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# Embodied Carbon in Buildings

- investigating drivers and barriers for the Swedish construction industry to address Embodied Carbon, and necessary policy support as deemed by the industry

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# Abstract

Mitigation of greenhouse gas (GHG) emissions is essential for us humans to curb climate change. Around a fifth of the anthropogenic GHG emissions stem from the construction sector. Much come from energy used for space and water heating within buildings, but an increasing proportion comes from the manufacturing of the building materials and is virtually embodied within buildings. This is called Embodied Carbon (EC). This thesis explores how industry addresses EC through posing three questions. These are 1) what actors within the industry address EC and how, 2) what are the drivers and barriers to address EC and 3) what policy support industrial actors perceive necessary for addressing EC to become business-as-usual. Through a literature review and semi-structured interviews, and with the aid of the theoretical framework of Technological Innovation Systems (TIS), it is found that a few actors throughout the industry are working with EC. This is done by conducting life-cycle assessments of buildings to form an image of where emissions originate. Some actors have started to use this tool to explore alternative designs and materials for the building. The drivers of this development are the green building certification systems as their inclusion of considerations of EC push actors to develop capabilities to address it. Identified barriers are lack of knowledge of ways to address EC and as well as lacking knowledge of the EC within the specific building materials. The complexity of the issue is seen as a barrier as it renders it difficult to find a coherent way of calculating EC. That residential buildings does not use certification to the same degree, thus missing out of the driving force they have is also seen as a barrier. It is found that the actors see that policy support is necessary. National regulative instruments are currently not perceived as a way forward, while informative instruments such as certification systems are preferred. As these are industry-owned, the thesis finds that Green Public Procurement is a good tool to increase the demand for certified buildings, thus pushing the market.

**Keywords:** Embodied Carbon, Construction Sector, Buildings, Climate Change Mitigation, Policy Support, Transitions

# Executive Summary

Science tells us that the need to mitigate Greenhouse Gas (GHG) emissions to curb climate change is as pressing as never before. Around a fifth of the anthropogenic GHG emissions stem from the construction sector. Much come from generation of energy used for space and water heating for buildings, but an increasing proportion comes from the manufacturing of the building materials and is virtually embodied within buildings. This is called Embodied Carbon (EC). While there is considerable focus in constructing and retrofit buildings to become energy efficient, not much attention is paid to EC. The industry has discovered the issue, however, and is beginning to address it; policymakers are slowly awakening as well, but it is industry that is leading the development.

Based on this, this thesis poses three research questions. These are:

RQ1 – What actors within the construction industry are engaged with Embodied Carbon today, and how do they address it?

RQ2 – What are considered to be the main drivers and barriers of this work today?

RQ3 – What support do industry actors identify as necessary to make addressing EC business-as-usual within the Swedish construction sector?

This thesis addresses these questions through a thorough literature review and nine semi-structured interviews with actors in a Swedish context. The actors include construction companies, construction clients, branch organisations and consultants. With the aid of the theoretical framework of Technical Innovation Systems (TIS), the findings were conceptualised and organised to formulate answers to the posed questions.

RQ1: What actors within the construction industry are engaged with Embodied Carbon today, and how do they address it?

> The thesis finds that a wide array of actors from all the actor groups interviewed are working with it, but only a few from each group. It is thus not business-as-usual to address EC within the industry. Additional findings are that other than the actors from the interviewed groups, universities and research centres emerge as important actors.
>
> Turning to the 'how' part of the question, industry has developed a number of voluntary regulative institutions such as the green building certification systems and standards for how to calculate EC that form the framework for how to work. National mandatory regulative institutions such as public regulations are largely non-existent, though some municipalities have started to enact regulations regarding EC.
>
> More concretely, the image that emerges of how EC is addressed is that Life-Cycle Assessments (LCA) is an essential and central tool. It is applied to specific projects, and actors use it to develop knowledge of which processes and activities GHG emissions stem from. From this point, actors use the LCA to explore what other design solutions, or choices of other materials would mean; it becomes a decision-making tool. There are also those who just have entered into dialogue with material manufacturers to find ways to improve the manufacture process. The knowledge is diffused both through networks, but mainly through the procurement of the service – this is especially true for the construction clients where few have developed in-house capabilities to address EC.

RQ2: What are considered to be the main drivers and barriers of this work today?

> The main drivers are the voluntary green building certification systems like BREEAM and LEED. They are drivers as BREEAM and the new version of LEED (version 4)

include considerations of EC in its criteria, thus pushing the actors to address it if they want to certify their buildings. The certification systems also play a role for market formation, as requests for certified buildings (on the higher levels of certification) create a niche market where actors capable of addressing EC have an advantage.

The lacking knowledge of EC in how to address it and how much EC specific building materials generate, and the complexity of finding an efficient and fair way of calculating EC in a material neutral manner are seen as the most significant hurdles to overcome. Some actors emphasises that it is a maturity question, and that the knowledge comes with time, while others see that more concrete measures have to be taken to deal with it. A barrier for residential buildings in particular is that certification does not occur to the same degree as for commercial buildings, and that the certification scheme mostly used for residential buildings, Miljöbyggnad, does not address EC.

RQ3: What support do industry actors identify as necessary to make addressing EC business-as-usual within the Swedish construction sector?

The actors are in agreement over one fundamental aspect – policy support is necessary for addressing EC to become business-as-usual within the industry. While some aspects will be taken care by the industry, it will not reach the entire way. Beyond this point, the viewpoint diverges. Employing a threefold typology of policy instruments, the industrial actors' perception of regulative, economic and informative instruments are accounted for. Green Public Procurement (GPP) is also considered.

National regulative policy instruments are ascribed thin potential effect – some actors see regulative policy instrument such as strict limits of how much carbon can be emitted per $m^2$ of floor space as inappropriate. With the present knowledge, there is no coherent and accurate way of calculating this number, meaning that a strict limit would likely result in sub-optimisations. Some see it, however, as possible in the future. Municipalities enacting regulative instruments are seen as a potential way by some. Economic instruments have a small role to play for knowledge development.

Informative instruments are perceived to offer more support. Informative instruments are both the standards of how to conduct an LCA for building materials as well as for an entire building, but also the certification systems. As described above, the certification systems are drivers so sharpening how EC is considered within them, as well as increasing the demand for these would boost the development within the industry. Essential, though, is that the certification systems are industry-owned and outside formal control of the public authorities. It is argued that this is where GPP comes in, as the public can demand certified buildings when acting as construction client. By enhancing the niche market for EC, knowledge development, diffusion and naturally market formation would speed up, advancing solutions for buildings with low embodied carbon. Going back to the regulative instruments, this stage where knowledge is more diffused would be when some actors saw it as possible to introduce strict regulation, establishing a celling for EC within the buildings.

These are the answers this thesis finds to the questioned posed. The conclusions are valid primarily for a Swedish context, keeping in mind that only a few actors were interviewed. Any transposing of them elsewhere has to keep in mind under which circumstances the attitudes and perception of the actors have developed in Sweden. Nevertheless, it is always possible to gather inspiration and build up curiosity by learning how the situation looks in one place, and then wondering how it could look somewhere else.

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# Abbreviations

ASBP - The Alliance for Sustainable Building Products

BAU – Business As Usual

BBR – Boverkets byggregler (The National Building Code)

BPD – Building Product Declaration

BREEAM – Building Research Establishment Environmental Assessment Methods

BVB – Byggvarubedömning (Building Product Assessment)

CEN – European Committee for Standardisation

$CO_2$ – Carbon dioxide

EC – Embodied Carbon

EED – Energy Efficiency Directive

EMS – Environmental Management System

EPBD - Energy Performance of Buildings Directive

EPD – Environmental Product Declaration

EU – European Union

GHG – Greenhouse Gases

IPCC – Intergovernmental Panel on Climate Change

ISO – International Organisation for Standardisation

IVA - Royal Swedish Academy of Engineering Sciences [Kung. Ingenjörvetenskapsakademin]

IVL – IVL Swedish Environment Research Institute [IVL Svenska Miljöinstitutet]

LCA – Life Cycle Assessment

LEED – Leadership in Energy & Environmental Design

LEED v4 - Leadership in Energy & Environmental Design version 4

$M^2$ – Square meter

MLP – Multi Level Perspective

OECD – Organisation for Economic Cooperation and Development

PCR – Product Category Rules

R&D – Research and Development

RQ – Research Question

SBUF – Sveriges byggindustriers utvecklingsfond (Construction Industry's Research and Development Fund)

SCF – Swedish Construction Federation [Sveriges Byggindustrier]

SGBC – Sweden's Green Building Council

TIS – Technological Innovation Systems

UNEP – United Nations Environmental Programme

USGBC – United States' Green Building Council

UK – United Kingdom

# 1 Introduction

**17 years, 97 days, 16 hours and 58 minutes,**

appears on the Guardian's webpage when this thesis was submitted. It is counting down to when we will burn through our global carbon budget, and likely irreversibly commit to at least 2˚C global warming (Guardian, 2015). It is calculated on current trends of burning fossil fuels, assuming an 1.8% annual growth rate in total emissions – a far cry from the decreases we need to see (UNEP, 2014b). A global carbon budget builds on that scientists can model what concentrations of carbon in the atmosphere are associated with what temperature increases. Furthermore, it is possible to calculate what we have already burnt; and what we have left if we want to avoid to change the climate to an unrecognisable state (IPCC, 2014). For a long time, climate change was portrayed as a threat against the relatively abstract idea of future generations – this time has come to pass. Humans born today are, in many parts of the world, expected to live close to the 2100 horizon that the climate models employ (WHO, 2015). The abstract concept of solidarity with coming generations has become solidified in the babies and toddlers of today.

Our knowledge of the consequences of climate change has never been as extensive, nor predicted such a dire future as now. Going beyond a 2˚C increase is to venture out of a "safe operating space for humanity" (Rockström et al., 2009, p. 4). Working Group II of the Intergovernmental Panel on Climate Change (IPCC) describes the projected impacts of climate change based on the most recent research in the 5$^{th}$ Assessment Report. Highlighting a few examples in the 1800-page report, climate change will affect the entire world, but strike the more vulnerable harder. As we observe an increased concentration of urban populations in costal and low-lying zones, predicted increases in sea levels as well as surges after more frequent storms pose a threat to urban populations due to flooding and costal erosion (Revi et al., 2014). While there are positive impacts of climate change on food production, globally, the negative aspects have become more common than the positive. The causes of negative impacts include extreme temperatures and changes in precipitation patterns (Porter et al., 2014). The water systems are also impacted. Droughts are likely to increase in arid regions, adding to other stressors towards food production (Cisneros et al., 2014). Moreover, climate change is increasingly perceived as a security issue, as e.g. more scarce water resources and instable food prices create and fuel tensions (see e.g. Busby, 2007; IISS, 2011; Murphy & Hurst, 2015). Taking into account that food shortages and price hikes are deemed to have fuelled the tensions and conflicts underlying the Syrian civil war (see e.g. De Châtel, 2014; Kelley, Mohtadi, Cane, Seager, & Kushnir, 2015) and the currently unfolding development where millions of people are forced to seek refugee elsewhere (UNHCR, 2015), and the worrisome sentiments this stirs within parts of the receiving societies (see e.g. The Economist, 2015), these predictions are serious at best – and apocalyptic at worst.

Currently, this tells a story of a global society heading straight for a cliff that we see looming ahead of us; it could be a different story though. Based on what we experience, and know will happen, we can look to the solutions - they are plentiful. There are numerous technical, social and financial solutions to the problems we face – we must just find a way to upscale and implement them. The need of a transition is clear. This will not happen by itself – it is up to us humans to change it. In Rockström's words: "True: We are the first generation to know that we are capable of undermining the entire Earth system. True: We are probably the last generation able to do something about it" (Rockström, 2015: 7:35).

A chief driver of climate change is the anthropogenic emissions of greenhouse gases (GHG) (Miller & Spoolman, 2011). A substantial part of these emissions originate from the building sector. 19 percent of all global GHG emissions stems from the building sector (Lucon et al., 2014, p. 8). Most of the emissions are indirect from electricity use within the buildings – around two thirds of the emissions. In terms of energy use, buildings account for more than a third of final energy, according to the International Energy Agency (IEA, 2013).

Due to the considerable part of GHG emissions originating within buildings, many initiatives have been to improve energy efficiency of buildings and reduce emissions related to energy use (WGBC, 2013). For example, the Commission of the European Union (EU) has issued the Energy Performance Directive that all new buildings constructed within the union should be near zero energy buildings by 2020 (Parliament & Council Directive 2010/31/EU). Looking at buildings from a life-cycle perspective, the focus lies on the use-phase of the life-cycle. The conventional understanding is that the use-phase accounts for 85% of the climate impact, while 15 % stems from the material manufacturing, construction itself and demolition (see e.g. Adalberth, Almgren, & Holleris Petersen, 2001). However, due to the increased energy efficiency of buildings, these proportions are changing and the carbon emissions virtually embodied in the buildings are increasing proportionally and absolutely (Liljenström et al., 2015; UNEP, 2014a). This calls for an increased interest and need to advance our knowledge of the embodied carbon; this so that pathways of transitions can be found to reduce the embodied carbon in buildings, and thus mitigate climate change.

## 1.1 What Is Embodied Carbon?

Embodied carbon (EC) is a concept capturing that buildings cause GHG emissions before they are in use. Simply put, EC entails the emissions from resource extraction, material production, construction as well as the transport caused by these activities. It stems from applying life cycle thinking on buildings which sheds light on the environmental impact of all the processes entailed in constructing a building, and not only the use-phase (Liljenström et al., 2015). As hinted above, it is becoming an increasingly important aspect of the GHG emissions from the building sector. In the United Kingdom (UK), studies conducted by among others the UK Embodied Carbon Industry Task Force and the UK Green Building Council (UKGBC) show that the current levels of EC within buildings in the UK range between 30-70% of the lifetime carbon emissions (Embodied Carbon Industry Task Force, 2014; UK Green Building Council, 2015). Likewise, an initial study in a Swedish perspective conducted by the Swedish Construction Federation (SCF) [Sveriges Byggindustrier] and IVL Swedish Environment Research Institute [IVL Svenska Miljöinstitutet[1]] revealed that a similar shift has occurred in Sweden – the climate impact of the materials and the construction of a particular concrete multi-family house equalled that of operating the house for 50 years. The emissions from before the use-phase – the so-called upstream emissions – stem to 84% from the manufacturing of the material (Liljenström et al., 2015).

## 1.2 Current State of Addressing Embodied Carbon

This changing proportion between the use phase and EC has been noted by the industry and policymakers alike. From policy-makers side, there are the beginnings of action. Starting from the supranational level, the EU has several policies in place addressing the building sector. The Energy Performance of Buildings Directive (Council Directive 2010/31/EU) and the Energy Efficiency Directive (Council Directive 2012/27/EU) are presented as key

[1] Henceforth referred simply to as IVL.

laws to reduce the energy consumption of buildings. However, neither of these addresses EC. Coming legislation, however, have the intension to address EC. The EU has launched a 'Communication on Resource Efficiency Opportunities in the Building Sector' (Commission Communication COM(2014)445 final). As the title shows, the focus is on resource efficiency rather than EC, but the two issues are closely connected. The Communication describes how another document, the 'Roadmap to a Resource Efficient Europe' (Commission Communication COM (2011) 571) emphasises that policies need to look at the environmental impact from a life-cycle perspective in order to achieve the goals. It continues by stating that existing policies governing the building sector do not adopt a life-cycle perspective "for the time being" (Commission Communication COM(2014) 445:4). Furthermore, the Commission plans to publish a Communication on Sustainable Buildings in the near future. Public consultations with stakeholders are currently ongoing (European Commission, 2015). The Roadmap for the Communication (a document preceding the Communication) states that "it is not expected that significant improvements will be achieved in resource efficiency with the current policy context" (DG Environment, 2012:2), before going on to sketch out possible policy options to be investigated. Summarising, the EU is in the midst of formulating policy, but has currently no policies directed specifically at EC.

Policymakers on the national level have taken initiatives regarding the EC. In Sweden, the previous government requested of the National Board of Housing, Building, and Planning [Boverket[2]] to map what is known about buildings' environmental impact from a life-cycle perspective. The mission also entails to investigate the need for and what type of information and guidance the construction sector and municipal actors need to address this. A report has been delivered at the end of September 2015, a week after this thesis was defended (see Boverket, 2015).

There are also initiatives on local levels in a couple of countries. Examples include local councils in the UK, whom are requesting assessment of EC as part of their planning process. An example of perhaps the most strict requirement is that of Brighton and Hove that require all developments to plan how they are to use materials that have a low embodied carbon level (Brighton & Hove, 2011). Some Swedish municipalities have also made efforts to address EC through the building materials. An example is Linköping municipality that in the development of a new city district, Vallastaden, has launched a land allocation competition for construction clients. The municipality revealed the criteria for how to score points, wherein it is established that a timber body of the house has a lower degree of EC than concrete body, whereby construction clients who commit to use timber will be rewarded with up to two extra points (Linköping Municipality., 2014). Other examples include Växjö Municipality and the City of Stockholm (see Växjö Municipality, 2015 and Stockholm, 2014 for further information).

While policymakers are starting to address EC, the industry itself has come further. In the UK, industrial actors together with academia formed the Embodied Carbon Industry Task Force. The aim is to "build industry-wide consensus on how embodied carbon should be measured and reported" (Embodied Carbon Industry Task Force, 2014, p. 4). There are also branch organisations such as The Alliance for Sustainable Building Products (ASBP) that seek to advance this agenda in the UK, engaging many of the participants of the Task Force as well (ASBP, 2015). In Sweden, the report by IVL referenced above, along with a report by

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[2] Due to the long English name, this authority will be referred to by its Swedish name in this thesis.

the SCF together with the Royal Swedish Academy of Engineering Sciences [Kung. Ingenjörvetenskapsakademin[3]] (see IVA, 2014), the question of EC was raised onto the industrial and political agenda. The governmental mission specifically mentions these reports in the mission (Regeringen, 2014). EC is also a component within the industry-led green building certification schemes that have proliferated in the past years. It appears within the British-based BREEAM, and is an integral part of the newest version of American LEED (see BRE, 2015 for BREEAM and USGBC, 2013 for LEED).

It is industry leading the development. However, while we know that the industry has started to address EC, we do not have a systematic overview of who works with it, or how. Neither do we know the drivers propelling them to address it, nor what barriers they might encounter in doing so, nor do we know what industry deems useful to support their initiatives of addressing EC. These are the knowledge gaps this thesis strives to close.

## 1.3 The Objective of the Thesis

The objective of this thesis is to provide insight into how the industry works with EC today, and what public support they see necessary to turn addressing EC into business-as-usual (BAU) within the industry. In doing this, three Research Questions (RQs) are posed to guide the research:

**RQ1** – What actors within the construction industry are engaged with Embodied Carbon today, and how do they address it?

**RQ2** – What are considered to be the main drivers and barriers of this work today?

**RQ3** - What support do industry actors identify as necessary to make addressing EC business-as-usual within the Swedish construction sector?

The thesis relies on a literature review as well as interviews with construction companies, construction clients and actors closely related to these, such as consultancies and branch organisations operating in a Swedish context. The theoretical framework of Technological Innovation Systems is utilised to conceptualise the findings.

## 1.4 Scope and Limitations

EC is an issue throughout the construction industry; it is, however, not possible to study the entire industry in this thesis. Some boundaries need to be defined, and justified. The limits of the study, partly existing due to the imperative of scoping the thesis, are then discussed.

### 1.4.1 Scope

The construction industry mainly constructs two types of projects – buildings and heavy construction. The category of buildings includes residential, commercial, industrial and other buildings, while heavy construction means infrastructure projects such as transport or energy projects. In a Swedish perspective, the division of GHG emissions from these two types of projects are around 60-40%, with buildings generating the smaller share (IVA, 2014). This thesis looks solely at the building side, where all types of buildings are included within the scope. It is only, though, the construction of new buildings that is studied. The reason for this is that the question of EC within the existing stock of building is not seen as so

[3] Henceforth referred to by its Swedish acronym, IVA.

interesting to address, as the emissions of manufacturing the material and construct the building has already occurred (see e.g. Liljenström et al., 2015).

