Closing the carbon cycle:

Active Carbonation technology for concrete production as possible sequestration method

A TIS analysis on the Dutch concrete system

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Defence on

12TH OF APRIL 2023

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Master thesis submitted to Delft University of Technology
in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in **Engineering & Policy Analysis**

Faculty of Technology, Policy and Management

by

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To be defended in public on April 12th 2023

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Acknowledgement

This report is the conclusion of my Master's thesis and the end of my student time in Delft. In this section, I would like to look back on the past few months of my research and thank everybody that has supported me in accomplishing this.

Before I started writing my thesis, I did not think I would learn so much and enjoy the process as much as I did. The process of writing the thesis did not quite go as usual, but thanks to the personal, motivational, and positive guidance of my committee, I look back proudly on the research process and the final result.

First of all, I would like to thank my first supervisor Gijsbert Korevaar. From the moment I presented the research direction I wanted to go, I felt supported in my choices and was given the freedom, positivity and guidance I needed. In addition, I would like to thank my second supervisor, Nihit Goyal, for his keen eye on my research. During the brainstorming sessions we had together, he often managed to help me figure out which way to go by myself by asking me the right questions. I would also like to thank Emile Chappin for his clear and structured way of chairing; this set a high bar for me to work harder every day to make it a success. Finally, my advisor Abraham Gebremariam, cannot be left out. Without his help, I could never have entered the concrete industry so easily without having any background knowledge about the civil world. He always made time for our sessions and ensured I had the resources available to learn about concrete.

I also want to thank my friends and roommates for their support; I wish everyone writing a thesis had such people around them. Whenever I was tired, grumpy, enthusiastic or in whatever state I put the thesis aside, my roommates were always there. They listened to my (sometimes endless) stories, had a plate of food ready or drank a beer with me: coming home was always the best. Furthermore, I want to thank all my other friends who listened to my thesis struggles, asked critical questions, gave useful opinions and held long coffee breaks when needed. Without all of you, this would not have been possible.

Then, in conclusion, the most important: my parents. Without your constant motivation and efforts to motivate me from grade 8 onwards to put in the maximum effort for study, I would never have completed a master's degree at TU Delft. Although I wouldn't say I liked it then, this is all thanks to your endless patience with me in always emphasising how important it is to do your homework. In addition, I would like to thank you for all the confidence in my choices during my student time; the space I was given to do what I wanted has ensured that I am now closing this chapter happily with this thesis.

Executive summary

Currently, the world population is facing perhaps one of its biggest challenges ever, namely the drastic reduction of CO_2 emissions to combat the Green House Gas (GHG) problem and prevent the associated increase in temperature on Earth. Two large factors currently contributing to the GHG problem are related to governments' inability to control CO_2 emissions at the source. The first combines the tragedy of the commons principle and carbon leakage, while the second is process emissions. Because of the complexity of the problem, it is marked as a wicked problem which requires many different solutions that contribute to solving the problem.

A new perspective

This research proposes a new perspective as an additional solution to mitigate the GHG problem and is focused on closing the CO_2 waste loop and promoting a circular carbon economy. The perspective involves using Carbon Dioxide Removal (CDR) to extract CO_2 from the atmosphere and repurpose it as a raw material in Carbon Capture and Utilization (CCU) products. The alternative perspective can offer a new way of looking at CO_2, shift the paradigm from treating CO_2 as waste to valuable raw material and create a niche market for capturing CO_2 from emission streams and the atmosphere. The primary obstacle for CCU is the limited number of ways society can efficiently and cost-effectively use carbon (C) atoms. While there are currently about five different alternatives to do so, creating building materials with CO_2 as raw material shows the largest potential and is further researched. The technology to use CO_2 during the production of building materials is called Active Carbonation (AC) technology.

The research scope

The addressed research gap is the lack of a systemic overview of the technology within society. The research objective is to analyse the implementation of AC technology in the Dutch concrete system, identifying current problems for the transition towards AC concrete and presenting opportunities for government intervention to stimulate this. The study aims to provide a systemic overview of the industry and research combined, facilitating better comprehension of the technology's possibilities and a smoother implementation process by the industry. To do so, the research uses the Technological Innovation System (TIS) framework to analyse AC technology in the Dutch concrete system.

A TIS encompasses actors, institutions, networks, and technology that together work to realise innovation as a collective activity. The first step of a TIS analysis is understanding how the system is structured concerning the actors, institutions, networks, and technology. The second step is understanding the system's current functioning based on seven prescribed functionalities. The third step is finding systemic problems in the system structure causing barriers for the technology to grow further, which is done based on the first two steps. When the barriers have been located, the policy goal and scope of the TIS are briefly discussed to finish the analysis so that recommendations can be made for policy interventions. The data needed to take all the mentioned steps comes from desk research and expert interviews.

Results

The first discovered barrier for the technology to grow is knowledge exchange, as the industry is not actively taking up the developed knowledge from the research sector. The high demand for concrete hinders innovation and creates a lack of incentive for the industry to innovate. Systemic problems also relate to the actors and network, including fragmentation and a slow knowledge exchange process. The institutions and technology also contain systemic problems, such as slow institutional procedures and uncertainties surrounding the different AC technologies. Finally, a nationwide labour market shortage exacerbates the barrier, making it challenging for the industry to find additional staff to create time for innovation.

The second barrier to technological growth is the guidance towards using AC technology. This barrier is caused by significant fragmentation within the industry, making it difficult to steer the TIS towards sustainability. This fragmentation originates from within the actors, where various products are demanded by concrete users, resulting in numerous niche products that increase fragmentation and competition. Fragmentation within the research and government sectors also contributes to this barrier, making it difficult to implement comprehensive sustainability plans. Fragmentation concerning technology leads to numerous uncertainties and slows down progress. Finally, the power position of European cement producers and many competing TISs are part of the external factors and create further fragmentation. Addressing this barrier is important to compensate for the lack of internal motivation from the last barrier to pursue sustainability and innovation.

The third barrier to AC technology is the formation of markets, which is hindered by uncertainties arising from different aspects. The first problem originates from the actors, where uncertainty slows the adoption of AC technologies. The institutional element further contributes to this by creating broad but unclear sustainable

plans, slow safety procedures, and an unclear future of programs and institutions from governments. These institutional problems lead to another systemic problem for technology, where it is unclear which technologies will be profitable, applicable, and valuable. The lack of internal incentives and external guidance to use AC technologies for the entire TIS also creates problems for the whole network. Overall, these systemic problems hinder the formation of markets for AC technologies. However, the business case for all AC technologies could improve if the ETS is used more integrally, resulting in a shift in costs and benefits of emitting and requesting CO_2.

The three mentioned barriers, namely market formation, search guidance, and knowledge exchange, are interrelated. The lack of internal incentives for concrete producers to innovate and incorporate available knowledge into their production processes and the high demand for traditional concrete products hinder market formation for AC technologies. The significant fragmentation of the existing concrete industry and vague sustainability plans make it difficult to provide proper guidance for AC technology, contributing to market formation problems. Finally, the lack of market formation and insufficient guidance towards AC technologies result in a lack of incentive for industrial players to collect and employ knowledge from research sectors.

Recommendations

The research makes several recommendations to the Dutch government regarding promoting and using sustainable concrete. The first recommendation is to focus on directing concrete users towards sustainable alternatives, such as AC concrete, as there is currently little demand for these products. The role of contractors as mediators in this process should also be considered. The second recommendation is to financially incentivize the production of sustainable concrete so that it becomes more profitable for companies. The third recommendation is to improve the safety verification process for new concrete compositions to enable more experimentation with sustainable alternatives in real-world building projects, including long-term monitoring of results. The fourth recommendation is to address the fragmentation within the concrete sector and provide more specific guidance to the various fragments of the industry. The fifth recommendation concerns better communication from the government about plans, as uncertainty within the industry can discourage innovation and investment.

Overall, the recommendations for the Dutch concrete system focus on taking a proactive approach towards sustainability, exploring sustainable concrete technologies that can be used in the current market, understanding each other's needs between the research sector and the industry, and making better use of the industry's fragmentation while handling it more effectively. In addition to that, concrete producers, users, and contractors should work more actively towards minimizing CO_2 emissions from the concrete system to stay ahead of any strict measures, and all parties involved should collaborate on production methods and safety tests to create a new market for sustainable concrete. Additionally, it is essential to identify where specific technologies are most appropriate and can be applied effectively in the different fragments of the concrete industry. By taking these steps, the Dutch concrete system can work towards a more sustainable and efficient future.

In addition to that, a potential development direction is located for AC technology worldwide. This method uses different binders than cement in the production of concrete, which can lead to harmful emissions results and help reduce the amount of CO_2 in the atmosphere. The development of such technologies has been recognized as essential and has gained attention worldwide. Some of the technologies currently on the market include CircaBuild, Carbstone, and CarbriCrete.

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List of Abbreviations

AC Active Carbonation. 14

BECCS Bio-Energy with Carbon Capture and Storage. 9

C Carbon. 9

CC Carbon Capture. 9

CCS Carbon Capture and Storage. 9

CCU Carbon Capture and Utilization. 9

CCUS Carbon Capture and Utilization and Storage. 18

CDR Carbon Dioxide Removal. 9

CE Circular Economy. 8

CO_2 Carbon dioxide. 8

CRAC Carbonated Recycled Aggregate Concrete. 30

CRAs Carbonated Recycled Aggregates. 30

DAC Direct Air Capture. 9

DMP Data Management Plan. 27

EU European Union. 18

GHG Green House Gas. 8

IEA International Energy Agency. 10

NAs Natural Aggregates. 30

PCPs Precast Concrete Products. 28

R&D Research & Development. 33

RAC Recycled Aggregates Concrete. 30

RAs Recycled Aggregates. 13

RMC Ready Mix Concrete. 28

RQ Research Question. 11

SQs Sub Questions. 11

TIS Technological Innovation System. 10

TRL Technology Readiness Level. 34

Contents

1 Introduction

Svante Arrhenius (1859-1927) was the first scientist to propose that an increase in Carbon dioxide (CO_2) levels could result in global warming (Enzler, n.d.). He put forth this argument in a study dating back to 1896 (Arrhenius et al., 2009), but it received little attention and was not scientifically confirmed for almost 80 years (Schneider, 2012). Since then, media coverage of the topic has constantly been increasing, exerting pressure on governments worldwide to address CO_2 emissions (Enzler, n.d.). Despite this, efforts to reduce emissions have not progressed satisfactorily (Peters et al., 2019). While global agreements such as the Kyoto Protocol (UNFCCC, 1998) and the Paris Agreement (UNFCCC, 2016) have increased international awareness and action, many countries have failed to meet their commitments, resulting in alarming global temperature increases (Maizland, 2021). These rising temperatures have resulted in significant damage to both the world population (Rossati, 2017) and the global economy (Revesz et al., 2014). A crucial question arises: why has the world been unable to reduce CO_2 emissions quickly?

1.1 Problem introduction

There are numerous reasons why the world struggles to reduce its CO_2 emissions, and there is much debate about which factors are most significant. The following section highlights several reasons that appear to play a significant role in the current Green House Gas (GHG) problem. These factors all point towards a common issue: governments struggle to control emissions at the source.

Tragedy of the commons & Carbon leakage

A theory known as the "tragedy of the commons" can help explain why reducing CO_2 emissions has been challenging. This theory applies to situations where multiple parties benefit financially from a shared resource, such as the Earth's atmosphere, which is not controlled by a single authority and can therefore be depleted and misused (Gardiner, 2001). The lack of global regulations on CO_2 emissions means that gaining control over all emissions is virtually impossible. Furthermore, the issue of "carbon leakage" exacerbates this problem, as industries that generate high levels of emissions may relocate to countries with less stringent policies or cheaper emissions regulations (European Commission, n.d.-d). The products produced in these countries are then exported back to countries with stricter emissions policies, resulting in even higher levels of CO_2 emissions (Böhringer et al., 2017).

Process emissions

Another reason why society is struggling to address the growing levels of CO_2 is the heavy dependence on industries that generate high levels of emissions, which is primarily due to economic growth and population expansion (Zhao et al., 2021). While certain industries, such as transportation, have viable alternatives to lower their emissions significantly (Zhao et al., 2020), others, like the cement industry, do not have feasible alternatives due to the CO_2 emissions generated during the production process itself, rather than from energy usage (Paltsev et al., 2021). Unlike energy generated from sustainable resources and replacing polluting fuels, these heavy process emissions cannot be substituted (European Commission, 2018). However, society is heavily reliant on products from these specific industries, which together generate approximately 20% of the world's total CO_2 emissions (IEA, 2021b). As a result, these large process emissions, combined with the tragedy of the commons and carbon leakage, make it challenging for governments to effectively address the GHG problem since they lack control over the sources of a significant portion of global emissions.

Complexity of the problem

The problem of GHG emissions is often referred to as a "wicked problem," as it is extremely complex and cannot be solved through a linear approach. This is because there is no clear problem formulation or cause, but rather a complex interplay of various factors leading to the issue (Ritchey, 2013). Because of this, it is unlikely that a single solution will completely solve the problem (Fawzy et al., 2020). As a result, numerous alternative solutions are being developed in various directions each year (Wang et al., 2018). Unfortunately, even with these combined efforts, the problem persists and has yet to be fully resolved (Paltsev et al., 2021).

1.2 Core concept

To address the issues outlined and offer another option to help mitigate the GHG problem, the following section presents a new perspective on closing the CO_2 waste loop and promoting a carbon Circular Economy (CE). This section will provide arguments and explanations from capturing CO_2 up to its eventual use in a finished product.

A different perspective

The proposed perspective starts as follows: using Carbon Dioxide Removal (CDR) to extract CO_2 from the atmosphere and repurpose it as a raw material in Carbon Capture and Utilization (CCU) products. This approach addresses the dependency of GHG-reducing governments on countries with lax climate legislation, as those countries can now capture CO_2 from the atmosphere and sequester it within their borders. This would eliminate the need for control over the behaviour of countries with weak climate regulations due to the tragedy of the commons and carbon leakage. Furthermore, this perspective could help solve the problem of industries that cannot substantially replace their emissions. By capturing large amounts of CO_2 from the atmosphere and repurposing it in products, emissions from such industries can be offset by sequestering the CO_2 in useful products.

This alternative perspective is not a comprehensive solution to the GHG problem. Still, it can offer a new way of looking at CO_2 and play a small part in addressing the issue, as is often the case with wicked problems. CO_2 is commonly viewed as waste and an undesirable byproduct. However, if CO_2 usage can become financially beneficial, it may shift the perception of its value. This could incentivize individuals and organizations to be more conscious of their emissions and capture CO_2 from the atmosphere. If one product can successfully incorporate CO_2 as a low-cost resource, this may pave the way for a range of new products using CO_2 and contribute to reducing GHG emissions. This could shift the paradigm from treating CO_2 as a waste to a valuable raw material and create a niche market for capturing CO_2 from both emissions streams in the atmosphere. The principles of reusing waste have been applied to various industries under the concept of CE, which has gained increased attention in recent years. Furthermore, several scientific papers have advocated for this perspective in the past (Geden et al., 2018; Kriegler et al., 2013; Rosa et al., 2021).

Capturing CO_2

CDR refers to various methods, among which Bio-Energy with Carbon Capture and Storage (BECCS) stands out. BECCS is a process that involves adding a Carbon Capture (CC) installation to combustion engines using bio-fuel (Rosa et al., 2021). The biofuel used in this process comes from biomass obtained from natural sources. Biomass naturally captures and stores CO_2 while growing (Van Oijen et al., 2010). When biofuel is burned, the CO_2 gets captured by the BECCS. At the same time, new organic material regrows, which can again be used to produce more biofuel (Gough and Upham, 2011). This creates a cycle that generates energy and cleans the atmosphere from CO_2 (Kim et al., 2020). Another method for capturing CO_2 is Direct Air Capture (DAC), which is a process where CO_2 gets captured by reacting with chemicals in engineered contactors (McQueen et al., 2021).

Although effective at reducing the overall amount of CO_2, BECCS and DAC are up to ten times more expensive than the cheapest CC methods, which are installations connected to large industrial processes that lower existing emissions (IEA, 2019). While technically feasible, capturing CO_2 from the air is not financially competitive. Therefore, this research focuses on finding ways to use the captured CO_2 rather than on technical developments of CC. For the usage of CO_2, it is assumed that cheap methods for capturing CO_2 will be used, like capturing at the end of industrial processes. As CDR technology becomes more advanced and cost-effective, it can be widely adopted to reduce atmospheric CO_2 levels and provide consistent viable CO_2 streams as raw materials for products.

Using CO_2

While CO_2 can be captured from the atmosphere, the question of what to do with it remains. Two mitigation methods, Carbon Capture and Storage (CCS) and CCU, have been developed to address this issue. CCS captures CO_2 and stores it in a geological location (Terlouw et al., 2021), a method that has been under development for about 45 years but has faced economic and technological difficulties (Ma et al., 2022; Cuéllar-Franca and Azapagic, 2015). These difficulties include concerns about CO_2 leakage from geological storage locations and the lack of profitability in storing CO_2 despite the need for significant upfront investments (Cuéllar-Franca and Azapagic, 2015). In contrast, CCU is a relatively new principle (Gür, 2022), but it has a large potential because it addresses the problems associated with CCS. CCU seeks to find a product or process for the captured CO_2 to be used, preventing it from flowing back into the atmosphere and providing a financial incentive for investment. The primary obstacle for CCU is the limited number of ways in which society can efficiently and cost-effectively use Carbon (C) atoms (Cuéllar-Franca and Azapagic, 2015).

The utilization of CO_2 and C atoms is currently limited to emerging niche markets that require further growth to become more mainstream (Raven et al., 2016). The success of a product in these markets could catalyze the development of additional CO_2 utilization methods and encourage the discovery of more viable business cases for the use of CO_2. Ultimately, this could lead to a chain reaction of innovative CO_2 capture and utilization techniques, potentially decreasing global CO_2 emissions. Therefore, the key question is which CO_2-based product has the potential to make the first step and drive further growth.

CO_2 based products

Extensive research conducted by the International Energy Agency (IEA) has identified five potential products that can be made using CO_2 as a resource: fuels, chemicals, building materials from minerals, building materials from waste, and enhancing yields of biological processes (IEA, 2019). Given the objective of finding a product that can use CO_2 as a permanent sequestration method, building materials from minerals and waste (also known as CO_2-cured concrete) seem to be the most suitable option. This is because it has a large potential for sequestering CO_2 (1 $GtCO_2$/year) and has better performance than regular concrete. This technology is also already being applied on a small scale (Chauvy and De Weireld, 2020). Figure 1 (IEA, 2019) provides a simplified overview of the production process of both products.

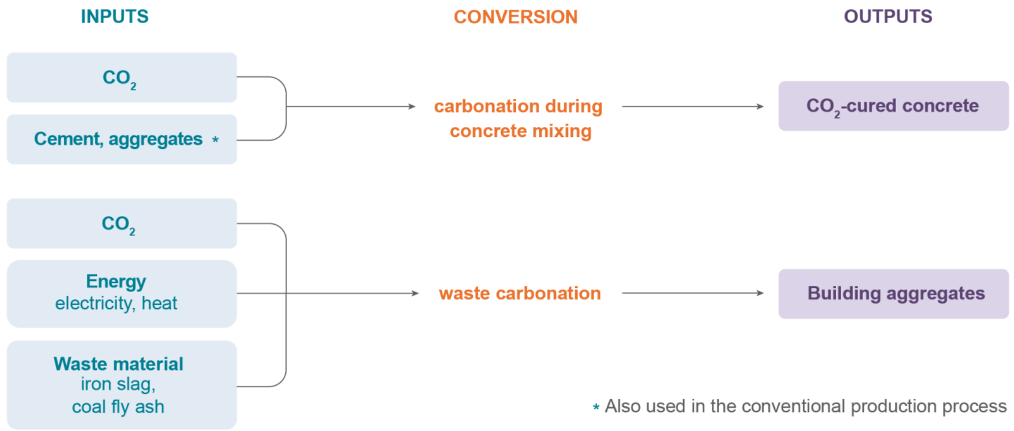

Figure 1: The two different production processes of CO_2-cured concrete (IEA, 2019).

1.3 Research scope

To follow through on the proposed different perspective, the research is scoped in the coming section. This is done by discussing the research gap and objective, both coming from the literature review of chapter 2.

Research gap

Chapter 2 reviews the technology of CO_2-cured concrete, which from now on will be called Active Carbonation (AC) technology. This has resulted in a research gap regarding the lack of a systemic overview of the technology within society. Although several articles have discussed aspects related to sustainability (Huang et al., 2019; Kashef-Haghighi et al., 2015), technical issues (Chen et al., 2022; Monkman, n.d.), and country-specific system aspects (van Deventer et al., 2020; Zhang et al., 2019), no literature has focused on the system the technology operates within. Therefore, there is limited knowledge about the various actors involved, boundaries for implementation, institutional matters, country-specific evaluations, and other system aspects. A more detailed explanation of this research gap can be found in Chapter 2.

The lack of information on AC technology from a systems perspective makes it challenging to direct the transition from conventional concrete to AC concrete in the right direction, as desired to contribute to the GHG problem. To address this issue, this research aims to analyze AC technology within the Dutch concrete system and identify any barriers hindering its development. Rather than solely focusing on the technology, this research takes a helicopter view of the system, recognizing the importance of understanding the actors, business models, financial possibilities, and other system aspects involved. To achieve this, the Technological Innovation System (TIS) framework will be applied to AC technology in the Dutch concrete system. By doing so, a comprehensive overview of the system can be created, and an understanding of why the technology is at its current implementation stage in The Netherlands can be gained. The TIS methodology is well-suited for this analysis since it focuses on understanding everything that happens within the system that influences the development of the technology. This is further explained in chapter 2. The Dutch concrete system was chosen as a case due to its technological development stage, openness to innovation, and its membership in the EU. A more detailed explanation for selecting The Netherlands as a case is presented in chapter 3.

Research objective
Following all that has been proposed so far, this thesis focuses on the implementation of AC technology in the Dutch concrete system. The potential benefits of using CO_2 in the concrete industry make this technology attractive for sustainable development. The primary objective is to analyze the current status of the technology system and identify possible opportunities for government intervention to facilitate the transition towards AC concrete. Sustainable developments often require support in their initial stages to become an independent market, as highlighted by Geels (2016). By studying how a CE principle could be applied to CO_2 as a resource, this research could serve as a model for other products identified by the IEA (IEA, 2019). The secondary objective is to provide a systemic overview of the industry and research combined. This perspective could facilitate a better comprehension of the technology's possibilities and a smoother implementation process by the industry. It could also lead to a shift in focus for research from scientific and technological development towards researching the best production methods for practical use. Combined, this tries to show engineers the technology from a societal systems perspective and vice versa to show system analysts the requirements and barriers coming from the technology from an engineering perspective.

1.4 Research questions

With a research gap and objective in place, a main Research Question (RQ) and corresponding Sub Questions (SQs) can be formulated in the coming section.

Main RQ
While it appears that AC concrete has the potential to be a competitive alternative to traditional concrete, it is crucial to gain a more comprehensive understanding of its current performance. The transition from conventional technology to this innovative approach is a complex process that requires careful consideration. To facilitate this transition, it is vital to thoroughly comprehend the system and identify any barriers that may impede its progress. To achieve this objective, the following main RQ is proposed:

"What is the status of AC technology within the Dutch concrete system, according to the TIS framework?"

Research SQs
To address the main RQ, it is necessary first to address three distinct smaller knowledge gaps. Each gap is encapsulated in an SQ, which logically follows the other. The sequence of the questions is aligned with the order of a TIS analysis, as delineated in the literature review section 2.2.2 and methodology section 3.3.

1. *What is the structure and development stage of the Dutch AC concrete system, according to the TIS framework?*

The initial step in a TIS analysis, as delineated in section 2.2.2, involves comprehending the system's structure, which includes actors, institutions, networks, and technology. Thus, SQ1 concentrates on collecting this data and acquiring these insights. Additionally, as demonstrated in figure 4, it is crucial to determine the development stage of the system before examining its functionality. Consequently, these two stages are combined within SQ1, linking it to the structural analysis aspect of the TIS analysis. A detailed explanation of this process can be found in section 3.3.1 of the methodology chapter.

2. *How is the Dutch AC concrete system functioning, based on the seven different functions from the TIS framework?*

Following the literature review on TIS analyses, SQ2 evaluates the system's functionality. This entails gathering insights into the system's functionalities based on the seven functions presented. SQ2 is connected to the functional analysis component of a TIS analysis, which is elaborately explained in section 3.3.2 of the methodology chapter.

3. *What system failures are present within the Dutch AC concrete system, and what does the political landscape look like?*

SQ3 focuses on identifying problematic functionalities and determining the system structures that give rise to these issues. As outlined in the literature review, it is feasible to uncover these systemic problems by analyzing the outcomes of SQ1 and SQ2 combined. This links SQ3 to the third component of a TIS analysis, namely systemic problems, which is explained in detail in section 3.3.3 of the methodology chapter. Subsequently, the political landscape relating to the problematic system functionalities must also be characterized within this SQ. Once SQ3 is wholly answered, all the necessary information will be available to address the main RQ and provide a comprehensive understanding of the system.

1.5 EPA relevance

The last step before ending this introduction is describing the relevance of this thesis to the master's programme. This thesis focuses on implementing technology to decrease the amount of CO_2 in the atmosphere to mitigate the GHG problem. This problem can be marked as a grand challenge due to its scale, complexity and impact. Next, AC technology brings possibilities for mitigating this problem, but it is not exactly sure how it can be used within the current concrete system. To start using it a transition must happen from conventional concrete to AC concrete to start using it. This means that the actors within the concrete system need to change part of their production processes and make different choices regarding their activities but also look differently at how they use different types of concrete. All this together makes the transition for the concrete industry to a socio-technical system. The method used to research this change, a TIS analysis, is focused on creating an overview of a technological system to find current barriers to this transition. After these barriers are located, and the political landscape is described, policy advice could be given based on these findings.

2 Literature review

This literature review has two parts. First, the research process is described. After that, literature about CO_2-cured concrete and TISs are examined. The main goal is to discover a knowledge gap on CO_2-cured concrete and deliver a suitable RQ.

2.1 Literature search process

The literature search process for this review is divided into two parts: CO_2-cured concrete and TIS frameworks. Both topics are searched on two different search engines: Google Scholar and Elsevier Scopus. CO_2-cured concrete had three search rounds, whereas TIS frameworks had two due to a higher level of starting knowledge.

The first search round for CO_2-cured concrete was broad and based on the keywords: "carbon dioxide concrete", "carboncure", "carbon capture concrete", and "sustainable concrete". The second round went more in-depth on the subject. It was performed after writing the first part of the literature review, which resulted in a better level of starting knowledge before articles were selected. The specific keywords used were: "carbon-cured concrete", "CO2-cured concrete", "recycled aggregates", "carbon-cured concrete production process", and "carbon-cured concrete sustainability". The last search round focused on finding extra literature or papers on specific subjects within CO_2-cured concrete. This resulted in the following keywords: "concrete carbonation", "carbon cement", "active carbonation", "carbonation process concrete", "conventional concrete production", and "concrete emissions".

The first round for TIS frameworks was focused on theoretical explanations of frameworks, with the following keywords: "technological innovation system", "TIS", "TIS framework", "TIS analysis", and "TIS theory". After the found articles were read and reviewed, a more directed search was performed to find TIS analyses on specific technologies. Search keywords were: "TIS solar panels", "TIS hydrogen", "TIS electricity", "TIS application", "TIS country", and "TIS nuclear".

2.2 Theory

2.2.1 CO_2-cured concrete

If all conventional concrete used for new buildings were replaced, the total demand for CO_2 would be around 1 Gt globally today and even 1.2 Gt in 2030 (IEA, 2021a). This comes down to around 3% of the world's emissions in 2021 (Statista, 2021). Therefore, it is no surprise that the IEA presents CO_2-cured concrete as the most mature and promising application of CCU in figure 2 (IEA, 2019). CO_2 can be used as a raw material in three different ways for concrete production: while mixing cement with aggregates (the production of concrete), while treating Recycled Aggregates (RAs) (Chauvy and De Weireld, 2020; Chen et al., 2022) and while treating Precast Concrete Products (PCP)(Huang et al., 2019; Kashef-Haghighi et al., 2015).

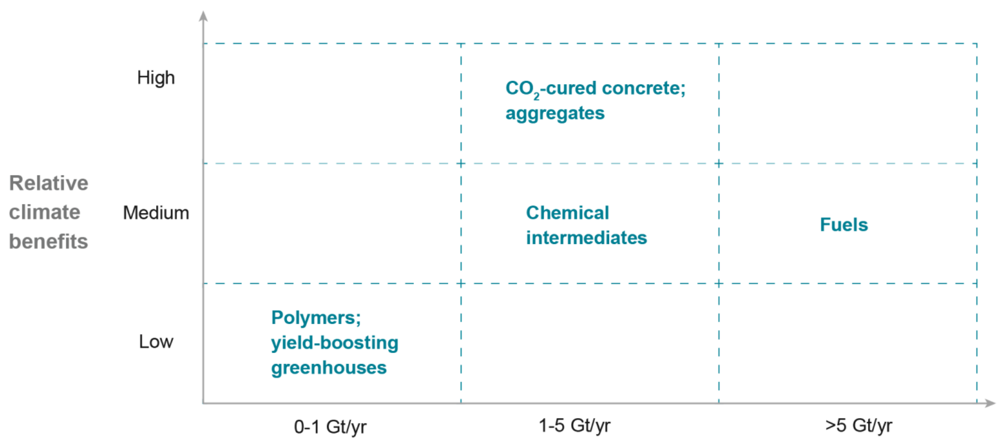

Figure 2: The potential environmental benefits of CO_2-cured concrete (IEA, 2019).

The first method, adding CO_2 while producing concrete, is already used in America on a small scale. One of the companies, CarbonCure, even claims that 80% of the CO_2 emissions during the production of concrete can be reduced, but this is not verified by other parties (IEA, 2019). The usage of CO_2 for the treatment of RAs is, on the other hand, still in the development phase, which also counts for the third method of using CO_2 during PCP production (Mistri et al., 2020). In the next part, concrete production on its own and these three different production methods are further discussed.

