längre i miljöfrågan?
- Vad skulle behöva förändras för att byggindustrin ska kunna kringgå/lösa dessa hinder?
- Vems ansvar tycker du det är att driva den här utvecklingen?

A.3 Interview guide for the second interview with the Environmental coordinators

Intervjuguide intervjufas 2 Miljösamordnare

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<u>Relation till projektörerna</u>

- Under intervju med projektörerna framkom det att de upplever att de inte har inblick i det arbetet ni på Hållbar byggande gör och hur det skulle kunna stötta deras eget arbete, exempelvis LCA som beslutsgrund för olika systemval.
  - Hur tror du att man bäst skulle kunna förbättra den situationen?
- Vad tror du är bästa sättet att motivera projektörerna till att jobba med mer klimatsmarta lösningar och systemval?
- Tror du att projektörerna hade varit mottagliga för en intern utbildning om miljö och hållbarhet?
- Vi har observerat att det ibland upplevs som svårt att ställa krav och driva på projektörer i projekteringsmöten med risk för att underminera dem framför kunden, är detta något du själv erfarit?
  - Hur tror du att man skulle kunna undvika den här typen av dilemman?

<u>Organisation</u>

- Vad upplever du att AFRY har för strategi gällande utvecklingen av er sektion?
- Vad tycker du om att individen själv behöver ta initiativ för att kompetensutvecklas?
- I och med att miljöområdet utvecklas och fler certifieringar kommer upp, ökas behovet av specifik kompetens. Vad tror du är bäst sätt för AFRY att organisera det på? Ska varje enskild individ ha specialistkompetens inom en certifiering eller ska alla kunna jobba med alla?
- Tycker du att den nuvarande organisationen inom AFRY fungerar bra?
- Hur tycker du att AFRY bättre kan sprida kunskapen och förbättra samarbetet mellan regionerna?
- Vi har både hört från intervju med projektörerna samt observerat under veckofika med sektionen att det hölls ett föredrag där erfarenheter lärda från ett specifikt projekt delgavs andra på sektionen. Vad har ni för rutiner gällande den här typen kunskapsåterföringsprocesser?
  - Vilka möjligheter ser du för att bjuda in andra sektioner på liknande föredrag, eller har några andra förslag på hur erfarenheter kan spridas och utvecklas mellan sektionerna?
  - Tror du att den här typen av möten/föredrag även skulle kunna bidra till diskussion om nya tekniker och innovationer som potentiellt skulle kunna implementeras?

<u>Law of diffusion of innovation</u>

<u>Kano-modellen</u>

<u>Beställaren</u>

- Tidigare uttryckte du att beställaren bär mycket ansvar för att ställa kraven på projektet. Vad hade fått beställaren att ställa bättre krav?
- Hur tror du att industrin hade kunnat förändras så att miljöaspekterna värderas högre än de gör idag?
- Finns det några riktlinjer gällande vilka kunder ni ingår avtal med och vilka ni inte gör det med?
- Anser du att det ska vara så mycket fokus på certifieringar såsom det är i branschen idag? Finns det bättre sätt att jobba mot bättre miljöprestanda?

Intervjuguide intervjufas 2 Miljösamordnare

Diskussion om vår LCA

- Än så länge finns det ingen standard på hur en livscykelanalys ska vara utformad utan det är tillåtet att sätta sin egna systemgränser, hur tror du att det influerar utvecklingen i branschen?