The thesis also adopts a national scope, focusing on the Swedish context. The reasons for these are two and they relate to the regulation of the industry and what is possible to include within the thesis. Turning to regulation, it is mostly a national and sometimes even a local competence (Seaden & Manseau, 2001). Legislation stemming from the EU plays a role in various ways, but the bulk of the regulation comes from public actors within the countries. In a Swedish perspective, the municipalities are important actors as well, though legal changes introduced recently have made the present situation ambiguous (Nohrstedt, 2015). The second reason is more practical – the allocated time and resources to the thesis did not allow for a study including more nations.

The thesis examines EC from an industry perspective. While there are examples of public actors addressing EC in a Swedish context, several industry initiatives exist. As mentioned before, a notable public initiative is that the previous Boverket the task to investigate the state of the art within the Swedish industry regarding EC (Regeringen, 2014) – this too indicates that the industry has come further than the public authorities. However, public policy is not voided from the thesis; RQ3 requires an investigation of what support industry actors perceive is needed from policy.

Industry is further scoped to primarily include construction companies, construction clients and actors closely related to these, such as consultancies and branch organisations. The reason for not including more is simply due to capacity – there was not sufficient time to gain and incorporate more perspectives into the thesis. The reason for the chosen focus is that it is mainly these actors who seem to start to address it, and these are also at the heart of the construction industry. It is possible to imagine that they maintain a certain degree of power within the industry structure – by understanding their drivers and barriers and what support is needed to boost drivers and remove barriers, their demands on e.g. material manufacturers could likely cascade down the supply chain.

In summary, the scope of the thesis is limited to investigating how industrial actors within Sweden addresses EC within the construction of new buildings, and what policy support they deem necessary to making addressing EC BAU.

### 1.4.2 Limitations

The scope above imposes limitations on the possibility to generalise the findings and conclusions of the thesis. The decision of only including construction companies and clients exclude a significant group – the material manufacturers. This is naturally an important perspective that is lacking in this thesis. Moreover, not addressing other environmental issues than carbon emissions also entails a limitation. While the emission of GHG and climate change are pivotal to our, humankind's, future on the planet, so are questions of biodiversity, land use changes, and water use (Rockström et al., 2009). It is worth to keeping in mind, given the enormous player that the construction industry is, and that we need to take care of many fronts simultaneously if we are to stay within the boundaries of our planet.

Also, this thesis is limited to a Swedish perspective. Transposing conclusion elsewhere decreases their relevance the more different the context is. It is not the ambition of the thesis to describe this context, as it goes beyond the scope of a thesis, but two important aspects can be highlighted. Firstly, consider the role of the municipalities in regards to planning and the physical structure. Swedish municipalities have a lot of clot as they have been granted a near monopoly in planning in regards to building (Magnusson, 2011). This point to that the role ascribed to municipalities in this thesis should be seen in a specific Swedish context. Secondly, on a more fundamental level, it is important to acknowledge the high priority environmental aspects receive in Swedish policy making. The Organisation for Economic Cooperation Development (OECD) states in its Environmental Performance Review of Sweden in 2014 that "Sweden remains a front-runner in environmental policy" (OECD, 2014, p. 3). Thus, the interviews take place in this context, where industrial actors are used to a high level of environmental policy.

## 1.5 Audience

There are three intended audiences of this thesis. First, on a general level, actors within the industry could find it interesting to gain insight into this study. As far as the author is aware, this thesis provides a first systematic review, albeit a limited one, of how actors within the Swedish construction industry address these issues. A second group is policy-makers. While the current ongoing review of Boverket will provide a more comprehensive report of the industry's perspective on the issue, this thesis could serve as a complementary perspective. Lastly, this thesis can be of interest for scholars of transitions in general, and technological innovation systems in particular, as it is another example of the framework applied to a case.

## 1.6 Disposition

The disposition of this thesis is as follows. Chapter 2 further elaborates on what constitutes EC, arriving at a definition. It also introduces the reader to Life-Cycle Assessments and their importance to address EC, as well as sketches up a conceptual framework for policy instruments. Chapter 3 scans the literature to devise a conceptual theoretical framework to help understand, organise and relate the studied industrial initiatives that exists. It carefully explains the theoretical framework of Technological Innovation Systems. Chapter 4 explains the method employed, and the methodological impacts it has on the generalisability of the research. Chapter 5 presents and analyses the findings of the research, as well as offering preliminary answers to the research questions posed. Chapter 6 discusses these further, and places them in a wider context by drawing on wider developments. Finally, Chapter 7 summarises the thesis and offers concluding remarks.

# 2 Explaining Embodied Carbon, Life-Cycle Assessments, and a Typology of Policy Instruments

This section aims to present background information on a number of central components of this thesis; it thus becomes eclectic. Firstly, Embodied Carbon (EC) will be more closely defined as to what part of the Greenhouse Gas (GHG) emissions from buildings it encompasses. Secondly, an overview of Life-Cycle Assessments (LCA) is given – in general and for buildings in particular. To make it more concrete for the reader, part three of the chapter gives a brief overview of different options to reduce EC in buildings. Lastly, policy instruments are discussed to provide a base for further discussion in the chapters to come.

## 2.1 Defining Embodied Carbon

There are several definitions of what the concept of EC encompasses. Liljenström et al (2015) list a few examples of how embodied energy has been defined in various studies. While embodied energy obviously is not the same as EC, the discussion of system boundaries still applies. Sartori and Hestnes (2007) defines it as the energy used for extraction of raw materials, and the manufacturing of building products. Stephan et al (2013) expands on the definition above by including renovations and maintenance of the building during its entire life-cycle. Lastly, Thormark (2002) includes material manufacturing, transport and maintenance, but not the construction of the building. Liljenström et al (2015) goes further by including the construction of the building as well. This thesis adopts the same definition as employed by Liljenström et al (2015) as this report has been instrumental in shaping the understanding of EC in a Swedish perspective. As it is from this report that much of the data and numbers on EC originates from, it is sensible to adopt the same

*Figure 1. Illustration of Different Modules in an LCA*

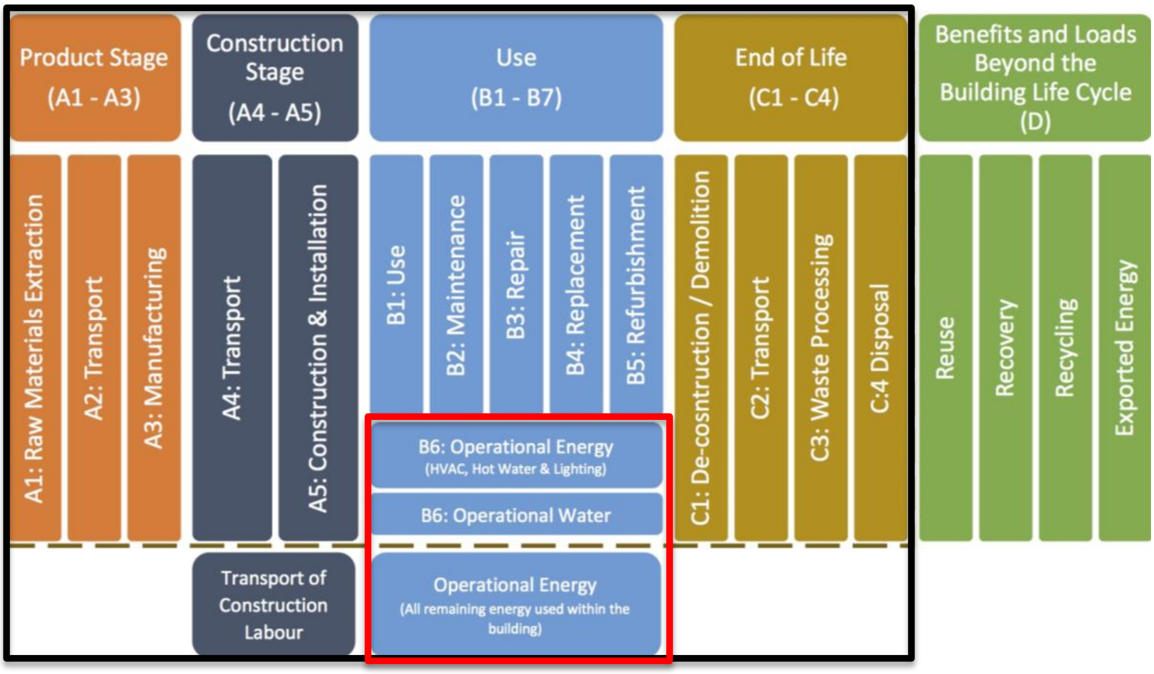



*Illustration of what the different modules of a life-cycle assessment for a building includes according to EN 15978. The black rectangle shows which processes the concept of EC encompasses, excluding those within the red rectangle. Image from (eTool, 2013).*

definition of the central concept. The definition employed include the carbon emitted from the extraction of raw materials, manufacturing of the building materials, the construction in itself, as well as the demolition and waste handling of the building. All the transport that these processes cause is also included. On top of this, phases in the use-phase are included. Only the operational energy and water use are not included. The scope is illustrated by Figure 1. This is thus a wide scope for the concept as it stretches into the use-phase of the building and beyond. The focus of this thesis, however, lies on the earlier phases relating to the material, namely A1-3. The reason for this focus is that this phase accounts for 84% of the climate impact of Module A (Liljenström et al., 2015, p. 38).

For the reader who is well acquainted with discussions on EC, two other sets of terms that are often referred to when discussing EC are 'upstream' and 'downstream'. This refers to whether the climate impact occurred prior to when the building became in use, thus upstream, or downstream from this point in time. Upstream is basically seen as Module A, while downstream includes Module B+C (Liljenström et al., 2015). Thus, to specify the focus of the thesis further, it is on the upstream activities of EC.

As pointed out in the introduction, the proportion of EC compared to GHG emissions from the use-phase is predicted to increase. There are a few reasons for this. Firstly, buildings have become more energy efficient, reducing the use of energy for space and water heating. Secondly, in a Swedish context, energy generation has become less carbon intensive over the years (Energimyndigheten, 2013). Lastly, there is also an increase in the use of materials to construct more energy efficient houses (Liljenström et al., 2015). Thus, the changing proportions are thus not only a result of more energy efficient houses with less carbon intensive energy generation, but also because the EC has increased in absolute numbers.

## 2.2 Life-Cycle Assessments

The data introduced above are calculated with the help of LCA. This section introduces what these are first in general, and then within the construction industry.

### 2.2.1 Life-Cycle Assessments in General

A LCA of a product, service or process is a comprehensive consideration of environmental impacts the studied object has over the course of its life-time. It usually has a so-called cradle-to-grave scope, meaning that the gathering of raw materials from Earth is the starting point, until the materials are returned to Earth. By systematically accounting for all inputs and outputs from the material extraction phase to the end-of-life, LCA provides a comprehensive image of the environmental impact of the product/service/process it is employed on (EPA, 2006). It is considered to generally provide the most comprehensive view of the current environmental assessment tools available (Zbicincki, Stavenuiter, Kozlowska, & van de Coevering, 2006). It does this in four stages, as illustrated by the Figure 2.

First, the goal and scope of the LCA are determined. The goal of the LCA study conducted by IVL and SCF, for example, was to quantify the climate impact and energy use of a new construction of a multi-family house, enabling a comparison between the upstream and downstream phases (Liljenström et al., 2015). The inventory analysis is the second step and contains the compiling of all relevant data. Relevant data in the case above are, *inter alia*, the energy use of the manufacturing of different materials as well as the GHG emissions related to this. It is naturally guided by the scope and goal, as it dictates what data that is necessary to find. The arrow pointing in the other direction indicates that often lack of data will require a redefinition of the goal and scope, underpinning the importance of data availability for an LCA. The third step assesses the data in the inventory in regards to what impact it will have on a number of categories. There are a number of sub-steps here, of which only the most relevant will be described here. An essential step is to decide which categories to consider, something that is guided by the goal and scope. Global Warming, Stratospheric Ozone Depletion, Acidification, Human Health, Land and Water Use are examples of categories commonly used. Hence, the Impact Assessment stage translates the quantified data of the inventory into particular environmental issues. This thesis focuses on the category Global Warming. The last step, Interpretation, is where conclusions are drawn, limitations considered and recommendations given (EPA, 2006).

*Figure 2. The Stages of a Life-Cycle Assessment*

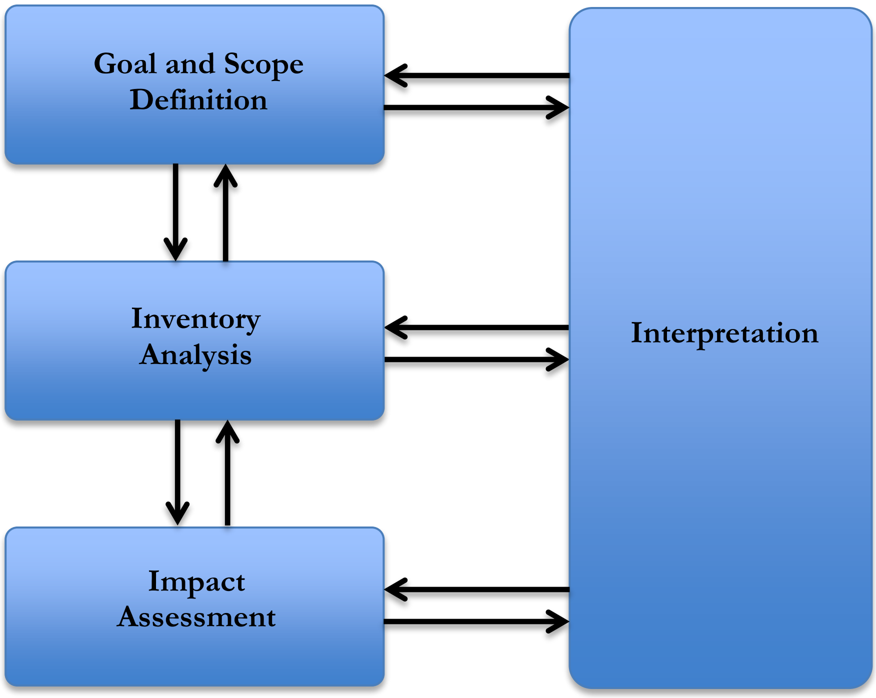



*Illustration of how the stages in an Life-cycle Assessment (LCA) and how they relate to one another. Based on (EPA, 2006)*

There are two types of LCAs – attributional and consequential. An attributional LCA is done to assess the environmental impact directly associated with a product, service or process. A consequential LCA, on the other hand, explores the consequences of a change to a system (Liljenström et al., 2015). An example of this can be the result of a change in land use if the demand for a certain product increases. As far as the author is aware, only attributional LCAs have been applied to study EC this far. Hence, the remaining section will focus on attributional LCAs.

According to Zbicincki et al., (2006), the history of LCA methods stretches a few decades back in time. The predecessor appeared in the late 1960s and early 1970s, then under the name 'Resource and Environmental Profile Analysis' – REPA. The first LCA conducted in the form we know now was commissioned by the Coca Cola Company to evaluate different types of packaging. European studies emerged simultaneously commissioned by, among others, Tetra Pak, a Swedish beverage container manufacturer. The focus of the studies conducted then was generally on energy and material use, and waste reduction. It was not until in the 1990s that the Impact Assessment was introduced, and the various Environmental Impact Categories developed (Zbicincki et al, 2006). These came about through a workshop hosted by SETAC – the Society of Environmental Toxicology and Chemistry – in the early 1990s. SETAC published a guideline in 1993 titled Guidelines for Life-cycle Assessment: A "Code of Practice" that became a sort of a LCA Bible for practitioners, according to some (Khasreen, Banfill, & Menzies, 2009).

The increasing use of LCA raised concerns about the comparability of the results. With the emerging guidelines, the use of LCA proliferated and hundreds of studies were published during the 1990s. As different practitioners made different assumptions and used different ways of assessing the impact, a need for standardisation arose. The International Organisation for Standardisation (ISO) published a series of standards called the ISO 14040 series. The standards were on Principles and framework, (ISO 14040, 1997), Goal definition and inventory analysis (ISO 14041, 1998), Life-cycle impact assessment (ISO 14042, 2000) and Life-cycle interpretation (ISO 14043, 2000). These were, in 2006, replaced by two standards that are relevant today. These are ISO 14040:2006 that replaced the previous ones, laying down the principles and framework of how to conduct a LCA. ISO 14044:2006 specifies this further by introducing standardised requirements and guidelines (ISO 14040, 2006; ISO 14044, 2006). The emergence of standards has made LCA into a recognised tool for comparing the environmental impact between different products and processes, though there still are issues with it (EPA, 2006).

### 2.2.2 LCA within the Building Industry

The practice of using LCAs within the building industry is not new. Large Swedish construction companies such as Skanska and NCC have routinely used it, and there have been several studies of single projects (Liljenström et al., 2015). Even so, LCA has not been applied as widely within the building sector as elsewhere. Khasreen et al (2009) highlight four factors that differentiate it from other sectors. Firstly, there are very long life times of the product making predictions of it difficult. A building stands for several decades, at times centuries. Compared to making an LCA for a laptop computer with a lifespan of a few years, this complicates the assessment. Secondly, the building might undergo changes during its lifetime – significant changes. This becomes apparent when considering many examples of how industrial buildings become offices or apartments. More spectacular examples include when old industrial silos are turned into apartments. Thirdly, a significant part of the environmental impact occurs during the use phase, which complicates things as scenarios for different uses need to be assumed and developed. To again compare with a laptop, the largest share of the environmental impact occur during the manufacturing phase (Ciroth & Franze, 2011). Lastly, the life-cycle of a building is a fragmented process with many stakeholders, including everything from the construction company, to the material manufacturers, to owners, occupants as well as investors (UNEP, 2014a). The above factors complicate the LCA as assumptions and choices on important parameters have to be made for each specific building. As these vary, the comparability suffers.

To illustrate this, an example is warranted. Baumann and Tillman (2004) points out that one essential method question in an LCA is the question of system boundaries[4]. They define what is to be considered as the life-cycle – what is included in the assessment. A potent question

[4] Baumann and Tillman (2004) also points to functional unit, and the type of data used. Each LCA needs to specify clearly how these aspects are defined and used within the LCA. For the purpose of this thesis, comprehensive understanding of all these concepts are not necessary for the reader; they are brought up to illustrate an example.

for LCAs for construction products is what to include of the end-of-life stage; the potency stems from that depending on what decision is taken, the environmental impact of two of the three conventional choices for the structure of a building varies. Steel, which can be recycled to a very high degree, benefits from system boundaries that allow for end-of-life practices like this (Jernkontoret, 2015). Timber, on the other hand, which sequesters carbon within itself, risks lose this beneficial aspect if its end-of-life scenario includes it being incinerated for energy recovery, releasing the sequestered carbon in the process (Liljenström et al., 2015). Due to this and other issues, efforts have been taken to standardise how to perform an LCA for a building. It is the European Committee for Standardisation that has published the standard EN 15978 in 2011 (eTool, 2013). The Liljenström et al (2015) study was made according to it.

Data availability is a central concern when doing an LCA. As described above, in the Inventory Analysis, all the input and output data of all material needs to be gathered. As a building is composed by thousands of different products, this is an onerous task. An ISO standard has also been published for how to create Environmental Product Declarations (EPD) for building products. ISO 21930 (2007) provides principles and requirements for EPDs for building products – it "provides a framework for and the basic requirements for product category rules […] for type III environmental declarations of building products" (ISO, 2015). It is in turn based on ISO 14025 which introduces the concepts of EPDs and Product Category Rules (PCR). A PCR is specific for a product and specifies the system boundaries and what type of data should be used for a LCA for a specific product. Once an LCA has been conducted for a product, an EPD can be created (ISO 14025, 2006). This is basically a score card, where all the environmental impacts of the product are stated. This information can then be used in the LCA of an entire building, naturally adjusted to the amount that is used for a specific product.