Three different CO_2-curing technologies

Concrete is made of a mixture of cement, aggregates and water. When these three are mixed, molecules from the cement start reacting with CO_2, which will harden and, over some time, become solid concrete (Petek Gursel et al., 2014). This process of reacting with CO_2 is called passive-carbonation and keeps happening to the concrete over its entire lifetime (Šavija and Luković, 2016). This will absorb small amounts of CO_2 from the atmosphere, which will form carbonates and increase the strength of the concrete (Andersson et al., 2013). Because only the surface of the concrete can react with and thus capture CO_2, this amount is small (Lagerblad, 2005). When CO_2 gas is added during the production process, the CO_2 can be absorbed by the entire mixture (instead of only the outer layer), which will increase CO_2 uptake as well as the strength of the concrete (Bandhavya et al., 2021). This process of adding CO_2 gas to the production process and artificially increasing the carbonation process is called active-carbonation (Tam et al., 2020).

One of the other methods, treating RAs, captures CO_2 based on the same principle. If earlier mentioned aggregates are made from old concrete, these are named RAs. This is produced by grinding old concrete into small particles, which can be used as aggregates for new concrete (Tam et al., 2020). When the old concrete is crushed, this highly increases the surface of the concrete (Lu et al., 2018). If this surface is then exposed to an atmosphere with a high percentage of CO_2 in a special curing chamber, the natural process as would happen in concrete in buildings will happen, which will strengthen the aggregates and capture CO_2 (Andersson et al., 2013).

The third method is similar to the second one. If precast concrete products come out of the mould, they are still wet. When an increased CO_2 level is present in the atmosphere of a closed environment, these wet PCPs can capture the CO_2 and become stronger (Kashef-Haghighi et al., 2015). What could be interesting is to see whether these three methods can also be combined for an even more significant uptake of CO_2 and thus strengthen the concrete even more. It is clear that the uptake of CO_2 is beneficial regarding CO_2 emissions, but strengthening the concrete also brings a benefit. Because the concrete gets stronger, less cement can be used (Santhosh Kumar et al., 2019). It is primarily the cement that creates most of the emissions during concrete production, so this again saves CO_2 from the atmosphere (Adesina, 2020).

These different production processes are all based on the same principle of artificially increasing the reaction between concrete and CO_2, which is called active-carbonation. Because conventional concrete also carbonates, but naturally (passive-carbonation), it seems useful to create terminology for this type of production method: Active Carbonation (AC) technology.

Current research status

All the AC technology production processes have different up- and downsides and are used in various locations for different purposes (Adesina, 2020; Bandhavya et al., 2021; Liang et al., 2020). Therefore, drawing specific conclusions about each production process's sustainability, usability, barriers, and opportunities is difficult. For example, each process uses a different resource composition, leading to concrete with other properties (Zhang et al., 2019). As can be understood, safety regulations for the concrete industry regarding these properties are essential. So, every type of concrete needs to be tested extensively (Yunusa, 2011). Therefore, new types of concrete cannot be directly used but need to be tested (5 to 10 years), which slows down the transition (IEA, 2019). Another example is the amount of CO_2 used per ton of concrete; different production processes use different amounts, which leads to various sustainable but also strength benefits (Adesina, 2020).

Within the literature, only technical and sustainable aspects are examined, which can be seen in table 1. Much research is done after details like specific strengths, specific durability, optimal production processes, different CO_2 uptakes, etc. But, there is no clear overview of these two main production methods where they are compared from a broader perspective, nor is there any analysis from a systems perspective to discover how the technology should be used in society. One article that creates something like an overview does this from a technical perspective and assumes everything else (institutions, economy, actors) in the system is given and unchangeable (van Deventer et al., 2020). Another article compares different curing technologies that remain entirely on a technical property perspective (Tam et al., 2020). Based on the lack of a system overview, it is currently not possible to unambiguously focus on specific aspects to increase the transition speed, which forms a knowledge gap.

Table 1: Literature on AC technology.

Topic	Title	Writers + Year
Production process	Technical note: Chemistry of Fresh Concrete Carbonation	Monkman, n.d.
Production process	Carbon dioxide sequestration on recycled aggregates	Lu et al., 2018
Production process	Studies on some factors affecting CO2 mixing or CO2 curing of cement concrete	Lee et al., 2018
Production process	An overview on the influence of various parameters on the fabrication and engineering properties of CO2-cured cement-based composites	Chen et al., 2022
Production process	Improvement of CO 2-Cured Sludge Ceramsite on the Mechanical Performances and Corrosion Resistance of Cement Concrete	Xu et al., 2022
Product properties	Mechanical properties of concrete when cured with carbon dioxide	Santhosh Kumar et al., 2019
Product properties	Ettringite-Related Dimensional Stability of CO2-Cured Portland Cement Mortars	Zhang et al., 2019
Product properties	Utilization of CO2 curing to enhance the properties of recycled aggregate and prepared concrete: A review	Liang et al., 2020
Product properties	Utilization of CO2-Cured Waste Cement Powder to Enhance the Properties and Microstructure of Cement Mortar and Paste	Jiang et al., 2022
Sustainability	Mathematical modeling of CO2 uptake by concrete during accelerated carbonation curing	Kashef-Haghighi et al., 2015
Sustainability	Life-cycle assessment of emerging CO2 mineral carbonation-cured concrete blocks: Comparative analysis of CO2 reduction potential and optimization of environmental impacts	Huang et al., 2019
Sustainability	Reduction of Greenhouse Gas emission by carbon trapping concrete using Carboncure technology	Bandhavya et al., 2021
Overview	A Roadmap for Production of Cement and Concrete with Low-CO2 Emissions	van Deventer et al., 2020
Overview	Utilising CO2 technologies for recycled aggregate concrete: A critical review	Tam et al., 2020

Arriving at this point, this part of the literature review has led to a specific CO_2 based product as a potential sequestration method to mitigate climate change from CO_2 emissions. The knowledge gap regarding this subject is the missing systemic overview of AC technology. A question that comes to mind for this knowledge gap is what the current AC concrete system looks like and how it functions. Next, it is interesting to know how the transition could move forward and if it can be stimulated. To address these questions, the right analysis framework should be selected and further researched in the next section. A framework that specifically lends itself to these types of analyses is the TIS framework.

2.2.2 Technological Innovation System (TIS)

When analyzing a technology like AC from a TIS perspective, many aspects influence the system. These are not only actors but also institutions and market forces: everything seems to have an effect on everything. TIS literature captures this and creates a narrative where technological innovation is a product of its environment (Wieczorek et al., 2015). This environment exists of actors, institutions, networks and technology, which all together realize innovation as a collective activity (Bergek et al., 2008). The structure of a TIS can thus be described as a set of actors playing by institutional rules in a network, which pushes the development of the technology in a specific direction under a specific speed (Hekkert et al., 2011).

When TIS literature was early, it focused on understanding how these four aspects formed the system's structure and what influenced what. This is now known as the first part of a TIS analysis: *system structure*. These four building blocks can capture every system structure; understanding how systems are structured is the first crucial step within TIS analyses (Hekkert et al., 2011). System structures are often stable over time, but emerging ISs are subject to constant changes. The structure and functioning of the system are built up in a certain way which is heavily dependent on this phase of the development. Different technological development phases ask for different activities and functionalities of a system. Awareness of the TIS development phase is also important when discussing the system structure. The five development stages are the pre-development phase, development phase, take-off phase, acceleration phase and stabilization phase (Hekkert et al., 2011).

Later on, when the method was more mature, it appeared that understanding this structure on its own was insufficient and a better understanding of how the system as a whole was functioning was needed. This second part of a TIS analysis is now known as *system functioning* (Hekkert et al., 2007). The functioning of a system can be measured on seven different criteria: entrepreneurial activities, knowledge development, knowledge exchange, the guidance of the search, formation of markets, mobilization of resources and counteracting resistance to change (Wieczorek and Hekkert, 2012). Contrary to the system structure, every TIS functions differently based on these seven criteria. Because of the system's functioning, complete systems evolve over time, bringing the central technology through different development stages. Every stage has different key functionalities, meaning that some functionalities are crucial in a specific phase and others are not. This insight is seen as a significant breakthrough within TIS literature (Hekkert et al., 2011).

Based on the findings from the first and second steps, research continued its search for technological innovation with a next step; how to act on findings from this functional analysis? The findings from the functional analysis were problems that were hampering the TIS as a whole and were marked as "functional barriers" caused by "systemic problems" which needed "systemic instruments". Within today's literature, this is known as the third step of a TIS analysis: *system failures* (Wieczorek and Hekkert, 2012). This last step tries to find the reasons behind the functional barriers, which is always a misalignment in the structure from step one (systemic problems). All systemic problems causing the functional barrier can be marked as a system failure. Hekkert et al. (2011) have created a manual for analysing TISs based on the three earlier-mentioned parts. The manual has five specific steps, which can be seen in figure 4, with specific questions and focus points for examining the system. If a system is analyzed with these five steps, an overview of the system failures, a description of the political landscape and a scope of the TIS are described. This should enable policy recommendations to be made for a well-functioning the TIS.

The TIS framework is commonly used to create systemic overviews of technology systems. Examples are the use of hydrogen in steel production (Kushnir et al., 2020), the use of electricity smart meters in Europe (Kochański et al., 2020), the development of solar panels in China (Huang et al., 2016) and nuclear energy production (Markard et al., 2020). Therefore, this research will also apply the manual to the AC concrete system. The specific use of the framework will be explained in chapter 3 when the methodology of this thesis is explained.

3 Methodology

This chapter examines the methodology for this research. First of all, the placement of this research within a broader perspective is discussed, and an approach is presented based on the nature of the research. After that, the choice for a single case study approach is discussed, followed by an explanation of the data analysis process. The data analysis is described on the hand of the three different SQs and the main RQ. Lastly, the different data collection methods and a data management strategy are described.

3.1 Placement and approach of this research

The focus of this research is creating an overview of the current Dutch concrete system and the potential role of AC technology. To do so, an examination of the system is given using a TIS framework to locate specific barriers hampering the system's development. Therefore, this research has a case study approach and, thus, a qualitative nature. Next, this research actively tries to connect two different research fields: a systems perspective and an engineering perspective.

On one hand, the perspective of socio-technical system analysis is taken into consideration because of the use of the TIS framework and the focus on examining the Dutch concrete system. This looks at the societal system from a broader perspective with a helicopter view. The aim of this part of the research is to provide insights and context on the desired direction for technologies to be developed from a societal perspective. On the other hand, the intention of the research is to pull the engineer's perspective more towards the system analysis side. In this way, a better understanding of the technological possibilities and barriers to using AC technology can be gained. The benefit here could be to make better choices for policy interventions to stimulate the technology implementation in the system.

Policy analysis style and activities

The main goal of a TIS analysis is to present barriers to developing a specific technology within a system, together with a description of the political landscape. Based on that information, developing a policy to decrease the barriers and foster a transition to the technology under attention becomes possible. Mayer et al. (2004) have created a framework to indicate specific analysis styles, which can be seen in figure 3. This framework provides an overview of the different policy analysis activities and their corresponding styles. It can be a powerful tool when designing policy research because it can help to indicate appropriate methods. An important note by the authors is that these activities will never be individually present. The strength of these activities is when they are combined and coherently used together.

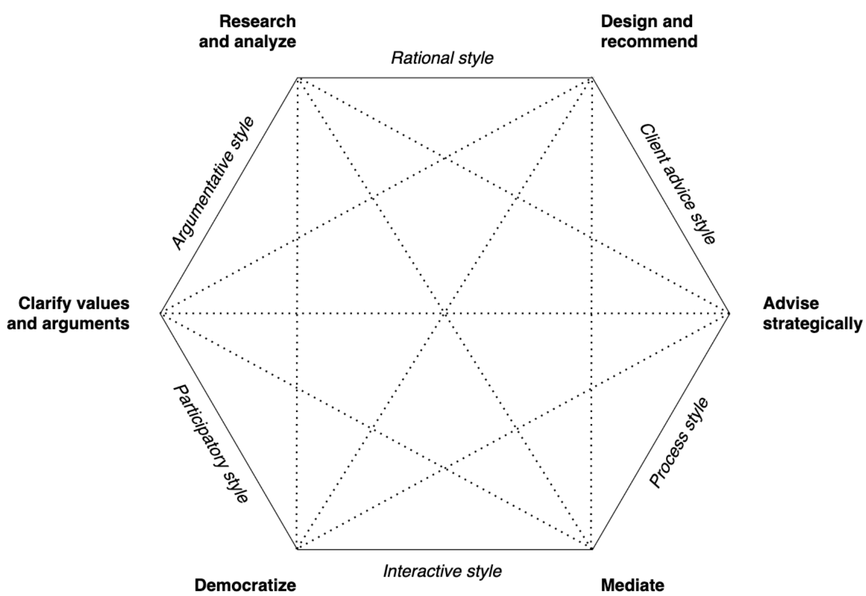

Figure 3: The hexagon of different policy advice styles (Mayer et al., 2004).

When applied to this research, the “Rational style” in the upside of the hexagon fits best. First, an essential part of the research is understanding the current system and exploring how it works. This implies that the "Research and analyse" corner is involved, the main activity of using a TIS framework. Next to that, the second part of the RQ is in the "Design and recommend" corner. The question is how governments should intervene within the system to increase the use of AC technology within the concrete industry by decreasing barriers. Together this results in the "Rational style".

3.2 Case study methodology

As mentioned in the previous part, this thesis is qualitative research. With the research objectives and methodology (TIS framework) in mind, a case study is the best method to do this. On the one hand, the focus lies on locating the current barriers in the Dutch concrete system for a transition to concrete production with CO_2 as a resource. Based on these findings, recommendations can be made for fostering the transition in the Dutch concrete system. On the other hand, with a larger scope, it is interesting to see how the new CE principle of CO_2 usage in an industry is working and what can be learnt from it. Findings on this specific aspect could be translated to other industries that also could use CO_2 as raw material and contribute to reducing the GHG problem. Both of these objectives can be achieved by researching the case of the Dutch concrete industry.

Single case study
Because of these two objectives, a single case study is chosen. One of the main differences between a single and a multi-case study is that multi-case studies are much more time-consuming (Gustafsson and Gustafsson, 2017). Next, a single case study focuses on finding specific aspects, while a multi-case study focuses on comparing these aspects between different cases (Gustafsson and Gustafsson, 2017). First, the RQ asks for a description of the Dutch concrete system because the knowledge gap is due to the absence of a systemic overview. This means focusing on what is happening within one system instead of comparing different systems. Therefore, a single case study fulfils that part best. Next to that, the technology under study is very new, and it is not much known about its industrial application, which makes it time-consuming to research this properly. A single case study can investigate what is happening within the system, and specific technical details can be better examined. Doing a single case study supports this in-depth research because it is less time-consuming than a multi-case study.

In addition to that, for the second objective, it is also new to see how the CE principle for CO_2 used as a raw material within an industry is taking place. Again, this makes it interesting to research the specific characteristics of using such technology within an existing system for the first time and examine specific details from that perspective. Thus, focusing on only one case and going more in-depth is better. In conclusion, these objectives are new and unknown, so it is important to understand how they work in one case. After that has become clear, a multi-case study could be interesting to compare different systems and look for similarities and differences. Only then does comparing cases and looking for specific theory-making become interesting.

The Dutch concrete system
The selected case is the Dutch concrete system, which is interesting for three reasons. First, it is interesting to research a TIS where the technology is between the development and take-off stages. Because the technology is partially in both stages, it is interesting to investigate the functions in play that are influencing the further growth of the technology to a potential take-off. Findings on these functions could be further investigated and compared to different TISs in the same situation to see if these patterns are reoccurring.

The second interesting aspect of The Dutch concrete system is a set of specific characteristics. First, The Netherlands is very supportive of innovations, which can be seen in its position on the European Innovation Scoreboard (European Commission, n.d.-e). It is interesting to see how a TIS in such a country functions. In addition, The Netherlands is a relatively small country in terms of surface, which makes it interesting to see how that affects the functioning of a TIS. Last, The Netherlands is part of the European Union (EU), affecting the system's functioning.

First of all, the EU has a high urgency to fight CO_2 emissions and use newer technologies like AC which is reflected in The Netherlands. This can be seen in large plans like their Strategic Energy Technology plan (SET-plan), which also marks Carbon Capture and Utilization and Storage (CCUS) as crucial mitigation technology (Chauvy and De Weireld, 2020). In addition, this means that large amounts of financial resources are available to fight emissions and use new technologies (European Commission, n.d.-e). It is interesting to see how this influences the Dutch TIS. What is also interesting is that The Netherlands is subject to European law, which is proven to result in the successful implementation of sustainability policies (Marques and Fuinhas, 2012). Because of this, governance interventions are likely to result in positive results. If suitable governance interventions are found, the EU can translate them to other European countries since they are part of the same government and legal system. The fact that The Netherlands is part of this larger system and experiences the influence of the surrounding environment is interesting to see back in the findings of this research.

Scoping of the case
Now that the case of the Dutch concrete system has been chosen, it is important to describe the scope of that case briefly. First of all, the Dutch borders are taken as geographical scope. This also means all interviewees will be Netherlands-based except for two. The first person works for VITO, a research centre in Belgium and occasionally works with the Delft University of Technology. The second interviewee also comes from Belgium and works for a company that exports AC technology from America to the Benelux. These interviews will give some insights into the system adjacent to the Dutch system and give some context on exchanging knowledge and goods. Furthermore, the interviewees are chosen to represent the entire industry, so that gained insights apply to the entire system. A combination of research, industry and government is meant with the entire system. The main reason is that this overall view of the system is missing, and for TISs to work properly, every part of the system must be considered.

3.3 Data analysis

As mentioned earlier, the Dutch concrete system will be analyzed from a TIS perspective. Hekkert et al. (2011) has constructed a complete manual to analyze different TISs, which will be followed for this research on the Dutch concrete system. Using this manual precisely will, on the one hand, give clear directions with prescribed questions that can be followed neatly for the analysis. On the other hand, this will be a good test for the manual to be used on a completely new and random case to see whether the manual applies to all TISs. The manual presents five steps to break down a TIS as seen in figure 4, which leaves a set of systemic problems and a description of the political landscape regarding these systemic problems. The five steps are structured in three parts, which can be matched to the three SQs of this research. The first part focuses on the system structure and can be linked to SQ1, the second part focuses on the system functioning and can be linked to SQ2, while the third part focuses on the systemic problems and can be linked to SQ3. The exact elaboration of the three different parts and corresponding steps of the manual is presented underneath.

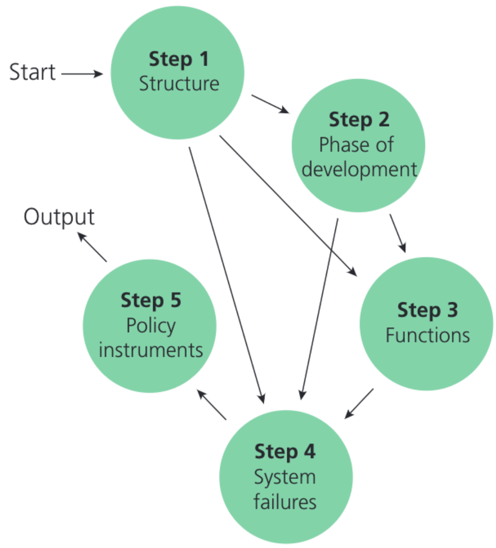

Figure 4: The five different steps of analysing a TIS (Hekkert et al., 2011).

3.3.1 SQ1: Structural analysis

The first part of the manual has two steps: examining the system structure and determining the development phase. Every system can be captured by the standard building blocks that make up the system structure and the ability to mark the TIS at one of four possible development stages. The most important goal here should be to know how the system is built and how far the technology is developed.

Step 1: Examining the system structure
As mentioned, a TIS structure has four building blocks: technology, actors, networks and institutions. Getting to know these building blocks gives a sense of *who* is active in the *technological* system, by what *rules* and in what *environment* they play. The manual presents questions to examine the different structural building blocks, which will be used for this research. All questions will be presented underneath with a brief explanation of how these questions will be answered. Together, the product of step 1 is a structured overview of the TIS, which forms a solid basis for further analysis.

1. Technology: What are the technological trajectories?

The question for the structural building block *Technology* focuses on examining the different technological trajectories. As shown in section 2.2, the current literature focuses mainly on the technical aspects of different individual AC technologies but does not compare them. The abundance of technical literature will be useful while creating an overview of the technology. This overview will have a literature review format, starting with conventional concrete production and then moving towards possible different AC technologies for concrete production. Creating this overview of the technology building block is expected to be a crucial part of the TIS analysis. This is because the technology is in an early development phase, and an overview like this is absent, making it both necessary and beneficial.

2. Actors: Who are the actors?
   (a) Research: Describe the state of the knowledge system
      i. Which parties develop knowledge?
      ii. Where are the knowledge producers located?
      iii. How much knowledge is developed?
      iv. What are the types of organizations involved in knowledge production?
   (b) Education: Are the education needs met?
   (c) Market: What does the market look like?
   (d) Politics and Policy: What are the policy goals related to the TIS?
   (e) Intermediaries: Which parties try to engage in collaboration between different parties?

The second question on the structural building block *Actors* focuses on who is acting within the system. To answer the main question, the manual has divided the actors into five smaller sub-parts, all with a related question. What stands out here is that the structural building block *Institutions* is not examined on its own but is part of the actor analysis. To create a complete actor analysis, each sub-part is analyzed individually, which leads to an answer to each sub-question. Since all the questions presented above directly come from the manual, discussing the particular questions is unnecessary. The only thing that stands out is that the research part is divided into more sub-questions, which will all be answered in the research sub-part and create an overview of the Dutch concrete research system. The rest of the sub-parts are all examined based on their main question with a small sub-system analysis.

3. Network: What does the network look like?

The results of the previous two questions are a good basis for the third question regarding the structural building block on the *Network*. The network analysis will combine all the gathered information from the previous questions and create a systemic overview of the different parts of the system. This will be a relations-type network with an overview of actors' relations regarding contact, information exchange, collaborations and other non-physical connections. This will form a clear conclusion and overview of the three building blocks because all gathered information from all building blocks can be combined in one visible overview figure. The added value of this specific structural building block is to zoom out from the first and second building blocks and look at the system from a slightly more distance.

Step 2: Determining the phase of development

The second step of part 1 is determining the development phase. Before going to part 2, knowing which development phase the TIS is currently in is essential. Within the manual, each stage is given a specific question which is presented underneath. When a particular question can be answered with yes, the TIS enters the next step according to the development curve in figure 5.

1. Pre-development phase: Is there a working prototype?
2. Development phase: Is there a commercial application?
3. Take-off phase: Is there a fast market growth?
4. Acceleration phase: Is there market saturation?
5. Stabilization phase: This is the highest phase a TIS can reach.

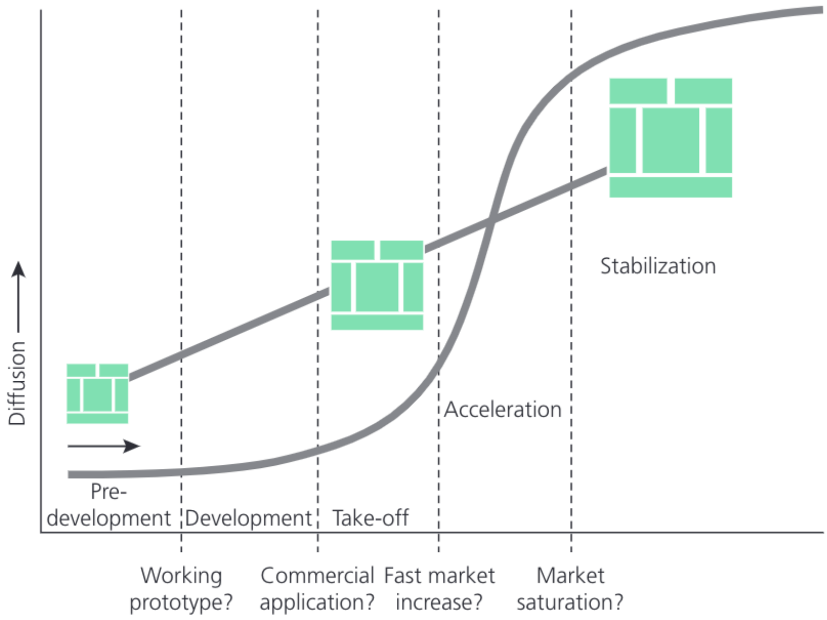

Figure 5: The five phases of system development (Hekkert et al., 2011).

3.3.2 SQ2: Functional analysis

With a clear view of the TIS's structure and phase, the TIS's functioning will be examined in part 2 with step 3. The difference with part 1 is that the focus has shifted from who is in it to what they are doing and whether it is sufficient for the system. The system functionality cannot only be measured by quantitative indicators; therefore, different experts and stakeholders from within the system should be involved for this step to succeed. The expert interviews are discussed in section 3.4.

Step 3: Measuring system functionalities
Within the manual of Hekkert et al. (2011), seven functionalities are presented with a large variety of questions to benchmark the IS. These questions are adjusted for this particular TIS and presented within table 2 for the seven different functionalities. These questions will all be scored by experts from within the industry on a Likert scale from 1 (very weak) to 5 (very strong), together with an explanation for every individual score. After all the interviews are conducted, the given scores and explanations are checked. Scores will be adjusted where needed when interviewees contradict themselves with their scores and are given explanations. All the adjusted scores will be combined, resulting in a spider diagram similar to figure 6. This will give an overview of the performance of the seven different functions.

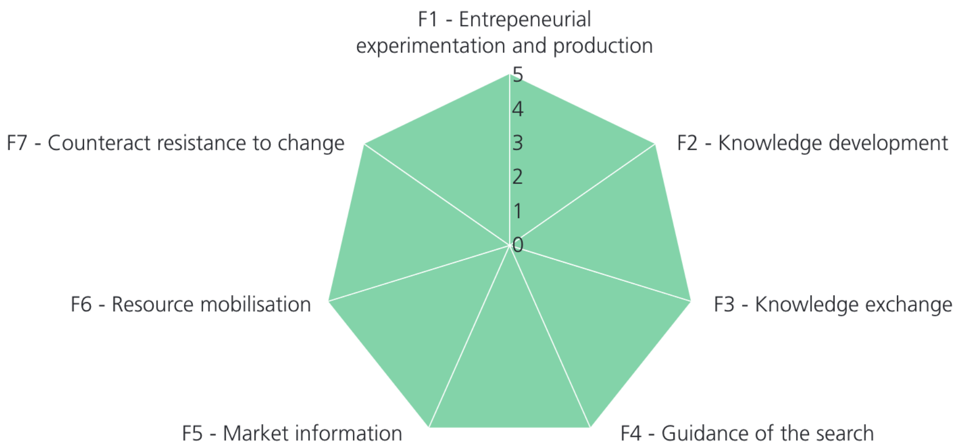

Figure 6: A spider-diagram to score the functionality of a system. (Hekkert et al., 2011).

Table 2: The seven system functionalities with corresponding questions.

System functionalities	Diagnostic questions
1. **Entrepreneurial activities**	1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production? 2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production? 3. Do the Dutch concrete system's industrial actors innovate sufficiently regarding CO_2 usage during concrete production? 4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production? 5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?
2. **Knowledge development**	1. Is the amount of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system? 2. Is the quality of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system? 3. Does the type of knowledge developed on CO_2 usage during concrete production fit with the knowledge needs of the Dutch concrete system? 4. Does the quality and/or quantity of knowledge development form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on a large scale?
3. **Knowledge exchange**	1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production within the Dutch concrete system? 2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production within the Dutch concrete system? 3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders? 4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production? 5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?
4. **Guidance of the search**	1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop: a. in terms of growth? b. in terms of technological design? 2. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production? 3. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production? 4. Are these goals regarded as reliable and doable? 5. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?
5. **Formation of markets**	1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient? 2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

6. **Mobilization of resources**	1. Are there sufficient human resources in the Dutch concrete system to increase CO_2 usage during concrete production? 2. Are there sufficient financial resources in the Dutch concrete system to increase CO_2 usage during concrete production? 3. Are there expected physical resource constraints for the Dutch concrete system that may hamper technology diffusion on CO_2 usage during concrete production? 4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?
7. **Counteracting resistance to change**	1. Is there resistance in the Dutch concrete system towards using new technologies during concrete production? 2. Is there resistance in the Dutch concrete system towards setting up projects for CO_2 usage during concrete production? 3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

3.3.3 SQ3: System failures

Within part 3 of the TIS analysis, the gathered information from parts 1 and 2 comes together to locate the systemic problems for the TIS. This process has two steps: the systemic problems must be located, and the policy landscape needs to be analyzed. Underneath, the steps are described.

Step 4: Finding systemic problems for functional barriers
The functionality scores of step 3 provide insights into the performance of all functionalities. The goal of step 4 is to select the functional barriers and find the reason behind these problematic functionalities of the TIS that combined cause system failures. A hampering system function often originates from systemic problems within the system structure. The manual presents the three steps below to find the systemic problems. After these steps are executed, different systemic problems should have become clear to take to the next and final step.

1. Determine which system functions are forming a barrier.

The functions that could form a barrier can be selected based on the function scores of step 3 combined with the essential functionalities per development phase as presented in figure 7. The black arrows show the most important connections for that specific phase, while the grey ones show these of the phases before. If the functionalities that are important for a particular stage are also scoring low, this indicates that the function act as a functional barrier which is blocking the buildup of the TIS.

2. Determine for each functional barrier which structural components cause problems. Look at the following structural components:
   (a) Actors
   (b) Networks
   (c) Institutions
   (d) Technology
   (e) External factors/Context
3. Describe the relation between cause and barriers. What are the functional consequences of the causes in the structure? Do the barriers have to do with a lack of structural components or with a lack of quality? What are the effects of the structural components on the system's functioning – which system functions improve or become worse due to structural problems?