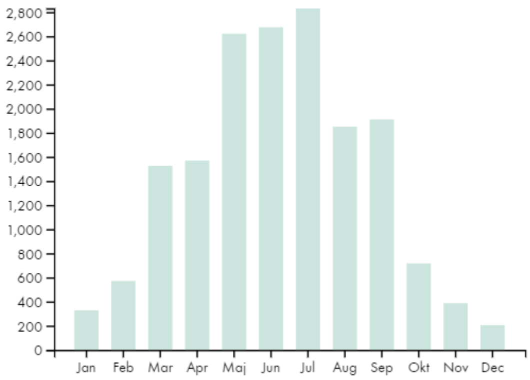
Avslutning

- Anser du att miljöcertifieringar är bra incitament för att motivera branschen till att nå klimatneutralitet till 2045?
    - Ser du några negativa effekter som miljöcertifieringar har på branschen?
    - Finns det några andra alternativ som bättre hade kunnat pådriva utvecklingen?
- Sen vi senast sågs har Boverkets nya databas för klimatdeklarationer kommit ut, har du hunnit testa den än? Och vad tycker du om den?
- Anser du att det är rätt strategi från Boverket att först sätta krav på deklaration och sen först fem år senare sätta krav på maxpåverkan?

A.4 Simulations of photovoltaic cells

Färdigt!

Återbetalningstiden för ditt system är beräknat till **17 år**. Investeringskostnaden förväntas vara **325 000 kr**, och de totala intäkterna under de första 25 åren är **473 000 kr**, dvs. en lönsamhet på **148 000 kr**.



Solelproduktion, i kWh

Din förväntade årliga elproduktion är **17 190 kWh**, vilket motsvarar **34%** av din elanvändning, och fördelar sig ungefär enligt diagrammet.

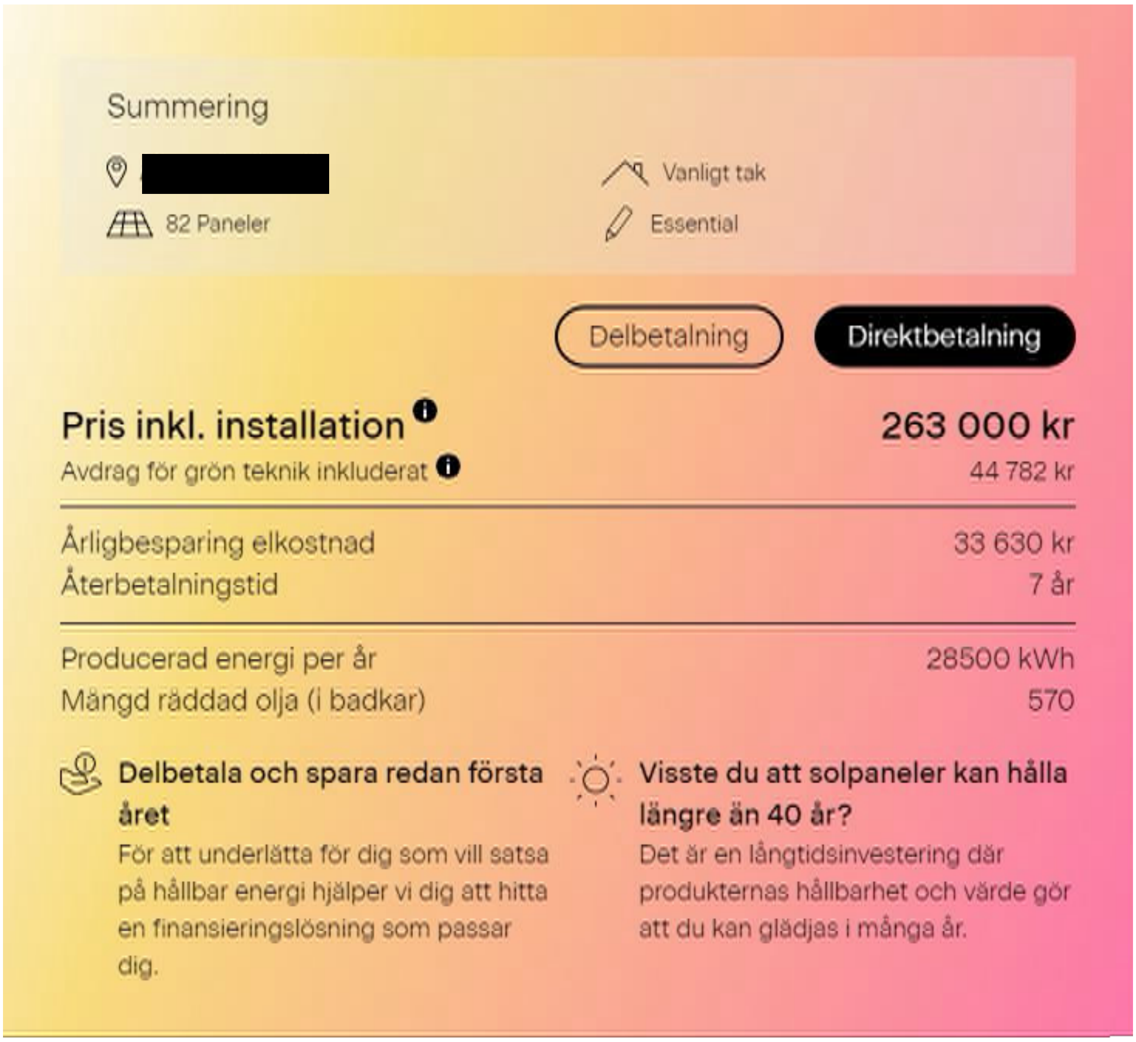
Du kommer att behöva kvitta el mot elnätet vissa timmar, då solel inte alltid produceras samtidigt som du använder el. Med detta solcellsystem blir det lätt då du klassificeras som **mikroproducent**. Det innebär att företaget som äger ditt elnät kommer att ta emot din överskottsel och bekosta en ny elmätare. Överskottselen säljer du till en elköpare, som du enkelt kan hitta. Du förväntas använda ca. **45%** av solelen direkt i huset, och resterande **55%** kommer du att sälja till elköparen.