These are thus existing standards for how to perform an LCA for a building, as well how to do so for the specific building products – the infrastructure seems to be in place. Exactly how the industry works with it remains to be seen.

## 2.3 Examples of Buildings with Low Embodied Carbon

There are currently several possibilities to construct buildings with low levels of EC. This section will illustrate two main roads – to improve the manufacturing processes of the materials, and to alter the design of the building, focusing on the structure of a building.

The first road is to address the way the materials are manufactured. There are numerous examples that can be brought up here. Here some illustrative example from a report by UNEP-DTU Partnership[5] on technological mitigation options for the building sector together with figures from the relevant Intergovernmental Panel on Climate Change (IPCC) report. The report lists three examples of low-carbon materials. These are concrete, bricks and tiles and are described below. As concrete and cement production is responsible for a considerable share of global emissions, focus lies there.

- Cement is a key ingredient in the manufacturing of concrete. It also generates a considerable amount of GHG emissions. There are two primary sources – directly

[5] UNEP-DTU Partnership stands for United Nations Environmental Programme (UNEP) and Denmark's Technical University (DTU). It is a collaborative centre for UNEP focusing on, inter alia, mitigation technologies and low carbon development.

through process emissions and indirectly through fuel use. These are responsible for 50% and 40% respectively of the emissions from cement production (Fischedick et al., 2014, p. 758). The indirect emissions stemming from fuel use to heat limestone, sand and clay to around 1450 C° can be tackled through either increased energy efficiency, but also through fuel switching. Today, coal is burnt in the majority of the cement kilns, but biomass waste could also be burnt. This is common in several countries – in the Netherlands, for example, more than 80% of the fuel used in cement production comes from waste fuel (Fischedick et al., 2014, p. 759).

The process emissions are "unavoidable" in so far as that the $CO_2$ will always be created (Fischedick et al., 2014, p. 758). There are, however, ways to reduce the need to create it, or to prevent it from escaping into the atmosphere. The IPCC highlights improving material efficiency as well as reducing demand as the two major ways forward. In improving material efficiency, the IPCC points to possibilities to reduce need of cement by 40% by using curved moulds instead of the standard ones (Fischedick et al., 2014). A UNEP report offers an example of how to reduce demand: by substituting cement by using fly ash (a waste product of the combustion of carbon for electricity generation) in concrete production, the demand is reduced (Chi-Nguyen Cam, 2012). Lastly, there are also discussions of initiating pilot projects of installing Carbon Capture and Storage technology. The IPCC report states that on a commercial scale, this is far from development as there are numerous barriers of different kinds to overcome (Fischedick et al., 2014). There are, however, initiatives from industry to overcome these barriers (see e.g. Energiforsk, 2015 for a Swedish example).

- In Sweden, bricks are normally produced through gathering of clay which later is mixed with water to be formed into bricks (Tegelinformation.se, n.d.). The low-carbon bricks use 40% fly ash to reduce the need of clay (Chi-Nguyen Cam, 2012).
- Tiles can be made by recycled glass instead, reducing the need for virgin material considerably. A side benefit with this is that the tiles also get a shimmering aesthetic quality (Chi-Nguyen Cam, 2012), reminiscent of butterflies.

Turning to the second road, there are three main options when constructing the frame of the building – concrete, timber and steel. This section will describe the discussion around the option least used, namely timber, and describe how the other two options can be designed so they generate less EC.

Of the three materials, timber has the lowest levels of EC (Khasreen et al., 2009) currently. Some feel the temptation to simply say that we should shift to only build in timber, solving much of the issue around EC. One counter argument heard is that all the qualities demanded of building needs to be maintained. An illustrative example was when a representative from the Swedish branch organisation for insurances raised a concern that building in wood would force demolition of the building if there was a water leak (De Frumerie, 2015), though this was a contested statement (Bengtsson, 2015). Another concern that is lifted is that it is not possible to build tall houses in timber. This needs to be seen in the context of the general trend of densification that many major Swedish cities are following (SKL, 2015), where tall buildings are seen as a central components. New technology, however, has made it at least theoretically possible to construct skyscrapers in wood; an architectural firm has proposed a 35 story building in wood to be constructed in Paris (Oldfield, 2015). Lastly, an argument also heard is that it should not be seen as a choice between one of these materials – they are generally used in combinations even in the body of the buildings. Tall multi-family buildings

*Figure 3. Tall Wooden Multi-family Houses*

*Multi-family apartment buildings in eight stories built in wood in Sundbyberg, Sweden. Image from (SR, 2012)*

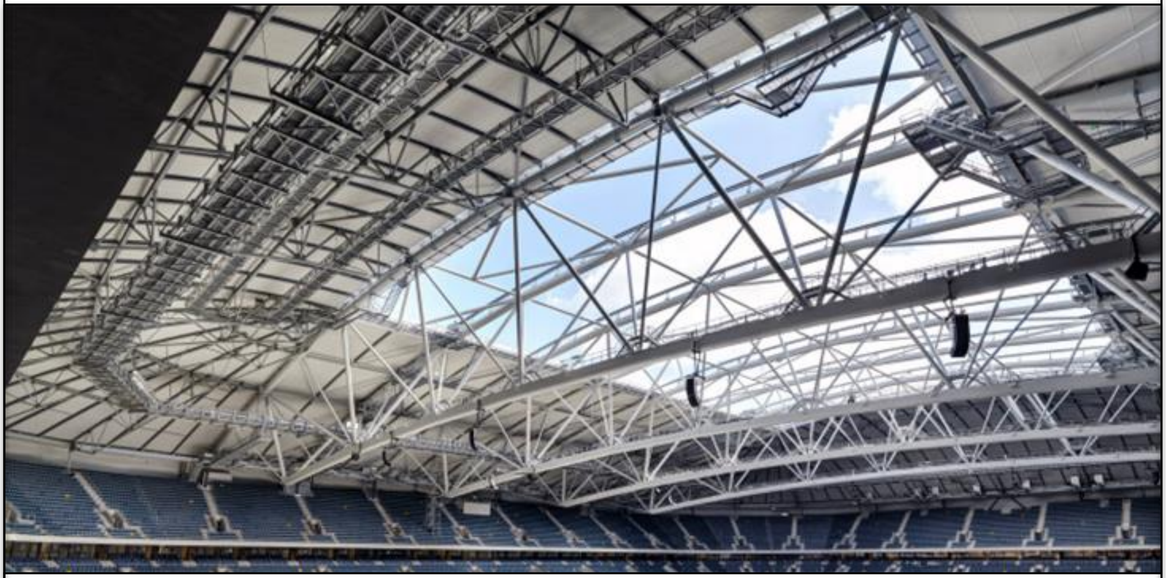
in wood have been constructed in Sweden. The picture in Figure 3 depicts eight story buildings in Sundbyberg, a municipality neighbouring Stockholm (SR, 2012).

The discussion of whether we should just abandon steel and concrete will go on for a long time – neither industry is likely to throw in the towel easily. In the meantime, the options of emissions reduction presented above exists. Moreover, emission reductions can also occur through smarter design of buildings. Slimmer constructions are presented as a solution for constructions in concrete. The idea is to increase the strength of the concrete enabling a reduction of the amount of concrete in the frames (Wirstedt, 2015). The IPCC points to savings of up to 40% in specific projects where 'ultra-high-strength' concrete has been used (Fischedick et al., 2014, p. 759).

Lastly, steel can be dealt with in a similar manner. By using steel that has a higher strength than ordinary steel, the quantity needed to bear the same burden is reduced. Thus, the amount of steel needed is reduced. An example the steel industry uses is the new national stadium constructed in Solna, Sweden (shown in Figure 4). A third of the steel used to construct the ceiling was steel with a higher strength. Calculations performed by Jernkontoret, the Swedish Steel Producers Association, estimated that 900 tonnes of $CO_2$ emissions was saved in this way (Jernkontoret, 2015).

These are a few examples that in no way aim to be exhaustive, but to provide the reader with an idea of different existing solutions, making the concept of EC more concrete.

*Figure 4. Friend's Arena*



*The roof of Friends Arena in Solna is constructed with high-strength steel, reducing the quantity of steel needed and the $CO_2$ emissions with 900 tonnes. Image from (Jernkontoret, 2015)*

## 2.4 Typologies of Policy Instruments

As a final section to this chapter, a framework on how to understand policy support for industry to address EC is presented. There exist many definitions of what public policy is, and it goes beyond this thesis to arrive at a 'correct' one. A useful conceptualisation of public policy is presented by Bemelmans-Videc (1998) in the book 'Carrots, Sticks & Sermons – Policy Instruments & Their Evaluation'. In the introductory chapter, public policy is perceived as the set of techniques utilised by governmental authorities to create social change. Bemelmans-Videc emphasises the political aspect of policy in that power is yielded with an intension to create change. Even so, government does not act alone, but policy instruments are "co-owned" with stakeholders through e.g. public consultations, and that stakeholders can be instrumental in implementing them (Bemelmans-Videc, 1998, p. 4). Another essential aspect is that public policy is seen as the "set of techniques" (Bemelmans-Videc, 1998, p. 3), indicating that an individual instrument is not perceived as a panacea. Rather, combinations of different types of instruments are used to foster change. This is as the different types of instruments have varying effect on various stakeholders – a point that will be returned to shortly.

First, a typology of the different kinds of policy instruments needs to be introduced. Vedung (1998) does so in the subsequent chapter of the book. He introduces a threefold typology of regulative, economic and informative instruments; another set of more illustrative names for these are sticks, carrots and sermons. Regulations, or sticks, are "measures undertaken by governmental units to influence [actors] by means of formulated rules and directives which mandates receivers to act in accordance with what is ordered" (Vedung, 1998, p. 31). Economic instruments, or carrots, works through "make it cheaper or more expensive in terms of money, time, effort, and other valuables to pursue certain actions" (Vedung, 1998, p. 32). An essential distinction here is that the actors this is directed at are not obliged to comply, but can chose to do so. The last kind, the informative, or sermon, tries to influence actors through "the transfer of knowledge, the communication of reasoned argument, and persuasion" (Vedung, 1998, p. 33). Examples of the type of information communicated include measures that can be taken to avoid the act that government is seen as undesirable.

On top of this, another option has emerged for governments, namely to use their purchasing power on the market to reward the businesses behaving as deemed desirable (Edler & Georghiou, 2007). This approach, when connected to environmental aspects, is called Green Public Procurement (GPP) and is a practice that is growing in the EU. Also, GPP in relation to buildings is identified by the European Commission as an area with potential, but in relation to energy efficiency but also the materials used (European Commission, 2011).

Tojo (2015) introduced a useful conceptual framework for environmental policies in regards to what effect they aim to have on the market. For illustrative purposes, Figure 5 was sketched up. It assumes a normal distribution of products in terms of environmental performance, with the best performing ones furthest to the right. As said, different policy

*Figure 5: Policy Instruments Effect on the Market*

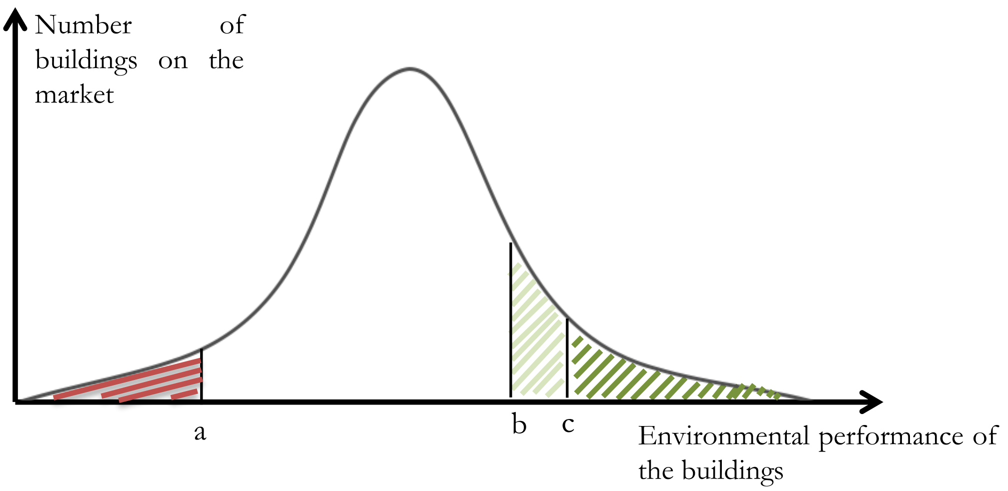



Illustration of different policy instruments effect on the market. Regulation of energy efficiency of buildings introduce a floor at point a, cutting of the tail, while certification schemes favour certified buildings in the areas beyond b and c. Based on Tojo (2015).

instruments act on different parts of the market. Regulations of energy efficiency of buildings, for example, sets a floor at point a. All buildings to the left of point a could not be legally constructed – the tail of the market has been cut off. Green building certification schemes such as LEED or BREEAM, on the other hand, act on the other end of the market. If we assume that it has two levels of certification at point b and c, those buildings within the light green area would be eligible for the lower level of certification, and those in the darker green for the higher level of certification. The idea is that as these buildings get a premium price as the certification distinguish and adds value to building, other products will strive to achieve this, pushing the market to develop – the entire curve would slowly shift rightwards. Other policy instruments have different effects, to which the thesis returns to when discussing the policy support more in detail.

Summarising the chapter, it has defined EC further, narrowing the focus to upstream activities in the life-cycle. An effort has also been made to exemplify different solutions of lowering EC from this phase of the life-cycle. A central tool, LCA, and issues surrounding it has been introduces as much of the ensuing discussion will build on it. Likewise, a typology of policy instruments has been introduced. Next, the theoretical framework used to conceptualise the findings is introduced.

# 3 Theoretical framework

Complexity abounds in how to calculate and compare embodied carbon (EC) between different materials, and buildings, as well as how to address it. There are numerous actors involved throughout the supply chain of the industry, as well as on different policy levels. Different approaches of how to support the industry in addressing EC also add layers to the complexity. In studying a complex reality, it is difficult to know what activities, mechanisms and processes to prioritise. This is where theories come in; in essence, it is the task of theories to make this prioritisation. A theory draws the attention to certain elements and processes it deems carry significance – it aids the research to know what to look for. Edward Carr, a historian who's book "What is history?" is drawn on by Moses and Knutsen (2007) in their book on Research Methodology, describes his envy of *"colleagues engaged in writing ancient or mediaeval history, [as he] find[s] consolation in the reflection that they are so competent mainly because they are so ignorant of their subject. The modern historian enjoys none of the advantages of this built-in ignorance. He must cultivate this necessary ignorance for himself"* (Carr, 2001, p. 9). Moses and Knutsen uses Carr's quote to explain the point of view that depending on which method and theory that are chosen, one's view of the studied Reality is shaped by them, and likely skewed (Moses & Knutsen, 2007).

The skewedness is something that will be returned to at a later stage, but for now, this chapter will introduce the theoretical framework utilised in this thesis. First, introducing the concept of transitions, to subsequently land in a more detailed framework called Technical Innovation Systems. By drawing a few other theoretical concepts, a conceptual framework is devised to enable sorting of the pieces of information uncovered when studying how the actors of the Swedish construction industry addresses EC.

## 3.1 Theoretical Transitions to a Low Carbon Economy

The need for transitions away from the current practices within the construction sector towards sustainable ways of working is clear. New technologies, processes and cognitive understandings are required for the climate impact, as well as other environmental issues, of the construction industry to decrease. Technological transitions, defined as "major technological transformations in the way societal functions […] are fulfilled" (Frank W Geels, 2002, p. 1257) have occurred before. Geels takes the case study of shipping, and how the function of sea transport shifted from sailing ships to steam vessels (Frank W Geels, 2002). In later research, the concept of technological transitions developed into socio-technical transitions, where the added "socio" reflects the social embeddedness of the technological system (Frank W. Geels, 2004). Users of the technology, as well as the legal, normative, and cognitive framework it exists within are taken into account. Geels description of the socio-technical transformation is evolutionary in that it describes the interaction of different social groups that shape and are shaped by the systems of production and consumption; technological development and the use of technology co-evolves (Frank W. Geels, 2004). From this description, the question of agency emerges as pivotal – is it governable? Smith, Stirling and Berkhout (2005) critique Geels for being overly functionalistic in the sense that a transition will happen by itself. However, the framework does not leave room for an actor, public or private, taking charge and foster a transition. Geels and Schot (2007) respond to this critique by drawing on Giddens' structuration theory. They argue that if a technology emerges and changes the institutional framework, actors will adjust their behaviour and the socio-technical system will evolve. The theoretical discussion reflects the situation described in the introduction; we do not have the possibility to hope for a Technological Transition to happen. Indeed, we need one; the question is how?

Sustainable transition is the theoretical concept answering this question. It is defined by Markard, Raven and Truffer as *"long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption"* (Markard, et al, 2012, p. 956), and the transition is purposeful and intended. This – how to initiate and maintain a transition – is a critical question within transition studies. It has not escaped the attention of both organisations such as the Organisation of Economic Cooperation and Development (OECD, 2011) or the United Nations Environmental Programme (UNEP, 2011), nor academic scholars. Markard et al (2012) describes that there are a number of theoretical frameworks that study sustainable transitions. They highlight four of them as having emerged as more prominent. These are Transition Management, Strategic Niche Management (SNM), the Multi-Level Perspective (MLP) and Technological Innovation Systems (TIS). The four frameworks work on different levels of aggregation. Both Transition Management, initially developed in Loorbach, (2007) and the MLP, introduced in Geels' paper (2002) mentioned above, have a wide focus in which systems they consider. The objects of study are the entire systems performing the societal functions, like transportation, where the sustainable transition is discussed from the fuel of the fuel of the cars, to the development of bicycle infrastructure to intermodal transport and mobility management (R Kemp, Geels, & Dudley, 2012).

SNM and TIS both focus on a narrower field of technologies. SNM focuses on how to foster, nurture and protect niches where new emerging technologies can expand and grow (René Kemp, Schot, & Hoogma, 1998). TIS does not only deal with emerging technologies, but can be also be used to analyse more mature, established technologies. The framework stems from a seminal paper by Carlsson and Stankiewicz (1991) in which the authors present a framework to study how technological change happens. Carlsson and Stankiewicz describes how contemporary economic models treated technology as an exogenous factor, making it difficult to study how to improve it. Thus, they develop the framework of technological systems which is defined as a *"dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization [sic] of a technology"* (B. Carlsson & Stankiewicz, 1991, p. 93). The authors highlight the importance of actors, networks and institutions (what will later be defined as the structural components of the TIS), and how these determine and shape each other, which in turn affects the generation, diffusion and utilisation of the technology.

On the foundation of technological systems laid by Carlsson and Stankiewicz, Hekkert, Suurs, Negro, Kuhlmann and Smits (2007) and Bergek, Jacobsson, Carlsson, Lindmark and Rickne (2008) develop TIS. It advances the innovation system by specifying certain functions it needs to perform to work well, and clarifies which levels it can be applied upon. The remaining part of this chapter elaborates upon this to devise an appropriate theoretical lens for the thesis.

## 3.2 Conceptualising Addressing EC as a Technological Innovation

Before the framework is described, the way the industry addresses EC has to be cast as an (emerging) technology concept. According to Bergek et al (2008), the concept of technology builds on two interrelated meanings. The first meaning is that technologies are material and immaterial objects used to solve problems. Hence, it can be anything from a handheld tool to computer software, or a procedure of how to address something. The second meaning builds on technical knowledge, where technical knowledge should be understood as the ability to solve complex tasks. In a nutshell – it is not sufficient to have the correct tools (the first meaning); one needs to know how to use them as well.