When describing the relation between causes and barriers, the given explanations by the interviewees for the scores will guide the story. In addition, I will use the acquired knowledge during the first three steps as a researcher from outside the system to add Context and arguments where needed. When this process is finished, an overview is created for each functional barrier existing in the different systemic problems mentioned in point 2 of this step. This should provide insights into the underlying reasons for existing barriers and present three complete system failures.

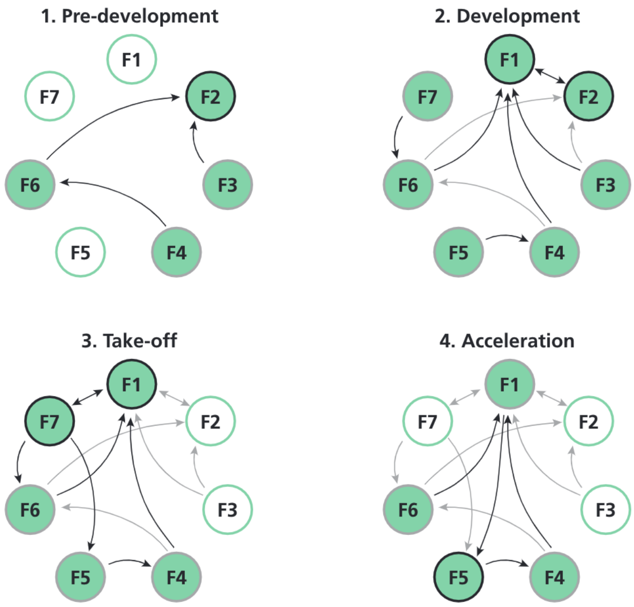

Figure 7: Functionality patterns for each systemic development phase (Hekkert et al., 2011).

Step 5: Defining problems for policy goals

Step 5 is the last and focuses on how a government could intervene to decrease the system failures as presented in step 4. According to the manual, choosing an intervention tool depends on three aspects: what systemic problems are causing the barrier, the precise policy goal of the TIS under study and the technological and geographical scope of the TIS.

The first aspect starts at the outcome of step 4. There is a big chance that the located system failures are entwined and together cause problems for the TIS, which makes it important first to analyse how the systemic problems are related to each barrier and how the located system failures are related to each other. When that overview has been created, the second aspect of this step will focus on the policy goals. Policy interventions stimulate companies to perform better and contribute to a wider social objective. It is important to have a clear view of the government's vision of what it wants to be and the societal result of the intervention. In that way, an instrument that handles the structural cause can be chosen so that the entire TIS can move towards the desired societal benefit. The third and last aspect looks at the technical and geographical scope of the TIS. When the TIS's main problem is clear and the government's perspective on how to act on it, it is important to be aware of the scope of the TIS. Some structural malfunctions can originate from outside of the scope; think of European laws that work through in a specific country and negatively influences a system's function, which can be hard for a country to resolve certain malfunctions. It will be useful to keep the importance of the scope in mind and see what is within and outside of the influence of the government.

With step 5 as the last step of the TIS manual, the data analysis has ended. From this point on, the conclusions chapter 5 will follow, where the SQs and RQ will be answered based on the data analysis. In addition to that, based on the data analysis, recommendations can be given. Nevertheless, before the data analysis of chapter 4 can begin, the data collection and data management are first presented in the coming sections.

3.4 Data collection

The data collection for this research has four methods, which all fulfil a different purpose and complement each other for the presented data analysis. Each method will be discussed underneath.

Desk research
The first method focuses on gathering the most basic form of information on the system for the structural analysis of section 4.1. Because the system is researched, much general information on the Dutch concrete system needs to be gathered, like specific actors, industrial production amounts, network configurations and production chains, which will mostly be available on web pages found via Google. This data has no scientific character but focuses on basic facts and numbers. Because the sources of this data often lack scientific quality, I find it important to separate this method from the literature research. In this way, the outcomes of desk research can be separated to guarantee the scientific quality of the literature research. Most of the time, these references are websites without a date. Next, most of the gathered information by this method will also be checked with experts during the unstructured interviews.

Literature research
In contrast to the previous method, the second focuses on gathering scientific knowledge, again for the structural analysis of section 4.1. This method uses scientific databases like Google Scholar and Elsevier Scopus to find literature. An important aspect is the publication year; since most relevant technology has been developed recently, it is an important metric to remember while searching. Next, technical research papers can be used worldwide, while systemic research papers need to address geographical locations in the neighbourhood of The Netherlands. As mentioned in the TIS framework (Hekkert et al., 2011), systems can vary greatly between countries, let alone continents. Next to that, the concept of forward and backward snowballing is used. This means finding useful articles and searching their references for more good literature. Overall, it is clear why this method complements the previous one; facts alone are a good start, but scientific knowledge adds another layer to the research.

Unstructured expert interviews
The third method is the next step in gathering information and supplementing the previous two for the first step in the manual: unstructured expert interviews. Again, this method gathers information for the structural analysis of section 4.1. During the unstructured expert interviews, the gathered data from the first two steps can be checked, but also field knowledge can also be gathered, which cannot be found in any written sources. A benefit of unstructured interviews is that they do not follow a specific order of topics, making it easy for experts to steer the conversation wherever they think it is most important. This can bring new topics and perspectives I could not have considered as a researcher with an outside view of the system. These insights from inside the system could be essential since this information usually stays hidden inside (Chauhan, 2019). Especially at the beginning of the structural analysis, it can be insightful to let experts talk about the system and see whatever comes up. Later on, it will probably help to ask some more specific questions and guide the interview towards specific questions or check specifically gathered data. Nevertheless, this would remain an unstructured character.

For this method, five interviews will be conducted with employees of various organisations from the Dutch concrete industry. The composition of the actors is chosen so that every part of the system is represented (overall system, industry and research). An interviewee with a government view is missing within this part. Still, the person from the branch organisation is related to many government-related aspects and can tell enough about it for the first structural analysis. An overview of the interviewees and their organisation can be found in table 2.

Table 3: Interviews to conduct for the structural analysis.

#	Company sector	Company name	Job title
1	Branche organization	Betonhuis	Advisor Technicalities and Regulations
2	University	Delft University of Technology	Assistant professor
3	RMC production	Dyckerhoff Basal Betonmortel B.V.	Manager Production and Concrete technology
4	Research centre	VITO	Researcher
5	PCP production	Bruil	Sustainability coordinator

Structured expert interviews

The fourth method for gathering data is structured expert interviews and provides data for the functional analysis of section 4.2. This will lead to scoring the seven functionalities of the system on a five-point Likert scale. Every functionality has specific questions that need to be scored on this 5-point scale. The experts' combined score will lead to a system score for all seven individual functionalities. The data for this scoring will be gathered with a survey that respondents will walk through during an online 1-on-1 video meeting. Next, every score can be provided with textual input, which will be added to an appendix and analysed for useful information. In case different experts give contradicting scores, these explanations can provide context. Last but not least, not every interviewee will answer all questions since not everyone is active in or knows everything about all system functionalities. A total of 12 interviews will be conducted throughout the Dutch concrete system, for which an overview can be found in table 3. A clear distinction is made between actors 1 to 4 (research), 5 to 9 (industry) and 10 to 12 (government). By making sure each part of the system is evenly represented, it is expected to gain a more realistic view of the system.

Within table 4, all interviewees from table 3 are mentioned again by the same number, but now it is presented which functionalities will be scored by which expert. This table was created after the structural analysis was finished since this analysis brought the knowledge needed on the different system parts and what functionalities the involved experts participate in. When interviewees mention during the 1-on-1 session that they do not know enough about a specific question, no score will be given for calculating the total score. Furthermore, the following style will be used when referencing findings from both the (un)structured expert interviews: (Interview X.i). The X will be filled in with an A (unstructured) or B (structured) to show what round of interviews it was. The i of the reference represents the specific interview of that round.

Table 4: Interviews to conduct for the functional analysis.

#	Company sector	Company name	Job title
1	University	Delft University of Technology	Assistant professor
2	Research centre	VITO	Researcher
3	Research centre	TNO	Senior consultant
4	R&D team of PCP producer	Bruil	R&D manager
5	Branche organization	Betonhuis	Advisor Technicalities and Regulations
6	PCP producer	Martens groep	Director
7	RMC producer	Dyckerhoff Basal Betonmortel B.V.	Manager Production and Concrete technology
8	CO_2 technology for concrete production	Edilteco Benelux	Technical Sales Consultant
9	Concrete producer	Hoco Beton BV	Head Business Office
10	Executive organization of Ministry	Rijkswaterstaat	Senior Advisor Bridges and Viaducts
11	Executive organization of Ministry	Rijkswaterstaat	Senior Technical Advisor Concrete Technology
12	Ministry	Interior and Kingdom Relations	Senior Policy Advisor Building Regulations

Table 5: Specific functionalities asked per interviewee.

	Q1: Entrepreneurial activities	Q2: Knowledge development	Q3: Knowledge exchange	Q4: Guidance of the search	Q5: Formation of markets	Q6: Mobilization of resources	Q7: Counteracting resistance to change
1. University (Delft University of Technology)		X	X	X			
2. Research centre (VITO)		X	X	X	X		X
3. Research centre (TNO)		X	X	X	X		X
4. R&D team of concrete producer (Bruil)	X	X	X	X		X	X
5. Branche organization (Betonhuis)	X	X	X	X	X	X	X
6. PCP producer (Martens groep)	X		X	X	X	X	X
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	X		X	X	X	X	X
8. CO_2 usage technology (Edilteco Benelux)	X		X	X	X	X	X
9. Concrete production (Hoco Beton BV)	X		X	X	X	X	X
10. Executive organization of Ministry (Rijkswaterstaat)	X		X	X	X	X	X
11. Executive organization of Ministry (Rijkswaterstaat)	X		X	X	X		
12. Ministry (Interior and Kingdom Relations)	X		X	X	X	X	X

3.5 Data management

Apart from desk and literature research, the data gathered will come from interviews. Before the beginning of every interview, permission is asked to make notes during the entire conversation and publish results afterwards within the research. It is mentioned that this research may become public, so no sensitive data should be given. After that is done, all the notes will be sent to the interviewee to give an opportunity to correct where necessary. Next to that, the same is mentioned for the given answers to the survey. After approval for the transcription and survey answers, it is added to appendix A and appendix B. Next to that, a Data Management Plan (DMP) is created on this website to make sure that this thesis follows the codes and regulations of the TU Delft on how to handle data.

4 Results

This chapter presents all the results of the data gathering and analysis of that data. Section 4.1 discusses the structural analysis, section 4.2 discusses the functional analysis and 4.3 discusses the system failures.

4.1 SQ1: Structural analysis

Within this section, the structural building blocks technology, actors and network are thoroughly examined. The last building block, institutions, is presented within the section on the actor building block just like described in the manual of Hekkert et al. (2011). After the description of the building blocks, the development stage of the technology is described.

4.1.1 Technology

The structural building block *Technology* is examined based on the question: what are the technological trajectories? These trajectories can be seen as the different production processes using AC technology. While all these production processes are developing parallel to each other and heading towards a future application, they need to be implemented in the current concrete production first to become an endpoint of transition. Currently, some AC technologies are being used for commercial application in The Netherlands but this is on a negligible scale (Interview A.1 & A.2). Nevertheless, an increasing amount of companies are testing different production methods to investigate the possibilities (Interview A.3 & A.4). This means that some starting points for the transition are becoming clear regarding the possibilities of using CO_2 in the current concrete production. The current concrete production methods will first be examined to understand the starting point better. After that, the different production methods using AC technology will be described. In addition to that, the actual handling and usage of the CO_2 gas will be discussed. The information will then shortly be reviewed to draw conclusions for each different production process on potential usage and development stage.

Current Dutch concrete production

As seen in table 3, concrete production in The Netherlands can be divided into two sectors; an industrial and a non-industrial sector. Together these sectors produced about 14 million m^3 of concrete in 2020 (Betonhuis, 2022). Industrial producers handle very large amounts of concrete at once (2.500+ kg) with machines capable of adding CO_2 to the production process (Interview A.3). Non-industrial producers (for example, construction workers and DIYers), on the other hand, only handle small amounts at once (25+ kg) and use machines that are not capable of adding CO_2 to the final product. Therefore, this technical analysis focuses on the industrial sector, and the non-industrial sector is left out of the further analysis. This left-out sector of contractors and DIYers is about 10% of Dutch concrete production, as seen in table 3. Industrial concrete production is mainly performed in two different forms: Ready Mix Concrete (RMC) and Precast Concrete Products (PCPs) (Interview A.1). Both of these forms are further explained underneath.

Ready Mix Concrete (RMC)

RMC is produced at concrete batching plants by combining large quantities of cement, aggregates and water in concrete mixers (Betonhuis, n.d.-b). If the concrete mixture is ready, it is transported to the construction site by a truck that deposits it in the right place or mould (Betonhuis, 2022). RMC is mostly used at house construction sites, engineering for ground, road and hydraulic purposes, and utility construction (Betonhuis, 2022). Because concrete hardens based on a chemical reaction while mixed, hardening is already happening when transported to the construction site. If concrete is hardened too much, it gets more difficult to deposit and the final quality of the concrete drops (Interview A.1). Because of this, transport time is an important factor for RMC and a guideline of using concrete within at least 2 hours after mixing is applicable (Interview A.1). Specific chemicals or substances can be added to the concrete to slow this process down when the transport is going to take long for example, but this is more costly (Interview A.1).

Precast Concrete Products (PCPs)

PCPs, on the other hand, are made at factories where the same RMC mixing setups are present (Interview A.3), but the concrete is poured into product moulds at the production location (Betonhuis, n.d.-a). The concrete then hardens for a period of time until the products can be taken out of the mould and hardened further until ready to use. PCPs can vary widely in form and usage, examples are stones, tiles, building blocks, stairs and even complete walls that can be made at factories. Within these different products, it is possible to add steel reinforcements to make products stronger (Betonhuis, n.d.-a). Something important for PCPs is the fact that production companies often have a time-bound daily process flow (Interview A.1). During the morning, the mixing process is prepared; during the afternoon, concrete is poured into moulds and during a certain period, the products can harden depending on their size. Then after a specific time, PCPs can be removed from the moulds if the necessary early strength is reached, and a new round of products can be made with those moulds (Interview A.1). Within the industry, early and late strength are two important terms. Early strength is measured after 24 hours; the higher this is the more can be done with concrete in an earlier phase because it is stronger. Late strength is measured after 28 days, almost as strong as its final strength, and nothing will further change. This early strength is important to producers, the faster companies can produce a new batch of products, the more they can sell and the more profit they can make (Interview A.1).

Table 6: Distribution per m^3 (1.000 litres) for producers within The Netherlands in 2020 (Betonhuis, 2022).

Product supplier	**Total liters**	**Liters per sector**	**Sector**
Ready Mix Concrete	510	200	Housing
(Industrial)		95	Ground, Road, and Hydraulic (GRH) engineering
		150	Utility construction
		35	Agricultural construction
		30	Other
Precast Concrete Products	375	140	Elements for residential and utility construction
(Industrial)		150	Paving stones, tiles and masonry stones
		50	Piles
		35	Sewers and other applications
Wholesale, contractors and dry ready-mix	110	50	Construction contractors and do-it-yourselfers
(Non-industrial)		35	GRH contractors for concrete roads, bus lanes, bicycle paths
		25	For masonry and floor materials

Passive vs. Active Carbonation

Carbonation is a vital process in concrete production, whereby CO_2 molecules bind with CaO molecules, solidifying the gaseous CO_2 within the concrete and providing strength to the final product. This occurs naturally through passive-carbonation, whereby CO_2 from the atmosphere reacts with the concrete mixture during solidification and over the lifetime of the concrete (Šavija and Luković, 2016). However, the amount of CO_2 that can react decreases over time as it can only penetrate the surface of the concrete, which gradually becomes more carbonated (Interview A.2). The extent of carbonation depends on the size and shape of the concrete product (Interview A.2). In optimal conditions, standard concrete made with 32.5% Portland cement can absorb a maximum of 162.5 kg per m^3 of concrete, although passive-carbonation only sequesters a small portion of this amount (Interview A.2).

Active-carbonation has the potential to significantly improve the carbonation process by adding more CO_2 to concrete in an artificial way (Tam et al., 2020). According to Tam et al. (2020), there are three different AC production methods: carbon-conditioning, carbon-curing, and alternative CO_2 technologies. Carbon-conditioning involves placing recycled aggregates (RAs) in a closed environment, such as a curing chamber, with high CO_2 gas concentration and controlled humidity and pressure. This environment causes the old cement on the RAs to bind CO_2 to its surface (Liang et al., 2020). In the second method, PCPs are placed in the same curing chambers. The reaction between cement paste and CO_2 is more efficient due to the porous nature of unhardened concrete (Tam et al., 2020). The third method combines the first two, which researchers have explored to identify potential benefits (Liu et al., 2021). One specific technology that has emerged from this method will be discussed. Further explanations of these three AC production methods are provided below.

Carbon-conditioning Recycled Aggregates (RAs)

RAs are created by crushing and grinding old concrete into small particles ranging from 0.2 to 15+ mm, which can be reused in new concrete production (Liang et al., 2020). The grinding process reintroduces the natural process of passive-carbonation to the old material, and the increased surface area of the old concrete particles enables the carbonation process to occur again with CO_2 from the atmosphere (Interview A.2). AC technology can be applied through carbon-conditioning the particles to enhance the quality of RAs before their use in new concrete (Interview A.2). Placing RAs in a closed environment with the right conditions accelerates the natural passive-carbonation process, leading to active-carbonation and the formation of Carbonated Recycled Aggregates (CRAs). This process sequesters CO_2 and strengthens the RAs (Mistri et al., 2020; Interview A.2).

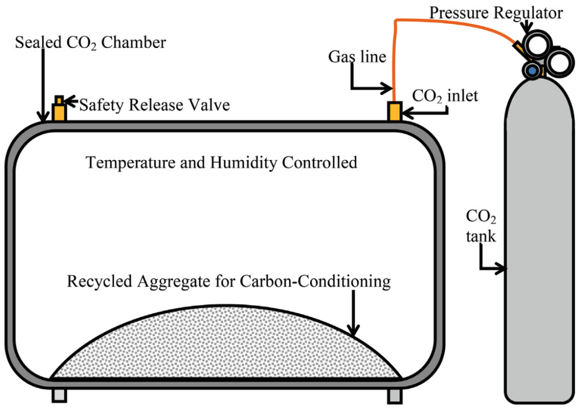

Figure 8: Simplified production setup for carbon-conditioning RAs (Tam et al., 2020).

The AC production method for CRAs in the curing chamber does not lead to a larger uptake when compared to passive-carbonation, but it can accomplish the same results without elevated temperature and pressure within 24 hours. This means that exhaust gases can be used, which helps to keep costs low and increase the speed (complete passive carbonation takes months). As a result, CRAs can sequester approximately 3 to 4% of their total mass in CO_2 (Interview A.4). While this percentage might appear low, it is worth noting that CRAs can contribute up to 30% of the total usage of aggregates, which makes a significant impact on the amount of CO_2 that can be sequestered (Interview A.3 & A.4). A simplified illustration of the setup for this method is provided in figure 8.

If RAs are used within concrete production, this concrete is called Recycled Aggregates Concrete (RAC). What is interesting about this specific type of concrete is that RAC is more porous because the RAs are more porous than Natural Aggregates (NAs). RAC is of lower quality because of the porosity. But, if the RAs are treated with AC technology, the strength and quality of the RAs and thus concrete gets higher, called CRAs. If these CRAs are then used in the production process of concrete, this gives Carbonated Recycled Aggregate Concrete (CRAC) which is better than RAC (Interview A.2). Creating CRAs from RAs is beneficial for sequestering CO_2 and enables concrete to use more RAs. The current maximum usage of 30% RAs has to do with the fact that using RAs lowers the quality of concrete. If the quality of CRAs is better, this would logically enable CRAC to be made from more CRAs.

It is important to notice that the size of RAs can vary from a diameter far over 16 mm to under 0.1 mm. When talking about RAs with a size smaller than 0.16 mm, the terminology changes to recycled fine powders. This powder can also be treated with CO_2 and later on used within the production of concrete (Jiang et al., 2022). As can be understood, mixing materials like CRAs and carbonated fine powder with other raw materials for concrete will affect the final concrete's properties (Jiang et al., 2022). Therefore, research has to be done on the different implications of these new recycled raw materials.

Overall, this method involves using AC technology to enhance the strength of aggregates and reduce CO_2 emissions. However, the lack of commercial benefits is currently hindering the adoption of this technology by the industry. For instance, interview A.5 revealed that concrete waste is only ground every few months and left unused until needed. Once used, the concrete scraps are ground again (Interview A.5). Although carbon conditioning is simple, there are a few areas where the method can be improved. One possible improvement is using different conditioning materials, such as fly ashes, as Carbon8 does. This would result in carbon-negative aggregates. Recent years have seen these technologies shift towards building materials made from alternative resources. These AC technologies should be considered second-generation technologies because the first generation needed cement with many emissions, and these new technologies can be used without cement. Because of this, they have a larger potential of sequestering CO_2 through negative emissions.

Carbon-curing Precast Concrete Products (PCPs)

The second AC production method is placing unhardened PCPs in a curing chamber similar to the previous method, which also leads to an active-carbonation process with all the earlier-mentioned benefits (Chen et al., 2022). To do this, the PCPs must have reached their early strength so they can be transferred to the curing chamber, where they will be cured for 24 hours to a maximum of 28 days. A simplified overview of the curing setup can be seen in figure 9. The main difference is that PCPs are not completely dry compared with RAs; therefore, the entire concrete block can be strengthened. Factors that influence the active-carbonation process of PCPs are CO_2 partial pressure, CO_2 concentration, CO_2 flow rate, curing temperature, curing relative humidity, curing time, components of binders, components of aggregates, admixtures, water/binder ratio and aggregate/binder ratio (Chen et al., 2022). Researchers have devised various production setups to vary these parameters to examine which production methods will have the best results (Lee et al., 2018). To increase carbonation, PCPs need to maintain enough moisture, which is done by placing wet cloths on top of them or sealing them in plastic wraps so that water cannot evaporate (Interview A.2).

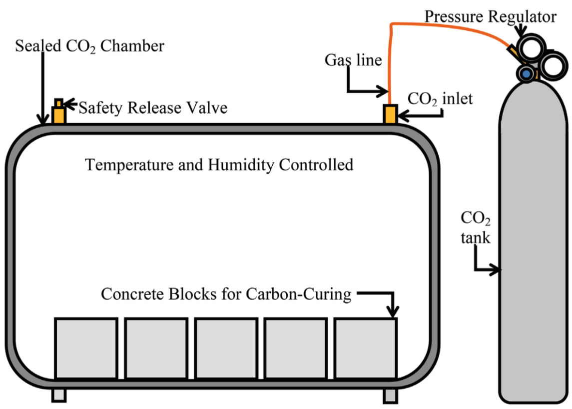

Figure 9: Simplified production setup for carbon-curing precast concrete products (Tam et al., 2020).

An important aspect of this process is that it cannot be used when reinforcement is used in the PCP. When CO_2 is added to the environment, the gaseous CO_2 can react with the H_2O in liquid form in concrete which creates carbonic acid. This is very reactive to the reinforcement, which then starts corroding (Interview A.2 & A.4). Next to that, conventional concrete has a very high Ph value, whereas it is most beneficial for the reinforcement to have such an environment with high Ph. As concrete becomes more carbonated, the Ph value drops, allowing the reinforcement to experience corrosion (Interview B.11). Therefore, from a building industry perspective, adding CO_2 to PCPs with reinforcement seems impossible because the corrosion risks are too high and its threats are too dangerous. Nevertheless, from the research sector, the arguments tend more towards the fact that despite the lower Ph value, the risk of corrosion is not a problem. When writing in hindsight of the structured expert interviews, it is still not sure what the risks of this combination precisely are and there is a very strong division in the TIS on what is possible with regard to this. During the rest of this thesis, arguments will be given in favour and against the use of CO_2 in concrete with enforcement. Nevertheless, I cannot find one unambiguous view on the matter and will treat it as such.

VITO, the interviewee's employer from interview A.3, has produced a technology called Carbstone which is also part of the earlier mentioned second-generation AC technology. This is because the technology enables PCP production without cement. The resources for these products are very finely ground steel slag powder with aggregates, water and some additives, which give a low early and late strength combined. When this mixture is poured in moulds and then placed in a curing chamber, the CO_2 reacts with the mixture, resulting in comparable late strengths to normal concrete products. This again not only removes the largest emitter cement, but it is also possible to sequestrate an amount of CO_2 up to 15% of the total mass of the PCP, which is high when compared to normal PCP curing (Interview A.4). Another benefit of this technology is that producing these Carbstone products is direct for the market, increasing profit margins and thus increasing financial viability (Interview A.4). Within the United States, a similar technology, CarbiCrete, seems to be somewhat further in its market development but based on the same principle of using steel slag.

VITO is co-owner of a patent to use the technology, and currently, about three companies are testing with the product or even selling products with this technology. The fact that this is based on the same principle of Carbon8 and CarbiCrete, shows a trend of experimenting with compositions of fly ash, steel slag and many more different additives as a potential binder. Again, these are not the conventional methods and resources, but they lead to increased possibilities for the concrete industry to sequestrate CO_2 and thus even products without cement. The most important upside of this technology is that cement is unnecessary, which enables negative emissions. When describing this specific group of AC technologies, I refer to them as second-generation AC technologies, building materials without cement with negative emissions. It is very promising to see these second-generation AC technologies develop over time.

Adding CO_2 while mixing concrete

The last promising AC production method is during the mixing process of cement, aggregates and water for RMC or PCPs. The setup for this method is presented in figure 10. This process takes place at concrete batching plants within mixers and is already commercially used in the United States (IEA, 2019) and tested within The Netherlands (Interview A.3). If these mixers are closed completely, a curing chamber can be created where CO_2 gas can be infused to create an active-carbonation process. While the mixture is still wet and constantly moving, CO_2 molecules can react with the entire mixture and thus create more chemical connections and more CO_2 can be sequestrated before it is placed in a mould on the construction site or PCP factory.

Next to that, if this mixture is ready, it can be used for PCPs with and without reinforcement in contrast to the previous method. This is because the CO_2 gas has already reacted with the concrete mixture, and no gaseous CO_2 is present any more, so no carbonic acid can be formed, which causes less damage for reinforcement (Interview A.2). Surprisingly, there is very little research on this method while it is being used commercially. It would be very useful if this method were analyzed from a scientific point of view to draw stronger conclusions based on research. The interviewee of interview A.3 stated that they are doing tests to see how this method works since there is almost no scientific proof (Interview A.3). This research could also improve the method, resulting in better application and sustainable benefits.

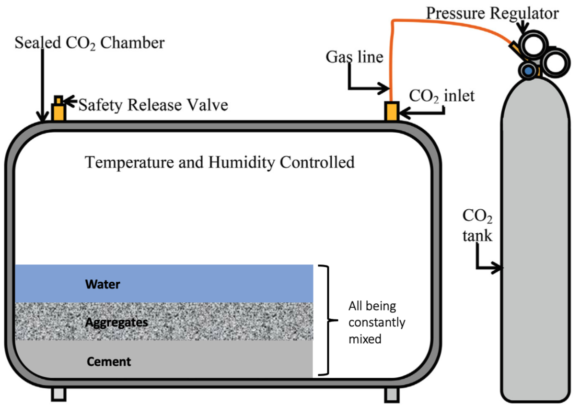

Figure 10: Simplified production setup for carbon-curing RMC.

The handling of CO_2 gas
Apart from all the different ways of using AC technologies to produce concrete, an important aspect is the actual CO_2 gas and its handling. All installations need CO_2 injected within their curing chambers to let the products react, which almost always comes from a certain tank that needs to be delivered to the production location. Within the literature, most of the presented setups namely mention that gas of high purity is used in their tests (80% to 99%) (Chen et al., 2022; Lee et al., 2018; Santhosh Kumar et al., 2019).

During section 1.2 it was already mentioned that capturing CO_2 gas from the atmosphere is currently technically possible. Nevertheless, the financial viability must be improved to create a better business case. In addition, transporting these CO_2 tanks is bad for the sustainable benefit of using the CO_2. If trucks must drive around with tanks only for using the CO_2 during production, the benefit will likely reach zero or even become negative. In addition, CO_2 gas of high purity is very costly to produce, which makes the usability of AC technologies which use high purity CO_2 economically unviable.

Because of both of these reasons, the interviewee from the company Vito mentioned they have tried using their AC technologies with CO_2 gas from industrial processes (Interview A.4). This means that the exhaust gases of industrial processes (low purity) are taken and directly used for their production methods. After their tests, they were viable and delivered large benefits. Thus, this enables companies to use AC technologies with exhaust streams of industrial processes, which strongly lowers CO_2 usage costs and removes the transportation problem. On the other hand, this also brings other challenges; concrete production locations must be very close to industrial processes to use these rest streams. However, this geographical closeness problem is a common problem for CE theory and solving this falls out of the scope of this research.

The different technological trajectories
With an overview of Dutch concrete production and the different AC production methods in place, an answer can be given to the question: what are the different technological trajectories? Overall, three methods to add CO_2 are possible: to the aggregates, while mixing concrete and while hardening. Combining these three methods and adding CO_2 in every stage will lead to much sequestration. When reinforcement is used, carbon-curing the PCP cannot be used but in that case, the other two methods still can be used. Next, carbon-curing PCPs and adding CO_2 while mixing seems to be developed the furthest while these are both very close to (or just begun with) commercial application in the Dutch concrete system. The other method is still in development, apart

from Carbon8 technology, which is also applied on a small commercial scale. In addition, there are currently two different methods for using CO_2 gas during concrete production, which have their limitations and benefits. As mentioned in the introduction, the development of CCS and CCU technologies is needed for the TIS under study to improve the business case and become more profitable to grow in the future.

Altogether, the conclusion can be drawn that all of these technologies are on the edge of entering the market with a wide variety of applications. Next, this shows a lot of development in different individual technologies, which are all part of these three methods. The last important notice concerns the second generation of AC technologies that use different compositions for the building materials. What can be seen from the Carbstone and Carbon8 technologies is the fact that different materials are being used than cement and NAs. This shows that building materials can also be made from different materials, while still being based on AC and having a negative emission.