Dina antaganden

Postnummer:	43351
Riktning:	Sydväst
Lutning:	30°
Elanvändning:	50 000 kWh
Storlek system:	20 kW
Kostnad före avdrag:	325 000 kr
Typ av avdrag:	Inget avdrag
Elkostnad:	1,4 kr per kWh
Elpris:	0,5 kr per kWh
Livslängd:	25 år
Degradering:	0,3 % per år
Underhåll:	2 000 kr per år
Elcertifikat:	0 kr per kWh
Nätnytta:	0,05 kr per kWh
Skattereduktion:	0,6 kr per kWh

Om kalkylen

Beräkningarna är utförda för skuggfria förhållanden. Det innebär att solcellerna åtminstone bör stå skuggfritt mellan **klockan 9 och 15** under sommarhalvåret. Elproduktionen är uträknad med hjälp av SMHI:s instrålningsdata från **centrala Göteborg** och för ett representativt år de senaste tio åren, vilket är viktigt då solelproduktion kan variera med +/- 10% från år till år. I allmänhet skall beräkningarna ses som rådgivande och Solcellskollen tar inget ansvar för att resultaten stämmer för verkliga förhållanden.


Summering
[redacted]
Vanligt tak
82 Paneler
Essential
Delbetalning
Direktbetalning
Pris inkl. installation
263 000 kr
Avdrag för grön teknik inkluderat
44 782 kr
Årligbesparing elkostnad
33 630 kr
Återbetalningstid
7 år
Producerad energi per år
28500 kWh
Mängd räddad olja (i badkar)
570
Delbetala och spara redan första året
För att underlätta för dig som vill satsa på hållbar energi hjälper vi dig att hitta en finansieringslösning som passar dig.
Visste du att solpaneler kan hålla längre än 40 år?
Det är en långtidsinvestering där produkternas hållbarhet och värde gör att du kan glädjas i många år.

6 VATTENFALL 7

Du har markerat en yta för 65

solpaneler på ditt hustak.

Du kan producera 24 523 kWh

fossilfri el/år

och sparar därmed 27 347 kr/år

Premium Effekt

En svart och silverfärgad solpanel med något högre effekt.