It is necessary to tackle the preconception of "innovations". An innovation is not just a concrete technical tool, machine or appliance, but can also be a process. Hekkert et al defines an innovation as "the successful combination of hardware, software, and orgware, where orgware refers to the various components of the innovation system" (2007, p. 414). As describe above, the tools employed to address EC are both concrete in the sense of that software needs to develop, but also relate to how the decision-making process of construction happens. The resulting innovation is the buildings with low levels of embodied carbon.

## 3.3 Technological Innovation Systems – The Framework

TIS is deemed to be a suitable framework for the tasks this thesis embarks upon. An important point is that the application of TIS within this thesis is based on the author's interpretation of it. All transition studies framework are conceptual – by using it, there is no implying that the reality is actually organised in the terms or configurations of the framework. Rather, the point is to allow for a categorisation and organisation of the ongoing processes into different components and functions. It facilitates focusing on important factors, and identifying important relations between them. Due to the conceptual nature, it becomes quite easy to develop an interpretation that uses the same concepts, but is filled with different mechanisms and processes.

TIS is thus the theoretical framework this thesis will apply to understand how actors within the Swedish construction industry address EC today, what the drivers and barriers are to do so, and what is needed, in their opinion, for it to become commonplace to address EC. It has a stepwise approach to how the analysis should be carried out. Tying it back to the Research Questions, figure 5 displays how the different steps contribute to answering the research questions. Step one is a pre-requisite to carry out the analysis. Step two and three generate the bulk of the data from which RQ1 (who and how is EC addressed?) can be answered. Step four and five does the same for RQ2, where step four is conducted to shed light on what functions are most important at the current stage of development. Step six uncovers the bulk of the data to answer RQ3.

*Figure 6. Illustration of Relation between RQs and the theoretical framework*

| | |
|---|---|
| Step 1 | → Pre-requisite |
| Step 2 & 3 | → RQ 1 |
| Step 4 & 5 | → RQ 2 |
| Step 6 | → RQ 3 |

A final note before the framework is described regards the operationalisation of the framework. An explanation will follow after each element of what activities are looked for in the interviews to justify that it exists. This is written in **bold**.

### 3.3.1 First step – Level of Analysis

Carlsson et al identifies three different levels on which a system of innovation can be analysed – on a specific knowledge field relevant for many products, related to a specific product or artefact, or on a set of related products that can be either complementary or substitutes (Carlsson, Jacobsson, Holmén, & Rickne, 2002). A knowledge field is the level of analysis that this thesis focuses on. To focus on a specific product does not reflect how it is actually employed. Though that it is slightly difficult to devise strict product divisions within the construction sector, it is possible to imagine a differentiation between e.g. commercial, residential and infrastructure construction. The work of developing the technology in question is not restricted to any particular product.

In order to further justify this choice, it is necessary to go a bit ahead of the thesis. Exactly how companies are working with EC is one of the research questions of this thesis; the answer is also necessary to have here to explain why this level of analysis is accurate. Hence, the following paragraphs are based on the results of the data gathering. A more thorough answer can be found in the result section.

The work to address EC revolves around LCAs of buildings. There are many challenges related to this – does the organisation possess the knowledge to perform an LCA? If so, is the necessary data available? Are the tools available to do it systematically? A second set of questions relate to how to use the findings of an LCA to change the construction of the building. How to organise so different actors to communicate? How to pose requirements towards materials that make sense? The solutions to these problems can be described as "a set of closely related technologies […] in the sense of a knowledge field" (Carlsson et al., 2002, p. 238).

### 3.3.2 Second Step – Identifying Structural Components

The second step is to identify the structural components of the TIS. There are three types of structural components – actors, networks and institutions – which are described below.

Actors are basically organisations. Firms, branch and industry organisations, research institutes and universities as well as public bodies such as public authorities on different levels. NGOs and interest organisations are also considered as actors. The entire relevant value chain of the technology can be included, making it potentially an extensive field. **It is organisations of different kinds that are looked for as actors.**

Networks can be formal and informal. The purpose of the networks differs from solving a specific task, influencing the policy arena or is just formed around actors who have frequent contact. Formal networks are often easy to identify while informal networks are more tacit. **The activities that are searched for are interactions of different actors, either in an ad hoc manner or within more systematic settings**.

Institutions are seen as "the rules of the game" and include formal rules such as regulations, and standards to more informal, implicit rules such as norms and culture. Formal institutions are rules and guidelines that are explicitly formulated and written down. They can be mandatory in the form of a law, regulation or directive from a public authority, where an actor does not have a choice but to comply (or face whatever consequences breaching the legislation would incur). Geels (2004) nuances the understanding of institutions by distinguishing between regulative, normative and cognitive ones. Formal institutions are seen as regulative. It is worth noting that this is very similar to the threefold policy instrument typology by Vedung (1998), and while they do relate, institutions and policy instruments are not the same thing. **Turning to what is search for are simply rules and regulations the interviewees describe as mandatory and contribute to them addressing EC.**

Cognitive and normative are both informal institutions. Normative institutions are the rules that "confer values, norms, role expectations, duties, rights and responsibilities" (Frank W. Geels, 2004, p. 904). It is changing normative institutions in terms of duties and role expectations that both permit and pressure actors to start addressing EC. Cognitive institutions frame our way of thinking and making sense of the world – it is the technological paradigms and frames of professional communities within sectors and firms. **For normative institutions, references to expectations, visions and self-shouldered duties pushing the interviewee towards addressing EC are looked for. For cognitive, references to a changing understanding of EC is and how to address it is searched for**

### 3.3.3 Third Step – Mapping the Functional Pattern

The third step is to map the functional pattern of the TIS. 'Function' is the term used to describe key processes that an innovation system should perform in order for it to work well. The idea is that the structural components above interact in various ways to perform these functions. Sometime they work well, other times they do not. There are variations in the lists of functions put forward by different scholars. The literature review revealed two lists which are similar, but differs on one crucial point – on the conceptualisation of knowledge development and diffusion. Bergek et al (2008) lists knowledge development and diffusion together as one category, while Hekkert et al (M.P. Hekkert et al., 2007; Marko P. Hekkert, Negro, Heimeriks, & Harmsen, 2011) keep them separate. These two functions are central for a TIS, yet despite both concerning knowledge, they fulfil different functions. The development of knowledge is, as will become apparent, not affected by the same activities as the diffusion of knowledge. Hence, the two functions are presented as separate functions below, in line with Hekkert et al (2007; 2011).

<u>Knowledge Development</u> – The development of knowledge is central to any TIS. It is an essential function within an emerging TIS, as will be elaborated upon later. The important mechanisms to capture are how the knowledge development takes place. **Bergek et al (2008) points to R&D, learning from projects, and imitation while Hekkert et al (2007) points to 'learning by searching' and 'learning by doing'. These are the mechanisms that the analysis will try to identify.**

<u>Knowledge Diffusion</u> – It is not sufficient if only the developers of the knowledge sit on the knowledge; it has to diffuse, enabling more actors to acquire it. An interesting aspect here is that knowledge diffusion is seen as something that has to be done only between actors. While this certainly is an important aspect, it overlooks the aspects of diffusing knowledge within an organisation; actors are black boxed. **The activity the framework describes is learning-by-interacting in different manners (Hekkert et al, 2007), which are the mechanisms that will be looked for, both internally and externally.**

<u>Entrepreneurial Experimentation</u> – An emerging TIS is inherent with uncertainty and will not develop if actors are not willing to shoulder the risks of developing a technology. An important point is that the experimentation does not have to be made of a new entrant, but also by an established actor venturing into unchartered territory. **The elements searched for are examples of actors undertaking initiatives despite considerable uncertainty of the outcome.**

<u>Direction of Search</u> – An innovation does not develop in isolation, but requires an entire range of factors help foster interest in it. Hekkert et al describes this function as "those activities […] that can positively affect the visibility and clarity of specific wants among technology users" (Hekkert et al, 2007; 423). It is not only communicated in a straight-forward manner, but more often through different mechanisms that creates a drive to get it to happen. Bergek et al (2008) points to that the visions and expectations of actors are important to stimulate the growth, as well as regulations and policy. Potential customers

articulating a demand is another mechanism[6]. **Thus, the mechanisms that will be searched for are activities that the actors see have been decisive in fostering the growth of the technology**.

Market Formation – Emerging technologies often have a difficult time competing with existing technologies due to a number of reasons. A more mature technology has had time for the production process to become specialised, lowering costs and reaping economics of scale (Hekkert et al, 2007). The emerging technology thus needs a protected space, a niche market, to develop within. A protected space can be established by actors creating a physical space where normal market conditions do not apply. **Thus, the factor that is looked for is evidence of physical space where certain requirements apply favouring addressing EC.**

Resource Mobilisation – Technological innovation requires resources, and an innovation system needs to be able to mobilise these. Resources can be in the form of competence or financial capital. Competence is nested within humans, while financial capital can be within firms, research institutes, venture capital or public institutions. (Bergek et al, 2008). **The mechanisms here are evidence of actors committing these types of resources to develop the technology.**

Development of Positive Externalities – The framework includes this function to enable the study of how one function positively affect others; positive externalities are processes that have positive feedback loops into the system. This is difficult to capture in a specific activity. Rather, **descriptions of feedback loops are looked for.**

These are the seven functions the TIS needs to carry out. However, there are several remaining steps of the TIS that become instrumental in answering RQ two and three.

### 3.3.4 Forth Step – Assessing Functionality

The fourth step regards assessing the functionality of the TIS. For the scholars of TIS, the quest to search for a framework to measure performance and compare different TIS has been a goal for long time. The discipline of innovation system has always been oriented towards improving policy, and comparisons have been seen as one powerful and clear tool (Bergek et al, 2008). However, to assess the functionality of the TIS in question is not the aim of this thesis. Nevertheless, step four contains one sub-step that will prove to be important when discussing ways to upscale the TIS to become BAU. It points to the fact that it is important to take the phase of development of the TIS into account, as different functions will vary in significance in different phases. It is first in Hekkert et al (Marko P. Hekkert et al., 2011) that this is fully developed. The authors describe four phases of development: Pre-development, Development, Take-off and Acceleration phase. In the Pre-development phase, a prototype of the technology is developed that then is commercially sold without being subsidised in the development phase. In the take-off phase, the market expands until it is statured, when the TIS enters the Acceleration phase. As

*Figure 7. Questions Posed by Step Four*

| | | |
|---|---|---|
| Pre-development | → | Is there a working prototype? |
| Development | → | Is there commercial application? |
| Take-off | → | Is there a fast growing market? |
| Acceleration | → | Is there market saturation? |

[6] For readers who are acquainted with the Multi-Level Perspective (Geels, 2002), this function is described as similar to the landscape level by Hekkert et al (2007).

these phases are only utilized as a conceptual aid, the process of analysing where a TIS positions itself is not especially rigorous. Four consecutive questions are posed, and if it is possible to answer yes, then the TIS is on, or have passed that development stage. The four questions are displayed in the Figure 6.

As said, the phase of development becomes important when discussing how an upscaling can take place, as some functions are more important within certain phases. Here, no specific elements are looked for; rather, the state of the system as a whole will be assessed.

### 3.3.5 Fifth Step – Identifying Drivers and Barriers

The fifth step is to identify drivers and barriers of the development of the TIS. Theoretically, the drivers are considered to be functions that are well-functioning, while barriers are non-existent functions, or just mal-functioning ones. In operationalisation this, however, two distinct methods are employed to identify these. The first is analytical, relying on the interviewees and other data to see what this reveals about the functioning or mal-functioning functions. The second method is meant to verify or contrast this by simply asking the interviewees what they perceive to be drivers and barriers. As neither Bergek et al (2008) nor Hekkert et al (2011) specify a list or typology of mechanisms to consider, **no specific activates are searched for**. There are no pre-defined categories as the author did not know what could be drivers or barriers prior to the interviews. Rather, these grew as the analysis went on.

### 3.3.6 Sixth Step – Specify Key Policy Issues

The sixth step is to specify key policy issues – i.e. where can policy intervene to improve the TIS the most. This step will be used to answer RQ3. The policies relate to the remaining framework in that they should either boost a driver, or tackle a barrier (Bergek et al, 2008). As with above, the interviewees are asked specifically about what policy initiatives they deem helpful. However, in order to sort through the answers, the typology of policy instruments introduced above. Hence, the desired policy instruments are seen as regulative, economic or informative.

Closing this section, that is the theoretical framework used in the thesis as an aid to conceptualise the findings. It is not strictly applied and is, as said before, the author's interpretation of it.

# 4 Method

The theoretical framework sketched out above places a high demand on data collection. It is through actors that this data is accessible. While some networks and institutions can be identified through internet searches, a more certain and efficient way is to talk to actors engaged with the technology in question to see what networks they are a part of, and what institutions that matter. Thus, the starting point is to identify the actors and through these gain access to remaining structural components, and how the functions work, what the drivers and barriers are and their perception of needed policy support. This is complemented with information from the literature review. It draws both on academic peer-reviewed article, as well as reports and information gathered from internet sourced deemed reliable by the author. Below, the method is described and its relation to the theoretical framework is made clear. The chapter sub-titles are inspired by the distinction made by what 6 & Bellamy states are the essential steps in their book 'Principles on Methodology' (6 & Bellamy, 2012).

## 4.1 Why Interviews?

The main method used to collect data is semi-structured expert interviews with industry actors within the Swedish construction industry. Hekkert et al (2011) emphasises that understanding how an innovation system is working is best explained by an expert. It is in line with this that this thesis relies on interviews with practitioners within the field. Moreover, Saunders and colleagues (Saunders, Lewis, & Thornhill, 2007) claims that semi-structured interviews are well suited for exploratory research when there is no clear sequence of how the questions and information will appear. This reflects the situation of this research.

## 4.2 Data Collection

An initial set of actors were identified by the author together with the supervisor of the thesis. The actors identified were deemed to have an ambitious level in their environmental work, and were judged to be able to offer an enlightening perspective.

The identified actors were contacted by telephone and emails. No specific position was asked for; instead, the actors decided themselves who was the most suitable person to be interviewed. One person per actor was interviewed. S/he was contacted via phone or email, and a brief explanation of the thesis and the purpose of the interviews were given. S/he was informed that the interview would be a telephone interview 30-45 minutes long and that their contribution would be anonymous and the content of a specific interview would be confidential. The reason for anonymity was to encourage them to speak more freely without revealing any potential sensitive information regarding their organisation.

S/he was asked whether it would be acceptable if the interviews were recorded. All agreed to this. Recording of interviews is explained by facilitating for the researcher to capture the entire interview as accurately as possible. In addition, the interviews would be summarised and they would have the opportunity to look over the summary, and correct any potential inaccuracies. This way of briefing as well as debriefing is what Kalve and Brinkmann (2008) calls informed consent, and is seen as important to obtain to stay clear of any ethical issues.

The initial actors were asked to suggest further actors to interview. This method, metaphorically called 'snowballing' as a rolling snowball grows as it rolls downhill, is advocated in several papers by actors studying the conceptual framework chosen (cmp, e.g. Bergek et al., 2008; Bo Carlsson et al., 2002; Rickne, 2000).

In total, nine interviews with different actors were carried out – see list in Appendix 1. While diverging views and perspectives on the posed questions emerged, it eventually became clear that many repetitions occurred; the information gathering became saturated as no new information was added. This is a common method within social science to determine when one has gotten sufficient data from interviews (Guest, Bunce, & Johnson, 2006).

In order to preserve anonymity, the actors are grouped so there at least are two in every group. The groups are the constructors, the construction clients who at times are divided into those working with commercial or residential buildings, and the branch organisation actors, who are presumed to offer more of an overview. As only one interview with a consultant was achieved, this was added to the overview group as well. This is displayed in Figure 8 below.

*Figure 8. Overview of Actor Groups*

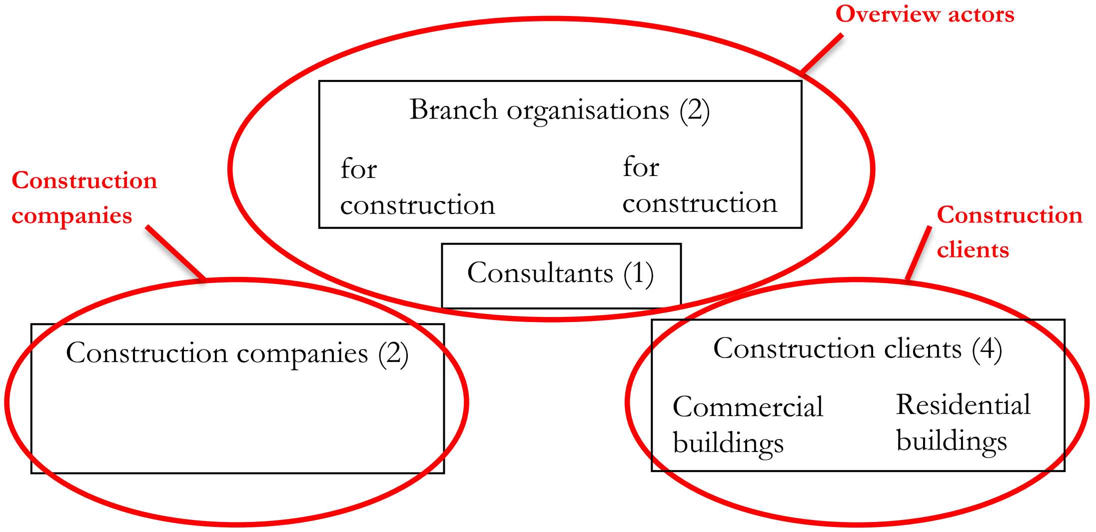



*Illustration of the actor groups with the type of actors within them. The numbers indicate the number of actors within the group.*

Before the interviews, the interviewee was sent the topic guide. A topic guide provides structure and direction of the interview, while allowing for flexibility (Seale, 2000). These were different according to what type of actor it was. Five broad categories of actors were identified: construction company (2), construction client (4), branch organisation for the construction companies (1), branch organisation for the construction clients (1) and construction consultancy company (1). The different interview guides can be found in Appendices 2-6.

## 4.3 Data Coding Method

After the interview, it was transcribed into a summary of the interview. Kvale and Brinkmann (2009) describes the need to find a balance between the time spent on transcribing interviews, and the need the ensuing analysis has. As the emphasis of the RQs lies on the content rather than the way of communicating the answers, the need for exact accuracy is relaxed. Hence, the goal of transcribing became summarising the content rather than capturing exact formulations and intonations. Spoken language was transformed into more formal written language, and pauses, laughter and verbal fillers such as "errr" and "ahem" were excluded. The summaries were sent to the respective individual, most of who subsequently read through it and gave their approval. The reason was to ensure that no misunderstandings had occurred during the interview or transcription. Only minor changes were made by the interviewees. The transcripts of the interviewees who did not give their approval were through this deemed to be reliable, as no significant misunderstandings had occurred before.

The language of the interviews was Swedish, as well as the summaries. As it is the native language of both the researcher and the interviewees, it allowed the interviewees to express themselves more freely compared to if the interviews had been in English, the language of the thesis. Moreover, according to Kvale and Brinkmann (2009), knowledge is created in the interaction between the researcher and the interviewee. Any impediments to this interaction that can be avoided are therefore a good thing.

## 4.4 Data Analysis Method

In order to ensure a systematic and as objective as possible analysis of the interviews, a technique called open coding was employed (Corbin & Strauss, 1990). It is usually used within the methodology of Grounded Theory, a framework developed by Corbin and Strauss, primarily to develop conceptual frameworks and theory grounded in data. Here, it is employed with a pre-existing theoretical framework. Categories were devised from the theoretical framework (and denoted with bold text within Chapter 3), but while going over the texts, new categories emerged. This ad hoc emergence of categories is acceptable, according to Kvale and Brinkmann (2009). The categories underwent a continuous revision to account for the appearing content.