4.1.2 Actors

The structural building block *Actors* is examined based on five sub-questions, all part of the main question: who are the actors? Each sub-question covers a part of the system: research, education, market, politics & policy and intermediaries. Underneath, these questions are examined individually, which leads to an answer to the main question.

Research
The first actor type is related to research, and the manual presents four research-related questions, which are again one by one answered to get a sense of the most important research-related actors.

Which parties develop knowledge?

Within the Dutch concrete system, three types of parties develop knowledge; these are universities, research centres and companies with their own Research & Development (R&D) teams (Interview A.2 & A.4). It is important to remember that companies with their own R&D teams can have a conflict of interest within their research. Next, they probably will or can not tell everything when asked about their research direction. This is because they can keep it secret to stay ahead of competitors or have non-disclosure deals with customers (Interview A.2). These three knowledge producers are further discussed underneath.

Where are the knowledge producers located?

Within The Netherlands, there are three technical universities with civil engineering study programmes for bachelor's and master's degrees. These are located in Delft (Delft University of Technology), Eindhoven (Eindhoven University of Technology) and Twente (University of Twente) ("Studiekeuzelab", n.d.). Next to that, the largest research centre in The Netherlands is TNO, which has offices and labs throughout the country. While TNO is the largest, there are also smaller research organisations like CE Delft, SGS Introm and ABT advisory bureau (Interview A.1). What stands out is that TNO and CE Delft, for example, are both very close to the university in Delft, and TNO even has multiple labs and offices in Delft. Where The Netherlands has TNO, Belgium has VITO, the company from interview A.4. VITO has contact with researchers from the TU Delft (Interview A.1), for example, so there is a network of knowledge production on a national level which also stretches over borders to an international level.

The last category, companies with R&D teams, are mostly the larger concrete production companies in The Netherlands. The main reason is that these companies have a budget to allocate resources to employees working in these teams (Interview A.1). What also stands out is that many concrete producers have large international mother organisations, so the developed knowledge can be shared with other parts of the larger company, enabling them to earn back resources better. Around 10 to 15 companies probably have R&D teams (Interview A.1). The next part explains how the knowledge of these three types of producers comes together.

How much knowledge is developed?

Knowledge cannot be expressed in absolute values, which makes it difficult to measure. One way of doing so is by finding the number of scientific publications on the topic, which will give an indication of the amount of knowledge. The search engine Scopus Elsevier makes it possible to search how many publications are done per country, university or even department, which can give useful insights. This method indicates the amount of knowledge produced by the above-mentioned universities. Because knowledge can be measured differently for commercial companies, another method is presented after this first indication.

For this first method, a search is executed on Scopus with the keywords "carbon cured concrete", "co2 cured concrete", "active-carbonation", "active carbonation", "carbonated recycled aggregates", and "concrete carbonation" and the results were requested for each individual university. I know that more or different keywords could have been added, but to my understanding of the current technology and scope of the research, these words best describe the technology. The outcome of this search is combined in figure 11 underneath, where the yearly publications for every university are presented with an individual line. The university in Delft has published 294 articles, the university in Eindhoven 130 and the university in Twente 25, a combined total of 449. If the filter for university is switched off, Scopus presents a total of 42.409 publications worldwide, leaving the Dutch university knowledge production at a total of 1.1% of the world. Next to that, from around 2010 onwards, substantial growth can be seen.

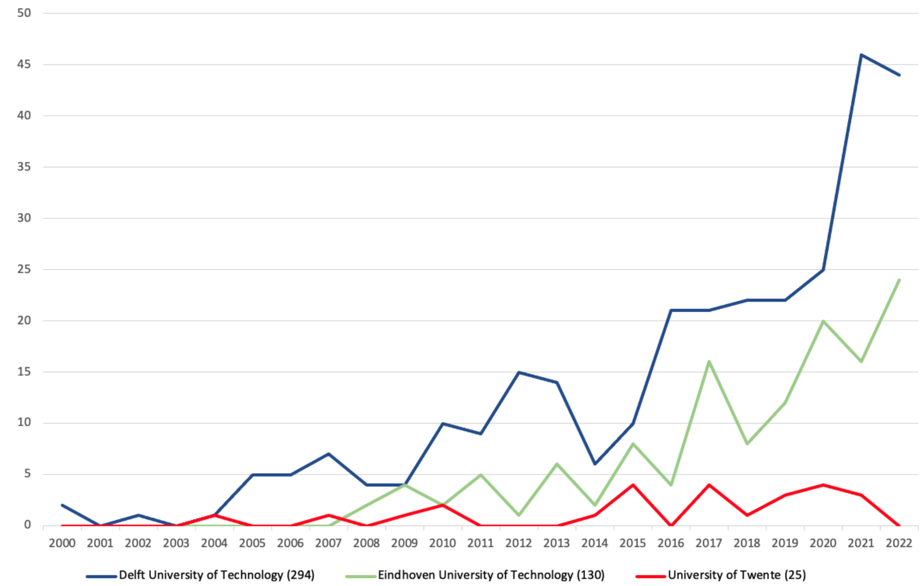

Figure 11: Scientific publications on carbon cured concrete by Dutch technical universities for 2000 - 2022.

Another method, mostly used for commercial knowledge production, is the Technology Readiness Level (TRL). This system gives a label to a certain technology from TRL1 to TRL9. TRL1 means the technology is at the lowest development phase possible, while TRL9 means a product is ready to sell. Next, the nine levels are combined into 4 phases: the Discovery Phase (TRL 1, 2 and 3), the Development Phase (TRL 4, 5 and 6), the Demonstration Phase (TRL 7 and 8) and the Deployment Phase (TRL 9) (SNN, n.d.). While publications are more standard for universities, the TRL system is more used within the corporate world. Universities often produce knowledge in the discovery and development phases, while research centres start to develop around the development phase. R&D centres often only start at the demonstration phase (Interview A.4). This method is also often used with subsidised research, where a requirement, in that case, could be that technology needs to rise 3 TRL levels in total within a period of time because of research organisations. Because research centres and R&D teams do not publish all of their research and probably will not give exact amounts, it is impossible to determine this knowledge production as precisely as for universities. Nevertheless, a good assumption can be made based on findings within the concrete industry and published industry research. For example, Dyckerhoff Basal Betonmortel B.V. is currently testing with Carboncure (Interview A.3), and the interviewee from Betonhuis mentioned that some companies are also testing with CO_2 usage (Interview A.1). Next to that, VITO in Belgium also has some ongoing projects with CO_2 usage in the production process of building materials (Interview A.4). Because of this, I believe the knowledge production for part of the technology is at TRL 5: the Development Phase and another part of the technology are at TRL 7: the Demonstration Phase.

What are the types of organizations involved in knowledge production?

Apart from these three types of organisations that produce knowledge themselves, an important actor type is governments. More specifically, the Dutch government and the European Commission are important since they provide knowledge producers with much funding (Interview A.2). Another interesting involved party exists of companies without R&D teams that reach out to research centres to pay to co-develop a certain product. VITO, for example, currently has shared ownership of a patent for Carbstone technology which is currently used in different products (Interview A.4).

Education

The question for the *Education* is formulated as: are the education needs met? The education for the building industry is organized on all levels of the Dutch education system. Pre-vocational secondary education and secondary vocational education (VMBO and MBO in Dutch) deliver employees for production at construction sites and factories, people from higher professional education (HBO in Dutch) often work at offices and become planners, while people from a university education (WO in Dutch) start somewhat higher in organizations and end up as concrete technologists and do research. All these education tracks are present and well organized but the number of people who join them has been decreasing for some years (Interview A.1). Next, most people want to be educated at a higher level, so there is a specific shortage of production employees. From the interviews A.1 (branch organisation) and A.3 (concrete production), it appeared that it is currently very hard for companies within the concrete production chain to find people for the industry (Interview A.1 & A.3). Nevertheless, it seems that this does not have to do with the education system.

The interviewee from interview A.3 mentioned that many companies, just like them, are concrete specialists within the market. This leads to a precise and specialized set of working activities for employees, so they must be concrete technologists. The larger firms within the industry (BAM, for example) are much broader and thus have broader job descriptions, giving a broader set of activities. The interviewee thinks there is a modern-day trend that people choose job diversity over speciality. Next to that, society is facing a shortage in the labour market, so that problem is everywhere (Interview A.1). But, the building sector is not very much wanted by possible employees because it is not very "sexy" (Interview A.1). A trend can be seen that the industry is seen as polluting and framed as not so good, which can also be a reason that people do not want to work in the industry.

Market

For the *Market* building block, the sub-question is: what does the market look like? The answer will be given on the basis of figure 12, which is a visual representation of the Dutch concrete production chain. All inflows of the system are chosen based on a scoping of the system under study, which means that these are not the actual borders of the system. There are different inflows of goods, services and energy within some of these inflowing sub-industries, which are left out on purpose. The scope of this part of the research is broad enough to include the important parts. Each individual part of the system is described based on corresponding numbers in the figure.

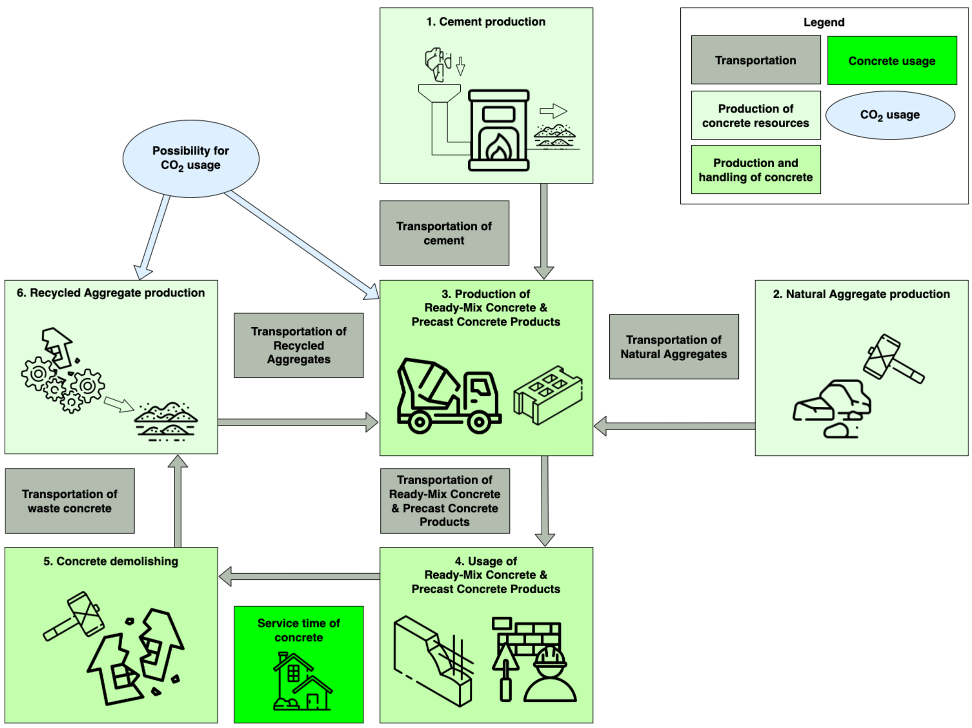

Figure 12: Overview of the Dutch production chain of concrete.

1. Cement production

The first and possibly most important part of the system is presented with number 1 in the figure: cement production. Cement is one of the three basic resources needed for concrete at the start of the production chain. Four cement producers are affiliated with the branch organisation Betonhuis, with only two located in The Netherlands and one in Belgium and one in Germany. Based on some desk research and expert interviews, it looks like there are around five cement suppliers in that case because Betonhuis has around 80 to 90% of the Dutch concrete industry as their affiliates (Interview A.1 & A.3). Barely any cement is produced within The Netherlands anymore, so almost all cement use is imported from surrounding countries (Betonhuis, 2020 & Interview A.3). The last cement factory with a burning process was located in Maastricht and closed in 2017 (Interview A.3). Altogether, the cement industry is thus large in quantity (5 million tonnes in 2020) but small in terms of suppliers (5)(Betonhuis, 2020 & Interview A.3). What is also interesting is the fact that next year's price for cement is probably going to be around 150% of the current price because of high energy prices and CO_2 rights (Interview A.3). Normally, the prices rise a couple of euros each year, but now it will be around 50%, creating a big push for cement users to come up with new, cheaper and more sustainable alternatives (Interview A.3). An example of this is the usage of cheap chemicals which gives extra quality to the concrete while less cement is used (Interview A.3). It is not only getting very expensive, but cement is also the biggest emitter of the entire industry with 850 kilograms of CO_2 emission from 1000 kilograms of cement production (Interview A.3).

Something very influential to the system is that almost all cement is imported. Within Europe, only a small amount of cement producers have much power within the system. From their perspective, it is important that everyone uses as much cement as possible because that brings them profit (Interview B.9). From a sustainable perspective, this is not wanted because cement causes the largest carbon emissions in the concrete industry. Because of lobbies and supplier power, the current concrete industry is built around this cement use with composition measures. Rules for building require specific cement use instead of specific performance. Something that could change this is the use of performance measures (Interview B.4). Because of this situation, the cement producers have a strong power position within the system and can decide largely what happens.

2. Natural Aggregate (NA) production

NAs are the second raw material needed to make concrete, represented by number 2 in the figure. NAs used in The Netherlands are most of the time a mix of sand and gravel, but also basalt, granite, limestone, quartz and concrete granulate can be used for certain property requirements (Betonhuis, n.d.-b; Interview A.3). This type of aggregate is extracted from natural sources and is thus a "new" resource, in contrast to RAs. These natural sources are often rivers which bring material (gravel and sand) downstream and the size of the aggregates decreases the lower it is captured (Interview A.3). Within The Netherlands, a couple of companies produce this aggregate material but also import it from Germany, both of which are getting harder and more expensive. Therefore, NAs are also starting to come from the sea as well as RAs are getting more and more interesting financially (Interview A.3).

3. Production of Ready Mix Concrete (RMC) & Precast Concrete Products (PCPs)

The third part of the figure, concrete production, forms the biggest part of the system under study. In this part, every industrial concrete production is represented, totalling to about 12.4 million m^3 of concrete yearly. This includes precast housing parts, RMC, sewerage parts production, pavement production, stone and block production, and constructive precast (Betonhuis, 2022). As mentioned in the description of the technology building block, this is one of the two places where CO_2 can be added to the production process. For this specific place, CO_2 can be used in two different ways: while mixing aggregates, cement and water but also while the concrete mixture is coming out of moulds and the PCPs are hardening. It is exactly this place which should receive attention in implementing CO_2 usage. A consequence of this implementation will mean that the receiving parties of RMC will have to get used to a change in the delivered product since this now contains a different composition and, for example, a decreased hardening time (Interview A.1). At the same time, the production process of PCPs will change since they now have to work with a concrete mixture that hardens faster as well as a different production process should be developed since the products need to be cured afterwards (Interview A.1 & A.2).

Many large concrete producers are subsidiaries of European cement producers, bringing them even more power on top of their supplier power (Interview A.3). Because of this, cement producers have a lot to say in choices made within concrete production methods. This means that specific innovations can be chosen by these large cement producers and probably will tend towards innovations that remain cement within concrete compositions. The cement producers want to keep selling as much cement as possible since this is their business model. In addition to this, it can be seen that these large concrete producers are also involved in the Dutch branch organization Betonhuis, which is a strong organization. This organization has connections to the European concrete organization Cembureau, representing the industry's interests on a European level. It is important to keep this in mind since this can be a large outside influence on the TIS because actors will try to protect their market share (Interview B.3 & B.5). The fact that these European cement producers can influence the system in the current structure makes it very hard for the Dutch government to steer individual companies in a certain direction, because of the strong power position of the cement producers. In a way, the Dutch government is also highly dependent on the delivery of their cement since it is needed for further building in the Netherlands.

The last important aspect of concrete production is that this part of the system has a very high level of fragmentation. What is meant by this is that the amount of varieties within concrete production is very large and has multiple key features that all can have multiple different adjustments, leading to a very large range of different products with different functionalities and requirements. This starts with the fact that concrete production is very much location-bounded since everything needs to be transported; an example is that within the entire Netherlands, there will always be an RMC producer within a radius of 25 km (Interview A.3). Because of this, the number of concrete producers is already large and widespread. On top of that, there is a very large variety in the applicability of different concrete products. For example, concrete is used for pavers, sewerage, structural concrete, and RMC concrete, which can be poured for different purposes at construction sites, and on top of that, most of these products require different strength measures for different applications (Table 6; Betonhuis, 2019). So, for example, one type of structural concrete needs to be stronger and safer because it is part of a tunnel compared to the usage in a small garage.

This complexity is further increased by using different innovations and technologies to improve the final concrete products further. For example, different materials can be added as cement replacements to become more sustainable, leading to CEM I, II and III, which all have different strengths (VVM Cement, 2019). In addition, concrete can have enforcements that can be used directly in concrete or with a special powder coating to decrease the chance of rust (Yeomans, 2013). On top of that, different aggregates give different levels of porosity, which gives different characteristics to concrete (Interview A.1). Lastly, a new innovation that can be applied is geopolymers to increase strength and decrease cement use, as well as different chemicals to increase or decrease the speed of solidifying, dependent on what is needed (Habert et al., 2011). Concrete, for example, solidifies slowly in warm and fast in cold weather. All combined, these different aspects can be filled in differently each time, making it a fragmented industry.

4. Usage of Ready Mix Concrete (RMC) & Precast Concrete Products (PCPs)

Part four of the figure receives both RMC and PCPs and as earlier mentioned, when CO_2 is added during production these parties have to adapt to a change in the delivered product (Interview A.1 & A.2). These companies mainly include construction companies and large project management companies. For receivers of PCPs, this change will probably be a little less since the products are already completely hardened. The delivery of RMC will probably change slightly more since the hardening of the concrete will be different. What is important for this step in the production chain is that these organisations can deliberately choose a specific product. This gives them the power to choose products that have used CO_2 during production and thus have a smaller carbon footprint. While the pictures thus show that the actual use of CO_2 happens one step earlier, with this step there comes a lot of power over how it is produced. It is important to keep this in mind.

What is also important for this specific actor is that a middleman often represents them: the contractors. Because large building projects are complicated, contractors execute the projects for the final users of the concrete. The group meant by this is not the residents of the final houses, but the organisation building the entire street, for example. The contractors act as a middleman in this process because they have the knowledge and experience to execute such a project successfully. The problem is that this middlemen role brings an extra set of interests and an extra station where knowledge needs to go through. The contractor wants to finish a project for the final user as well as possible and as cheaply as possible because that is in the best interest of the final user. The fact that sustainable innovations cost more and have been tested less since it is new decreases the use of sustainable innovations.

5. Concrete demolishing

Within the figure, concrete demolishing is the fifth step after the service life of the concrete has passed. In the past, this concrete demolishing was straightforward and could be easily broken down and transported to a waste location. But, with the next step being the recycling of this concrete into RAs, the processing of this concrete needs to be more careful (Interview A.2 & A.3). The waste product should be known because the properties need to be right for recycling. Therefore, waste concrete can be researched in labs before it can be used in some cases (Interview A.2). Another important aspect of this situation is that producers should consider what they put inside the concrete. It can be very beneficial to design with the recycling process in mind to make sure that process will be easier (Interview A.2).

6. Recycled Aggregate (RA) production

The production of RAs is represented in the figure as step six. Within The Netherlands, around 6 million tonnes of concrete are currently demolished in a good way (Interview A.3). This means that concrete comes out, which could be used to produce RAs. Unfortunately, it is unclear how much of this concrete is currently being used (Interview A.3). There is also another method of recycling concrete. After the ready-mix concrete is deposited at the construction site, some are always left. This is then transported to a dumping container where it can harden and be crushed like demolished concrete from old buildings (Interview A.3). As can be seen, CO_2 can be used to treat the RAs and improve the quality as explained during the technology building block. While this delivers a substantial quality benefit, the production time of aggregates is increased by this method. This is because the aggregates need to be treated for a certain period of time. Understandably, producers of RAs need to have some benefit to actually use this method (Interview A.1 & A.2).

Politics and Policy

The fourth actor-related sub-question on *Politics and Policy* is: what are the policy goals related to the TIS? This question does not directly ask to present specific actors but is more focused on the effects these actors have on the TIS by their formulated goals. In my opinion, these goals are mainly formulated on three different levels and flow down in a pyramid-like structure: a global level (UN), a continental level (EU) and a national level (the Dutch government). Regarding these goals, the ones applicable globally will set goals in motion on a continental level, which repeats itself from a continental to a national level. Because of this reason, these three levels will be discussed underneath in that order. The combined conclusion of these goals will then be an answer to the sub-question mentioned earlier.

Global level - United Nations (UN)

On a global scale, the UN plays a crucial role in identifying worldwide requirements for specific policy goals and coordinating efforts accordingly. The issue of GHG emissions serves as a prime example of this responsibility. To achieve this, the UN establishes broad and comprehensive goals that motivate lower-level actors to develop more specific goals tailored to their region. Attempting to create worldwide goals, for example, to make concrete with a certain percentage of CO_2 would not work due to the differences in cultures and standards across different regions.

To tackle this challenge of reducing CO_2 emissions, the UN sets broad objectives, such as goals 12 and 13 of the UN Sustainable Development Goals (United Nations, n.d.-b), the Paris Agreement (UNFCCC, 2016), and the Net Zero coalition (United Nations, n.d.-a). The development of these objectives promotes collaboration among various parties and motivates lower-level actors to take action against climate change, resulting in goals that are better suited to the specific needs and standards of their regions. These efforts are vital in bringing together continents to work towards achieving the overall objective of reducing CO_2 emissions.

Continental level - European Union (EU)

At the EU level, the policy goals are starting to be industry-specific. The UN has made it clear that global action is necessary to combat climate change, and this requires reducing CO_2 emissions and building circular economies. The EU takes the large global goals and adapts them to their continent, making them challenging enough to make a difference but still achievable enough to motivate individual nations to strive for them. These goals are often more specific and actionable, with the EU setting industry-specific goals from the present until 2050, whereas the UN simply mentions achieving net zero emissions by 2050.

As the EU is closer to the national level, it can better understand a country's cultural, economic, and environmental standards and discuss these with member nations to adjust goals accordingly, thereby increasing the chance of success. In addition, the EU has access to significant funding, which it can use to incentivize member nations to work towards specific goals through subsidies and other means. The European Commission has developed several plans, including the Sustainable Cycles plan (European Commission, 2021), the 2030 Climate Target Plan (European Commission, n.d.-a), the 2050 Long-Term Strategy (European Commission, n.d.-b), and the European Green Deal (European Commission, n.d.-c). Each plan specifies the percentage of CO_2 emission reductions and efficiencies needed before certain dates in specific sectors. This allows the sectors to devise their own ways of achieving these goals.

The Cembureau, which is similar to the Dutch branch organization but at the European level, has created a 38-paged roadmap for the decarbonization of the cement industry (Cembureau, n.d.), which is based on the European Green Deal (European Commission, 2019). While the European concrete industry is complex and cannot be fully captured by such an abstract plan, the roadmap does present a useful variety of alternatives for reducing the industry's carbon footprint across five areas (clinker, cement, concrete, construction, and (re)carbonation). The alternatives mentioned include using biofuels, waste sorting, hydrogen as fuel, renewable electricity, different transport methods, and concrete compositions, but it is difficult to implement these specific measures to reduce the carbon footprint at the country level, as the Dutch TIS market analysis has shown. Therefore, while the creation of roadmaps is a positive step, their applicability to individual countries is limited and needs further action on the national level.

National level - The Dutch government

At this level, it's important for policy goals to be more actionable. While Europe sets measurable targets regarding percentages and deadlines, the Dutch government must activate industries by providing them with actionable tasks and agreements. The government provides subsidies for research conducted by companies and institutions like CE Delft to increase the concrete industry's sustainability. These institutions have presented studies on actions that the industry could take to reduce its environmental impact. In addition, the government also uses sustainability points in tendering processes by calculating MKI scores. These scores are based on the environmental cost of all resources used in a product. Every raw material has a specific value on about 40 different parameters, combined into one score used country-wide and across all industries. This system encourages sustainability within tenders and can even give preference to environmentally-friendly products. Although the branch organization criticized the current working of this system, it has the potential to be improved. This tendering procedure can have a significant impact as the government orders about 40% of the total Dutch concrete production and can thus steer at least part of that production towards CO_2 usage.

The clearest example of actionable policy goals in the concrete industry is the "Betonakkoord" or Concrete Agreement. This is an agreement between industry organizations and the government in which a broad range of actors make promises about their actions regarding concrete usage. Concrete producers, contractors, demolishers, ministries, municipalities, the Dutch railway company, the branch organization, and many more have signed the agreement. Seven different executive teams work within this agreement to develop plans for the tangible implementation of the goals and ambitions of concrete production. While this makes the policy goals much more actionable, the agreements in the Betonakkoord are still focused on too broad concepts. Examples include cooperation in the value chain for sustainability, consistent demand for sustainable concrete, 30% decrease of CO_2 emissions and the stimulation of innovations and social capital. The problem with these goals is that they cannot be measured or ever completely reached. An example of a reachable goal would, for example, be a maximum CO_2 emission of 100 kg per m^3 of concrete from the year 2028 onwards.

In addition to this, there is a set of 28 action perspectives which present 28 principles to make concrete more sustainable for organizations, with only one of them being AC technologies. Companies can choose the perspectives that best fit their processes and incorporate them into their operations. The danger of this concept is that 28 different perspectives are very large, which divides attention over all these different methods. Although the agreement has encouraged companies in the industry to work together and act more sustainably and has helped set expectations for other companies, the goals could be much more direct and specific to give more direction towards sustainability. While the agreement was initiated in 2016, gaining traction has taken some time. One interviewee noted that it often takes time for such efforts to be collectively embraced (Interview A.3.

Intermediaries

The last sub-question for the building block actors is applicable to *Intermediaries* and is: which parties try to collaborate between different parties? One party that already showed up in figure 12 was transport companies. Because the concrete industry is an industry of a physically heavy product, transport is an important factor. Nevertheless, this actor does not experience many changes due to the new technology. The second important factor in this category is the contractor, more specifically, the actor that gives the orders to a concrete producer on what needs to be built for the client. While discussing the concrete industry, a focus goes out to the different actors within that system, but the final client has much to say about what he orders. In the end, the companies within the industry build what the client wants and if that needs to be AC concrete then they will do that (Interview A.1). Thus, the contractor counts as a middleman in that process and can greatly impact the chosen products. The third actor with a useful function is licensing companies (Interview A.5). The industry properties of concrete are important, and the company SGS Introm performs tests and certifies companies on the quality and composition of their concrete. Another important certifier is Nibe, this organization checks Life Cycle Assessments and MKI-scores of companies. This makes sure that claims about sustainability are backed with tests.

The final and probably most important actor within this category is the branch organization Betonhuis. In the past, there were different smaller organizations for the different sub-sectors within the concrete industry. These were sectors like Ready Mix Concrete, Prefab Concrete Products, sewerage products, tiles and stones, and cement production. In 2017, some of these organizations took the initiative to bring these organizations together in one umbrella organisation. All organizations still have their own saying but act coordinated. This includes lobbying, presenting statistics on the industry, coordinating actions like research, and acting on sustainability. The best example of this is the initiation of the Betonakkoord. During the interview, everyone was very happy with the existence and performance of Betonhuis (Interview A.1, A.3 & A.5).

4.1.3 Network

For the building block *Network*, the question to answer is: what does the network look like? To answer this question, the presented information for the previous structural building blocks are combined into figure 13. This figure represents the Dutch concrete network of three main parts: industry, governance and research. It is a deliberate choice to focus on the non-physical network in this section because the physical network is already discussed during the market analysis of section 4.1.2 with figure 12. Examining this non-physical network creates the possibility of involving the other parts of the system within the physical structure and uncovering the places where parts overlap. The most important connections within the system are further explained underneath.

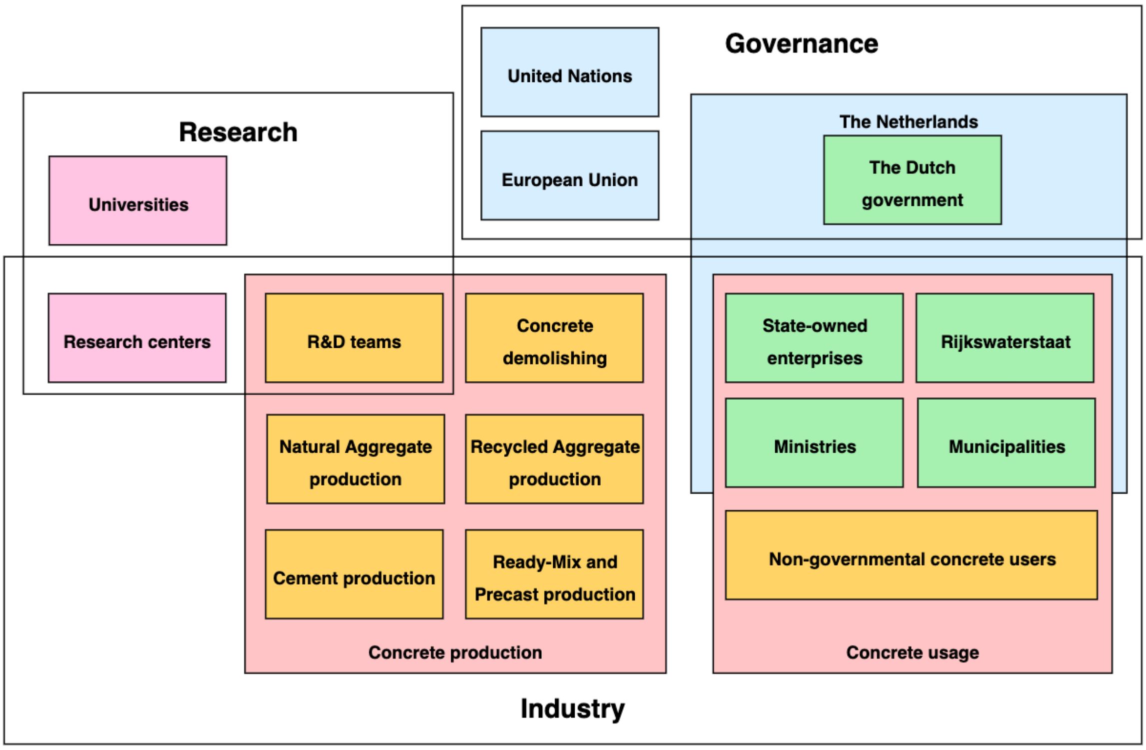

Figure 13: Overview of the Dutch concrete network.