Pris inklusive installation: **252 709** kr

Med delbetalning i 12 år: **2 128** kr/mån

Pris med skattereduktion för grön teknik

Intresseanmälan Ny beräkning

Sammanställning Solcellskalkyl GoSoL Energi

Inledning

Nedan redovisas din sammanställning från GoSoL Energi AB:s solcellskalkyl. Utifrån dina angivna val och uppgifter har en solcellsanläggning beräknats för din fastighet. Sammanställning inkluderar antal solcellspaneler, sammanlagd installerad effekt och förväntad solelproduktion. Sammanställning inkluderar också beräknat pris, lönsamhet och återbetalningstid.

Kontaktuppgifter

Ref.nr:

Datum: mars 26, 2021

Namn:

Adress:

Postnr och Ort:

Telefon:

E-post:

Solcellskalkyl

Antal paneler: 78 st

Installerad toppeffekt: 28080 Watt

Beräknad elproduktion:26965 kWh/år

Produktion/Förbrukning: 54 procent

Gmail

Din kalkyl
1 meddelande

Solcellskalkylator <jamtkraft@solkollen.se> 26 mars 2021 08:17
Svara: jamtkraft@solkollen.se
Till:

Så här mycket solel kan du få från ditt tak

Årsproduktion	20 517 kWh
Beräknad kostnad efter ROT	254 800 kr
Besparing per år	24 620 kr
Återbetalningstid med ROT	10,3 år

Kalkylen är baserad på ett solcellspaket med 22.4 kW.