The findings are at times supported by quotes. These have been translated by the author. Despite the transformation from spoken to written Swedish in the transcribing process, the English translation has at times been 'sharped up'. All quotes are anonymous, but have been sent to its respective individual to approve the use of it. This as many of the interviewees requested this. In addition, this reduces any potential changes of meaning that the 'sharpening up' could have induced, as the original source controls that it is what s/he intended to convey. Many individuals 'approved' their quotes, but not all. The same rationale as with the summaries was applied for those who did not 'approve' their quotes.

The data gathered from the interviews sketched out a patchwork of how Embodied Carbon (EC) is addressed. Often, an interviewee pointed to an existing scheme that is of importance, but due to the time frame of the interviews, it was not possible to dig deeper into it. Instead, the patchwork created has been filled in by subsequently searching for information. An illustrative example is that of the certification systems for green buildings. Many pointed to their importance, but it was not possible to get the full picture both of how they address EC, their extensiveness and so on. This information has been supplemented afterwards by the literature review.

Lastly, it is important to point out the difference between how the data regarding the functions and that of drivers, barriers and needed policy support has been generated. For the functions, the coding has drawn heavily on the theoretical framework. The framework has been instrumental in shaping the author's understanding of the TIS. It has helped to conceptualise activities into functions, and described the relations between them. Thus, the coding relies on the theory to find what to focus on. Turning to the drivers, barriers and needed policy support, the coding process is not as connected to theory. Rather, the interview guide poses open questions regarding perceived drivers and barriers, resulting in that it can be used to verify or shed light on what the theoretical framework indicate as necessary. For policy support, a pre-defined theoretical framework does exist, but it is not as detailed as TIS. Moreover, points that emerges and do not fit into the framework are included as well, to not let the theoretical framework (completely) dictate what is of importance.

## 4.5 Generalisability

In the following chapter, the findings of the interviews will be analysed and discussed to finally boil down to conclusions. This section makes a first dent in discussing how generalizable the conclusions of this thesis are. Based on the book Principles of Methodology (6 & Bellamy, 2012), internal and external generalisability is discussed. Internal generalisability concerns to what degree does the uncovered data represents the actors studied. As the actors themselves chose the person, they will likely have chosen a person able to speak for the entire organisation. Even so, most were within the environmental or sustainability department where these questions are naturally deemed important; a different image might have emerged had the interviewees predominately been from a more technical department. Despite these concerns, it is judged that the image portrayed in the interviews reflect 'Reality' sufficiently well.

Turning to the possibility to generalise these results to a wider 'Reality', more caveats appear. Only a few companies were interviewed, and the starting point was as explained above, that they were 'the best in the class', so to speak. Thus, it is important to remember that the answers to the RQs will be based on these actors. In addition, turning to the possibilities to transpose the results internationally, this has to be done very carefully. There are many idiosyncrasies to each country and context; but some lessons can carefully be exported.

# 5 Findings and Analysis

The following chapter presents and analyses the findings of the research of this thesis. The findings build on the interviews, and are complemented with information found in literature. It is structured according to the Research Questions (RQ), and each RQ will be answered at the close of its corresponding section. While RQ1 draws on concepts from the theoretical framework, RQ2 and RQ3 rely on it for structure but not so much for content. This as no specific activities were searched for in the coding of the interviews.

## 5.1 Research Question One – Who and How?

The first RQ is divided in two parts – who and how? The "who" part is a fast ordeal to answer as it only concerns the actors, while the "how" is more complicated. It is partly answered by the description of the remaining structural components, the networks and the formal and informal institutions. The functions are also central in answering this question. The functions are partly derived through the coding of the interviews, and subsequently connected with the relevant structural components. To remind the reader, the elements searched for when coding the interviews are repeated in a grey box at the start of each component/function. This is complemented with findings from the literature review.

### 5.1.1 TIS Step Two – Identifying Structural Components

The structural components are actors, networks and institutions. Actors for interviewing were identified through the snowball method, as described above, but the interviews also uncovered numerous others which are presented below.

#### 5.1.1.1 Actors

Elements search for: organisations of different kinds

The interviewees pointed to many different types of actors that become relevant when examining how Embodied Carbon (EC) is addressed. Other than those groups represented by the interviewees, material manufacturers emerge as particular important due to their central role concerning materials. They need to both produce the data required to calculate the impact of the materials and at a later stage, incrementally improve or radically innovate new processes to reduce the climate impact of the production process. The standardisation organisations (International Organisation for Standardisation (ISO) and European Committee for Standardisation (CEN)) developing standards for how to conduct Life-Cycle Assessments (LCA) for different materials are mentioned in connection with the quantification of the impact. Research institutes and universities are also important as partners in developing and diffusing knowledge, as well as branch organisations such as the Swedish Construction Federation (SCF) and the Construction Industry's Research and Development Fund [Sveriges byggindustriers utvecklingsfond] (SBUF). The actors are added to the figure displayed in Chapter 4. It is worth noting that these actors were not interviewed because they would not represent an industrial perspective within the scope of the thesis.

#### 5.1.1.2 Networks

Elements search for: ad hoc and more systematic interaction between actors

There are not plenty of network interactions that are noted, which likely have to do with the emerging nature of the questions surrounding EC. In terms of occasional interaction, the political meeting of Almedalen[7] is mentioned by several actors. It is described as a place to receive information, exchange experiences and gain knowledge – the reports by IVL Svenska Miljöinstitutet (IVL) and Royal Swedish Academy of Engineering Sciences (IVA) advancing the cognitive understanding of EC in a Swedish perspective were presented there. It needs to be noted that while Almedalen certainly can be an important meeting place within Sweden, the fact that the interviewees took place the weeks surrounding Almedalen might have inflated its importance as many of the interviewees were preparing to partake in the event.

Turning to the regular interactions, there are three types – interaction due to the certification schemes, cooperation with universities, and through environmental committees of e.g. branch organisations. For example, two of the overview actors interviewed have sustainability/environmental committees. The interaction due to the certification schemes occur mainly because it is a complicated process to gain a certification. The certification systems will be expanded on in the coming section on formal institutions. Cooperation with universities or research institutes seems to have knowledge development as a goal. Examples of these are IVL Swedish Environment Research Institute and KTH Royal Institute of Technology [Kungliga Tekniska Högskolan]. An international player that is also mentioned is the CEN who were working on standardisation of Environmental Product Declarations (EPD) and Product Category Rules (PCR) for building products.

#### 5.1.1.3 Formal Institutions

Elements search for: rules and regulations described as mandatory and contributes to them addressing EC

The theoretical framework identified regulative institutions as the only existing type of formal institutions. However, in applying the framework, there are two types that emerge: regulative mandatory institutions and regulative voluntary institutions. The few actors pointing to mandatory institutions highlight municipal regulations. Within the voluntary institutions, three main sub-types exist – standards of how to conduct LCAs, the certification systems, and voluntary municipal agreements.

##### *5.1.1.3.1 Regulative Mandatory Institutions – Public Requirements*

The interviewees do not have a unified perception regarding the existence of requirements from public authorities. One the one hand, many actors from all groups state that there are no regulations or requirements from public authorities regarding this. On the other hand, some interviewees point to that a few municipalities have introduced requirements of considering the emissions of the materials. The examples mentioned are, among others, Norra Djurgårdsstaden in Stockholm and Lidköping Municipality (for more information on these projects see Stockholm, 2014 and Lidköping Municipality, 2013) Their approaches vary – Lidköping introduced regulations for all new public buildings within a city, while Stockholm did so for a city district that has high sustainability ambitions.

The interviewees have different perceptions of whether it is within the legal mandate of the municipality to utilise these types of requirements. It is clear that this is a continuation of the discussion regarding the appropriateness of municipalities sharpening the requirements

[7] "Almedalen" is a park in the town of Visby on the island of Gotland in the middle of the Baltic Sea. For eight days in early July every year, Swedish politicians from every level, representatives from business, civil society and public authorities gather for some akin to a festival for anyone with an interest in society. They attend or hold seminars, debate large and small issues, and mingle. This year, Almedalen hosted some 3500 "programpunkter", whereof at least 10% had sustainability, climate and/or environment as the main topic (Region Gotland, 2015).

beyond those specified in national building-code (called Boverkets Byggregler (BBR) in Swedish), the so-called "further demands discussion" [kommunala särkravsdiskussionen]. This was a discussion whether municipalities should be allowed to impose stricter requirements than BBR. The previous government put a stop to this by the introduction of legal changes (Sveriges byggindustrier, 2014). However, despite attempts of the previous government to clarify the rules, it seems like there are still uncertainties what actually applies (Nohrstedt, 2015).

There is, however, agreement that there are no national legal requirements regarding EC. Rather, the storyline that emerges is that public authorities have become aware of the issue through the industry initiatives around it and are starting to consider different initiatives. That Boverket currently is working on a report reflects this.

#### *5.1.1.3.2 Regulative Voluntary Institutions – the Certification Schemes*

As said above, regulative voluntary institutions emerged as a category during the coding. They are voluntary as the actor can choose whether to abide by them, but if doing so, it comes with a regulative package that one has to follow. All actors bring up the certification systems as institutions one can choose to participate in that addresses EC. There are, however, some distinctions that are made by the actors. Firstly, the idea behind certification carries more weight for commercial buildings than for residential ones. Construction clients engaged within the residential housing market all give less significance to the certification systems. One reason is that the value-added of certification is not as high for residential as commercial buildings. One of the construction clients active on the residential market describes that "we do not experience a similar increased value of the building as the commercial buildings do, and it does not make it easier to rent".

Secondly, an important point concerns how the relevant certification systems address EC. There are three schemes that are mentioned by the interviewees: BREEAM, LEED and Miljöbyggnad. In brief, BREEAM awards points for addressing EC, LEED does so in the newest version, and there are discussions to include it in the coming version of Miljöbyggnad as well. The three systems are presented below in general and in particular their dealings with EC.

*Figure 9. BREEAM's Logo. Image from* (BRE, 2015a)

BREEAM is an abbreviation of Building Research Establishment's Environmental Assessment Method, and is the first sustainability certification system for buildings (Ebert, Essig, & Hauser, 2011): it was created in 1990. It is UK based BRE, Building Research Establishment, that is the organisation behind it. However, the Sweden Green Building Council (SGBC) has adjusted the requirements to fit better with the Swedish building code to facilitate certification. There is thus a Swedish version of BREEAM (SGBC, 2013). As a point of reference, there are 199[8] certified projects in Sweden, with "offices" being the leading category with 98 projects. The distribution is displayed in Table 1[9] (GreenBookLive, 2015).

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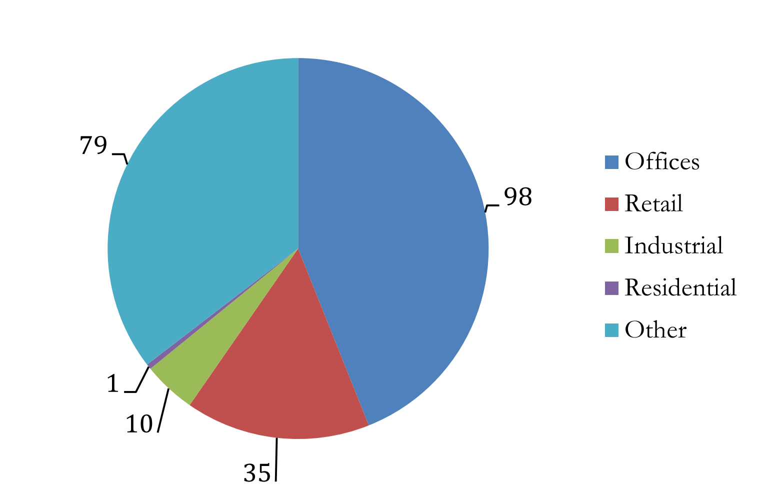
[8] This figure includes all types of projects, *inter alia* refurbishments (GreenBookLive, 2015). Thus, it overstates the figure slightly yet can be used as a point of reference.

[9] Note that a project can be categorised as several types simultaneously, resulting in that the figure displays slightly more projects than are certified. Moreover, regarding all the figures displaying the spread of certified buildings for the

*Table 1. BREEAM Certified Buildings in Sweden*




The system works on a point basis that a building needs to score in order to be awarded a certification. There are several different areas where there are minimum requirements to become certified, including energy efficiency. There are six different levels of certification, where more points are required to become certified at a higher level (SGBC, 2013).

EC is addressed under the heading of Materials. It accounts for a relatively small share (around 1/8) of the total possible allocation of points, and of the 1/8, around 1/3 is related to the life cycle impacts of the materials. They are voluntary to address, unless one wants to score the two highest levels; then it becomes obligatory to address it (SGBC, 2013). Currently in Sweden, there are 32 projects that score or are underway of scoring sufficiently high for these certification levels (GreenBookLive, 2015). The certification organisation, BRE, has also developed the Green Guide as a helping tool for users. The Green Guide aggregates and averages LCA data for numerous elements within a building, allowing users to generate a simplistic LCA for a building based on those available choices. By having the material data accessible, and providing a system of how to perform an LCA-like assessment, it increases the accessibility of LCA to users (BRE, 2015b). The interviews revealed that many actors use this tool.

*Figure 10. LEED's logo. Image from* (USGBC, 2015b).

LEED stands for Leadership in Energy & Environmental Design and originates with the United States Green Building Council (USGBC). It was unveiled in March 2000, and has developed considerable since then (USGBC, 2012). Several different versions of LEED have developed for different types of buildings and projects. These are, among others, Building Design + Construction as well as Building Operations + Maintenance. Existing buildings go under Building Operations + Maintenance, while new buildings and major reconstructions go under Building Design + Construction (USGBC, 2015b). Due to the focus on new constructions, it is this rating system that henceforth is referred to as LEED in this thesis.

There are four levels of certification. Currently, 125 projects have become certified in Sweden. In 2009, it totalled two, so there has been a steep increase of projects during the last few years. In addition, there are 145 projects that are registered and in the pipeline of getting a certification. The most common type of building to enter into a certification process is "Office", with more than 70% of the projects. The distribution is shown in Table 2 (USGBC, 2015a).

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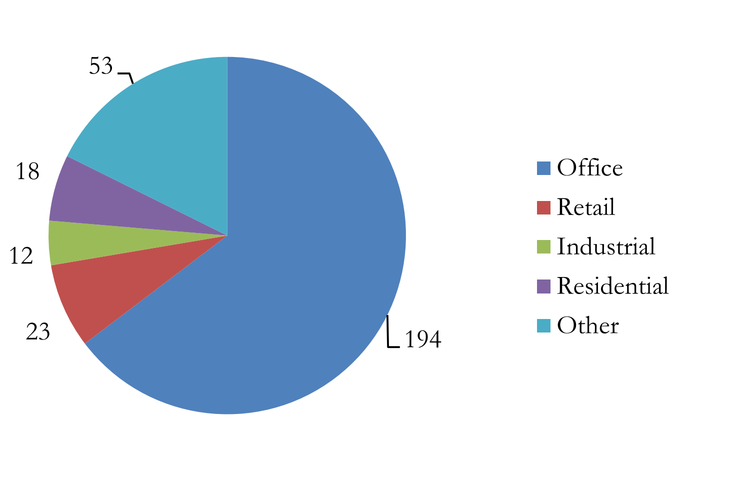
respective schemes – the categories of buildings does not correspond exactly between the systems. Thus, these have been adjusted and merged to facilitate comparisons.

*Table 2. LEED Certified Buildigns in Sweden*




Currently, there are two versions of LEED available for new buildings. These are version three (v3) that was launched in 2009, and version four (v4) that was launched in 2013. V4 is by some described as a "thorough overhaul" that has caused much debate within the construction sector (Malin, 2013). Due to the large changes, the USGBC allowed for the two versions to co-exist, granting time for the industry to familiarise and prepare for the more demanding LEED v4. The last date to file for registration was originally set to end of June 2015, but was extended to November 2016 (USGBC, 2014).

One of the key differences between the versions is the approach to materials. While v3 hardly dealt with the environmental impact of materials, v4 has increased the requirements considerably in several ways. Roughly described, choosing a certain number of materials from manufacturers who disclose the environmental impact of their products in EPDs following the relevant ISO standard is awarded with one credit. If these materials have below the average industry environmental impact, another credit is awarded (USGBC, 2013).

*Figure 11 - Logo of Miljöbyggnad. Image from (SGBC, 2015b).*

Miljöbyggnad is a Swedish certification scheme that is based on the Swedish building code. It is since 2011 handled by SGBC, and there exists two main versions – for existing buildings and new construction. Here, it is the new construction version that is considered. Certification can be awarded at three levels. Statistics regarding the number and types of certified buildings seems not to be available on the webpage of SGBC. However, it was announced in September 2014 that the 250th building was certified according to Miljöbyggnad (SGBC, 2015a). As there have not been any further announcements of new milestones reached, it seems plausible to assume that the current number is roughly around this number.

Miljöbyggnad does currently not address EC. Material is one of the three components that are considered, along with energy and indoor climate, but it is the chemical content of the material that is the focus. There is an ongoing discussion, however, regarding version three of Miljöbyggnad, where leading experts within Sweden argue that it should include LCA components (Erlandsson, 2014). It can be noted that a study conducted by two master students at Lund Technical University also find that the inclusion of LCAs within Miljöbyggnad is deemed as the fourth most wanted factor to be included by the respondents to their survey. It is not possible to generalise from this finding, something the authors emphasis themselves (Ericson & Larsen, 2013); yet it illustrates an awareness regarding that the question is approaching.

Common for these three system is that they are industry owned – the criteria is not set by public authorities, but in committees consisting of industry representatives as well as academia and sometimes few governmental representatives (BRE, n.d.; SGBC, 2014; USGBC, 2009). It is important to note that this does not mean that it is air-tight between governmental bodies and the committees in the organisations – individuals having connection to government might very well also work in the committees. The point is rather that it is not the sole purview of public authorities to decide over the certification systems.

##### *5.1.1.3.3 Regulative Voluntary Institutions – the Development of Standards*

A set of institutions that are often mentioned by the constructors and overview actors are standards of how to conduct a LCA on both a complete building as well as on a material level. A priority is to ensure that it becomes material neutral in that it does not systematically benefit one material over another. The image that appears regarding the existing standards is not clear. While some actors express a wish for a working standard for a full building, others point to that the current ISO standard is sufficient. It is difficult to judge what is correct of these two options, but it is possible to say that if there is a workable standard, the knowledge of it has not diffused.

One of the actors point out that, it is not common practice for material manufacturers to produce EPD in Sweden. This complicates things for an actor who considers doing an LCA as the necessary data is not available, hence requiring either data collection which is resource intensive or relying on assumptions which have impacts on the reliability of the LCA.

##### *5.1.1.3.4 Regulative Voluntary Institutions – Municipal Agreements*

Another voluntary institutional scheme that is brought up by one actor is the possibility for municipalities to enter into voluntary agreements with construction clients, where they commit to work together to achieve better practices within agreed areas. "[I]t is possible to reach voluntary agreements so if a construction client commits to do certain things, they [the municipality and the construction client] can work together". The actor points to the Climate Contract that the municipality of Malmö has entered into with, among others, the energy supplier E.ON, where they commit to develop a smart energy system for the city district of Hyllie (E.ON, VA Syd, & Malmö Stad, 2011). A similar approach might be possible regarding EC.

#### 5.1.1.4 Informal Institutions

> Elements search for normative - expectations, visions and self-shouldered duties. For cognitive - changing understanding of EC

Turning to informal institutions, the conceptual framework pointed to two types of institutions – normative and cognitive. The interviews have shown that there is an underlying normative institution acknowledging that climate change is occurring, and that the construction industry has a responsibility to break the trajectory, or at least reduce its impact. It has also pointed to a changing cognitive understanding of where the impact originates from – hence the focus on EC.