Concrete production and Concrete usage

As seen from figure 13, the industry covers the largest part of the concrete network with a concrete production and usage block. In other words, these represent the supply and demand side of the system within the network. From the market analysis in section 4.1.2, it became clear that the role of concrete usage for sustainability (and thus AC technology) is much bigger than expected. The reason for that is that the usage side of the industry can decide what specific concrete is produced because of their demand role and thus have an influence on the sustainability of the concrete production. What can be seen from the figure is that each section links one of two external parts to the industry part. Research is connected to the production and, thus, supply side, while governance is connected to the usage and, thus, demand side. When presented like this it also makes sense from a supply and demand side; the demand can be governed, and what is demanded needs to be further developed with research. It is important to emphasize that the concrete usage is within the production chain in figure 12. For this network analysis, this means that the concrete production and concrete usage block are connected to each other and constantly exchange goods and information. This way, the industry is connected and functions in the right direction. The linkages between the different parts are further explained underneath.

Concrete production and Research
The concrete production block, or supply side of the industry, is presented at the centre of the network. As expected, concrete production is at the heart of the network and the rest exists around it. What stands out is that research is connected to the industry because of research centres and even more through R&D teams within the production chain. As explained in the research analysis in section 4.1.2, the knowledge of technologies can be expressed with the TRL system. This flow can also be seen within the network, from TRL1 to TRL3 at universities to TRL4 to TRL7 at research centres entering the industry until finally at TRL8 and TRL9 at R&D teams ready for the market within the concrete production block. In reality, these levels are crossed daily, so universities at TRL6 and R&D teams at TRL4, because these different actors work together and development is steered in the right direction. This enables a useful connection between research and industry.

Concrete usage and Governance
The concrete usage block, or demand side of the industry, is presented slightly right to the centre of the network. This block exists for governmental and non-governmental concrete users. The fact that many government actors are present creates a strong link between governance and industry and provides power to the Dutch government. As mentioned earlier, the demand side of the system can ask for concrete with higher sustainability from the demand side. If the Dutch government can make sure that governmental organizations choose sustainable technologies more often, this will have a direct impact. An example of this already happening is that many of these organizations have signed the Dutch concrete agreement, which shows the intention of becoming more sustainable (Betonakkoord, n.d.). Next, many of these organizations must allocate work for concrete production based on tender procedures because government funds mainly fund them. This tender process has shown results and potential in section 4.1.2 to foster the implementation of AC technology. The other party, non-governmental concrete users, is also part of this block but can be steered less towards sustainability by the government. Nevertheless, there are still ways in which they are stimulated to become more sustainable.

Further important relations
Lastly, there are relations within the network which are not visible in terms of relations between actors, but certainly by other definitions. The first important one is the influence of the green block "The Dutch Government", which can create policy regulations for the entire industry to increase sustainability. An example is to steer non-governmental concrete users in the right direction and influence concrete production directly. A second important influence within the network is the given funding, as can be read in the politics & policy section 4.1.2; the EU and the Dutch government give large amounts of money to research to foster technologies like AC technology.

4.1.4 Technological development stage

The second step after the structural analysis and before giving an answer to the first SQ is determining the development stage of the TIS. This has to be done based on the four questions presented in section 3.3.1. If the answer for a phase can be given, the TIS moves one stage forward in its development. After discussing the TIS during the previous structural building blocks, the conclusion can be drawn that it has just entered the take-off phase but this is still very minor and a big part of it still is in the development phase. An explanation will be given in the next part by walking through each question from the pre-development to the take-off phase.

Pre-development stage
The question for the first phase is: is there a working prototype? Before answering this question, it is important to refer to the end of section 4.1.1 where the different technologies were discussed. Different technologies at different development stages are part of these methods when looking at the three main methods of adding CO_2 as a resource. Therefore, answering this question for the three individual methods is important before concluding the entire TIS. The first method, carbon-conditioning RAs, has a working prototype since there is a lot of research on improving the method, as can be read in section 2.2.1 and 4.1.1. This method does not have a lot of different technologies, because the process is quite simple and not many things can be changed in the process. The second method, carbon-curing PCPs, has a lot of different technologies, and all have working prototypes (Carbstone, Solidia). As mentioned during the technological analysis, different companies are already

experimenting with these technologies or creating products for the market. The last method, adding CO_2 in the mixing process, exists of only one technology and is also used commercially. The answer to the question is thus yes, there is a working prototype.

Development stage
If these methods are examined for the second development phase, the question is as follows: is there a commercial application? When related to the first method discussed, this is partly true and partly not. It is currently not beneficial to companies to treat RAs with CO_2; however, the use of RAs by concrete producers has been increasing fast in the last few years, which thus shows potential. Next, Carbon8 produces aggregates with CO_2 and is commercially used. Nevertheless, this method is not using recycled aggregates but other waste streams but it is used during concrete production. The second method discussed definitely is experiencing commercial application since multiple technologies and companies use these technologies. The last method is also clear; it is being used in America and now moves to countries like The Netherlands with tests at some companies. In conclusion, all three methods thus have commercial applications, which means that the TIS thus moves forward to the third phase: The take-off phase.

Take-off stage
If this enters the third phase, the question becomes: is there a fast market growth? This is a no for the first method since only Carbon8 is starting to enter the Dutch market. When looking at the second method, this is not the case. Since most companies are experimenting with the technology, the right applications still need to be found. Next, the third method is growing slowly since it is just now entering the Dutch concrete system. Nevertheless, it is becoming more known among concrete producers, which could lead to an increasing growth speed. If a conclusion is drawn on these three methods, the answer to the question is no, so the TIS has not yet left the take-off phase. In addition, I want to conclude that the TIS is very early in the take-off phase and probably is still in the development phase for the largest part. All methods are just out of the development stage or have not even left that stage, which leaves the entire TIS in between the development stage and the take-off stage.

4.2 SQ2: Functional analysis

For the functional analysis of this research, structured interviews were conducted. The exact outcomes of these interviews are presented in appendix B while the cleaned data used for this analysis is presented in appendix C. The exact cleaning process can be explained in that same appendix. Within this section, the results of the interviews will be discussed one by one per functionality, concluded by an overview table which presents all final average scores for the spider diagram.

Before going into the results, an important notion needs to be made about the use and interpretation of these scores. Because this research is qualitative, the scores cannot be seen as hard numbers that indicate exact measures or conclusions. These scores must indicate whether specific parts of the system or functionalities are working well or badly. All scores are relative to each other and most value comes from the explanations from the interviewees on why these specific scores are given. Therefore, throughout this section, a score will be presented to give direction, which will then be followed by all different arguments given by the interviewees to provide context on that score.

Within every table, an average score for every question is presented per sector (research, industry and government) and the total average score for that question. In addition, the question scores are combined in the bottom row to present average functionality scores for each sector and a total average for all interviewees. Remember that the total average scores are not the average of the three different sector scores combined, but of all interviewees. Another important aspect here to keep in mind is the fact that some questions are only scored by one interviewee per sector, whereas every interviewee from another sector can score other questions. A score based on more interviewees from a sector has more value than a score from only one interviewee. To remain sight on this, the number of interviewees that answered per sector is given in the upper row behind every sector.

4.2.1 Entrepreneurial activities

The first functionality discussed is *Entrepreneurial activities*, which is scored based on five different questions as seen in table 7. The questions were answered by one interviewee from the research sector, five from the industry sector and two from the government sector. Overall, the functionality scores a 3.4, indicating a sufficient level of entrepreneurial activities. What stands out is the high score from the industry (3.7) in contrast to both the research (2.8) and the government sector (2.9). Another thing that stood out was that one interviewee from the government sector stated that he did not know enough about the technologies to answer the questions. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.1.

Table 7: Average sector scores for functionality 1

	Research average (1)	**Industry average (5)**	**Government average (2)**	**Total average (8)**
Q1: Sufficient relevant and diverse actors?	2.0	4.4	2.0	3.5
Q2: Sufficient industrial actors?	2.0	4.0	4.0	3.8
Q3: Sufficient industrial innovation?	4.0	3.4	2.5	3.3
Q4: Sufficient large-scale production?	2.0	3.4	2.0	2.9
Q5*: Experimentation forming a barrier to growth?	4.0	3.2	4.0	3.5
Functionality score	2.8	3.7	2.9	3.4

* This row represents a question where a positive reaction has a negative effect on the system and vice versa; the scores are converted to the right Likert scale from appendix B to appendix C.1.

Q1: Sufficient relevant and diverse actors?
The average score for the first question on the sufficiency of relevant and diverse actors is 3.5, with research scoring relatively low (2.0). The given argument is that in The Netherlands, the primary focus is on reducing emissions from raw material use and the production process of concrete instead of looking at how production processes can keep emitting while compensating for it by putting CO_2 back into concrete (removing emissions from the source instead of compensating afterwards). Because of this, there are not enough relevant and diverse actors focussing on these technologies.

The industry was much more positive (4.4), as two interviewees mentioned that the industry is starting to see a collective benefit in working towards sustainability. This results in the Dutch concrete system moving towards sustainability, with many parties open to using new technologies like these. Others emphasized that many concrete producers are present within this system, which again brings many opportunities to implement these technologies. One interviewee was more negative and mentioned that while the industry has the Betonakkoord in place, more active participation from multiple parties, such as ENCI, contractors and others, is necessary to be successful.

The government sector was also negative (2.0), mentioning the industry's lack of growth and instability. This is caused by factors such as the nitrogen crisis and a decrease in demand from Rijkswaterstaat, influencing actors' ability to use new technologies. At the same time, they mention that the industry wants an innovation that the government is stimulating. Nevertheless, Rijkswaterstaat has not been offered any pilots related to these AC technologies, so they cannot stimulate them. They also emphasize, like research, that the focus is mainly on reducing energy and raw material consumption during production (removing emissions at the source) instead of putting CO_2 back.

Q2: Sufficient industrial actors?
The average score for the second question on the sufficiency of industrial actors is 3.8, with research scoring again relatively low (2.0). For research, the same explanation was given as the previous one; the primary focus

in The Netherlands is on reducing emissions from raw material use and concrete production process instead of putting them back.

The industry was much more positive (4.0), mentioning that there are many possibilities for using technologies such as Carboncure and Carbon8 in the concrete industry, as these can be applied to a wide variety of types of concrete. Although some specific technologies require special characteristics, such as porous structure for Carbstone, all technologies offer enough opportunities for industrial actors. Other interviewees note that concrete is one of the most used materials worldwide, mentioning different industries, housing, infrastructures and, for example, the large demand from the Dutch government. Because of this great usage and Dutch demand, there are a lot of concrete plants in The Netherlands and thus, many opportunities for industrial actors to use these technologies. A last interviewee was more negative, noting he does not see many industrial initiatives that apply these technologies and that there is a lack of cohesion within the concrete industry. This results in many different initiatives but little focus on specific ones.

The government sector was also positive (4.0), mentioning that industrial actors could implement these technologies, but this is currently not going very well. One obstacle mentioned is the need for CO_2 capture and usage to be geographically close to mitigating transportation emissions, a problem due to cement production outside of The Netherlands and concrete production within The Netherlands. They also noted that the housing sector might be more successful in adopting these technologies due to less disruption during the recent nitrogen crisis. Nevertheless, they see enough opportunities for industrial actors, to increase their actions towards these technologies.

Q3: Sufficient industrial innovation?
The average score for the third question on the sufficiency of industrial innovation is 3.3, with the research sector scoring substantially higher (4.0). The interviewee from the research sector stated: "I can see various initiatives being applied, which shows that a lot of innovation is happening in this area. Especially the number of different technologies is starting to increase."

The industry's opinion is mostly positive (3.4), while a number of innovations have started to enter the market, and some are already being used. Technologies like Carbstone are being used for certain products, while others such as Solidia, Carbon8, and Carboncure are still somewhat earlier in development. Despite this, there is a lot of general experimentation within the industry, which is also the case with the use of CO_2. However, it is opined that the industry should prioritise innovating using CO_2, which is currently insufficient. Nevertheless, The Netherlands is considered more innovative than Belgium, with a more focused search for new production methods in the building sector. However, there is a lack of industry initiatives that use these types of technologies, and there is a lack of cohesion within the concrete industry, which results in many different initiatives but little attention to specific ones.

The government sector was substantially more negative (2.5), mentioning that the industry is willing to adopt new technologies but also has to deal with regulations. They can experiment as long as they stay within the regulations, but it becomes difficult when they go outside. The government requests validated products with a standard of 100 years of usability, often seen as challenging for new technologies. If companies want to use these technologies, they ultimately have to go through the validation process, which an innovation desk supports. Another innovation-stimulating aspect is the obligation from Rijkswaterstaat for market participants to have a yearly decreasing annual MKI score. Again the argument about solving the problem at the source is brought up; within The Netherlands, there currently is not much belief in the idea of capturing and reusing CO_2.

Q4: Sufficient large-scale production?
The average score for the fourth question on the sufficiency of large-scale production is just below neutral with 2.9, while research scored low again (2.0). The research sector mentions that the concrete industry is very large and produces on a large scale, but challenges arise when these new technologies are used. For example, processing and reusing concrete waste is much easier on a laboratory scale than on a large scale. It is difficult and complicated to process and reuse concrete waste, which makes the large scale of the industry actually a problem rather than a benefit.

The industry is much more positive (3.4), mostly because of the volume-driven character of the industry. This partly comes from the cement industry, which wants to turn over as much cement as possible and partly because concrete producers experience cost benefits when they produce on a large scale. A downside is the industry's fragmentation level, which sometimes creates problems for large-scale production, and some technologies cannot be used for certain products. Nevertheless, there is enough production on a large scale to implement the technologies. Last but not least, it is emphasized that this large-scale production brings major upsides for technologies like Carboncure (which decreases cement percentages in concrete). Cement has become very expensive during the last year and with technologies like Carboncure, the amount of used cement can decrease. If a few % of cement can be left out for 400.000 m^3 that means enormous cost savings.

The government was much more negative (2.0), mostly because the technologies cannot be used when load-bearing constructions are made and the fact that the industry is largely influenced by the European cement industry, which has a monopoly position. This gives them the power to control what technologies are used because, in the end, they want to sell as much cement as possible.

Q5: Experimentation forming a barrier to growth?
The fifth question on experimentation forming a barrier to growth scored an average of 3.5, with the research sector scoring relatively high (4.0). They argue that there is no barrier because it is business as usual within the industry until new technologies are available that work well. This is mainly a sliding scale, where new ideas are developed daily with small step-by-step adjustments until they are implemented when they are ready to use. This, thus not leads to barriers to the large-scale implementation of technologies.

The industry scored the question neutral (3.2), with two main arguments. The interviewees that say there is no barrier say that because, in their opinion, there cannot be too much experimentation because the entire industry needs to change. The opposite opinion, saying there is a barrier, points at the repeating argument that the industry is fragmented, dividing all attention over different innovations. In their opinion, focusing on fewer innovations would create more financial and human resources for these specific ones to be implemented faster.

All interviewees from the government sector were very positive (4.0) and argued that, in their opinion, there is no barrier to the technologies because there is little experimentation with CO_2 use as raw material and the innovation process for other technologies does also not experience similar problems. This would mean that there is no barrier to the implementation of these technologies.

4.2.2 Knowledge development

The second functionality discussed is *Knowledge development*, which is scored based on four different questions as seen in table 8. The questions were answered by four interviewees from the research sector, one from the industry sector and zero from the government sector. Overall, the functionality scores a 3.6, indicating sufficient knowledge development. What stands out is that the research (3.5) and industry sector (4.0) score this functionality substantially above neutral. The last important notion is that only one interviewee represents the industry for this functionality, and the government sector was not interviewed. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.2.

Table 8: Average sector scores for functionality 2

	Research average (4)	Industry average (1)	Government average (0)	Total average (5)
Q1: Sufficient amount of knowledge production?	3.3	4.0	-	3.4
Q2: Sufficient quality of knowledge production?	3.5	4.0	-	3.6
Q3: Sufficient fit between knowledge and needs?	4.0	4.0	-	4.0
Q4*: Quality/Quantity forming a barrier to growth?	3.3	4.0	-	3.4
Functionality score	3.5	4.0	-	3.6

* This row represents a question where a positive reaction has a negative effect on the system and vice versa; the scores are converted to the right Likert scale from appendix B to appendix C.2.

Q1: Sufficient amount of knowledge production?
The average score of the first question about the sufficiency of knowledge production is 3.4, with the research scoring similar (3.3). Interviewees from the research sector gave varying opinions, with one noting that the knowledge available in the community is quite large and that the process of science behind the carbonation process of limestone is very fundamental and thus far developed. Nevertheless, another interviewee adds that the industry could increase current knowledge. Another interviewee was more negative and mentioned that the development of knowledge on this technology is low, with the same argument as functionality 1: the focus in The Netherlands is on producing concrete with as little emissions as possible (solving the problem at the source) instead of capturing and reusing CO_2. This interviewee notes that the lack of development in CO_2 technologies is not a problem. It is a European market and the technology will come to The Netherlands if it succeeds in other countries. Lastly, another interviewee is more negative and notices a fragmented industry, with everyone doing their research without collaborating.

The industry sector was more positive (4.0), with the notion that research is going well because of the system and that the large companies are doing most of the research work for the industry.

Q2: Sufficient quality of knowledge production?
The second question on the sufficiency of the quality of knowledge production had an average of 3.6, with research scoring similar (3.5). Most interviewees from the research sector have a positive view of the quality of AC technologies. They state that the principle of carbonation is quite obvious and that the knowledge is of good quality since it is replicable. Nevertheless, tension is mentioned for the technology between CO_2 use and reinforcement within the concrete. It is mentioned that AC technologies cannot be used when these are present, because the reinforcement could start to corrode after a while. One interviewee scored 2 and stated that the knowledge development about these technologies in The Netherlands is low due to a fragmented Dutch concrete market which misses opportunities for scale advantage.

The interviewee from the industry sector had a positive view (4.0). He stated that the Dutch quality system demands that new technologies are thoroughly demonstrated and that research must ensure that the quality of these new products is of good quality. He emphasizes that the system works well in The Netherlands and is well structured.

Q3: Sufficient fit between knowledge and needs?
The average score for the third question on the sufficiency of fit between knowledge and needs is 3.8, while the research sector scored similar (4.0). One interviewee from the research sector stated that the knowledge developed on CO_2 usage during concrete production will always be the right type because it is a very simple

process. Carbonation is a natural process that can be applied within concrete production, and knowledge can be applied. Another interviewee explained that the Dutch research system is very well organized. Because of this, the right knowledge will always find its way to the right place in the industry. All interviewees agree that the knowledge fit with industry needs is good and that the system works well.

The interviewee from the industry also noted that the knowledge developed is suitable for the industry (4.0), but the industry does not make enough use of it. This is due to a lack of investment and demand from contractors. The investments made need to be earned back, but when there is not enough demand for these products, that will not happen. The reason that demand does not come in is because of the contractors. Unless the client asks for them, they have no direct incentives to use these technologies to make buildings more sustainable. But, the knowledge is only entering the industry part of the system, so contractors and clients do not know about them.

Q4: Quality/Quantity forming a barrier to growth?
The average score for the fourth question on whether there is a barrier to growth because of quality or quantity of knowledge scored 3.4, with the research sector scoring similar (3.3). The interviewees from the research sector provided various explanations for this score, with one interviewee mentioning that there is a barrier in the application of the technology, but that this is more of a usage issue rather than a quantity or quality issue. Another interviewee stated that it depends on which part of the system is being considered, and then also mentioned an applicability barrier. Another interviewee mentioned that there is not too much knowledge development for the industry, but some outsiders might think it is. He emphasizes that the system works well; anybody that wants to differ from the safety rules to innovate can do that. Finally, another interviewee mentioned that the industry is currently scaling up the technologies, so it can be seen as a challenge that is being addressed rather than a barrier.

The industry sector scored the fourth question high (4.0) with the explanation that there are possibilities due to the amount and quality of the research, but the question is how much the industry wants to use it. The current barrier is not about the knowledge type, but the fact that we do not use it.

4.2.3 Knowledge exchange

The third functionality discussed is *Knowledge exchange*, which is scored based on five different questions as seen in table 9. The questions were answered by four interviewees from the research sector, five from the industry sector and three from the government sector. Overall, the functionality scores a 2.7, which indicates an insufficient level of knowledge exchange. What stands out is the fact that research (3.2) thinks it is at least neutral, while the industry (2.6) and the government sector (2.4) both score the functionality substantially insufficient. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.3.

Table 9: Average sector scores for functionality 3

	Research average (4)	Industry average (5)	Government average (3)	Total average (12)
Q1: Sufficient knowledge exchange (science & industry)?	3.7	2.4	2.7	2.8
Q2: Sufficient knowledge exchange (industry & users)?	2.3	2.4	2.3	2.3
Q3: Sufficient knowledge exchange across borders?	3.7	3.0	2.3	3.0
Q4*: Problematic parts for knowledge exchange?	4.0	2.8	2.0	3.1
Q5*: Knowledge exchange forming a barrier to growth?	2.5	2.6	2.7	2.6
Functionality score	3.2	2.6	2.4	2.7

* This row represents a question where a positive reaction has a negative effect on the system and vice versa; the scores are converted to the right Likert scale from appendix B to appendix C.3.

Q1: Sufficient knowledge exchange (science & industry)?
The first question on the sufficiency of knowledge exchange between science and industry scored slightly below neutral with 2.8, while the research sector scored much more positive (3.7). Interviewees had mixed opinions, with someone mentioning attention to the technologies some years ago which disappeared for a while and is now gaining interest again due to government environmental actions. Another mentioned that knowledge exchange is going well since the branch organization, universities, and research centres have well-performing partnerships. Others felt that the technologies were starting to be picked up in certain areas, such as concrete production in Belgium, leading to increased contact between industry and research. Lastly, there was also a notion of tension between industry and science, with actors from the industry not wanting to share knowledge, while science is obliged to share knowledge since they are being funded by public money.

The industry sector was much more negative (2.4), with various arguments on the level of knowledge exchange between science and industry. They cited a lack of time to focus on innovation due to the high demand for construction, a lack of human resources to implement the technologies, and the fact that companies need to earn back their investments. The complexity of the process and difficulty in making changes to factories and training staff were also mentioned as barriers. Next, an interviewee noted an important difference between research and industry. The industry has a financial stake, while research has a scientific stake, which creates a situation where they are not always on the same page. The research should understand that the industry sometimes thinks from a different perspective. Lastly, one interviewee mentioned that they went to Gent to see a test setup for using such technologies, a positive example of knowledge exchange.

The government sector scored the first question low (2.7) with mixed opinions on the level of knowledge exchange between science and industry. Some felt this was developing well and mentioned much contact between Rijkswaterstaat, TU Delft, TNO and the industry. Two others responded more negatively, arguing that they think research sometimes does not match reality because of different perspectives from research and industry. A consequence is that they are sometimes not on the same page.

Q2: Sufficient knowledge exchange (industry & users)?
The second question on the sufficiency of knowledge between industry and user scored low at 2.3, with the research sector scoring similar (2.3). Interviewees from the research sector were mostly negative. They noted that the main reason is that concrete producers are just starting to understand the technology, so up until now, they could not explain or present the products made with these technologies to developers and contractors. It is only now that producers can bring these products to the market (developers and contractors). One interviewee added that larger contractors have R&D teams that can effectively communicate with concrete producers and

exchange knowledge on this topic. This will result in smoother exchange and earlier adaptation by the companies with R&D teams, but this is also starting to happen.

The industry sector scored similar (2.4), with mixed opinions on the question. Some felt that the industry is too busy with production and reporting on sustainability to focus on implementing new technologies. Multiple others mentioned the same as research, it is not yet clear to the industry what can be done with the technologies and how it will impact their products which makes proper communication with developers and contractors not possible. Lastly, two arguments are contradicting, but at the same time describe the current situation. On the one hand, developers and contractors are asking for products with better ecological results demonstrably. While the other interviewee mentions that there is almost no real attention to environmental certifications and that most of becoming sustainable is about image. One of these interviewees closed with the statement: "If a scientist starts talking about this technology, the industry thinks that is going to cost me money. But, if the user asks about this technology, the producer thinks this will make me money". This points out that the industry is currently creating sustainable measures to create sustainable measures, while this should be to guide the final user in the right direction to make the right choice (which is currently not happening).

The government sector had mostly negative opinions (2.3), with someone stating that the technology is not yet known to Rijkswaterstaat so knowledge exchange seems lacking. Another interviewee again referenced the different perspective of The Netherlands on solving the emission problem at the source (reducing emission) instead of compensating afterwards by putting it back. The last interviewee mentioned that using such new technologies will cost substantial money (80k to 100k) to be completely tested and verified. However, the technology is considered reliable and can be used when that is done. It will then be put up within the National Environment Database, which shows specific sustainability to possible users (developers and contractors). Nevertheless, this does cost a lot of money and currently seems like a barrier.

Q3: Sufficient knowledge exchange across borders?
The average score for the third question on sufficient knowledge exchange across barriers is neutral at 3.0, with the research sector scoring substantially higher (3.7). Some research interviewees argue that there is indeed knowledge exchange across borders, referring to the example of a Canadian company that started with Carboncure, which is currently also found in Belgium. They also note that there are many local initiatives in different countries, which will go over borders when seen that these technologies work well. Another interviewee adds, just like for the previous functionality, that the system is doing its job. The exchange of knowledge is not rooted in organizations but relies on individuals that maintain their international network and keep looking for these technologies. This Carboncure example is a perfect illustration of that. The last interviewee was more negative, mentioning that countries go their own way and do not exchange much knowledge.

The industry sector scored slightly more negative but still neutral (3.0), with one interviewee arguing that there is not much knowledge exchange because of an earlier given argument. They are too busy with production and lack personnel to focus on installing new technologies. Two other interviewees scored even lower, stating they could not give any example or experience of knowledge exchange across borders. However, some interviewees gave a more positive score, stating that there is indeed knowledge exchange. Examples are given of the earlier mentioned visit to Gent to learn about new technologies but also the import of the technology Carboncure from Canada.

The government sector scored the third question low (2.3), with two interviewees arguing that they have very little knowledge of this question. They had the idea that there is very little or no knowledge exchange. The reason for this is that The Netherlands is probably not a strategic goal for these technologies since the perspective on the solution for the problem is different within The Netherlands (rather removing emissions from the source). Nevertheless, it is emphasized that the European concrete industry has some very large players, creating a strong network that can probably implement technologies quickly if they want to.

Q4: Problematic parts for knowledge exchange?
The fourth question on whether there are problematic parts for knowledge exchange is neutral with 3.1, while the research sector scored high (4.0). Research interviewees all agree that there are no problematic parts to knowledge exchange. They note that knowledge development is relatively active, and some large companies are frontrunners in developing knowledge. According to them, it is normal for some companies to be more innovative than others. Next to that, in their opinion, actors find each other where needed, supported by platforms like congresses and different actors like the branch organization. In conclusion, two side notes are given: it is important that enough funding is available for development, and industrial actors must take the initiative to look for this knowledge exchange.

The industry sector scored average (2.8), with interviewees having mixed opinions. Some argue that there are problems with knowledge exchange because of a lack of capacity and time due to high production demands and a lack of personnel. They mention that everyone is in the same position, wanting to exchange knowledge and innovate but unable to because of time constraints. Two other interviewees argued similarly, mostly mentioning that this process takes time. In addition, they both also point to the economic perspective of the industry. Industrial actors do not see any clear proof of these technologies for profitability. That creates a situation where the industry has no incentive to pick these technologies up. Another interviewee was more positive and argued that there are few problems with knowledge exchange. Lastly, someone mentioned he did not know enough about these technologies to give an answer.

The government sector scored the fourth question low (2.0) and all agreed on that. Interviewees generally mentioned problems with knowledge exchange, stating that the technology is not known and, therefore, there is little to exchange. They also mention that they do not believe that capturing CO_2 emissions is the solution to the problem (Dutch perspective); therefore, it is not done right now. One interviewee also stated that he had no answer to the question.

Q5: Knowledge exchange forming a barrier to growth?
On average, the fifth question about knowledge forming a barrier scored 2.6, with the research sector scoring similar (2.5). Interviewees noted that the technology is relatively simple to understand, but there are challenges in terms of implementation, such as sourcing CO_2 and the potential costs and benefits for companies. Others pointed out that technology cannot be forced and that communication is key in addressing difficulties. Additionally, some interviewees highlighted the lack of follow-up on experiments in real-world situations, and that this is a barrier due to a lack of budget and communication. Some interviewees also mentioned the importance of knowledge exchange platforms and the role of industry associations, but that it is ultimately up to individual organizations to participate. These arguments point in the same direction; the barrier in exchange is a lack of communication on application, uncertainty, benefits and possibilities for the industry. If too many uncertainties exist and the industry is not incentivised to implement these technologies, they will not be used.

The industry sector also had a low score, with interviewees noting the amount of work being too much combined with too few people and too little time. This results in a choice between development and production, with the latter often prioritized for financial reasons. Something that is in line with this argument is the lack of incentive to exchange knowledge and take action within the industry, just as mentioned by the research sector. Other interviewees stated that a lack of knowledge is a barrier to knowledge transfer, which was also mentioned by research as a reason why there is no incentive. Some interviewees also mentioned that there is no current problem and that the transition from fossil fuels to renewable energy is similar. They emphasize that the industry is already changing direction and needs time since it is so large.

The government sector scored the fifth question also low (2.7), with some interviewees noting that in The Netherlands, there is an open system of knowledge exchange and that there is thus no barrier because of knowledge exchange. Others disagreed and again emphasized that these technologies cannot be applied for load-bearing constructions, which makes this technology unusable for them. A last interviewee referred to a recent meeting between Rijkswaterstaat, a research organization and the branch organization about concrete compositions. In his opinion, he notices a barrier regarding knowledge exchange during that meeting.