... 1/1

A.5 KJ-analysis of the first interview phase

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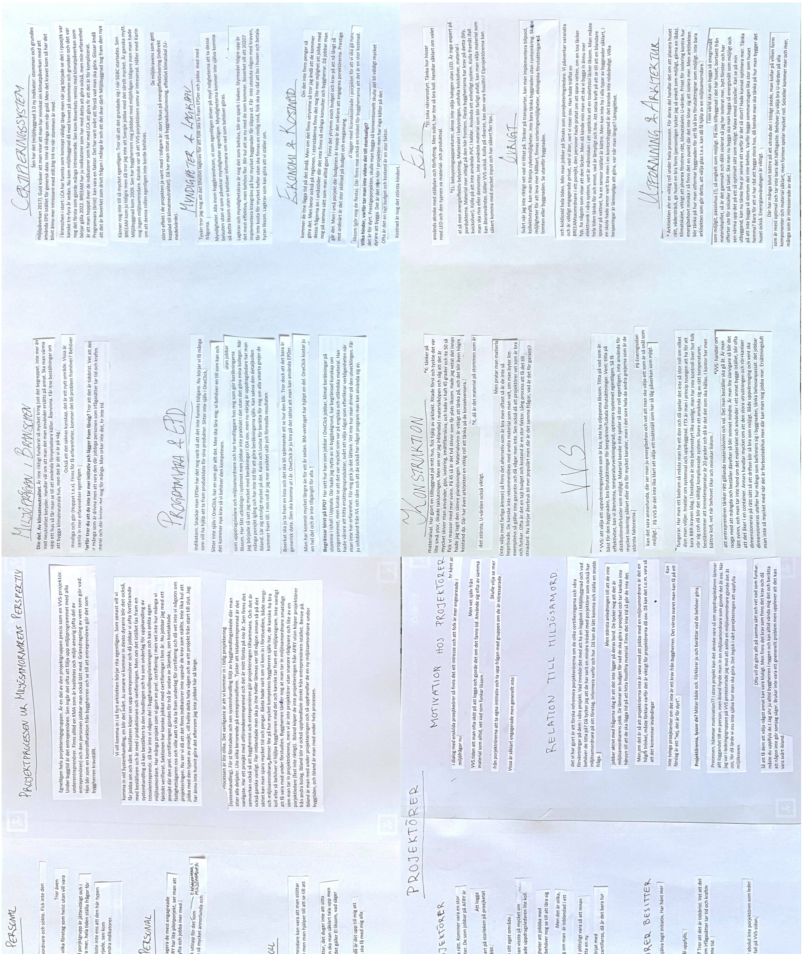
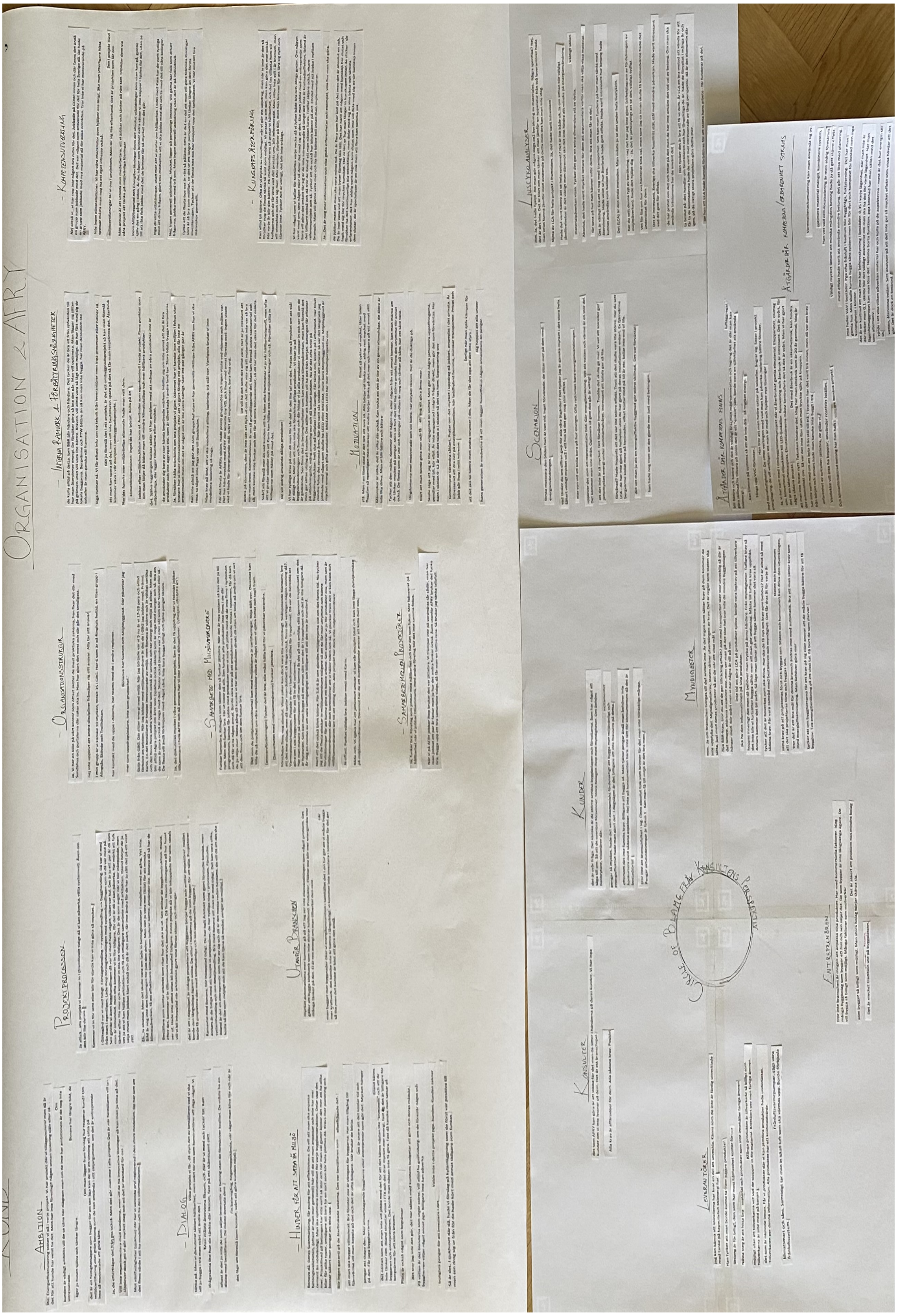


A.6 KJ-analysis of the second interview phase



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