Several of the actors directly express concerns of environmental issues, and discuss either the sector as a whole or their organisation's effect on the surrounding environment. Regarding the normative institutions, admittedly, none of the questions of the interview guide dealt directly with environmental sustainability as a motivating factor. Yet it is possible to interpret the answers in their context to see that there is an underlying concern for the environment. A caveat to have in mind, though, is that the individual interviewees all work with sustainability issues within their organisations, which make it plausible to assume an interest and awareness of these questions.

Across the board, there is a developing cognitive understanding highlighted by several interviewees. One actor states that the construction industry has been "[s]tuck in a way of thinking - this is how-we've-always-done kind of thinking". However, this is changing. It is reflected by that the industry has understood that the 85/15 proportions – that 85% of the environmental impacts originate during the use-phase and the remaining 15% in the material manufacturing – does not apply any longer. This is also expressed in several reports. There seems to be no doubt that the two reports that SCF together with IVA, and IVL and KTH Royal Technical High school respectively (IVA, 2014; Liljenström et al., 2015) published has resounded throughout the Swedish industry. Several interviewees pinpoint them as those which placed the question on the agenda, and have altered the cognitive understanding of the sector.

There were several explanations of why the dawning understanding comes now. Some perceive it as a question of maturity – the knowledge regarding EC "has started to mature now, and one realises that one has to work more with the material given the possibilities one have". One actor emphasises their Environmental Management System (EMS) as the reason that the question has gained importance. The EMS builds on the ideal of "continuous improvement" and systematic review of significant environmental aspects. These practices are central to the ISO 14001 EMS but also can be found in other EMSs (Brorson & Larsson, 2011). These fundaments require the company to (re)consider its environmental aspects, and as the technical developments shifted the proportions between EC and emissions from the use-phase, it became a "natural next step" to start addressing it, as one actor expresses it.

Summarising TIS step two regarding the structural components, there are many types of actors who address EC, though the networks between them are quite weak. There are considerable voluntary regulative institutions, while the mandatory are not so significant. Along with the functions that are described next, an answer to the first RQ will come at the end of section 5.1.

### 5.1.2 TIS Step Three – Identifying Functions

Here, the different functions of the TIS will be systematically dealt with. The point of departure is the information uncovered by the interviews, which is complemented with information from elsewhere.

#### 5.1.2.1 Knowledge development

> Elements searched for: learning-from-projects, imitation 'learning by searching' and 'learning by doing'.

Learning-by-doing was mentioned by all actors as the main way the organisation learns. One of the construction clients contrasts how employees learning through courses with practical application: "Courses are good, but it is difficult to learn. It is when one works with it hands-on that they learn". A few actors, though from all groups, have done their own research on projects to get an idea of how their share of EC looked like. Moreover, some overview actors have focused on getting actors on the same page by developing standards. This also, to a degree, reflects the point of view offered by the constructors who seem to prefer that R&D of these practices to take place on a central level in order to ensure congruency.

When tools become available, primarily the constructors, but also some overview actors, underline the importance of integrating them into their existing tools. Concretely, this generally means that in the modelling tools used to plan the construction of a building, the Building Information Modelling programmes, the life-cycle data for the materials used is continuously available so that the planning engineer directly can receive information what consequences different designs and choices of material have on the building. This is presented as a crucial component for them to be able to address EC systematically; that it becomes an integrated part of their current work practices and not an ad hoc practice that is added occasionally.

Construction clients stress that they are in a learning process of how to work with EC. All relevant actors point to that the construction clients learn through specific projects. The common trend is that they are in the early phases of starting to address EC, and are learning through working with it hands-on. However, the construction client who states that they have started to address EC concretely emphasised the importance of "finding tools so they [the employees] can find the right things to focus on". This illustrates that there is still a long way left to wander before the sector can address it completely.

Cognitive institutions are, unsurprisingly, central for this function. Some actors strengthen the existing ones through their own initiatives, and integrate them into existing tools, while others see that it is better to strengthen the institutions centrally. Networks are sparsely used.

#### 5.1.2.2 Knowledge diffusion

| Elements searched for: Learning-by-interacting both internally and externally |
|---|

Different forms of cooperation are identified as important ways of diffusing knowledge. Cooperation between commercial actors and research institutes are presented by all types of actors as important because it generates mutual understanding, hence contributing to strengthening the developing cognitive institution mentioned earlier – especially regarding standard development. One overview actor expressed that through cooperation "there is a smaller risks that if one of the other actors is asked at a later stage [how to perform an LCA], you'd get a different answer". However, the most common form of knowledge diffusion was through procurement of knowledge. Three out of the four construction clients describe their dependency on good consultants since strong in-house capacities regarding this question have yet to develop.

Another avenue of diffusion is through the use of existing tools. The Green Guide within BREEAM certification system is mentioned by several actors across the board. The construction clients emphasises that their use of the Green Guide primarily is to familiarise themselves with the question rather than actually to do the work. Some actors also mention Building Product Assessment [Byggvarubedömningen (BVB[10])] as a tool, despite that it only concerns itself very little with EC. BVB is a tool hosted by an independent organisation that is owned by the construction industry. The organisation classifies building materials according to its content, and applies a system to rate it (Byggvarubedömningen, 2015). The actor's explanation is that simply by starting to consider the material, the employees start to think about EC.

[10] Will be referred to by its Swedish acronym, BVB.

Turning to internal diffusion, an activity identified beyond the theoretical framework, some interesting points can be highlighted. For those actors who started to actively address EC, it is especially the improvement of existing tools that is lifted as the way to make the existing knowledge accessible to everyone internally. That the tools should be user-friendly and relatively easy to use is an often repeated goal. Also, internal seminars and courses are important to spread the knowledge internally. It also seems that if these become systematic, such as a "green week" as one constructor points to, or that employees have to undergo training as part of an ISO 14001 EMS (Brorson & Larsson, 2011), the interviewees are more confident that it has effect.

On the topic of diffusion, it is expected that networks become more important than in the previous function. Other actors use e.g. the formal voluntary institutions (standards) and rely on the cognitive institutions advanced by others. These are diffused through networks, but especially business networks as procurement of competence is common.

#### 5.1.2.3 Entrepreneurial Activity

Elements search for: undertake initiatives despite considerable uncertainty

There were not many actors who had taken an entrepreneurial risk, yet they could be found within all the groups. An actor described it as that the actors "who have started [are] usually the enthusiasts who have thought this is important". A construction client state that "[w]e want to show the way onwards", while another actor connected being advanced in these questions with the possibility to attract green capital. The actors pioneering this seem to share two characteristics - the companies expressing that care for the environment is a core value for them, but also that they perceived addressing EC as a business opportunity.

This function builds on that actors rely on normative institutions encouraging and enabling them to take these risks.

#### 5.1.2.4 Direction of Search

Elements search for: activities seen as decisive in fostering the growth of the technology.

There were three categories that appeared when coding the interviews. To begin with the one mentioned least, it was policies and regulations pushing actors to reduce their emissions. One of the overview actors express it as "it is possible to say that there is not a large pressure from states driving these questions, but rather internal, often political, goals that one should be good at this".

A second element for which many actors not saw was present was articulation of demand. The construction companies along with an overview actor see that there is demand for the final product (buildings where EC has been taken into account) through the certification systems. One construction company describes how a few clients specifically have requested buildings with low EC, but stresses that it normally is derived from a request for a certified building. The construction clients are in-between as they can both articulate demand and tell whether their clients have expressed any interest. Regarding their articulation of demand, one actor acknowledges their own responsibility for this - if we "do not start demanding and show that there is a demand, there is a risk that the construction companies will continue with business-as-usual". Another point specifically to the certification systems and that demand comes through these. Turning to what demand they experience being articulated for their buildings, a clear divide can be seen between commercial and residential buildings. For commercial buildings, there is a demand for certified buildings while this is not the case for residential buildings to the same degree.

The last mechanism is seen more frequently, namely that the actors have internal visions to be good stewards of the environment. This is recurring from actors across the board. One of the construction companies state that "it is in [the company's] interest as community builders [to work with EC]", while an overview actor saw "that it could contribute to a sustainable future". A construction client states that they work with EC "because we want to reduce our climate impact. Our long term goal is that our organisation should not contribute to global warming". All construction clients state that being good stewards is important for them.

It is clear that the formal mandatory institutions are not that significant. However, the formal voluntary institutions once again appear to be used by the actors in various ways to perform this function as well. Also the normative institutions of caring for the environment is utilised to formulate visions.

#### 5.1.2.5 Market Formation

| Elements search for: physical space with certain requirements |
| --- |

The emergence of niche markets is the identified element. The construction companies point to that certified buildings constitute a market segment where EC is considered. One also connects municipalities to this as "many municipalities have announced that all future new construction of their residential housing companies will be certified". The construction clients engaged with commercial buildings also point to that all their new construction will be certified.

Actors again use the formal voluntary institutions, resting on the developed cognitive institutions to motivate their requirements. Public actors, which are exogenous to the framework, also act in a similar manner.

#### 5.1.2.6 Resource Mobilisation

| Elements search for: actors committing human and financial resources |
| --- |

The construction companies and overview actors have dedicated human capital towards developing knowledge and solving tasks regarding EC. However, the construction clients have little human capital to mobilise regarding this as they are dependent on procurement of expertise. Regarding financial capital, there is less to show for. One overview actor explains that they managed to secure a significant amount of financial capital internally to develop knowledge regarding EC. A few actors have managed to mobilise external resources, such as getting a grant to develop tools. SBUF has also supported several projects related to development of LCA standards for construction products.

#### 5.1.2.7 Positive Externalities

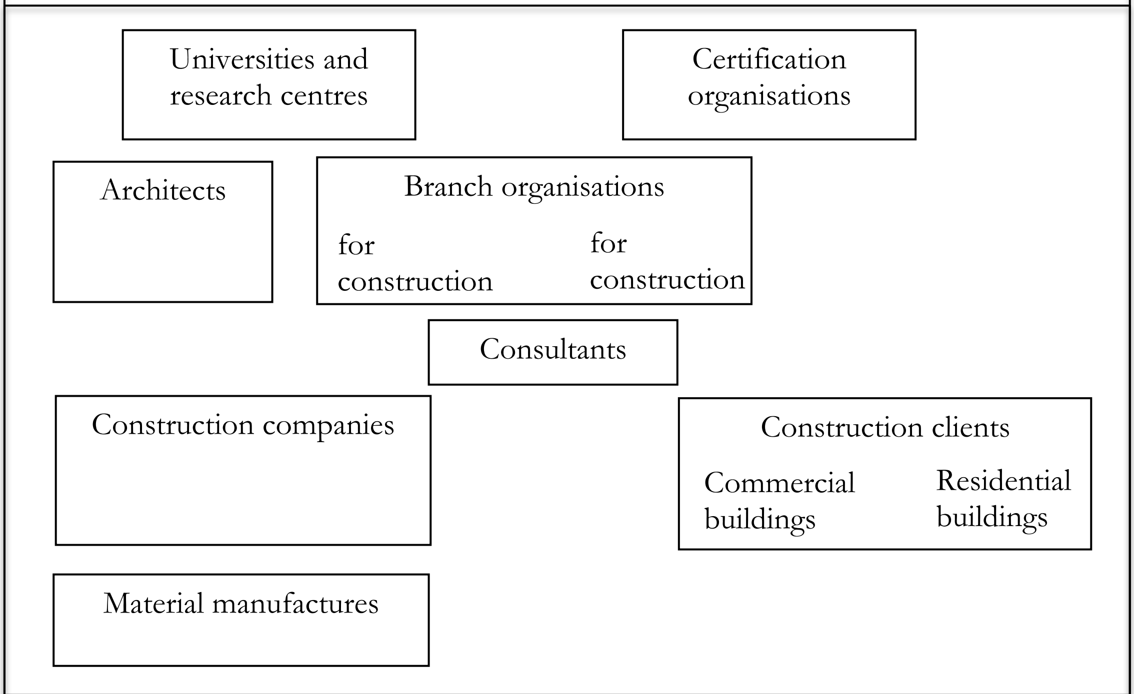
There are few different elements that can be seen as positive externalities that emerged from the interviews. One actor points to regards how the cooperation within research development strengthens the cognitive institution as actors communicate more. This applies both between actors, but also within an organisation as several departments might cooperate. One actor expresses it as follows: "Everybody cooperates in order to conduct these calculations, and that is another benefit with LCAs - that we get everyone to talk to each other". In a publication on the mitigation technologies and practices within the construction sector, UNEP echoes this point in the discussion around life cycle and integrated design processes. By employing a life cycle perspective from the start, important design decisions that locks the development along a certain trajectory of high EC can be avoided (Chi-Nguyen Cam, 2012).

### 5.1.3 Answering Research Question One

**RQ1** – What actors within the construction industry are engaged with Embodied Carbon today, and how do they address it?

Sufficient findings are now presented and analysed to be able to give an answer for RQ 1. Regarding who, a wide array of actors from many different groups appears, but only a few from each group. These are presented in Figure 12. As pointed out above, the point of departure with the actors were also the ones who are most advanced regarding environmental sustainability questions – it is difficult to say that the current image stemming from this is likely to represent reality completely.

*Figure 12. Overview of Actors within and close to Industry Addressing EC*




*The Figure illustrates the main type of industrial actors who address EC, as well as actors outside industry who have appeared as influential.*

Turning to how EC is addressed, more can be said. The actors address it by developing a number of institutions that are used in various ways. It is voluntary regulative institutions such as the certification systems that are utilised to a high degree. Mandatory regulative institutions are deemed to be largely non-existent, though some actors point to that municipalities have started to enact regulations regarding EC.

The interviews reveal that the main activities regarding EC today are to develop knowledge of how to address EC. The construction companies have come further in this, with a few construction clients also being quite far ahead. However, it seems many do not house the knowledge, but are rather dependent on consultants. This is currently a common way of diffusion – the procurement of services, though there are other avenues as well, as described above. Networks play a role in the development of knowledge as industry actors usually pair up with academic institutions such as universities or research centres. Networks also play a role regarding diffusion of knowledge, though this mainly happens through the procurement of knowledge, where one party contracts another actor to carry out an investigation.

Those actors who have the knowledge of how to (start) to construct low EC buildings integrate it into their existing tools. By integrating the LCA data at an early stage, it becomes possible to consider the EC in the materials both in the design as well as planning phase, which makes it easier to maintain a creative mind-set in finding solutions. One actor point to another essential aspect regarding this, and that is that the creativity of finding solutions is not quelled – employees are not bound to only go for materials with low levels of EC (and thus become locked-in to the functions and aesthetics qualities that particular material can provide), but can innovate new design and construction solutions to reduce the need for another material. This is seen as the way forward from all actors – that addressing EC needs to be an integrated part of the construction process from the start and that it becomes a decision-making aid between different designs and material choices.

The developing cognitive institutions (that we increasingly know the significance of EC and how to address it) as well as the normative institutions are driving the direction of search - the reasons why actors look into this. Both regulation and policy, as well as articulation of demand are lacking aspects that could become stronger. A few actors have shown their entrepreneurial spirit by mobilising internal resources to develop knowledge of how EC looks for them, and what actions they can take.

This is a description of who and how EC is addressed today. The thesis now turns to the second and third research questions.

## 5.2 Research Question Two – Drivers and Barriers

RQ2 focuses on barriers and drivers. Step four and five are used as the base to answer this question, naturally drawing on findings from the early steps as well. The lack of grey boxes specifying what was looked for is explained by that in neither of these steps specific elements are searched for in the coding process.

### 5.2.1 TIS Step Four – Assessing Functionality: Defining the State of Development

*Figure 13. Questions Posed by Step Four*

| | | |
|---|---|---|
| Pre-development | → | Is there a working prototype? |
| Development | → | Is there commercial application? |
| Take-off | → | Is there a fast growing market? |
| Acceleration | → | Is there market saturation? |

Based on the findings presented above, it is difficult to provide unambiguous answers to the questions posed by step four. While some actors do currently work with systems that do work, it is not a flawless prototype as it is severely limited by the lack of EPDs for different materials, a standard that enjoys widespread support of being material neutral, and knowledge of what type of demands that can be posed by construction clients. At the same time, there is a commercial application for it, as construction companies point to that BREEAM and the new version of LEED includes EC. Yet, as described above, it is a minor part of the certification systems that is optional to address in most cases. Consequently, the TIS is somewhere between Pre-Development and Development. In the Pre-Development phase, knowledge development is the central function, together with knowledge diffusion, resource mobilisation and direction of search. In the Development phase, all functions are deemed as essential to boost the development of the TIS. These findings are used to triangulate the discussion of which drivers and barriers are important to boost/tackle.

### 5.2.2 TIS Step Five - Drivers and Barriers

Turning to the drivers and barriers, the findings are not connected to specific concept of a theoretical framework as the findings up to this point have been.

#### 5.2.2.1 Drivers

The strongest drivers of the development towards addressing EC are the green building certification systems – all actors identify these as having a strong influence on the question. The exact way how the certification systems affect the way EC is addressed varies a bit depending on the actor. Some point to that the inclusion of it within BREEAM and LEED have brought attention to the question, and raised it onto the agenda. Other actors see that as the certification systems develop, this question's salience will increase within the systems. Those pointing to that it will bring attention to the question often draws a parallel with how other questions have become important through inclusion of them within a certification system. A few actors make the comparison with daylight within Miljöbyggnad, where the inclusion of daylight there has really brought the issue onto the agenda in its own right. Either way, the certification systems inclusion of EC encourages the actors to develop capabilities to address EC, as it becomes useful in the certification process. Indeed, to reach the top levels, it becomes imperative to be able to address it as specified by the systems.

Some actors also point out that it is necessary to address EC for the sake of maintaining competitiveness. Being able to work with EC signals advanced abilities to work with environmental questions, it is said. That is good for competition. Another actor points out that other schemes they engage in, e.g. securing green capital, rely on them being perceived as spearheading the green development of the sector – "to be able to attract that capital, then our environmental work needs to spearhead the development to avoid it being seen as greenwash". Nevertheless, there is disagreement on this point in general, as some actors state that working with EC has not provided any type of competitive advantage. In line with this, some stress that addressing it will become like a "license to operate" rather than providing a competitive advantage. A "license to operate" indicates that addressing EC becomes a minimum requirement one has to fulfil in order to actually have a chance of doing business within the sector.

There are also a number of drivers that just some actors mention. A construction client points to that applying the systematic review and continuous improvement that are engrained within EMS made them start to consider EC. The practise of reviewing the environmental aspects periodically sheds light on this question, as it has first emerged as a significant environmental factor as the proportions have changed. Thus, in this light, the focus on the question becomes a product of the EMS system. Another driver that is highlighted by several actors is curiosity among the employees. As employees within the companies get to know more about the question, it sparks interest upon which they develop more knowledge about it.

A few actors mention that the requirements municipalities pose in a few new city districts with high sustainability aspirations act as drivers. In line with this, a potential driving force mentioned primarily by the overview actors is the tendering practices of municipalities. It is stressed that municipalities need to act as role models in their practices and understand the complications of requirements before imposing them on actors. Thus, addressing EC in their own procurements of buildings (e.g. schools, roads, etc.) is seen as a good first step as it creates a demand for the knowledge of how to address EC, incentivising the actors to develop it. An actor pointed to the fact that this is currently under investigation in a SBUF project, though on the infrastructure side. The project aims to investigate what type of demands the Swedish Transport Administration [Trafikverket] could pose in order to reduce energy use and climate impact in the construction of roads (SBUF, 2014).

#### 5.2.2.2 Barriers

There are a several different kinds of barriers that appear. The most prominent are the view that complexity makes the introduction of regulative policy measures difficult if not impossible, and that there is considerable lack of knowledge regarding EC throughout the value chain. Several concerns regarding a number of things also appear, perhaps reflecting an uncertainty of what addressing EC actually would mean. Below, the different barriers are described in more detail.