4.2.4 Guidance of the search

The fourth functionality discussed is the *Guidance of the search*, which is scored based on six different questions as seen in table 10. The questions were answered by four interviewees from the research sector, five from the industry sector and three from the government sector. Overall, the functionality scores a 2.8, which indicates an insufficient level of guidance in the search. What stands out is the fact that industry (2.9) thinks it is at least neutral, while the research (2.5) and the government sector (2,2) both score the functionality as substantially insufficient. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.4.

Table 10: Average sector scores for functionality 4

	Research average (4)	Industry average (5)	Government average (3)	Total average (12)
Q1: Clear vision on growth development?	2.5	2.4	3.0	2.5
Q2: Clear vision on technological design development?	2.5	2.8	2.0	2.5
Q3: Positive expectations regarding technological field?	3.3	3.6	3.0	3.4
Q4: Clear policy goals regarding technological field?	2.5	2.4	2.0	2.3
Q5: Goals sufficiently reliable and doable?	2.0	2.8	2.0	2.5
Q6: Stakeholder visions and expectations aligned?	2.5	3.5	2.0	2.8
Functionality score	2.5	2.9	2.3	2.8

Q1: Clear vision on growth development?
The average score for the first question, whether there is a clear vision on growth development, scored 2.5 on average, with the research sector scoring similar (2.5). Three research interviewees state that there is a vision of CO_2 reduction, and the focus is on reducing total emissions, but not on specific technologies and how to realize this. Another interviewee mentions the Betonakkoord and notes that one of the twenty-eight methods to increase sustainability has to do with these technologies, which shows how fragmented the industry is. Concluding, while on the one hand, it is emphasized multiple times that actors have the freedom to choose their own methods and technologies, the question can be asked whether it is currently not too free and too diverse with all these different options and possibilities (28 acting perspectives).

The industry sector also scored very low on this question (2.4). Three interviewees argue that there is currently no clear vision of how the applicability should develop, with one noticing that the technology is mentioned as one of the acting perspectives from the Betonakkoord but this is not quantified. Two other interviewees are slightly more positive, one mentioning that there are plans within the 2030 agreement to halve emissions, but not much is changing. Right now, emissions are being reported more clearly and it appears that things are getting better, but in reality, they are only reported better. An interviewee from Belgium says that The Netherlands is further along than Belgium with their vision; they know where they want to be in a certain number of years.

The government sector scored this question higher, with a neutral score (3.0). One of the interviewees could not answer the question, while another one again emphasized that Rijkswaterstaat does not believe that CO_2 usage is the solution because, within The Netherlands, there is a different view on this. It is also added again that these technologies cannot be used when reinforcement is present in PCPs, making them less attractive for load-bearing constructions. The last interviewee is slightly more positive and sees new technologies and ideas, but these must be further developed.

Q2: Clear vision on technological design development?
The average score of the second question, whether there is a clear vision of technological design development, is low at 2.5. The interviewees from the research sector combined gave the same score (2.5) with similar arguments, most of which mentioned a lack of vision. The vision from the government that is present is on CO_2 reduction, but not on specific technologies that can contribute to that. From a research perspective, it is more on all aspects required for these technologies, but not how all these aspects can be brought together in reality, which in their opinion, is a government task. The last interviewee emphasizes how these visions are formulated, enabling companies to choose their technologies. This leads to many technologies that must share all resources and attention, which can slow progress. Nevertheless, this does not directly means a problem, but it is more a

chosen way of organizing a system.

The interviewees from the industry scored this question similarly (2.8) with many arguments on a lack of clarity in the vision because different things are still uncertain. Interviewees mentioned examples like, it is not sure how CO_2 usage is going to be handled financially (emission trading system), how the technologies are going to be scaled from laboratory to industry, what the possibilities within the market are, what the financial gains will be and what the right specific technological design for the industry is. It is emphasized that the industry has the willingness and resources to innovate, but the government could guide this process more.

The interviewees from the government scored this question lowest (2.0). Arguments are similar to the answers to the previous question, emphasizing that most actors within The Netherlands do not believe in capturing and using CO_2 as raw material and the argument about these technologies being unable to be combined with reinforcement due to corrosion. Another interviewee mentioned that the vision is still very diverse, but this is common for new technological fields that need to find their way since everybody still has many different ideas. One interviewee also mentioned he did not know enough about the technology to answer the question.

Q3: Positive expectations regarding technological field?
The average score of the third question, whether there are positive expectations regarding the technological field, is relatively high to the other questions for this functionality at 3.4. The interviewees from the research sector scored this similarly (3.3), with some interviewees noting positive expectations about specific subsections of the technologies like PCPs, RAs and Carboncure technology. Other technologies were seen as more difficult and a notion was made about technologies like Carbstone, which are not really concrete (because there is no cement) but will compete with concrete in building materials. Another interviewee mentions the strong position of cement producers within Europe because they produce most of the cement for the European market. They are expected to be held accountable for the future CO_2 emissions and thus will probably decide which technologies are chosen to resolve the emissions problem. He is negative regarding this question since he sees no technologies for CO_2 usage from these players.

The interviewees from the industry scored the question even higher (3.6) and all argued positively. Most mention that the companies working on the new technologies are positive, but it is more applicable to some industries than others. In addition, a side note is made that many things are still uncertain and need to be found out better. It is also mentioned that the current innovation is increasing since pressure on the industry is rising; some parties will step up if the problem becomes too large or the pressure becomes high enough. The same counts for cement producers; they see decreasing cement sales and actively try to protect their market share.

The score from the government sector was neutral but the lowest of this question (3.0) with very mixed arguments. One of the interviewees was not able to answer the question, while another one was very positive and mentioned a large trust in the Dutch innovation power but emphasized that this often needs some support from the government. Nevertheless, another interviewee strongly disagreed with this, again mentioning the two arguments about The Netherlands focussing on reducing emissions at the source instead of putting it back in concrete and the lack of applicability of the technologies for PCPs with reinforcement.

Q4: Clear policy goals regarding technological field?
The average score of the fourth question, whether there are clear policy goals regarding the technological field, is low at 2.3, with the interviewees from the research sector scoring similarly (2.5). Two interviewees mention they cannot answer the question due to a lack of knowledge. One interviewee mentions that there are no clear policy goals and emphasizes that the industry is fragmented, with everyone following their own course. The last interviewee states that most goals are too abstract, like the Grondstofakkoord, the climate goals of Paris, different transition agendas and the Betonakkoord. Within the last agreement, things become slightly more specific with the 28 action perspectives, but this is still unclear.

The average industry score for the fourth question is similar to the overall average score (2.4), with arguments from various perspectives. The interviewees that score low have different arguments, one of them arguing that the Dutch way of looking at the emission problem is to minimize emissions instead of putting them back into the concrete. Another interviewee stated that the technologies are mentioned within the acting perspectives of the Betonakkoord, but this is still not a very clear way of steering. The last negative argument was that they wanted to address the problem, but the implementation is not yet. Awareness of the problem is increasing and some small innovations are popping up but it is not yet catching on completely. Two others are much more positive, one also mentioning that these technological goals are absent, but according to him, this is a very good thing. Requirements to use specific resources are bad since this takes away the freedom of the industry. Policy tools like the MKI score are much better since these steer in a much broader way with a higher goal than specific methods. Another interview thinks there is a lot of steering on this aspect, also from the higher European order.

The government gave the lowest score to this question (2.0), with one interviewee mentioning that he did not have enough knowledge to answer the question. Another interviewee again argued that Rijkswaterstaat is currently not believing in these technologies because of the different way of looking at the problem in The Netherlands and the lack of applicability of the technology in PCPs with reinforcement. The last interviewee had not seen any clear policy goals regarding the technologies.

Q5: Goals sufficiently reliable and doable?
The fifth question on the reliability and doability of goals scored 2.5 on average, which is relatively low. The average score given by the research sector was even lower (2.0). Most interviewees could not answer the question because they knew nothing about these goals, and their scores were not used. Arguments were that this should be asked of actors from the industry, interviewees only knowing this for Belgium and the fact that others did not know. Another interviewee stated that there are no industry-wide goals and only individual goals, which he hopes are executable.

Interviewees from the industry sector scored relatively high compared to other sectors (2.8). One interviewee mentioned that these goals are not there, with two other interviewees having doubts about the timeframe in which these goals need to be achieved. They think the goals are executable but not within the addressed timeframe. Another one answered with the mention that the industry wants these goals to be achieved and are working on them, while the last interviewee mentioned that in Belgium, the industry is somewhat more hesitant about the trustworthiness of the goals but has trust in the executability of the goals.

The government sector scored this question very low (2.0), just like the research sector. The arguments for this were exactly the same as the previous question; one could not answer the question, another had not seen any of these policy goals and the last interviewee brought up the same two arguments. Rijkswaterstaat does not believe in this approach to resolve the emission problem; these technologies and PCPs with reinforcement also lack applicability.

Q6: Stakeholder visions and expectations aligned?
The average score for the sixth question on aligning stakeholder visions and expectations was neutral, with a 2.8. Interviewees from the research sector scored the question slightly lower (2.5), with three interviewees being negative and one being positive. Two interviewees refer to the large fragmentation within the industry and add the high level of uncertainties around the technologies. This leads to a situation where everybody has their own goals and visions, which causes the misalignment of visions and expectations. The last negative interviewee gives examples of perceptions within the building industry. Architects, for example, often choose wood or biobased materials when building sustainably, because concrete has a bad image. Better information and more clear norms could help in aligning these visions.

The average score from the interviewees from the industry sector was relatively high (3.5) with one negative, one neutral and two positive interviewees. Next, one interviewee did not know enough about the matter to answer the question. The negative interviewee mentioned the differences in interests between clients, contractors and concrete producers, creating tension between these three. The neutral argument stated that people do not think this is the only solution, because more and better solutions will arise. As an example, the concrete production in America and The Netherlands are compared because in America, mostly CEM I type cement is used, which is very unsustainable, while in The Netherlands, the cement use is far more developed and sustainable (CEM III). Both of the positive interviewees emphasize that there are also a lot of shared visions and motivations, mostly about the urge to become sustainable to save the planet (higher goals).

The interviewees from the government sector were much more negative (2.0). They mentioned that Rijkswaterstaat, for example, is negative about these technologies because they think solving the problem at the source is a better strategy than putting it back into concrete afterwards. The interviewee points out that the cement industry thinks of this differently because they want to retain their market share, which is a perfect example of different stakeholder visions. Another interviewee mentioned that these visions and expectations are still searching for a way to settle among stakeholders, with little coordination. The last interviewee did not know enough about the matter to answer the question.

4.2.5 Formation of markets

The fifth functionality discussed is the *Formation of markets*, which is scored based on two different questions as seen in table 11. The questions were answered by two interviewees from the research sector, five from the industry sector and one from the government sector. Overall, the functionality scores a 2.8, which indicates an insufficient level of formation of markets. What stands out is the fact that both research (3.0) and industry (3.1) think it is at least neutral, while the government sector (1.0) scores the functionality extremely low. The last important notion needs to be made that one interviewee represents the government sector for this functionality. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.5.

Table 11: Average sector scores for functionality 5

	Research average (2)	**Industry average (5)**	**Government average (1)**	**Total average (8)**
Q1: Sufficient current and expected market size?	3.0	2.8	1.0	2.6
Q2*: Current/Expected market size forming a barrier to growth?	3.0	3.4	1.0	3.0
Functionality score	3.0	3.1	1.0	2.8

* This row represents a question where a positive reaction has a negative effect on the system and vice versa; the scores are converted to the right Likert scale from appendix B to appendix C.5.

Q1: Sufficient current and expected market size?
The average score for the first question on the sufficiency of current and expected market size is 2.6, while the research sector scored slightly higher at neutral (3.0). Both research arguments suggest that while there is potential for a large market for CO_2 usage technologies, success highly depends on factors such as policy, pricing, choices made by various parties, costs, and level of competition in the market. Because these factors are not clear yet, they remained neutral.

The industry was also neutral and scored slightly lower (2.8), which indicates doubts about the market potential. One interviewee suggests that the industry can benefit greatly from AC technologies, but with a side note that transportation of CO_2 to production locations could cause problems. A second interviewee also believes that the market potential is large if the technology is usable, and the coverage of concrete producers is significant, which ensures a guaranteed market size but only if it is widely adopted. Another interviewee thought that the market potential is uncertain as the usability and applicability of the technology are still unclear. Lastly, a fourth interviewee stated that he was unfamiliar with the technology and could not comment on its market potential.

The government sector was much more negative (1.0). Mostly because the first and third interviewees stated they knew little about the technologies, the second interviewee suggests that the technology in question cannot be used in load-bearing constructions, thus eliminating a large portion of the market, giving other potential innovations a significant advantage and making them more relevant in solving the problem.

Q2: Current/Expected market size forming a barrier to growth?
With a total average score of 3.0 on the question of whether the market size is forming a barrier to growth, there seems to be some form of a barrier but not very large. The research sector scored similar (3.0) and thought that uncertainty surrounding the technology and its implementation is causing hesitation among companies. However, if the legislation becomes clearer and more defined, companies may be more likely to adopt the technology and in total, they do not see any barrier.

The industry even scored slightly higher (3.4). However, to them, the applicability of the technology to specific products is uncertain. Next, transporting the captured CO_2 to other industries may also pose problems. Despite this, many parties are experimenting with the technology; if one party is successful, others are expected to follow.

The government sector again scored extremely low (1.0) and emphasized that the technologies cannot be used in load-bearing concrete, which is a large downside for the technology and its market size, so that forms a barrier.

4.2.6 Mobilizations of resources

The sixth functionality discussed is the *Mobilizations of resources*, which is scored based on four different questions as seen in table 12. The questions were answered by one interviewee from the research sector, five from the industry sector and two from the government sector. Overall, the functionality scores a 3.4, indicating a sufficient level of mobilisation of resources. What stands out is the fact that the research sector (3.0) thinks neutral of the functionality, and the industry (3.4) and the government sector (3.6) score it as sufficient. Another interesting aspect of this functionality is that all sectors gave similar arguments for all questions, which shows uniformity in these matters. The last important notion needs to be made that one interviewee represents the research sector for this functionality. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.6.

Table 12: Average sector scores for functionality 6

	Research average (1)	**Industry average (5)**	**Government average (2)**	**Total average (8)**
Q1: Sufficient human resources?	2.0	2.6	3.0	2.6
Q2: Sufficient financial resources?	4.0	4.0	4.0	4.0
Q3*: Expected physical resource constraints?	3.0	2.8	3.5	3.0
Q4: Physical infrastructure sufficiently developed?	3.0	4.0	4.0	3.9
Functionality score	3.0	3.4	3.6	3.4

* This row represents a question where a positive reaction has a negative effect on the system and vice versa; the scores are converted to the right Likert scale from appendix B to appendix C.6.

Q1: Sufficient human resources?
The first question on whether sufficient human resources within the Dutch concrete system was scored insufficient at 2.6, with the research sector rating it even lower (2.0). The interviewee from the research sector scored low and mentioned a shortage in the Dutch labour market, which also affects the concrete industry. This means that most available people have to produce tasks instead of innovating with new technologies because there is currently a lot of demand for concrete.

The interviewees from the industry sector scored in line with the average rating (2.6) but gave diverse arguments. One interviewee argued that there is a personnel shortage in the industry and a large demand, so all people working at production companies are needed for the production process. Three others focused more on the requirements these people should meet to be able to implement these new technologies. Working with these technologies requires specific engineering knowledge of concrete. Another interviewee sees this more positively and argues that people will be found to work if possible.

The interviewees from the government sector scored higher (3.0) than the industry sector and gave similar arguments. Both mention a nationwide shortage in the labour market and the requirement for these human resources to be concrete technologists and researchers with specific knowledge. Nevertheless, one interviewee mentions that he believes the industry has enough people to implement the technologies and can solve this internally.

Q2: Sufficient financial resources?
The second question on whether there are sufficient financial resources scored relatively high with 4.0, while the research and industry scored the same (4.0 and 4.0) with similar arguments. One interviewee from the research sector and three interviewees from the industry sector mentioned that this does not need any further explanation, because money will be available when there are good opportunities with these technologies. One interviewee added that these technologies might result in a cost increase, which will be passed on to the customer. Another industry interviewee stated that plenty of subsidies are available for these technologies, but the question is whether this ends up in the right place. Concrete users are also willing to pay more, but the interviewee is unsure whether that ends with the producers.

The government interviewees rated this question with a positive score (4.0), mainly mentioning that many subsidies are available because the government wants the industry to become sustainable. Nevertheless, one interviewee questioned whether the industry actors could reach these subsidies. In addition, she mentioned that, in principle, there is never enough money because more money can put more things to work. Another interviewee emphasizes that it is a large industry, so there is always money; for example, banks that will always listen to a good investment plan are mentioned.

Q3: Expected physical resource constraints?
The total average rating of the third question on whether there are expected physical resource constraints was neutral at 3.3, with the research and industry sectors giving scores close to that average (3.0 and 3.2). The interviewee from the research sector expected few problems, at least nothing that the industry could not solve. One thing mentioned is the challenges of gathering and reusing concrete waste. Three of the interviewees from the industry also saw no real constraints, while one interviewee mentioned available CO_2. This is needed in high purity and needs to come from other industrial processes. This makes it expensive and reliant on that processes if they stop because no more products can be produced for whatever reason. Another interviewee mentioned that there are risks with one production method of someone dying when that person was in the curing room while products are cured; if these risks are present he will not use these technologies. Altogether, no interviewees saw real big threads from all these mentioned arguments.

Interviewees from the government rated the third question the highest (3.5), with both arguments explaining that the current Dutch concrete system is structured and functioning well. Both mentioned that they are unfamiliar with the technologies, but from their understanding of the system, they think there will be no problems.

Q4: Physical infrastructure sufficiently developed?
The third question on whether the physical infrastructure is sufficient was rated with an average score of 3.9, which comes from a uniform set of scores from the different sectors (3.0, 4.0 and 4.0). The interviewee from the research sector referred to his answer to the previous question, the overall physical structure will be sufficient but there will probably be some challenges for such new technologies. The other interviewees from the industry and government sectors were even more positive, with all of them uniformly stating that the infrastructure of the Dutch concrete system is developed sufficiently to facilitate the implementation of these new technologies. Some of the examples given were the current cement transport network, the national coverage degree of concrete and a large amount of professional, long-standing companies within the system.

4.2.7 Counteracting resistance to change

The seventh functionality discussed is *Counteracting resistance to change*, which is scored based on three different questions as seen in table 13. The questions were answered by three interviewees from the research sector, five from the industry sector and two from the government sector. Overall, the functionality scores a 3.4, indicating a sufficient level of counteracting resistance to change. What stands out is the fact that both the research (3.3) and the industry sector (3.9) score the functionality as substantially sufficient, while the government sector (2.0) scores it as substantially insufficient. In addition, it needs to be emphasized that this score is based on a Dutch TIS perspective. The strong power position of the European cement producers is often mentioned with their capability of resisting certain specific innovations. It is clear that when these forces were considered, the score would be much lower, and the resistance would be larger. Nevertheless, this influence is now seen as an external context since Europe is outside this research's score. More explanation about the individual questions and sector-specific functionality scores can be found underneath, while an overview of the individual interviewee scores for this functionality can be found in appendix C.7.

Table 13: Average sector scores for functionality 7

	Research average (3)	Industry average (5)	Government average (2)	Total average (10)
Q1*: Resistance towards new technologies?	3.7	4.2	2.0	3.6
Q2*: Resistance towards CO_2 technologies?	3.3	3.8	2.0	3.3
Q3*: Resistance because of regulations?	3.0	3.8	2.0	3.1
Functionality score	3.3	3.9	2.0	3.4

* This row represents a question where a positive reaction has a negative effect on the system and vice versa; the scores are converted to the right Likert scale from appendix B to appendix C.7.

Q1: Resistance towards new technologies?
The first question on whether there is resistance towards new technologies within the system scored relatively well with 3.3. Interviewees from the research sector scored higher (3.7) with one negative and two positive arguments. One interviewee stated there is no producer resistance, mostly from the users/clients. He emphasized that the concrete industry is very old, and the old production methods are familiar and trustworthy. Changing to different production methods brings certain risks because the products of these new technologies are not as old as conventional ones. Two other interviewees do not think there is resistance. One mentions that existing parties are protecting their market share and will not be against innovation but will act in their own way regarding the technologies they use.

The industry scored this question very high (4.2) with multiple positive and one neutral argument. Almost all interviewees mention that the market is open to innovation for multiple reasons. Someone compared The Netherlands to other countries and noticed a very open innovation system, while others mentioned that innovations are no longer seen as threads but as opportunities. One important side note is that current stakeholders are protecting their market share, which is quite obvious. It is important to realize this force within the system because these actors make deliberate choices on which innovations they are betting on.

The score given by the government sector is very low (2.0) with all negative arguments. Both interviewees mention that new things always gain resistance because there are uncertainties. New technologies for producing the concrete of buildings bring many safety risks. They both also emphasize that there need to be frontrunners who guide this process by using new technologies and showing success to create enthusiasm under critics. A reference is also made towards the innovation curve, where this process is represented in.

Q2: Resistance towards CO_2 technologies?
The average score for the second question is slightly above neutral with 3.3. The interviewees from the research sector scored this similarly (3.3) with the same arguments as the previous question. Two interviewees again mentioned that changing technologies for products that need to be used for over 50 years is hard because people want trusted products. If no products have worked for so long, other positive testing results need to deliver proof. Another interviewee brings up a new argument that the company's management needs to invest in these technologies, not only in technology but also in market approach and production facilities.

The interviewees from the industry sector again scored relatively high (3.8) and gave similar answers to the previous question. Four interviewees clearly mentioned that they do not know why stakeholders would be against this if the technology benefits the environment. They also bring up that the attitude within the industry is changing because there is an understanding that changes need to be made, which opens up many possibilities. One interviewee mentioned that he heard that there is a risk of people dying when they enter a curing room that is being used. If these risks are too high, that would be a reason for him not to use these technologies.

The interviewees from the government sector again score very negatively (2.0) with similar arguments as the previous question. New things create resistance, and frontrunners must make the first steps before others join. Another interviewee emphasizes that there are a couple of barriers that need to be taken for new technologies to make sure everything stays safe. This exists in tests, entering the National Environment Database and meeting certain requirements and standards. These things are probably easier for people with a government background because they know exactly how they work and what is needed.

Q3: Resistance because of regulations?
The average score for this question about resistance coming from regulations scores is 3.1, with the research sector scoring similarly (3.0). All three interviewees mentioned that some very basic principles and procedures could be followed to enable new innovations like this to be tested. Things like standard concrete norms, building codes and permit procedures are mentioned. These regulative tools create boundaries which thus enable actors to try innovations out in real life, but they also slow innovation processes because it costs extra time and money.

The industry sector again scored high (3.8), with most of the interviewees emphasizing that there are certain boundaries for innovation but these are to make sure everyone can try to innovate safely. These boundaries are thus not barriers but actually enable innovations to test in real life and show proof of concept. Nevertheless, another interviewee also pointed out that certain requirements are slowing down the process, like a set maximum of 30% of RAs that can be used within concrete production. If actors do want to use more, specific permits need to be requested, which often is a slow requesting process.

The average score of the government sector scored this question low (2.0). Both interviewees emphasized the importance of the current procedures and rules protecting the building industry from using unsafe technologies and products. On the one hand, this thus creates a barrier, but at the same time, you can ask if this barrier is so negative after all. When actors want to use new types of concrete, they will have to be critically examined and Rijkswaterstaat wants to see test reports. There are guidelines on which you can have these new concrete types tested at TNO, so it is a process in which industrial actors have to invest time and money. It is a process that these technologies need to go through. Unfortunately, it is somewhat slow, but this is what needs to be done.

4.2.8 Overview of the systems functionalities

When all these scores are combined, this leads to the overview of table 14. The first, and most important thing that arises is that functionality 3, 4 and 5 scores substantially lower, with scores of 2.7, 2.8 and 2.8. The rest of the scores are all 3.4 and one is 3.6. This means that the functionalities *Knowledge exchange*, *Guidance of the search* and *Formation of markets* score lowest of the TIS.

Table 14: Overview of the system functionalities

	Research average	Industry average	Government average	Total average
F1: Entrepreneurial activities (1/5/2)	2.8	3.7	2.9	3.4
F2: Knowledge development (4/1/0)	3.5	4.0	-	3.6
F3: Knowledge exchange (4/5/3)	3.1	2.6	2.4	2.7
F4: Guidance of the search (4/5/3)	2.7	2.9	2.8	2.8
F5: Formation of markets (2/5/1)	3.0	3.0	1.0	2.8
F6: Mobilization of resources (1/5/2)	3.0	3.4	3.6	3.4
F7: Counteracting resistance to change (3/5/2)	3.3	3.9	2.0	3.4

4.3 SQ3: System failures

This section identifies the systemic problems present in the TIS causing system failures. To find these problems, the information of section 4.1 and 4.2 will be combined. This will be done as explained in step 4 from section 3.3.3 and result in an overview of each functional barrier with all systemic problems coming from the different structural building blocks. After that, based on step 5 from section 3.3.3, the problems for policy goals are described. This results in a brief analysis of the political landscape with regard to the located systemic problems from step 4 and a description of the technical and geographical scope of the TIS. This last step will lead to an overview with specific requirements for choosing intervention tools.

4.3.1 Locating functionality barriers

To indicate the functionalities that could cause system failures for the development of the TIS, the results of section 4.2 presented in table 14 are combined with the functionality importance overview in figure 7. Table 14 shows that F1, F2, F6 and F7 are functioning relatively well with scores around 3.5, while F3, F4, and F5 are functioning badly with scores of 2.7 and 2.8. As concluded in section 4.1, the TIS is currently in between the "Development stage" and the "Take-off stage". If this is checked with the key-importance functions of figure 7, it becomes clear that F4 and F5 are important for both stages, while F3 is of key importance to the "Development" stage. Because of the importance of these three functions to both stages, they all will be further analyzed in the next section.

4.3.2 Functional barrier 1: Knowledge exchange

The first functional barrier is *Knowledge exchange*, which scored an average of 2.7 and represents poorly functioning knowledge exchange on AC technologies. The research sector considered the function slightly better than neutral (3.2), while both industry (2.6) and government (2.4) scored it as inadequate. The arguments for this low score mostly point to the fact that the demand for concrete products is too high for the industry. They do not have time to produce the demanded amounts of concrete and look for innovative technologies simultaneously. This is in line with the sector-specific scores because, on the research side, knowledge exchange is scored as good enough. However, the scores of the government and industry sectors are low and it is mentioned that they do not collect the provided knowledge well because of this pressure. In addition to these arguments, it is mentioned multiple times that concrete producers have to choose between producing (which earns them money) or innovating (which costs them money) and currently, the industry chooses financial gain. To conclude this first part, a problem is seen where the industry is, at least not enough, actively looking for or picking up the available knowledge on AC technologies.

I think there is something behind this lack of search by the industry and government, which is not directly mentioned by interviewees but can be seen from a combination of problems in different building blocks. The main reason given by interviewees is the pressure on the industry because of the great demand for concrete. It is said that the industry does not have time to implement new innovations, but I think there is no internal incentive for the industry to look for these new sustainable innovations. Because of the large demand for concrete, the industry is guaranteed to sell products. Why must these companies innovate and take risks when they sell the amounts they want? When the demand for their products is lower or competition increases, innovation suddenly becomes important to be better than the rest and sell all products. When the existence of their company comes into play, they surely will have time to innovate, but when selling targets are reached, why would they? The problems within the structural building blocks contributing to this situation will be discussed.

Actors

Regarding the first building block *Actors*, the main problem originates within the market part of all actors. The current production chain of concrete is given in figure 12, with concrete production (section 3) and concrete usage (section 4) at the heart of the system. It has become clear during the market analysis in section 4.1.2 and it is often mentioned during the interviews that the Dutch concrete system is highly fragmented. Because of this, a large variety of concrete products is used in the system, with only a few companies producing that specific product. Combined with the mentioned large demand from concrete users, the producers have a power position over the concrete users since these are already satisfied whenever they can get the products for an acceptable price. Because of this, the producers have little competition within their own niche of products and there is little incentive to stand out from the rest. This highly slows down innovation and as a result, arguments can be given that the demand is so high that there is no time to innovate.

Network

The second aspect that contributes to the current situation originates in the *Network* building block. From figure 13, it can be seen that concrete production and research overlap in the form of R&D teams. While the research centres, universities and R&D teams sometimes work together on innovations, the R&D team is the actor that needs to make the translation from scientific knowledge to a usable product within the market. It is mentioned within the interviews that the perspectives of concrete producers and universities are different from each other (economically vs scientifically). This leads to the fact that research from universities comes with usable principles for the industry, but the industrial actors need to translate these into usable technologies for their production. But, because of the earlier lack of incentive to innovate, there is little attention from the industrial actors to make these technologies applicable.

Something that is also decreasing this incentive for innovation is the deviance between concrete production and concrete usage, as shown in figure 13, which contractors create. Because contractors act like a middleman between production and usage, there is another step in knowledge exchange and an extra set of interests that will be mixed within the process. This is also represented by the individual question scores, where the exchange between the industry and the user is very low (2.3). Different interviewees also confirmed this, saying that concrete producers are just starting to understand these technologies, but concrete users have never even heard of them. The producers have heard of the technologies but cannot explain how they work or know what products can be made with them. The fact that contractors are between producers and users makes this process slower and more complex, as a contractor will also make some choices based on his interests. A statement from an interviewee perfectly visualizes the tension within the network: "If a scientist starts talking about this technology, the industry thinks that is going to cost me money. But, if the user asks about this technology, the producer thinks this will make me money." The only two problems are that contractors are between these parties and users are not asking for AC products.