The lack of data relates to the barrier that is most often is pointed to: the complexity of the issue. It stems from the flexibility around an LCA – how one draws the system boundaries, how the functional unit is defined, and so on has significant implications on the result of the LCA. Thus, using the result as a ground for policymaking is seen as dangerous as it could result in sub-optimisations. This, in turn, relates to that it seems like there is no standard on how to perform the LCAs. This is the case despite that ISO standards exists for how to do an LCA in general (ISO 14044), and how to perform one for building materials (ISO 21930). Moreover, there is a standard of how to compile these into an EPD for an entire building (EN 15978). As said, the identified issue is the lacking EPDs for materials, which relate to the lacking PCRs for materials. The issue has been that there has not been any demand for these before. One overview actor points to that there "there was an ambition to include lifecycle assessments within the Building Declaration Standard that exists today, BVD 3, […] but there was an irritation from the material producers in that the information was required, but never used". Thus, the disagreement of how to calculate EC makes it difficult to reach an agreement of how to address it.

A second prominent point, related to the one above, is the lack of knowledge within the sector. This applies both to the sector that is the focus of this thesis – the construction companies and clients as well as consultancies and branch organisations – but also upstream with the material manufacturers. One of the construction actors point out that "there is a lack of knowledge in the entire sector. They [landlord companies] know that they should take this aspect into account, but does not know exactly how". One interviewee reveals that they are in the midst of developing a set of requirements regarding EC that they will present to one of their material suppliers to see how they are received. This related to the second aspect of a lack of knowledge upstream. The interview with the construction actor above goes on, describing how some of the companies upstream, the material manufactures surely "have this type of data [LCA data] available, but the majority has probably a lot of work to do". An overview actor describes a project where the ones working on it identify lack of data from exactly the material manufacturers as the most challenging aspects within the project. The actor continues with stating that there are very few EPDs accessible for Swedish construction materials today, which hampers the development of addressing it.

A few actors also point to a more fundamental aspect – they do not perceive that EC should be a highly prioritised concern for the industry. The chemical content of the material and its effect on human health and the environment is one aspect presented as more important to address, as well as resource efficiency. That the chemical content has, and perhaps still is, considered as more important is reflected in that established systems, described above, exist to deal with it. Likewise, the importance of resource efficiency is backed up by that this is the focus of the Communication on Resource Efficiency Opportunities in the Building Sector issued by the European Commission, rather than EC. Even so, as described above, most actors perceive that EC is an important issue, though precisely how important is up for debate.

There are several other concerns that are raised by a varying number of actors. Many point to that an increased emphasis on EC might crowd out other environmental concerns such as waste generation or water use. Other actors point to that the inclusion of EC within the certification systems might increase the cost of complying with these to such a degree that smaller actors will not be able to get their projects certified, thus creating an excluding effect. This is expressed by several interviewees, including interviewees representing large constructors who would not face the same difficulty dealing with an increasingly onerous certification process. A few actors also raise the concern that starting to address EC could drive up the costs of building, which in turn would drive up rents. The actors point to a difficult situation on the housing market in general, where such a development could have social consequences that are deemed undesirable.

### 5.2.3 Answering Research Question Two

**RQ2** – What are considered to be the main drivers and barriers of this work today?

Summarising the drivers and barriers section, the main drivers are the voluntary certification systems like BREEAM and LEED. They provide an incentive to develop capabilities to address EC. It is interesting to see that they are considered as the main driver despite that EC does not carry much weight within the systems themselves. Hence, a future larger focus upon the question could have significant effect on how much it is addressed. The certification systems also play a role for market formation. Part of the niche market establishment found is when municipalities state that all new construction will be certified to this or that level. As the certification systems increasingly include and address EC, it comes as part of a package.

Regarding barriers, the lack of knowledge and the complexity of calculating and finding an effective and fair way of addressing EC systematically are seen as the most difficult barriers to overcome. Lack of knowledge manifests itself in two ways: First, construction companies and clients do not know exactly how to address EC – they lack an answer to the question 'What are ways to decrease EC?'. Second, they do not have the LCA data for all the materials used, and do generally not know the amount of EC in their buildings. This stems from that material manufacturers upstream are not in the habit of generating EPDs for their products. Some actors emphasises that it is a maturity question, and that the knowledge will come with time as actors work more with it; others are not as confident. Another barrier is that it is mostly commercial buildings that become certified, while this does not matter so much for residential buildings. Miljöbyggnad's current lacking inclusion of EC compounds this problem. Applying the concepts of functions on this, it is possible to see that knowledge diffusion as well as knowledge development to a certain degree are lacking functions.

Turning to what step four emphasises as important, knowledge development and diffusion are crucial in this stage to advance the innovation system. Currently, diffusion happens through procurement. Internally, an EMS has proven to be useful as it systematically promotes diffusion. The certification systems are central in both diffusion and development of knowledge. Neither direction of search nor resource mobilisations are functions that are particularly strong, indicating that these might need additional support to grow stronger.

## 5.3 Research Question Three – Policies

RQ3 focuses on the necessary polices as deemed by the interviewed actors. The policy framework presented in section 2.4 is used to sort the answers of the interviewees.

### 5.3.1 TIS Step Six – Polices

There seems to be a general agreement that policy support is needed for this to become Business-As-Usual (BAU). An actor points to that "it does not stand still without policy, but steering is needed" to get all actors on-board. The interviewees do not agree on how far the industry would come without policy support, but they agree that it would not be all the way. One overview actor nuances the discussion and points to an important distinction between the commercial versus the residential side of the buildings market. The interviewee emphasises that while "the commercial side of the market will relatively quick be steered over [and address EC]" the situation looks different for residential buildings. If we expect that "it will be demand-driven and we await that the individual house-buyer [will ask about, and take EC into account in a purchasing decision], then we will have to wait a long time". Hence, there is agreement that policy support is needed, though in varying degree between different market segments. Next, what type of policy support deemed needed is discussed.

Turning to the question of what type of policy instrument, the findings have been organised according to the typology introduced first with regulative, economic, and informative and Green Public Procurement (GPP) as four types of policy instruments. The findings reveal that there is not much agreement between the actors which way forward is most suitable.

### 5.3.2 Regulative Instruments

The main discussion of regulative instruments revolves around whether a strict limit of how much carbon a square meter ($m^2$) on average can emit should be imposed or not. It is compared to the current limits imposed in BBR on energy consumption per square meter (Boverket, 2011). Four actors deem a similar demand – a maximum limit of $CO_{2e}/m^2$– to be the desirable end-point of the development. It should be noted that all four actors, who represents the three different categories, emphasis that currently, such a limit would be ill advised as the way to measure and compare it are not sufficiently developed or diffused. In the words of the theoretical framework, this would create a regulative mandatory institution that certainly would change how EC is addressed.

However, most of the other actors, also representing all three groups, specifically bring up such a requirement and dismiss it as unrealistic due to the complexity of the question. One overview actor expresses a concern that policy-makers does not introduces "requirements such as $CO_{2e}/m^2$ because it does not work – there are different pre-conditions in different projects". The core of the explanation is that the calculations of EC are too complicated to ensure that there is a standard that everyone follows, as well as that there is a risk of lowering EC occurs at the expense of other environmental, social or economic concerns.

Summarising the perceptions expressed, it is clear that all actors find that the current situation is not mature for a regulative limitation to be imposed. Some see that as the question matures, it will likely become possible, while others do not see this kind of regulation as workable. Some actors favour regulations in terms of reporting instead; that it should become mandatory to disclose the EC content of a building according to a standard.

Either way, both set of actors suggest other policy instruments as substituting it, or boosting the development in that direction.

There are also discussions regarding that municipalities can introduce and enforce regulative instruments. Actors point to e.g. Norra Djurgårdsstaden and other examples where there are requirements regarding the materials. However, the legality of this seems ambiguous. As described above, the previous government made it illegal for municipalities to go further than BBR in demands regarding buildings. However, the changes in the law have been criticized for being unclear regarding what municipalities can do when they own the land. It also seems like there is a difference in how municipalities address this – Växjö, for example, have decided to continue placing requirements with the outspoken intention to test it in courts (Nohrstedt, 2015).

Moreover, while waiting for a legal clarification, one actor points to voluntary agreements between municipalities and construction clients. The example brought up is the Climate Contract between the City of Malmö, the energy supply company E.ON and the waste-water treatment company VA SYD. The three parties commit to cooperate to create a sustainable smart energy system in the new city district of Hyllie in Malmö (E.ON et al., 2011). This way of working is presented as a potential way around the newly changed law as the municipality does not impose requirements.

### 5.3.3 Informative Instruments

The strongest driver identified above is also the policy instrument that all actors see as the most likely way forward. The certification systems, which are categorised as informative policy instruments[11], are developing and the question of materials are advancing within especially LEED. One of the construction clients state that as they will start to use the new version of LEED, they have to address EC *"in principle every project in order to become certified"*. BREEAM currently addresses it, though, as said, it is voluntary to include it if one does not strive to get the highest levels of certification.

On the residential side, actors that deal with residential buildings in one way or the other point to the significance of EC becoming a part of the certification system used mostly by residential buildings, namely Miljöbyggnad. Again, the actors do not agree on exactly how it should be incorporated – as a limit to keep below, or to show that an LCA has been performed – but state that it would be good if it is included.

One actor also point to that certification of new commercial construction will not become a competitive advantage, but rather an informal licence to operate; a building without a certification will be very difficult to get any tenants for. The same sentiment is expressed by the CEO of one of the interviewed actors to compete with real estate without an environmental certification today is like being under 2-0 in a football game that has not even started yet – one is handicapped from the start (Glennegård, 2014, p. 5).

The interesting question is how policy can affect these systems. The certification systems are hosted and developed by independent organisations – LEED by USGBC, BREEAM by BRE and Miljöbyggnad by SGBC – whereupon government and the public does not have a

[11] An attentive reader might remember that certification systems were seen as 'voluntary regulative institutions' before. In policy terms, this type of institution becomes an informative policy instrument.

decisive role to play. The development of the certification system is thus formally out of the control of the public.

Another informative instrument identified as important is the development of standards. It is interesting to first juxtapose the different perceptions of the readiness of the standard. One overview actor who has conducted several studies state that "the standard is done to the extent that it can be used [to conduct LCA studies of buildings]". Several other actors call for exactly a standard; one of the representatives of construction companies express it that what is needed is that one "within the sector finds one good way to conduct LCAs that are accepted within the sector, and that makes it possible to compare buildings". Thus, there are conflicting perceptions of the state of the standard. It is not possible to conclude from the interviewees whether the existing standard as explained in Chapter 2 is as ready as ready as it needs to be or not. What can be concluded is that either diffusion or development of the standard is needed.

### 5.3.4 Economic Instruments

Turning to economic instruments, some actors express that for example tax rebates for buildings with low levels of EC could be one way forward, though the specifics around how to measure and where to draw the limit remains unclear. A more popular economic incentive among the interviewees relates to the development of knowledge. Several actors point to that further knowledge development is seen as essential, and that policy should support this. Again, exactly how not elaborated upon within the interviews, but plausible options were might be to increase grants for universities and other public authorities to enable them to initiate research projects, or to participate in projects launched by e.g. SBUF.

### 5.3.5 Green Public Procurement

A policy option identified by the construction actors, as well as some of the overview actors, is for public authorities to address EC when they act as construction clients – to make it part of GPP. When public actors are to build something – say a hospital or a school – the interviewees point to that the public body then could demand that EC to be addressed within the project. This is also relevant for infrastructure projects, which fall outside the scope of this thesis, but where it briefly can be mentioned that an ongoing SBUF project will develop what type of conditions the Swedish Transport Authority can pose in their tender processes to reduce the EC within infrastructure projects (SBUF, 2014).

### 5.3.6 Answering Research Question Three

**RQ3** - What support do industry actors identify as necessary to make addressing EC business-as-usual within the Swedish construction sector?

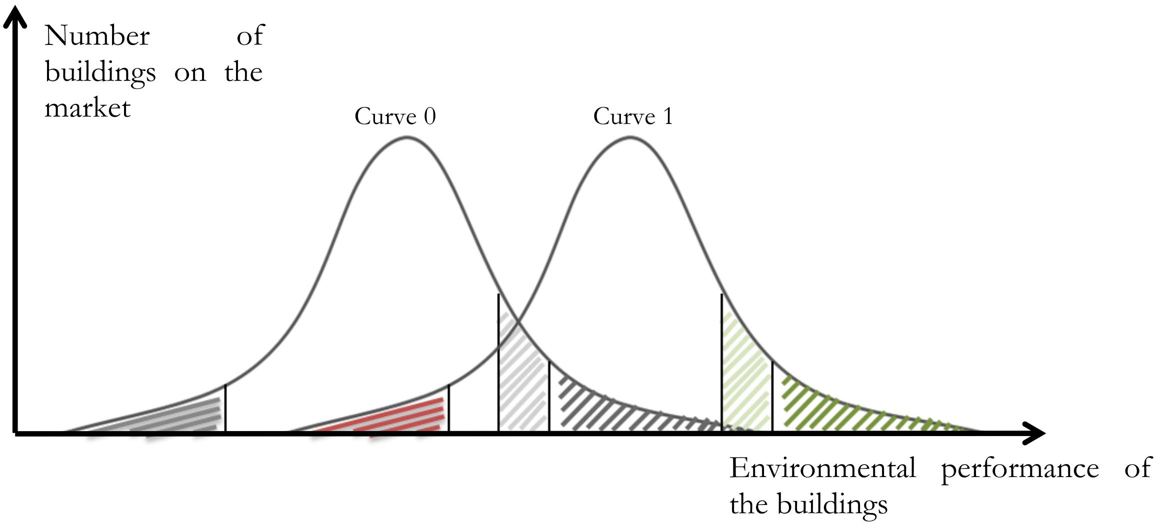
In summary, the review of the findings does not reveal much agreement regarding this except on one fundamental point; policy support is needed for ensuring that addressing EC becomes BAU. The way to formulate this policy support, however, is discussed.

National regulative policy instruments are ascribed thin potential effect. They are seen as inappropriate by some and as desirable first in the future by others. Generally, strict limits in terms of how much carbon can be emitted per $m^2$ are not workable with the present knowledge situation, as there would be no coherent way of calculating this for all types of buildings. Some see it as possible further on, while others disagree. A few actors point to other regulative measures such as reporting of EC in a coherent way, though not many identified this as a potential way forward. Local regulative policy instruments, on the other hand, were seen as a more plausible way forward. As some municipalities already have enacted requirements regarding addressing EC, this is not so surprising. A point made by a few actors is that the requirements regarding EC have to be as concretely formulated as possible, as the current requirements of only building in wood or just to conduct an LCA is not material neutral, or will not result in much. The recent legal changes following in the wake of the "further demands discussion" [särkravsdiskussionen] and the ensuing ambiguous legal state of this sort of requirements made actors both hesitant regarding them, as well as suggesting that voluntary agreements also could work.

Economic instruments do appear as workable, and come up in regards to knowledge development as research grants, but are not discussed much more than this. Informative instruments as well as GPP are favoured as instruments with a larger potential effect. The informative instruments are both standard development, but mostly concerns the certification systems. An essential point regarding the certification system is that the development of these are not in the hands of public authorities; the certification systems are industry-owned. It is not possible for a public actor to directly decide over the systems.

This does not leave policy without tools though – GPP appears as a preferred tool. It becomes more powerful if combined with the certification systems. Going back to what was described in Chapter 2, Tojo (2015) introduces a framework of how to think about how different environmental policies affect the products on the market. Certification schemes work through elevating the top performing products, adding value to them due to the received certification. If considering only the top certification levels, these would be awarded only to the buildings with the lowest environmental impact. As a certification increases the value of the building, (some) producers will strive to get it and the market will evolve better techniques to improve the environmental performance. Gradually, the market would shift, improving the environmental performance of the entire market (the previous market situation illustrated by the grey curve 0 and the new situation is illustrated by coloured curve 1).

*Figure 14 - Illustration of GPPs Effect on the Market*




Through GPP, public actors could specify that their new construction will be certified according to a certain level[12], contributing to the niche market formation. This could certainly

[12] It could also be done without referencing to a certification system but simply say that the EC of the material should be taken into account, though many questions would arise from this.

be done when the public act as a construction client, building e.g. schools or other public buildings. Also, in a Swedish context, there are many municipality-owned public housing companies that could decide to systematically take EC into account. As residential housing usually use Miljöbyggnad, it is problematic that this certification scheme does not address EC currently, though as described above, there are discussions that it might. Depending on which criteria set within the GPP, buildings to the right of the defined criteria (the red-striped area) would benefit.

Also, the strict regulative instrument of a limit can also be illustrated with the help of Figure 11. It should be understood as a floor, removing all products below this. It cuts the tail, so to speak. As said, many actors do not see this as workable, because where a building exists on this graph is not only a result of some (relatively) easily controllable factors such as choice of material, but is highly dependent on a number of factors such as type of building, location and purpose of it. Other actors see that it would be possible to do this in some years when the knowledge has developed and spread more. Moreover, if announced some years in advance, it could also provide an incentive for faster knowledge development and diffusion. As one actor says – "I find that it is completely necessary to have a long-term perspective on these questions, so there is a clear roadmap of where to go".

# 6 Discussion

Above, answers to the Research Questions were presented. Here, the implication of these answers will be discussed starting with issues lying close to the focus of the thesis, to gradually expand and gain perspective.

In the previous chapter, the certification systems appear central in how Embodied Carbon (EC) is currently addressed, what is driving the development, and what is seen as doable policy instruments forward. There is a considerable challenge in how to ensure data quality and availability for the materials needed. The rough framework exists with ISO standards of how to perform an Environmental Product Declaration (EPD), and standards of how to develop a Product Category Rules (PCR) for the different products; the work to fill out this skeleton is yet to be done. It has to grow in both ends at the same time – the construction clients must start to request that the constructors take it into account. The constructors need to be able to handle the information, and act upon it. The material manufacturers need to have the Life-Cycle Assessment (LCA) data required, and be able to supply it.

It is therefore interesting to see what impact version four of LEED will have, as it rewards projects that use materials that have EPDs. It incentivises material producers to make the effort to perform a LCA on their material, and if they are the first in their product group, also go through the effort of creating PCR. This is beyond the scope of this paper, but it did appear in the interviews where one of the overview actors pointed to the risk of preventing Small-and-Medium Enterprises (SMEs) to compete, thus concentrating material manufacture industry to oligopolies.

Moreover, an important question that arises is the degree of market penetration the certification systems have. They have grown much in the past few years and it is difficult to know where this will take it, but it has mostly been for commercial buildings. Moreover, currently, some 600-odd[13] buildings are certified under the 'New construction' umbrella for the three systems in Sweden. This does not encompass the entire market, highlighting the need for policy support. This point becomes stronger if taking into account the results of a study commissioned by the Director General of Energy of the European Commission. It points to that the demand for certified (commercial) buildings are higher in a Western European context compare to elsewhere in the EU (Rademaekers, 2014). Thus, the large role that the certification scheme plays in Sweden cannot be expected in many other contexts.

The review in the previous chapter pinpoints the need of achieving a policy mix that is able to address EC through many means. The certification systems on their own are not sufficient, but coupled with Green Public Procurement (GPP) favouring these, the ensuing market formation could foster knowledge development as more actors would work with it hands-on. As said, learning-by-doing is identified as the way the actors learn, and as tools develop and become accessible, knowledge is also diffused. Moreover, perhaps the promise, or threat, depending on one's point of view, of introducing stricter regulation in the future, might create an upscale of the innovation system, scaling up the transition towards buildings with low levels of EC.

Becoming more theoretical, it is interesting to briefly discuss how to perceive the development that this thesis describes – is it a new technological trajectory that can be said to

[13] 125 BREEAM certified, some 240 Miljöbyggnad and 125 LEED certified buildings, aggregating the numbers from section 5.1.1.3.2

be developing, or is it the continuation of an existing one? Within the literature on innovation systems, the concept of development along technological trajectories is a central concept. A technological trajectory is defined as a set of technologies that build on and complement each other (Smith et al., 2005) One aspect that several interviewees hinted to was the link they drew between the dramatically increased focused on the content of the building materials as a consequence of some scandals in the 1990s, most notably the debacle around the rail tunnel construction through Hallandsåsen, a ridge in southern Sweden. Part of the debacle was due to the release of toxic material into nature. The actors described how the scandal initiated and spurred the development of the Building Product Assessment (BVB and the Building Product Declarations (BPD) in the industry. The actors described how currently, many material manufactures have these BPDs for their products. Their point was that addressing EC and developing EPDs became a natural next step once the chemical and possibly toxic content was dealt with. In this way of thinking, addressing EC is a continuation of a technological trajectory of developing tools to think more sustainably about the material as well.

Regardless of the theoretical understanding, addressing EC is an essential component for us to be able to stay below 2˚C warming. This point is made in Chapter 1 of the thesis, and it is time to add some perspectives. First, the importance of achieving a transition within the construction industry turns into an imperative when considering the central role of construction for transitions of other sectors. Transport and energy generation are often pinpointed as sectors that need to transition; this would require significant construction of new physical structures (see e.g. Frank W. Geels, 2012). Being able to reduce EC could save significant amounts of carbon emissions that otherwise would be embodied within the infrastructure and buildings. Moreover, the construction sector is also instrumental in ensuring fundamental benefits in our society, as well as it is a key towards addressing other challenges. For example, there is also a growing literature that demonstrates a significant relationship between the built environment and public health (see e.g. Engquist, Larsson, & Pelin, 2012; Rydin et al., 2012)

It is also essential to consider the tremendous growth that the global construction sector is predicted to go through over the next decade. A report published by Global Construction Perspectives, a group of experts sponsored by the industry, forecasts a 70% growth until 2025. It will be centred in the United States, India and China (Global Construction Perspective, 2013). Given this, finding ways to address and reduce EC becomes more pressing. Admittedly, this study is of a Swedish perspective, but pioneering environmental policies have been known to spread to other countries before (Jänicke, 2005). Moreover, the effect of policy instruments introduced in Sweden can affect the developments in other countries as well, even without similar policy instruments being introduce there.

A highly interesting aspect of policy instruments affecting the level of EC is that it does not only target emissions that nations normally can regulate, but goes beyond it. As construction materials are traded across national borders (Fischedick et al., 2014), the introduction of a policy instrument to address the EC could also affect foreign producers. Thus, through the industrial supply chains, one nation's or even one municipality's policies could generate a decrease in the emissions elsewhere. Given the previous stalemate of the international climate negotiations under the UNFCCC, these options are looking promising.

Yet, as a last point in this discussion, a word of caution of rushing too fast will be raised. There are two aspects to this, both raised by actors in the interviews. The first is that a focus on EC cannot become a one-sided focus with the risk of a trade-off with other environmental impacts. Construction materials can be toxic, as well as create problems in terms of land-use changes or water use (Liljenström et al., 2015). It is fortunate that LCA has the capability of also considering other environmental impacts other than carbon. It would be wise to ensure that development regarding how to systematically address those issues are not forgotten. The second point regards costs of housing, and if addressing EC could become cost driving. The concern raised is that by taking EC into account, changing manufacturing methods of materials or changing materials, the costs of constructing a house could increase. In a Swedish perspective, where lack of housing is an existing and growing problem requiring construction of hundreds of thousands of housing the next couple of years according to Boverket (Hellekant, 2015), more expensive housing is an issue.

# 7 Conclusion

With the increasingly disastrous predictions coming from established climate scientists, achieving a reduction in greenhouse gas emissions becomes imperative. This thesis has focused on Embodied Carbon (EC) as an important area to mitigate greenhouse gas emissions. The thesis continued by describing where EC originates from in more detail, and elaborated on Life-Cycle Assessments (LCA) which is central to how it is addressed. The theoretical framework of Technological Innovation Systems (TIS) was introduced to conceptualise how the process of addressing EC can be seen as an innovation that need to take off and develop. The construction industry itself is seen as instrumental in this, and a typology of policy instrument able to offer support in this process was also introduced. Building on this, three Research Questions (RQs) were answered. These are

RQ1 – What actors within the construction industry are engaged with Embodied Carbon today, and how do they address it?

RQ2 – What are considered to be the main drivers and barriers of this work today?

RQ3 - What support do industry actors identify as necessary to make addressing EC business-as-usual within the Swedish construction sector?

This chapter provides the concluding answers to these questions in section 7.1, and calls for further research in section 7.2. This also closes the thesis.

## 7.1 Concluding Remarks

The study has shown that there is a wide array of actors, from industry to academia to branch organisations that address EC. Focusing on the industrial actors, these include construction companies, construction clients as well as consultancies. Some actors often collaborate with academia to investigate and write reports regarding EC. Currently, the way to address EC is through specific projects where conducting an LCA gives an initial account of which materials are responsible for what emissions. The actor describe that employees learn to address EC through working with it, indicating that knowledge develops as more actors address it. However, few actors have started to use the information to try and reduce the EC. Those that do attempt to reduce EC have integrate LCA data with existing planning and modelling tools, allowing engineers to utilise it as a decision-making aid between different design and material choices. A few actors are formulating how they can pose demands on the material manufactures that lowers EC, but at the same time maintains a balance between this and quality and cost.

As said, actors often choose specific projects to begin with. The projects are chosen either due to that the building should be certified through any of the green building certification schemes, or because it is located in an area where the municipality has asked for EC to be addressed. Examples of areas are new city district with high environmental sustainability ambitions, such as Vallastaden in Linköping, or Norra Djurgårdsstaden in Stockholm. Few actors identify these requirements as driving forces though.

The certification systems, however, are seen as drivers for the industry to address EC. As BREEAM, the British based environmental certification system, demands that builders needs to take the materials life-cycle into account in order to become certified at the highest levels, actors need to develop capabilities to address EC if they want to reach those levels. As the new version of LEED addresses EC, and there are discussions to include it in Miljöbyggnad, a certification system used mostly for residential buildings in Sweden, the incentives for actors to develop capabilities increase. The certification systems also play a role in market formation for the technology, as construction clients (and their clients) that request a building certified at the highest levels of certification creates a niche market where EC needs to be taken into account. This too drives the development of the innovation.

Turning to the barriers, the lack of knowledge is seen as a barrier. There is a lack of knowledge of how to address EC practically, but also about how much EC the construction materials actually generate. A few actors have started to formulate concrete ways of how to reduce EC. Examples include working with the design of the structure of the building to find less material intensive designs. One actor has entered into dialogue with one material manufacturer to find ways to reduce the EC from the manufacturing process. These examples have yet to diffuse into the industry. Regarding the levels of EC generated by the materials, the lack of knowledge revolves around EPDs and the standards for how to calculate these. As few material manufactures make Environmental Product Declarations (EPD) for their products, construction companies lack the data to actually know what levels of EC have been generated. The lack of EPDs for the material is both due to the lacking demand for them, as well as a limited acceptance or awareness of the existing European and international standards of how to account for it. This thesis is not conclusive on whether there is lacking acceptance of the standards, or just a lacking awareness of them; either or, the knowledge of the EC of the materials does not exist to the extent needed.

Policy support is needed for addressing EC should become business-as-usual (BAU) in the entire sector; this is the fundamental aspect that all actors agree on. Some emphasis that more development will come even without support, but for addressing EC to become completely BAU, support is necessary.

Turning to specific instruments, regulative, economic, and informative as well as Green Public Procurement (GPP) instruments were explored more in-depth in the thesis. Introducing regulative instruments from the national level is currently not seen as a desirable way forward by any actor. The imagined regulative instrument is to impose a limit of how much EC can be emitted per $m^2$ of floor space. The argument presented by the actors is that such a limit will likely result in sub-optimisation as the way to calculate and deal with EC is underdeveloped. Some deem this type of regulation as a potential future policy celling to be introduced, establishing a maximum level of EC per $m^2$, once the way to calculate it has become more standardised and established; others do not agree. There are those who present the possibility that regulation could come from the local level rather than the national. Municipalities could introduce regulation, either strict or enter into voluntary agreements where industry actors would commit to address EC. The first approach builds on the requirements introduced in e.g. Norra Djurgårdsstaden or Vallastaden, where municipalities when creating a new city district with high sustainability aspirations, introduce a requirement that EC needs to be taken into account in the construction. Future requirements need to be more concrete than the current, though. There are potential legal issues with this, as recent legal changes circumvent municipalities' ability to introduce requirements beyond the national ones. Thus, voluntary agreements between the municipality and the construction clients are seen as a potential way forward.

Economic instruments are not seen as particularly beneficial, other than research grant for developing more knowledge. Also, it should be remembered that as knowledge develops through 'learning-by-doing', it might be sufficient to boost the drivers so that more actors get to engage more with it, thus fostering knowledge development.

Informative instruments are seen as having much potential. The certification systems are as said drivers, and the continued development of these are seen as a plausible way forward. Actors see that they have to develop their capabilities to address EC further if the requirements regarding EC become stricter in the certification systems. Moreover, if there is a larger demand for certified buildings, the niche market where capabilities to address EC are valuable grows. Though, as the certification systems are industry-owned, public authorities cannot decide over the development of these. However, this is where GPP is seen as an important instrument. When public actors act as construction clients and build e.g. schools or hospitals, they can introduce demands regarding EC. It can be done by referring to a certification system or by introducing the demands by themselves.

The point consequently discussed is that priority should be in achieving an adequate policy mix to nurture the innovative spirit of the industry and turn addressing EC into BAU. The strongest driver, the certification system, only encompasses a small part of all new buildings – for it to become more commonplace to address EC than just in the most prestigious building projects, policy needs to focus on diffusing the practices as well as developing it. Only then can we break the trend of growing greenhouse gas emissions, and avoid changing our climate into unrecognizability.

These are the conclusion drawn from the research conducted in this thesis. They are generalizable to a certain extent. One must keep in mind that the actors who agreed to be interviewed all had started to at least consider EC. Given that the actors described addressing EC as a quite high-hanging fruit, the actors interviewed are at the top-of-the-class, so to speak. Thus, their experience of what are drivers, barriers and necessary policy instruments might not be representative for e.g. construction companies who have never worked with EC. Furthermore, there were several groups who were not interviewed due to the scope of the thesis. Clear examples are architects and material manufacturers. The conclusions are thus not applicable to them, and have to be read with this in mind. Also, as described in the theory section, TIS has been instrumental in shaping the author's understanding of what activities are important to focus on. Hence the above results cannot be said to accurately depict how the Swedish construction industry perceives and values the questions discussed. However, it provides valuable insight into how actors who have come quite far in addressing EC works with and thinks regarding these questions; something that can be the base for discussion and further research.

## 7.2 Further research

The above thesis is based on interviews with a sub-set of industrial actors in a Swedish context – the results are indicative for this context, as has been explained above. There are many research initiatives that could be taken to counter these limitations, and develop knowledge valid for other areas as well. Here, are few suggestions are developed.

The articulation of demand and market formation are highlighted as two important functions to develop. In this thesis, it was only the demand that construction clients can articulate towards construction companies that was investigated. Construction clients were dealt with as a group, with differences only hinted at. There are two aspects that can be further developed - expand the group to accentuate and explore potential differences between public and private actors, commercial and residential, and look at demand from other actors as well. Where is the critical mass level for demand for building materials with EPDs? Is there a potentiality that the customers of the construction clients will concern themselves specifically with EC? These are examples of questions that would require more research.

It is also essential to continue the expansion of LCA to include more environmental categories than just climate change. As explained above, LCA have several existing categories for other environmental impacts that could be used if the data becomes accessible. While the emission of greenhouse emissions is important, mitigation of them cannot be at any environmental expense. Also, the connection between addressing EC and cost-effectiveness needs to be investigated further. As addressing EC has much to do with resource efficiency as well, it is likely that it can be a good tool to handle costs for materials as well.

Lastly, employing a different theoretical perspective to conceptualise 'Reality' might offer different insights than what has been achieved in this thesis. TIS has been influential in shaping the author's understanding of the question at hand, and a different theoretical framework might shed light on other processes and activities.

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# 8 Appendices

## 8.1 Appendix 1 – Overview of interviewed actors

| Actor type | Actor | Individual | Position | Date of interview |
|---|---|---|---|---|
| Construction company | PEAB | Maria Franzén | Utvecklingsingenjör Affärsområde Bygg | 17-06-2015 |
| Construction company | Skanska | Jeanette Sveder Lundin | Green Development Manager | 23-06-2015 |
| Construction client | Diligentia | Markus Blomqvist | Hållbarhetssamordnare | 29-06-2015 |
| Construction client | MKB | Jenny Holmqvist | Miljöstrateg | 20-07-2015 |
| Construction client | Riksbyggen | Charlotta Szczepanowski | Hållbarhetschef | 22-06-2015 |
| Construction client | Vasakronan | Anna Denell | Hållbarhetschef | 03-07-2015 |
| Overview actor | Byggherrarna | Per Lilliehorn | Consultant for Byggherrarna | 12-06-2015 |
| Overview actor | Sveriges Byggindustrier | Maria Brogren | Energi & Miljöchef | 02-07-2015 |
| Overview actor | Tyréns | Anders Enebjörk | Sustainability Counsultant | 12-06-2015 |

## 8.2 Appendix 2 – Interview guide for construction company

| Interview guide: Construction company | |
|---|---|
| **Main question** | **Follow up questions** |
| 1. When addressing sustainability challenges as a construction company - what importance does embodied carbon have? | |
| 2. What are your capabilities to work with EC? | 2.1 What tools are used? According to which, if any, standards? |
| | 2.2 Is it addressed in all projects, or rather in specific projects? |
| | 2.3 Who/which department is it that does the work? |
| 3. How has these capabilites developed? | 3.1 Are there seminars/courses that employees can attend? |
| 4. What are the reasons behind | 4.1 Is it driven by internal ambitions and |

| | |
|---|---|
| addressing/not addressing EC? | goals? |
| | 4.2 Is it driven by demands from clients? |
| | 4.3 From public authorities? To stay ahead of regulations? |
| 5. What is needed for this to become business as usual? | 5.1 Are policies needed, or will it come by itself? |
| | 5.2 In your opinion, would voluntary or mandatory approaches be preferable? |
| | 5.3 What type of policy instruments are most preferable - informative (e.g. gudiance), economic (e.g. tax breaks) or regulative? |
| 6. Lastly, what have been the consequences for the process when considering EC? | 6.1 Has there been any changes as to how the building process is run? |

## 8.3 Appendix 3 - Interview guide for construction client

| **Interview guide: Construction client (byggherre)** | |
|---|---|
| **Main question** | **Follow up questions** |
| 1. When addressing sustainability challenges as a construction client - what importance does embodied carbon have? | |
| 2. What are your capabilities to work with EC? | 2.1 What tools are used? According to which, if any, standards? |
| | 2.2 Is it addressed in all projects, or rather in specific projects? |
| | 2.3 Who/which department is it that does the work? |
| 3. How has these capabilites developed? | 3.1 Have there been any cooperations with other actors? (companies, universities, research institutes, etc) |
| | 3.2 Are there seminars/courses that employees can attend? |
| 4. What are the reasons behind addressing/not addressing EC? | 4.1 Is it driven by internal ambitions and goals? |
| | 4.2 Is it driven by demands from clients? |
| | 4.3 From public authorities? To stay ahead of regulations? |
| 5. What is needed for this to become business as usual? | 5.1 Are policies needed, or will it come by itself? |
| | 5.2 In your opinion, would voluntary or mandatory approaches be preferable? |
| | 5.3 What type of policy instruments are most preferable - informative (e.g. gudiance), economic (e.g. tax breaks) or regulative? |

| | |
|---|---|
| 6. What have been the consequences for the process when considering EC? | 6.1 Has there been any changes as to how the building process is run? |
| 7. Lastly - anyone else I should talk to within the sector? | |

## 8.4 Appendix 4 - Interview guide for branch organisation for construction companies

| Interview guide: Branch Organisation (Sveriges byggindustrier) | |
|---|---|
| **Main question** | **Follow up questions** |
| What challenges does embodied carbon pose to the construction sector today? What importance does it have? | |
| What are the capabilities of the industry to work with EC? | Are the capabilities to address EC housed in-house, or rather within networks of actors? |
| | Is it addressed across the board, or rather in specific projects/areas? |
| What are the reasons behind addressing/not addressing EC? | Is it driven by internal ambitions and goals? |
| | Is it driven by demands from clients? |
| | From public authorities? To stay ahead of regulations? |
| What is needed for this to become business as usual? | Are policies needed, or will it come by itself? |
| | In your opinion, would voluntary or mandatory approaches be preferable? |
| | What type of policy instruments are most preferable - informative (e.g. gudiance), economic (e.g. tax breaks) or regulative? |
| What have been the consequences for the process when considering EC? | Has there been any changes as to how the building process is run? |
| Lastly - who else should I talk to? | |

## 8.5 Appendix 5 – Interview guide for branch organisation for construction clients

| Interview guide: Construction client branch organisation | |
|---|---|
| **Main question** | **Follow up questions** |
| 1. When addressing sustainability challenges as a construction client - what importance does embodied carbon have? | |

| | |
|---|---|
| 2. What are your capabilities to work with EC? | 2.1 What tools are used? According to which, if any, standards? |
| | 2.2 Is it addressed in all projects, or rather in specific projects? |
| | 2.3 Who/which department is it that does the work? |
| 3. How has these capabilites developed? | 3.1 Have there been any cooperations with other actors? (companies, universities, research institutes, etc) |
| | 3.2 Are there seminars/courses that employees can attend? |
| 4. What are the reasons behind addressing/not addressing EC? | 4.1 Is it driven by internal ambitions and goals? |
| | 4.2 Is it driven by demands from clients? |
| | 4.3 From public authorities? To stay ahead of regulations? |
| 5. What is needed for this to become business as usual? | 5.1 Are policies needed, or will it come by itself? |
| | 5.2 In your opinion, would voluntary or mandatory approaches be preferable? |
| | 5.3 What type of policy instruments are most preferable - informative (e.g. gudiance), economic (e.g. tax breaks) or regulative? |
| 6. What have been the consequences for the process when considering EC? | 6.1 Has there been any changes as to how the building process is run? |
| 7. Lastly - anyone else I should talk to within the sector? | |

## 8.6 Appendix 6 - Interview guide for consultant

| **Interview guide: Consultant** | |
|---|---|
| **Main question** | **Follow up questions** |
| 1. What are the sustainability challenges for the construction industry? | 1.1 What is your view on embodied carbon (EC) role within this? How significant is it? Are there any aspects that we are missing? |
| 2. How do you work with EC? | 2.1 What are your capabilities to deal with EC? |
| 3. How has these capabilities developed? | 3.1 Was it at the initative of a certain group internally? Any specific external group that is more interested? What is it used for? |
| 4. Turning to the rest of the industry - are all clients equally interested in addressing EC? | 4.1 Who is/is not? |

| | |
|---|---|
| 5. When working with clients - who do you work with? | 5.1 Any particular department? Any particular type of project? |
| 6. From your experience, what are the reasons behind addressing/not addressing EC? | 6.1 Is it driven by internal (to your company) ambitions and goals (whos?) |
| | 6.2 Is it driven by external requests from clients? Why are their reasons? |
| 7. What is needed for this (addressing EC) to become business as usual? | 7.1 Why is it not always addressed today? |
| | 7.2 Do you think it will be addressed at a later stage? Why/why not? |
| | 7.3 Could voluntary industry initatives develop? Could exisiting initiatives strengthen their commitment? |
| | 7.4 Could public (mandatory) policies be a possibility? What type of policies? Informative, regulative, economic? |
| 8. Lastly, what have been the consequences for the process when considering EC? | 8.1 Has there been any changes as to how the building process is run? |