Institutions

From the *Institutions* building block, two problems arise. One reason users are not asking for AC products is that within The Netherlands, there is a narrative of solving the concrete emission problem by decreasing it at the source. This means producing concrete with as little resources and energy as possible so that the initial emitted CO_2 is as low as possible. This means that a technology where CO_2 is put back in afterwards is seen as "compensating" for earlier emitted CO_2. The narrative in surrounding countries like Belgium is more about compensating where possible. The consequence is that industrial actors are probably focusing on different technologies, and international companies have their strategic focus and goals on other countries since The Netherlands is less likely to adapt to these AC technologies. In addition to this, there are strict safety measures for building with new concrete compositions. Various tests and verifications need to be done when using new compositions to guarantee that these buildings are safe. From interviews, it appeared that these costs are around 80.000 to 100.000 euros to be verified. It is no problem that these tests must be done; it enables the industry to innovate. The only problem is that there is currently no benefit to creating these new compositions due to the earlier-mentioned position of the industry, where they have no incentive to innovate. In this light, the high costs for verification are suddenly a barrier to innovation.

Technology
The next problem mentioned by interviewees originates within the previous aspects and causes a barrier within the *Technology* building block. The interviewees often mention that the technologies are not widely used because many uncertainties surround them. This regards the profitability of new technologies, applicability within production processes, use cases by the actual concrete users and many more. Because there is no incentive to innovate, no actors will investigate the possibilities and no actors will try these technologies out because there is nothing to win by taking the risk. In addition to this, the earlier-mentioned costs also slow down this process. Because of this, the technologies are currently seen as uncertain, creating a barrier for industrial actors to search for knowledge on the technologies.

The previously mentioned issue in the *Network* building block, which relates to the gap between research and industry, has resulted in another problem for the *Technology* building block. The research sector has primarily focused on AC technologies with the aim of maximizing CO_2 sequestration during concrete production from a scientific standpoint. However, the industry's perspective is primarily driven by economic considerations, and based on interviews, they do not perceive any advantages in implementing these technologies. The industry is more concerned with increasing production speed, simplifying the process, and reducing costs. This indicates that for the industry to adopt new technologies, they must be economically beneficial.

External factors
Regarding *external factors* one small aspect that increases all problems slightly is mentioned. Within The Netherlands, there currently is a general shortage in the labour market, so the industry also has difficulty finding people to hire and focus on innovation.

4.3.3 Functional barrier 2: Guidance of the search

The second functional barrier is *Guidance of the search*, which scored an average of 2.8 and represents poor guidance of the search towards AC technologies. The industry sector considered the function slightly below neutral (2.9), while both research (2.5) and government (2.3) scored it as inadequate. From the scores per question, it can be seen that there is no clear vision of growth development (2.5), no clear vision of technological design development (2.5), there are no clear policy goals regarding the technological field (2.3), the goals that are in place does not seem to be reliable and doable (2.5) nor are the stakeholder visions and expectations aligned (2.8). The only question that scored positive was about positive expectations regarding the technological field (3.5). Most of the given arguments for these low scores have to do with the fact that the Dutch concrete system is very fragmented. This means the Dutch concrete TIS exists in many small subsystems with specific concrete products and associated sets of specialities and requirements.

It is understandable that guiding such a fragmented industry towards sustainability is a difficult process, because of the large number of different production methods, interests, requirements, safety regulations and uncertainties from that diversity. What can be seen is the fact that the guidance of the system is currently very broad, to make sure every aspect of the system can be included. A result of keeping this guidance broad is a situation where goals and measures can become too abstract and vague, resulting in no real action or a broad spectrum of actions that do not align or sometimes even contradict. This is happening in the Dutch concrete industry from all the different interviews. The first functional barrier problem was that the industry had no incentive to actively search for useful knowledge from the research sector to increase sustainability. This can be interpreted as a lack of internal guidance by the industry, which makes the second functional barrier even more important. The current problem is that this guidance process is very hard because the system is so fragmented. Within the further explanation of this functional barrier, the causes originating within each building block contributing to the current situation will be given.

Actors
Just like for the first functional barrier, the main cause of the underlying problem starts within the structural building block *Actors*, specifically within parts three and four of the market figure 12. Because concrete users have so many different requirements for the things that need to be built with concrete, producers find ways to

make these products and meet their needs. Over the years, this has resulted in an industry with many products, including sustainable solutions, concrete compositions, production processes, specific requirements and safety norms. These aspects include the different AC technologies, adding geopolymers to concrete, and different cement types (CEM I, II and III) but also changing entire constructions with less or more reinforcement or concrete in specific places. Altogether, this wide variety of products within the market creates fragmentation and works through to other parts of the network of the TIS.

Networks
When looking at the *Network* building block, the fragmentation of the actor building block flows through to both sides of figure 13. Namely, within the research sector, these products are developed further in their own direction, resulting in many distinct development paths. Altogether, these different development paths result in a fragmented research sector competing internally, resulting in an uncoordinated search. In addition to this, the government sector also becomes fragmented. Broad sustainable plans and transition agendas are needed to include all the products used within the industry. An example is the 28 different acting perspectives from the Betonakkoord, which is a good thing that gives alternatives to companies. Nevertheless, it may give too many options or stay too vague, so the steering is not strong enough to make an actual impact. Thus, this leads to certain guidance of the search, but this guidance is focused only on CO_2 reduction, which is probably too vague and results in little action. More on these institutions in the next building block.

Institutions
The discussed fragmentation within the government part of the network comes back clearly in the building block *Institutions*. With so many interests, requirements and visions coming from fragmentation, it is hard to guide the TIS in an institutional matter. A general focus is on decreasing the total CO_2 emissions, which seems clear and broadly supported within the industry by the interviewees. The challenge from there only is how this can be realized. A great example is the twenty-eight different acting perspectives from the Betonakkoord, with only one focused on AC technologies. This industry-wide agreement with its acting perspectives symbolizes the fragmentation of the industry. This plan includes many different innovation paths, and every part of the industry is trying some things. However, multiple interviewees openly questioned whether this current strategy is too free and diverse for the industry to move in a certain direction truly. In addition to this, and as an example of varying visions, government actors are unconvinced about AC technologies. This concerns the Dutch perspective on solving the problem at the source and that AC technologies cannot be used within PCPs with reinforcement. On the other hand, the industry sees lots of potential for AC technologies when these can be made applicable to production methods.

Technology
The other problem from the network building block, fragmentation in the research sector, is causing problems for the *Technology* building block. Because of the mentioned fragmentation, uncertainties occur for all different kinds of reasons. For example, the usability of AC technology in combination with reinforcement is questioned, the possible technological applications are questioned, the financial potential of these applications is questioned, and the uncertainty of the Emission Trading System is mentioned as a barrier. All of these uncertainties are partly present, but because there are so many different alternatives for the fragmented market, it is not sure which uncertainties are relevant for specific parts of the system. In addition to that, because of the large number of solutions, all attention to sustainable technologies is shared with all innovations. If there were only three innovations, these would gain much more interest and resources, pushing these innovations forward faster and decreasing uncertainties. It is often mentioned by interviewees that a lack of certainty is forming a barrier for industrial actors to start using AC technologies.

External factors
For external barriers, fewer explanations or problems contributed to the TIS's large fragmentation. An interviewee about the strong power position of the European cement producers mentioned the only thing standing out. Because the cement producers are a handful of extremely large exporters, they control what happens to the cement market and, thus, the concrete market. It is somewhat contradictory that the Dutch system is so fragmented, while the European cement industry is so centralized. In addition, the large fragmentation means many innovations, which means many TISs. This means a large competition among the different TISs, making it harder for this specific TIS to break through.

4.3.4 Functional barrier 3: Formation of markets

The third functional barrier is *Formation of markets*, which scored an average of 2.8 and represents a poor formation of markets. The research and industry sector considered the function neutral (3.0 and 3.1), while the government sector scored it extremely low (1.0). From the scores per question, it can be seen that there are doubts about the current and expected market size (2.6) but it is believed that this is not currently forming a barrier to growth (3.0). Nevertheless, this neutral score also means market formation does not stimulate growth. The general underlying problem mentioned mostly during the interviews is uncertainty. Part of these uncertainties can be linked to the structural building blocks and the previous two functional barriers. This will all be further explained underneath based on the structural building blocks.

Actors
The problem for this functional barrier starts with the structural building block *Actors*, which faces different uncertainties. According to the interviewees, the formation of markets is highly dependent on choices made by various actors within the system. This regards concrete producers and users, contractors and different government actors. Overall, the potential of AC technologies is seen but due to a large number of uncertainties, it is not sure if this potential will be fulfilled in the future, which creates hesitation among industrial actors. The different uncertainties mentioned by interviewees regard all kinds of things. They can be further explained according to the three structural building blocks institutions, technology and external factors, which are further discussed underneath. In addition to this, the previous two functional barriers also have an important influence on the lack of formation of markets which is further explained in the structural building block of the network.

Institutions
A large part of the uncertainties is coming from the *Institutions* building block, which is already partly discussed during the previous functional barrier. For the previous functional barrier, it was mentioned that institutional guidance was broad and vague. For this barrier, it is added that the future of the institutions is also unclear. Current institutions are more like guidelines than hard rules; policies are not very strict, and it is unclear how this will change in the coming years. In addition, the Emission Trading System is present but has a small influence and is not sure how strict this will become in the coming years. This creates a situation where there are uncertainties regarding the institutions, which creates hesitation among actors in the industry to invest in different innovations. This hesitation is increased because of the strict rules for concrete safety when companies want to innovate with different concrete compositions. As earlier said, the fact that this strict system is in place is good because it enables a safe way of innovating. Nevertheless, in the end, this brings high costs for innovating companies and forms a barrier when it is uncertain whether the future products from these innovations will bring benefits or profit under uncertain future institutions.

Technology
The uncertainties from the previous structural building block cause extra uncertainties for the *Technology* building block. Because future institutions are unclear, there are uncertainties about what specific technology will best fit future circumstances. This, for example, affects the applicability, usability and profitability of different AC technologies. In addition to this, it is unclear whether carbonation can be used when reinforcement is present in PCPs. This partly creates a negative image of AC technologies and increases uncertainty for potential industrial users.

External factors
A last layer of uncertainty comes into play from *External factors*. The ETS was mentioned earlier during the institution building block and the external factors. Because this is decided on a European level, it is out of reach for the Dutch government to really influence it. However, it is important to keep this system in sight because it greatly influences the entire working of this technology. Because the ETS is focused on internalizing the costs of CO_2 emissions, these technologies can greatly profit from it. If the ETS starts giving emission rights for "removing" CO_2 from the atmosphere by sequestering it in certain ways, this would give a large economic benefit in using these technologies. Nevertheless, this is currently not the case and it is uncertain how this will progress in the future.

Network
The problem for this functional barrier coming from the *Network* building block has to do with the previous two functional barriers and causes the formation of markets to be bad. This can be explained with the network figure 13, where there is currently little exchange of AC concrete products from production to users. From the first functional barrier, it became apparent that the industry had no internal incentive to innovate with AC technologies. From the second functional barrier, it became clear that guidance towards these technologies is also lacking. This results in a system where no force is driving the growth of the technology, which will not lead to any market formation or, in other words, AC products going from the production side to the user side.

As earlier mentioned, research is pushing from the left inside the production part of the network towards AC technologies. Nevertheless, concrete producers are currently not doing enough with the knowledge. On the other hand, there seems to be a lack of guidance from the governance side, as mentioned in the previous functional barrier. When this is translated to the earlier mentioned figure 13, it can be seen as a lack of pull from governance on the concrete user side. If the concrete user side were forced to pull on the concrete production part in the figure for AC products, this would incentivise the concrete producers to pick up the knowledge from the research part of the network. As mentioned, there currently is a lack of pull from within the concrete producers to the research. If explained like this, a lacking formation of markets seems to be the missing puzzle piece for the network to start naturally flowing from research to production, through to usage, to governance.

4.3.5 Problems for policy goals

At this point, the analysis of the TIS concludes by examining the systemic problems identified in step 4 through a policy lens. This involves linking the three systemic problems and exploring their interrelatedness. The subsequent step involves outlining the specific policy objective of the TIS in addressing the coherent problem arising from these systemic problems. To provide a broader perspective, the technological and geographical scope of the TIS is then described to contextualize these findings.

System failures

The three system failures discussed in step 4 of the analysis are partly entwined. Figure 14 illustrates the system failure of *Formation of markets* at the top, with the issues of *Guidance of the search* and *Knowledge exchange* presented below. In the Dutch concrete system, the formation of markets for AC technologies is not functioning properly. This is partially due to insufficient internal incentives for concrete producers to innovate and incorporate available knowledge into their production processes. The demand for traditional concrete products is currently too high, leading to a lack of competition in the market and a lack of focus on innovation. The other part is caused by a lack of demand from concrete users and contractors for products made with AC technologies. As a result, there is currently no market formation since producers only produce what customers demand.

Moreover, the guidance of the search for AC technologies is also facing issues. This systemic problem is connected to the problem of the formation of markets through an arrow, as improved guidance could potentially address the market formation problem but currently fails to do so. This issue mainly stems from the significant fragmentation of the existing concrete industry with vague and broad sustainability plans. Consequently, AC technologies represent only a small fraction of the entire system, causing attention to be spread over numerous innovations, leading to intense competition among various TISs.

Given the previous points, the issue of knowledge exchange can be viewed as a natural consequence. As there is no inherent development of a market for AC technologies and insufficient guidance in that direction, the industry has little motivation to seek out or utilize knowledge from the research sector. As a result, industrial players lack the incentive to collect and employ knowledge from research sectors, as they have no tangible benefit. Instead, they will continue to sell conventional concrete products, as contractors and concrete users remain primarily interested in those.

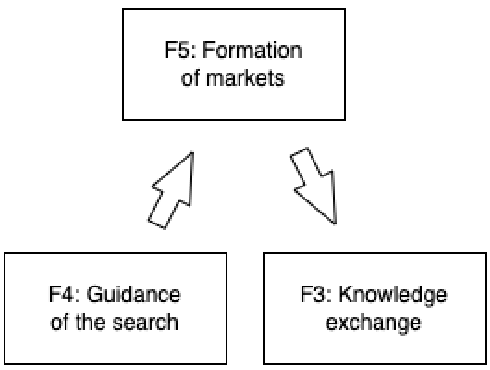

Figure 14: Coherence between the different system failures.

Policy goal of the TIS

The policy objective of the TIS is closely tied to the coherence of the systemic problems that were previously discussed. AC technologies, developed in the TIS, serve two purposes. Firstly, it provides the industry with a way to reduce the carbon footprint of concrete production. Concrete involves burning limestone, releasing a significant amount of CO_2 into the atmosphere. By utilizing AC technologies, a substantial amount of this emitted CO_2 can be returned to the concrete mix, reducing the carbon footprint and making concrete more sustainable. Secondly, from a broader societal perspective, AC technologies are the first step towards creating a CE for CO_2. While it might not be entirely circular to burn limestone and release CO_2, only capturing a portion of it, AC technologies are rapidly evolving. They may soon be able to operate without cement with second-generation AC technologies. This shift can spark a discussion on a CE in which gaseous CO_2 can be used as the binding agent for building materials instead of cement.

The manual proposes two dimensions for determining policy goals: environmental and economic. Environmental concerns for the TIS being studied seem more pressing, as the Dutch concrete system needs to become more sustainable. This recurring theme in most interviews is reflected in the Dutch government's focus on the Betonakkoord. Economic considerations were also marked as important during interviews, particularly regarding earning back investments by the industry. In addition, the high score of 4.0 for function 6 about the mobilization of resources suggests that the industry has enough resources. I do not know the government's vision regarding the concrete system, but I would argue that they find it important that the industry remains stable. On the other hand, I would like to argue that The Netherlands is a prosperous country which can afford to spend money on increasing sustainability. An example is that sustainable plans may cost more during tender procedures. While it's unclear how this exactly translates to the government's vision, they likely want to increase the industry's sustainability. Based on this, I would assume that the government focuses about 70% on environmental improvement and 30% on maintaining the industry's economic benefits. Considering both environmental and economic factors, the manual's two dimensions will be useful for determining the best course of action for the TIS.

Technological scope of the TIS

Regarding the technological scope, the most important aspect is that within The Netherlands, the perspective is on reducing CO_2 emissions at the source. AC technologies make use of cement, which during production emits a very large amount of CO_2 (80-90% of total emissions from concrete production). Using these AC technologies thus is a somewhat cumbersome process, because first, a lot of CO_2 is emitted while afterwards, during concrete production, only a part of that can be put back into the concrete. This leads to AC technologies not being within the Dutch narrative of making concrete production more sustainable.

One interviewee emphasized that a requirement of concrete is to contain cement. Otherwise, it cannot be marked as concrete. Nevertheless, second-generation AC technologies being developed and currently entering the market create building materials with compositions without cement, reaching late strength performances similar to concrete. This means that a shift could occur where building materials will be made with other compositions than concrete, where CO_2 reacts with a different binder that emits less to none CO_2. When this develops this far, there could go more CO_2 within the final building material than was emitted during the production of the actual building material (negative emission products). This then shifts the narrative from making building materials more sustainable towards building materials being a sink for CO_2 where it can be sequestered.

This creates a technological scope for the TIS where AC technologies can make concrete more sustainable within the current system by reducing the total amount of emitted CO_2. But, when the technologies and compositions are developed far enough, gaseous CO_2 can react with a different binder within building materials and make building materials to a CO_2 sink. The challenge is finding binders that react with gaseous CO_2 when mixed with water and show performances similar to conventional concrete. Moving away from cement as a binder could change the entire building industry.

Geographical scope of the TIS

The geographical scope of the TIS is an important aspect to consider, particularly its existence within Europe. The Dutch TIS has unique characteristics that influence its operations, as discussed in section 4.1. Notably, the Dutch TIS is highly innovative, open to government direction, emphasizes reducing emissions at the source, and has a strong linkage between research and industry. While the Dutch TIS can operate independently, external factors impact it on a European level. One such factor is the dominant position of large European cement producers. With few companies controlling much of the market, they may resist any moves towards a cementless building industry, as it would threaten their market share. Additionally, these companies own many Dutch concrete firms, giving them significant influence over which innovations are developed further.

The EU is another significant influence on the Dutch TIS. For instance, the current Emissions Trading System

(ETS) could be improved by allowing actors to earn ETS credits when they sequester CO_2, which would greatly benefit AC technologies. However, future institutional measures are uncertain and could impact the TIS. Finally, the Dutch TIS is seen as more innovative than surrounding countries and is better equipped to handle new technologies. The government's openness to industry guidance has also helped the TIS perform well. Due to their strong linkages, the technologies and findings will likely be readily transferred to other European TISs if the Dutch building industry undergoes significant change.

5 Conclusions and Recommendations

This chapter draws conclusions on the results of chapter 4 and, from that point, presents recommendations for the Dutch government, the Dutch concrete system and future analysts in the second section.

5.1 Conclusion

The first section of this chapter answers the three different SQs. Combining these answers should lead to overall conclusions and an answer to the main RQ. It is structured in a way that each sub-conclusion is an answer to one of the SQs, while the last part is an answer to the main RQ.

5.1.1 Answer to SQ1: Structure of the TIS

SQ1 focuses on the structure of the TIS, which is analyzed in section 4.1. The question for this first part is: what is the structure and development stage of the Dutch AC concrete system, according to the TIS framework? This will be answered in the coming section by briefly summarizing the findings for the structural building blocks *Technology*, *Actors* and *Networks* and the development stage of the TIS.

Technology

The first structural building block described is *Technology*, and the conclusion can be drawn that there are currently three main production methods using Active Carbonation (AC). It is possible to add CO_2 to cement and recycled aggregates (raw materials) while mixing raw materials together with water for a concrete mixture (concrete production) and while the concrete mixture is hardening after it is poured in moulds (PCP production). Next to that, it is possible to use all these methods in a row for the production of concrete, which would lead to the largest amount of CO_2 sequestration.

An important sidenote is that new 'concrete' compositions are discovered where different binders are used instead of cement. It is important to divide the AC technologies into first (with cement) and second (without cement) generation since real environmental benefit can be gained from removing the cement. I strongly suggest that these alternative binders are part of this TIS and should lead the technological development direction. In addition, the two largest problems for AC technology are the fact that there is no consensus on the usage when reinforcement is present in concrete and the fact that the technology currently seems to bring no benefit for concrete producers other than a decreased CO_2 footprint.

Actors

The second structural building block discussed is *Actors*. For research, there is the TRL system (TRL1 to TRL9), as discussed, which seems to bring universities, research centres and R&D teams of concrete producers together. Activities and TRL levels overlap when parties co-develop technologies and exchange knowledge, which benefits the system. In addition to this TRL system, about 1% of the world's knowledge production on AC technologies comes from The Netherlands. The educational system also seems to be in place, but the problem is that the number of people entering the concrete industry is decreasing. This results in a decreasing number of people being educated and prepared for a career in the concrete industry, leading to a shortage in the labour market.

With regard to the concrete production market, there are six important actor types related to the different production stages, which can be seen in figure 12. The first two are cement production (1) and natural aggregate production (2). It has become clear that group 1 operates on a European scale and has a strong power position over the system because of their large scale, supplier power and ownership of concrete producers in The Netherlands. The next actor type is the production of RMC and PCP (3), while the fourth one is the usage of concrete on construction sites (4). The concrete system is highly fragmented, starting within these actor groups (3 & 4). It turned out that group 4 had a much more powerful position within the system than expected. In the end, the user of concrete (4) orders it from the producer (3), making group 4 the decision maker on what concrete products are chosen and, thus, which production methods are used. Because concrete users (4) have highly diversified their needs for different types and possibilities of concrete, the producers (3) have developed concrete where a lot of aspects (7+) can be individually changed in many different ways. This leads to many concrete types with different challenges and requirements when implementing AC technology. At the end of its life cycle, the actor group demolishes concrete structures (5) and the actors create RAs from the gathered concrete waste (6). Altogether, within groups 1, 2, 3 and 6, there is the possibility to add CO_2 while group 1 has much supplier and ownership power and group 4 has much user power.

For the institutional actors, the current pressure on the system to become sustainable is deeply rooted since the GHG problem is still becoming larger and will probably not be gone within the coming years. This expresses itself as a growing pressure flowing from top to bottom as explained in section 4.1.2. The largest actor formulating policy goals is the UN, which is not part of the TIS but does have a large influence. The second largest actor experiencing this pressure is the EU, which also falls outside the scope of the TIS but again has a large influence. All this pressure comes down to the Dutch government, part of the TIS. The two most notable results for the Dutch concrete system are the Betonakkoord and MKI scores. With the Betonakkoord, policy goals are becoming more actionable for the entire industry to become sustainable. In addition to that, the MKI score system is an important tool to steer the use of concrete towards sustainability. Unfortunately, the Betonakkoord remains relatively broad and vague, with 28 different acting perspectives and goals that lack measurability.

The intermediaries are the last notable group of actors within this part. The contractor is an important intermediate since this is the middleman for the concrete producers and clients. If this contractor uses his power to enable the client to choose sustainable production methods like CO_2 usage, this stimulates the use of these technologies. Another important intermediate is the licensing companies, which enable the use of the MKI score and has a refereeing role in protecting the system.

Network
The network of the Dutch concrete system is presented in figure 13 and exists in three parts: industry, research and governance. The industry comprises concrete production (supply) and usage (demand). It turns out that the system exists around these two sides, with the research and governance parts being connected to one. Research is connected to the concrete production side since this brings knowledge to the producers. On the other hand, governance is connected to the concrete usage side since the government is a large user of the concrete itself and can steer its usage in a certain direction. Next, the government can intervene to steer the non-governmental usage side in a sustainable direction. Lastly, the influence of the Dutch government and the EU on the research is not visible in figure 13. Because these parties have large financial resources available to resolve the GHG problem, they stimulate research with these funds.

Development stage
Currently, the TIS is situated between the development and take-off stages due to the uneven progress of the three different methods that comprise the technology. This discrepancy is primarily driven by the varying degree of ease of application and benefits to production processes associated with each method. Despite this, high innovation occurs across all three methods, and one specific method can suddenly make significant progress. As a result, the method leading the development continuously shifts between the three methods. Notably, an increase in the number of AC technology companies entering the market can be observed, and these companies are competing with each other, driving development and contributing to the current state of affairs, where all three methods are moving towards full entry into the take-off stage.

5.1.2 Answer to SQ2: Functioning of the TIS

SQ2 focuses on the functioning of the TIS, which is analyzed in section 4.2. The question for this second part is: how is the Dutch AC concrete system functioning, based on the seven different functions from the TIS framework? This will be answered in the coming section by summarizing the findings from the structured interviews for the seven functions of the TIS. An overview of the functioning of the TIS is represented in the spider diagram underneath in figure 15, which shows that the functions *Knowledge exchange*, *Guidance of the search* and *Formation of markets* are relatively scoring lowest around 2.8. As can be seen from the figure, the other functions all score similarly, around 3.5. An in-depth explanation of the different scores is given underneath.

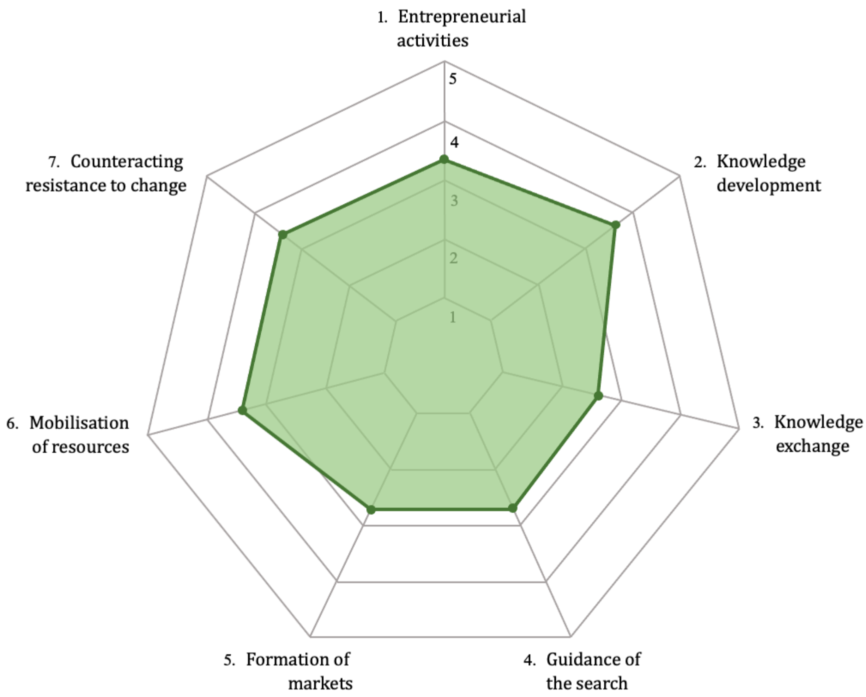

Figure 15: Spider diagram of the seven functionalities.

F1: Entrepreneurial activities - 3.4
There seems to be a normal amount of entrepreneurial activity for incorporating AC technologies into concrete production. The research and government sectors mostly argued why AC technologies were not used in the current industry. They both explained that the Dutch approach to addressing emissions does not align with AC technologies, which are seen as compensating for emissions rather than addressing them at the source. The government sector added that AC technologies are not suitable for load-bearing constructions, making them irrelevant to products used by Rijkswaterstaat. Nonetheless, the research sector acknowledged the increased adoption of these technologies and their potential for large-scale implementation. The industry sector reasoned more from possibilities for AC technologies due to the size of the Dutch concrete industry, the urgency to become sustainable, the variety of concrete products, and the recent rise of sustainable technologies. However, this also shows that the industry is highly fragmented. The different fragments have their characteristics and limits for implementing technologies, slowing development and cooperation.

F2: Knowledge development - 3.6
The knowledge development of AC technologies for the Dutch concrete system is good. Across all answers, one main message emerged with some additional notes. Almost all responses emphasized that the Dutch system for knowledge is effective and resolves knowledge issues on its own. While fundamental knowledge seems to be well-developed, the applicability of AC knowledge is lacking due to the Dutch approach to solving problems at the source. However, this is not a major issue because European TISs are well-connected. When AC technologies are effectively applied in an industrial product, the international knowledge systems quickly bring the working technologies to the Dutch system. Another important note is the fragmentation of the Dutch concrete system, with insufficient cooperation among actors and contractors failing to utilize developed knowledge. But, this is more of a knowledge exchange issue discussed at the next functionality rather than a problem with knowledge development.

F3: Knowledge exchange - 2.7
As became clear from the previous function, the knowledge exchange within the Dutch concrete system shows some problems. The main message from all interviews is that the knowledge of different innovations and the industry are not coming together. From the industry, it sounds like they are currently experiencing large demand and a shortage of personnel, making it hard for them to go and look for these new technologies. It is also often mentioned that the technologies are not clear enough, there are too many uncertainties, and investments need to be returned. There are no clear benefits for industrial actors to implement them. Because of this lack of incentive to investigate the possibilities, the concrete producers do not know anything about the technologies. They cannot tell users (developers and contractors) that these products exist and can be bought. In conclusion,

this all comes down to communicating the specific applicable technologies that benefit the industry. If they see the opportunities, they can start talking about and selling products and automatically need to start using these technologies. But, in the current situation, the industry is not taking the knowledge from the research sector.

F4: Guidance of the search - 2.8
There are also problems regarding the guidance of the search for applicable AC technologies. The interviews demonstrate a shared understanding of the primary challenges facing the search direction, with most interviewees citing three main factors. Firstly, the Dutch concrete system is highly fragmented due to the wide variety of concrete products, necessitating broad government sustainability policies that only focus on reducing the overall carbon footprint. As a result, the search direction lacks precision, and each actor follows its path towards sustainability, illustrated by the 28 different perspectives of the Betonakkoord. Secondly, these broad policies divide the attention and financial resources for sustainability over many innovations, slowing down the process. Finally, AC technologies remain uncertain, as they only apply to a small selection of concrete products and are being tested relatively slowly. The lack of clarity in government guidance exacerbates these uncertainties, as future sustainability requirements are unknown, making it unclear whether AC technologies will be profitable and practical in the future.

F5: Formation of markets - 2.8
Concerning market formation, there are also some problems. Both the research and industry sectors mentioned a lack of evidence for AC technology's applicability, resulting in uncertainties. Nevertheless, they also emphasized the significant potential market for the technology once the uncertainties are resolved. The government, on the other hand, having a demanding role, saw no benefit from AC technologies in their products. They argued that using such technologies could lead to corrosion of the reinforcements, which is undesirable from a user's perspective. Moreover, the government pointed out that the technology faces a competitive disadvantage against other technologies that can be used in load-bearing constructions. Therefore, it is understandable why the government gave a low score for this functionality.

F6: Mobilization of resources - 3.4
The mobilization of resources in the Dutch concrete industry looks to be in order. The interviewees provided consistent arguments, agreeing that sufficient financial resources are available to invest in the right technologies. Still, there is a shortage of human resources due to the concrete industry's decreasing image and a nationwide labour shortage. Some comments were made on physical resource constraints and the adequacy of the current infrastructure. While challenges and difficulties are expected with new technologies, the interviewees highlighted the industry's resilience due to its strong foundation and well-established network of cement transport and professional companies. Overall, the interviewees expressed confidence in the industry's ability to overcome any challenges posed by innovations.

F7: Counteracting resistance to change - 3.4
Lastly, counteracting the resistance to change does not seem to be a problem. The interviewees discussed two main topics: general resistance to innovation and safety regulations for the innovation system in the Dutch concrete industry. Regarding the first topic, it was noted that current concrete users are hesitant to use new concrete types due to a lack of long-term proof of performance. New concrete types have a lower track record, making choosing conventional concrete used for decades easier. However, the industry pointed out a high demand for improved sustainability, making it more permissible to adopt new innovative technologies to become more sustainable. It should be noted that the low level of resistance to change is socred from the perspective of the Dutch TIS. A much lower score from a European scope would represent a larger resistance to change. This has to do with the strong power position of the European cement producers over choosing different innovations.

Regarding the second subject, new technologies and compositions must undergo extensive testing and meet various requirements, with aftercare to monitor the concrete's development over several years. Nevertheless, each interviewee stressed that this process acts as a safeguard for the Dutch concrete innovation system. The strict requirements enable everyone to innovate and search for new technologies and concrete compositions. Without these safety regulations, all innovations would be very dangerous, and no safe discoveries could be made. In conclusion, while the current system does slow down innovation, it is necessary to enable the entire innovation process, and the system should deal with it as best as possible.

5.1.3 Answer to SQ3: System failures of the TIS

SQ3 focuses on the systemic problems of the TIS, which is analyzed in section 4.3. The question for this third part is: what system failures are present within the Dutch AC concrete system, and what does the political landscape look like? This will be answered in the coming section by summarizing the findings from the third part of the results chapter, where it became apparent that the functionalities *Knowledge exchange*, *Guidance of the search* and *Formation of markets* were acting like barriers. Next to that, their coherence is discussed, as well as the political landscape and scoping of the TIS.

Excess demand decreases incentive to innovate

The first functional barrier for the TIS is *Knowledge exchange*, with the industry not actively taking up the developed knowledge from the research sector. The industry mentions the high demand for concrete as a hindrance to innovation, forcing them to choose between meeting demand or innovating. However, I believe this large demand causes a lack of incentive for the industry to innovate. I hypothesise that when demand is much lower, the industry will be forced to innovate to keep existing, and innovation will gain more priority. In addition, there is currently very low benefit for concrete producers when producing more sustainably, lowering the incentive to innovate for sustainability. In conclusion, the first system failure is the excess demand decreasing the incentive of the industry to gather the presented knowledge from the research sector to innovate.

One systemic problem contributing to this system failure comes from the large fragmentation within the *Actor* building block. It leads to a lack of competition among different concrete product niches, reducing the industry's incentive to innovate. The gap between the research and industry sectors within the *Network* building block also slows the knowledge translation process. Because research and industry have different perspectives (science vs profit), knowledge must be translated from research to applicable producing technologies. Because of the lack of incentive to innovate, this gap becomes a systemic problem. Another systemic problem within the *Network* block contributing to the system failure is the split between concrete producers, contractors, and users. The knowledge of AC technologies and the potential products they enable must travel from producers to contractors and then to the final users. This exchange is slow and inefficient and brings in contractors as middlemen, adding an extra set of interests. This combination slows down and worsens knowledge exchange.

The *Institutions* building block presents two more systemic problems. Firstly, the Dutch narrative to reduce emissions at the source rather than compensate for emissions using products contradicts the narrative for AC technologies, which compensate for emissions by storing them in products. Secondly, the institutional procedures to create new types of concrete are extensive and impede innovation. Within the *Technology* building block, the significant uncertainties surrounding AC technologies create hesitation among industry actors to invest in research and development, which again lowers the incentive to innovate. Furthermore, the gap between research and industry sectors again compounds this problem, as industry players must translate research into applicable technologies, which creates further uncertainty. Finally, a nationwide labour market shortage is a minor systemic problem in the *External factors* block that exacerbates the system failure. The industry needs to produce large amounts of concrete, and hiring more personnel could help create time for innovation. However, the labour market shortage makes it challenging to find additional staff.

Fragmentation causes problems for guidance

The second functional barrier for the TIS is known as the *Guidance of the search*. This barrier is primarily due to the significant fragmentation within the industry, which extends to the TIS as a whole. As a result of this fragmentation, the efforts to steer the TIS towards sustainability (mainly through the Betonakkoord in this case) need to be broad to encompass all aspects of the TIS. However, I hypothesize that a major risk of keeping the plans broad is that they can become general, vague, and lacking in impact. Unfortunately, it seems that this is the second system failure for the TIS under study: fragmentation causes problems for guidance. Given the conclusion of the first system failure, which identified a lack of internal motivation to pursue sustainability and innovation, addressing this obstacle is especially important to compensate for the lack of internal guidance.

The fragmentation within the TIS originates from the *Actor* building block, where concrete users have demanded a wide range of products. Producers have created numerous niche products to fulfil these requests, resulting in the first systemic problem. This problem occurs within the *Network* building block, where diverse products are further developed within the research sector, creating various innovation pathways. This increases fragmentation and competition among sustainable TISs, which also causes the government sector to become fragmented. This fragmentation within the different sectors of the network creates difficulty in internal guidance. Still, the guidance by the government in institutional matters over the entire TIS also becomes a systemic problem for the *Institution* building block. As a result, all sustainability plans become vague and difficult to implement, exemplified by the 28 different perspectives within the Betonakkoord.

In addition to that, the fragmented research sector earlier mentioned for the *Network* creates a systemic problem for the *Technology* building block, leading to numerous uncertainties as each innovation path has different benefits, downsides, and applications. Additionally, all available resources for innovation are shared by different paths, slowing down progress compared to a scenario where resources were distributed among fewer innovations. Regarding the *External factors*, two systemic problems arise. Firstly, the European cement producers' strong power position determines which innovations receive more resources and are chosen. Secondly, the large number of innovation paths for research creates many TISs competing for the same resources, leading to further fragmentation.

Uncertainty creates hesitation for market formation

The third functional barrier for the TIS is *Formation of markets*, which according to the interviews, is caused by the many uncertainties for the TIS. All the uncertainties come from the different structural building blocks, leading to the final system failure: uncertainty creates hesitation for market formation. In addition, both of the presented system failures also affect this system failure.

The formation of markets for AC technologies is hindered by several systemic problems. The first one arises from the *Actors* building block, where uncertainties about the different structural building blocks create hesitation among actors and slow the adoption of these technologies. Although many actors see potential in AC technologies, there is too much uncertainty to act on it. Some uncertainties stemming from the *Institutions* building block include the broad sustainable plans mentioned in the previous functional barrier. On top of that comes the unclear future of these plans and institutions from governments. In addition to that, the slow and extensive safety procedures for new innovative concrete contribute to this problem. Nevertheless, it has to be said that all interviewees mentioned that this extensive safety procedure overall is good for the innovation system because it enables innovation even to exist.

Nevertheless, both institutional problems lead to another systemic problem in the *Technology* building block, where it is unclear which technologies will be profitable, applicable, and useful. Concerning *External factors*, an important aspect is the current and future working of the ETS. When this system is used more integrally, a large shift in costs and benefits of emitting and requesting CO_2 could take place, which would largely improve the business case for all AC technologies.

Lastly, the previous two system failures also create systemic problems for the *Network* building block, as there is a lack of both an internal incentive for the industry and external guidance to use AC technologies for the entire TIS. When looking at figure 13, research pushes knowledge on the left side towards the industry. Still, the industry lacks the incentive to innovate and thus gather or receive this knowledge. Additionally, the lack of guidance means that the government is not pulling on concrete users to ask for sustainable concrete products from the concrete producers, resulting in no market formation. Overall, it can be concluded that these systemic problems in different building blocks also hinder the formation of markets for AC technologies.

Coherence of system failures

The three located system failures are interconnected, shown in figure 14. The market formation for AC technologies is not functioning well due to a lack of internal incentives for concrete producers to innovate and incorporate available knowledge into their production processes. This is because the demand for traditional concrete products is high, leading to a lack of competition in the market and a lack of focus on innovation. Additionally, there is a lack of demand from concrete users and contractors for AC technologies, further hindering market formation.

The guidance of the search for AC technologies also faces issues because of the significant fragmentation of the existing concrete industry, with vague and broad sustainability plans. This results in AC technologies representing only a small fraction of the entire system, causing attention to be spread over numerous innovations and leading to intense competition among various TISs. As a result, improved guidance could potentially address the market formation problem, but currently fails to do so. The issue of knowledge exchange is a natural consequence of the previous two issues. Due to the lack of market formation and insufficient guidance towards AC technologies, the industry has little motivation to seek out or utilize knowledge from the research sector. There is a lack of incentive for industrial players to collect and employ knowledge from research sectors, as there is no tangible benefit for them. Instead, they will continue to sell conventional concrete products, as contractors and concrete users remain primarily interested in those.

Policy goal and scope of the TIS

The policy goal of the TIS is closely tied to environmental and economic considerations. The Dutch concrete system needs to become more sustainable, and this is reflected in the government's focus on the Betonakkoord, a pact for the sustainable production and use of concrete. The industry also needs to remain stable economically, but the focus is about 70% on environmental improvement and 30% on maintaining economic benefits. The manual's two dimensions of environmental and economic considerations will be useful for determining the best course of action for the TIS.

The technological scope of the TIS is focused on reducing CO_2 emissions at the source of concrete production. AC technologies currently rely on cement, which emits a large amount of CO_2 during production. However, some developed AC technologies can create building materials without cement, using other binders that emit less to no CO_2. This shift could make building materials a sink for CO_2, where more CO_2 could go into the final product than was emitted during production. The challenge is finding binders that react with gaseous CO_2 and perform similarly to conventional concrete.

The geographical scope of the TIS is influenced by external factors, such as the dominant position of large European cement producers and the EU's Emissions Trading System. These factors could affect the TIS's operations and innovations, as cement producers may resist moves towards a cementless building industry that could threaten their market share. The Emissions Trading System could be improved by allowing actors to earn credits for sequestering CO_2, incentivizing the development of AC technologies and other CO_2 sequestration methods.

5.1.4 Answer to RQ: Status of the TIS

With the three previous SQs being discussed, the main RQ can be answered. This question is: what is the status of AC technology within the Dutch concrete system, according to the TIS framework? To address this question in a structured manner, the question will be answered, followed by arguments in the same order as the structural analysis of section 4.1. This will describe the technology and current development stage and discuss the most relevant actors. To conclude, a brief placement within the network is described.

Status of the TIS
As an answer to the question, I would propose that the current status of AC technology in the Dutch concrete system can be scored with a 4/10. Nevertheless, this could become a 6.5/10 with minor changes due to the good existing basis. This basis comes from the fact that the technology and the Dutch concrete system are well-developed. In addition, there is a large pressure for the industry to become sustainable, and AC technology could play an important role in reaching that. What also adds up is that the current problem seems to lack market formation. When the urge to increase sustainability grows, this market for sustainable concrete will grow, decreasing or even removing the main problem for the TIS. Altogether, the current status is insufficient but has a large potential for the future. More explanation is given based on the different structural building blocks underneath.

Technology
The status of AC technology currently scores a 6.5/10 due to its maturity and applicability. Current industrial concrete suppliers produce two types of products: Ready Mix Concrete (RMC) and Precast Concrete Products (PCP). RMC is delivered to construction sites unhardened and will be poured into the right place or mould where it can solidify. PCPs, on the other hand, are manufactured at factory locations where the same mixture as for RMC is poured into moulds and then hardened before being sold and used. AC technology can be used for both of these products and the production of Recycled Aggregates (RAs), a raw material that can be used to produce both products. An important side note is that there is a lot of disagreement on whether AC technologies can be used in PCPs with reinforcement. Part of the actors thinks it is possible, and part thinks it is impossible. It stands out that this is an uncertain point since the actors are so divided. Nevertheless, all of these three methods are currently starting to be used within the Dutch concrete industry, with technologies like CircaBuild from Carbon8 (RA), CarbonCure (RMC) and Carbstone (PCP) as frontrunners.

When translated to a development stage, it is currently between the development and take-off stages. The reason for this is that the mentioned technologies are starting to grow within the market. Still, more and different technologies are being developed and may have more potential. An important aspect is that new compositions are developed where cement is removed, and different binders are used (second-generation AC technology). Because cement production is responsible for most of the total emission during concrete production (80 to 90%), replacing cement with binders that emit substantially less CO_2 would be very beneficial.

Actors
Concerning research, the status of AC technologies is good and scores 7.5/10. The fundamental knowledge about the carbonation principle has been known for a long time and developed far, as seen on the Technology Readiness Level (TRL) of around 5 and 7. In addition, the attention to the topic is also increasing, which can be seen in the local research overview in figure 11. To conclude on research, the system for bringing knowledge to the market is also properly formed. This can be seen in how universities, research centres and R&D teams

work together and naturally take responsibility for some TRL levels.

Regarding the market, the status of AC technology is not good and scores a 3.5/10. Within the market, AC technologies are unknown to concrete producers, and they are just starting to learn about the different alternatives. Because of this, producers do not know what products can be made with the technologies, so they cannot tell concrete users about it. If they cannot tell users about it, they will not know about it and will not show interest or buy it. This results in the fact that concrete producers have no incentive to try these technologies because they will produce what the user wants. Nevertheless, the Dutch concrete industry is very old, leading to a strong, well-developed system. On the one hand, this makes it easy for new technologies to overcome small barriers because the infrastructure is strong and resilient. While on the other hand, it also enables new technologies to grow quickly when successful.

For politics and policy, the status of AC technology is not very good but also not very bad and scores a 5/10. On the level of the United Nations (UN) and European Union (EU), there is a large focus on sustainability, which is translated to different plans and transition agendas and creates a large drive and attention to become sustainable with the Roadmap from Cembureau being the most applicable. This flows through to the level of The Netherlands, where it becomes more applicable to the concrete system through the Betonakkoord. While this agreement stimulates sustainability within the Dutch concrete industry, one of the 28 acting perspectives mentions AC technologies as a possible solution. While it is a good sign that it is mentioned, it only is 1 out of 28 different solutions, which shows large competition among different TISs. In addition, many acting perspectives indicate that the industry is very fragmented. Because of this fragmentation, the plans and governance of the industry need to be broad to include all fragments. This leads to general measures which can be vague and lack impact.

Regarding AC technologies, contractors are an important intermediary group of actors. Contractors act as a middleman between concrete producers and concrete users, which seems to influence the TIS in a bad way. On the one hand, the role of the middleman adds an extra set of interests and an extra station for knowledge exchange from the producer to the client. Some interviews questioned whether the contractors misused their middleman role only to gain benefits. On the other hand, these contractors could fulfil a perfect role in stimulating AC technologies with the concrete user and act as a knowledge distributor. Although it currently looks like contractors are worsening the situation, it has not become completely sure from this research, and in addition, they could fulfil an important role in the future.

Network
Concerning the network, the status of AC technologies is not good and scores a 4/10. First, as mentioned earlier, the link between concrete production and usage is missing. There is no request for AC products from concrete users to concrete producers, which leads to a situation where the concrete producers have no incentive to use or develop production methods with AC technologies. In addition to that, there currently is a very large demand for concrete products, which also lowers the incentive for concrete producers to innovate. This is noticeable in the way that from the concrete production part of the network, there is no link to the research part because the producers do not pick up the available knowledge. On the other end of the network, there is no good link between the government and concrete users. Because of the large fragmentation of the concrete industry, the government cannot purposefully steer the entire industry towards a specific solution. Especially this steering by the government should work well because of the lack of incentive for concrete producers to innovate and the lack of demand for sustainable concrete from concrete users.

5.2 Recommendations

Regarding recommendations, I would like to refer back to figure 14, which shows the interrelationships between the various system failures. All my recommendations aim to reduce or possibly eliminate these three system failures because that is the best way to tackle the root of the problem. When one type of system failure is reduced or eliminated, it also positively affects the other. Nevertheless, I think that it is most important to reduce the top system failure formation of markets because the conclusion showed that when the market solves itself, the AC technology will continue to grow on its own, while the other two system failures are partially solved on their own or have less impact.

5.2.1 For the Dutch government

The first recommendation is to focus more on directing concrete users, as there is not currently a high demand for AC concrete. The interviews revealed that concrete producers want to produce what the end user wants. Since that is not currently AC concrete or other sustainable concrete, producers are also not exploring alternatives to provide it. In addition to this, it is also important to be aware that contractors have a mediating role between these two groups. Contractors may play a problematic role in this, as they may exploit their mediator position for their gain. But on the other hand, these mediators may very well be used to steer. If there is going to be a focus on concrete users steering toward AC concrete, then this mediator can play an important role.

The second recommendation is to be aware that the industry is focused on making money and try to incentivize sustainable concrete to become more profitable financially. Interviews revealed that the industry has sustainability higher and higher on the agenda and feels it is becoming more important. On the other hand, it is also clear that companies place economic importance high, which makes sense because companies are thinking about their future existence. It seems that concrete producers can make little to no money producing sustainable concrete, partly due to the lack of demand from the concrete user and contractor. Interviews revealed that tender procedures with benefits for more sustainable concrete are in place, for example, but this is not yet working optimally. In addition, the MKI score also seemed to be a good tool to identify the sustainability of concrete; only this is also not yet optimally used in the system.

The third recommendation is to improve the safety verification process of new concrete compositions. This is because this process is slow and expensive, and there is a lack of follow-up on long-term testing. During interviews, it was mentioned several times that the verification process currently plays a very important role because it enables the system to innovate safely. After all, the system is a lock on the door, so everything tested is safe. However, this pathway could be faster, better, and cheaper through more subsidies and long-term oriented. If improved, it would make it easier for companies to experiment with new concrete compositions such as AC concrete.

The fourth recommendation is that the government can better deal with the large size and associated high degree of fragmentation within the concrete sector. Almost all interviews mentioned that the current concrete sector is very large and fragmented due to the large variety of concrete needs and related products. Currently, the Betonakkoord is the main plan from the government to make the sector more sustainable, but this plan is very broad to include all the separate fragments. This ensures that the plans remain general and only focus on lowering CO_2 emissions, giving a lot of choice to the industry and providing very little direct guidance in specific alternatives. By zooming in on the various fragments of the industry and responding to local opportunities and challenges, steering can be done at a lower level, increasing the impact of plans made.

The fifth recommendation concerns better communication from the government about future plans. Something that emerged from the interviews is the fact that there is currently a lot of uncertainty within the industry about certain goals and plans from the government. However, these plans are important for the industry, as time is needed to recoup investments, which all depend on government actions. For example, it is not clear how strictly emissions will be taxed in the coming years, whether there will be certain standards or laws and regulations for emissions, what will happen with subsidies for different sustainable forms of concrete and whether, for example, there will be even more flexible regulations for sustainable concrete in tender procedures. Because there is much uncertainty about these issues, many industry players wait to innovate and invest for clarity.

5.2.2 For the Dutch concrete system

The first recommendation for the Dutch concrete system is to take a more proactive approach towards sustainability. No strict measures are in place, so extreme internal sustainability measures are not yet mandatory. However, this will likely change in the coming years since the current measures have not solved the problem, and clear goals with deadlines have been set for 2030 and 2050. Currently, there is a situation in the industry where everyone agrees that sustainability should be prioritized, but due to the high demand for concrete from users, very little progress is being made. This is a concern because it could lead to a situation similar to the Stikstofcrisis, where construction came to a complete standstill, causing significant problems. To avoid this, concrete producers, users, and contractors should not just do the minimum required by the guidelines. Instead, they should actively work towards minimizing CO_2 emissions from the concrete system to stay ahead of any strict measures.

The second recommendation builds upon the first one and suggests that all three parties involved - concrete producers, contractors, and users - should explore concrete technologies that can be used in the current market. This may seem obvious, but it's essential to consider whether a manufacturer can produce sustainable concrete and whether contractors can offer it to users willing to pay. Currently, there is a lack of demand for sustainable concrete in the market, which makes it risky for producers to invest in creating new products that may not sell. However, when a producer develops sustainable concrete like AC concrete, contractors and users should evaluate whether it can be used and is financially viable (possibly with government subsidies). If feasible, the parties can collaborate on production methods and safety tests to create a new market for sustainable concrete, reducing investment risk.

The third recommendation concerns the difference in perspectives between the research sector and the industry (science vs financial). It's important for the industry to realize that while research can provide useful principles for sustainability, they need to work with it themselves to apply it in production processes. The Dutch knowledge system is well-organized, from research to market, but theoretical knowledge needs to be applied more in practice. However, this can also be an argument for the research sector. They need to know that the industry has economic interests and can use knowledge to improve their production processes. For instance, if carbonation principles like AC technology could lead to faster hardening (unsure, but if this would be the case), the industry is more likely to adopt this technology and adapt sustainability principles automatically. The recommendation here is for both sectors to understand each other's needs and look for ways to link and apply them.

The fourth recommendation is to use the industry's fragmentation better while handling it more effectively. The concrete industry consists of fragments with specific advantages, disadvantages, challenges, and opportunities. For example, AC technology may not be suitable for concrete with reinforcement because of corrosion or load-bearing structures that require extensive testing, whereas, for example, pavers require very little testing. Additionally, AC technology is considered out of the Dutch narrative because it compensated emissions afterwards instead of decreasing emissions at the source. Nevertheless, second-generation AC technology shows negative emissions, which are exactly within the Dutch narrative. It's noteworthy that different technologies are often dismissed quickly or deemed unusable, whereas certain places in the industry could benefit from these technologies to solve specific problems or exploit opportunities, due to the fragmentation. The advice is to identify where a technology is most appropriate and can be applied effectively on a small scale, then explore its potential for other fragments of the concrete industry.

5.2.3 For future analysts

One recommendation for the Dutch concrete system highlights a gap between the research and industry sectors. To bridge this gap, the first suggestion for future analysts is to try and connect AC technology with the needs of concrete producers. Producers' needs are typically driven by financial considerations such as reducing cement usage, shortening hardening time, increasing concrete strength, or streamlining production methods. Integrating AC technology to contribute to these needs, can stimulate producers to use AC technologies and, at the same time, support sustainability. Because linking the demands to AC technology requires extensive knowledge of concrete technology, this recommendation is targeted at engineering analysts.

The second recommendation for future analysts is also intended for engineering analysts. AC technology can currently be used in two types of concrete compositions: one with cement and one with industrial waste streams such as steel slag. Cement composition has large emissions upfront, but AC technology can partially help reduce these emissions afterwards. On the other hand, the composition of industrial waste streams can actually add more CO_2 to the final product than was released during production, resulting in building materials with negative emissions. These building materials are the ultimate goal that the TIS should strive for, as they allow CO_2 to be sequestered. To achieve this goal, it is recommended to investigate whether other substances, like steel slag, have low emissions and can be used to produce building materials. Only a few industrial residues meet these criteria, and even these are limited due to their dependence on steel production.

The third recommendation is aimed at policy analysts. It's been concluded that the Dutch concrete system suffers from a high degree of fragmentation, which poses challenges for steering the industry towards sustainability. Therefore, it would be valuable to properly investigate how to steer a fragmented industry. Moreover, in today's world, systems are becoming increasingly fragmented and governments are often required to steer towards difficult-to-achieve goals such as sustainability. Therefore, exploring the right framework to do this would improve governance in the Dutch concrete system and contribute to a better understanding of how to govern fragmented systems.

The fourth recommendation is aimed at systems analysts and focuses on AC technologies with negative emissions. As mentioned before, AC technology can be used with both cement-based and industrial waste stream-based compositions, but the latter has the potential for negative emissions. Therefore, it is recommended to conduct another TIS analysis for the Dutch concrete system, but this time only focus on AC technologies with negative emissions. This approach has the advantage of providing a large head start regarding the starting level of knowledge on the system and a specific focus on the part of AC technology that can achieve the best sustainability outcome: sequestration of CO_2, rather than just reducing emissions.

The fifth recommendation is once again aimed at systems analysts. It's recommended to conduct a TIS analysis for a technology that uses CO_2 as feedstock in the production of plastics, as mentioned in the introduction. By doing so, two separate TIS analyses are carried out using CO_2 as feedstock in two industries with significant potential. This approach would help shift the perspective of seeing CO_2 more as a raw material rather than waste. Overall, this recommendation can contribute to a better understanding of how to incorporate CE principles into industries that generate significant amounts of CO_2 emissions.

6 Discussion

In this chapter, the research results will be discussed. First, I will interpret the results within the "real world" by comparing them to literature outside the scope of the research. Then, the research limitations will be extensively discussed, focusing on TIS methodology and used data. With the help of the previous two sections, it can also be described what the contribution of this research is for both the TIS methodology and the Dutch AC concrete system. Finally, some concrete recommendations will be given for future research.

6.1 Interpretation of the results

To put this study's results into perspective and better interpret them, this research will be compared with other similar studies and information about the system. For this purpose, firstly, comparisons will be drawn with two different TIS analyses conducted by graduate students, using a single and a multiple case study. Then, the results of this study will be examined in comparison with literature from outside the research scope. To conclude the interpretation of the results, some major findings of the study will be briefly discussed from a personal point of view.

6.1.1 Comparisson with TIS studies

Multi-case study: US Technological Innovation Systems for Service Robotics
The first TIS study being compared to this research is one about service robots (Van Den Brandt, 2010), a more general technology than the application of AC technology in concrete production. The study is a multi-case study that compares the systems of America and The Netherlands. Regarding the research SQs, the first two SQs are the same (focusing on the description of the structure and then the functionality), but the third SQ is different. Here, the external theory about innovation motors refers to functionalities that allow a system to innovate more quickly. This also results in a different main question than my research, as the focus is on how innovation can be accelerated rather than what currently hinders innovation. Also, the building block technology is missing in the structural analysis, but the institutional building block is included, while all functionalities are further the same.

One thing to note is that the study is relatively old, as it is from 2010, which is mainly reflected in the literature about TIS analyses. The data collection is also based on past knowledge production and mainly focuses on how it has developed over the years. Therefore, it revolves around historical data rather than the system's current status. To verify the findings, interviews were conducted with experts from the system, just like in my research. The results from this research are more general than mine and remain superficial. Therefore, conclusions are drawn, and advice is given about different system clusters, but specific systemic problems at an underlying level are not really delved into. This is partly because it is a multi-case analysis that inherently remains somewhat superficial.

Single-case study: Electrochemical synthesis of hydrogen in the Dutch energy system
The second TIS study that is being compared to this research is about the electrochemical synthesis of hydrogen (Zonneveld, 2022), which is a similar technology in terms of scope, novelty, and specialization as the AC technology in concrete production. This TIS analysis is a single case study about the Dutch energy system with similar SQs. All SQs have exactly the same structure as my research, focusing on describing the structure and then the functionalities followed by a description of the systematic problems that arise from them. In addition, there is a fourth SQ about recommendations to the company where the student was conducting their research at the time, which will probably slightly influence the perspective of the research towards market application. Furthermore, the main question has the same focus as my research: identifying different barriers slowing down innovation. Finally, it is worth noting that the method does not follow a manual, and the institutional building block is added here and is also extensively described contrary to my research.

Another thing that stands out is that interviews were also conducted a lot, but no distinction was made between structural and functional analysis. In the functional description, desk research is also done, so the researcher gives a score from his research and there is a score from the expert interviews. This results in two different spider diagrams, which can be of added value. In addition, for the functionalities, the researcher zooms in on the systemic problems at play, making them clear directly at the system functionalities and not just in the final section where the overall problems are discussed. Regarding the results of this research, they are very similar to the outcomes of my research. They start with general findings at the level of functionalities, but then slowly go in-depth and end with interconnected systemic problems that hinder innovation in the system. In general, it can be said that this research is very close to my research and that the method of conducting a TIS analysis in this particular way leads to good in-depth insights into the system.

In comparison to these two studies, it is clear that the single case study is the closest match. For example, it shows that it is good that my research also became a single case study because it allows for more in-depth analysis and reveals underlying problems. Furthermore, using interviews is consistent across both studies, and the institutional building block added value to the electrochemical synthesis research. Finally, I personally see an advantage in the approach of my own RQ and the compared single case study to focus on identifying barriers, as this is more fitting for an emerging technology where the system is still being developed. The last noticeable difference is that the single case study calculates two scores per functionality, one through desk research and one through expert interviews. This approach differs from the one I used to address a limitation described in section 6.2.1, but it is very useful.

6.1.2 Comparisson with the real world

The final conclusion of the research regarding the functional barriers revolves around the three interconnected functionalities of *Formation of markets*, *Guidance of the search*, and *Knowledge Exchange*. As previously stated, the formation of markets is the most crucial, while guidance of the search currently contributes to the lack of formation of markets, and knowledge exchange is a consequence. Additionally, the second conclusion of this study is that AC technology should develop towards negative emissions since this production method does not emit CO_2 first to sequester it later and contributes the most to reducing the sector's total CO_2 emissions. These conclusions are placed in a broader perspective below based on other literature beyond the scope of this research.

The main functional barrier is the lack of market formation for products made with AC technology, which generally has two main causes. The first cause relates to the financial feasibility of sustainably produced products. The TIS analysis showed that there is hardly any demand for AC technology products, among other reasons, because they are more expensive than conventional concrete, which has to do with the fact that the market always seeks the lowest price for equivalent products (Skitmore et al., 2006). The fact that products with lower CO_2 emissions are often more expensive than similar products with higher emissions is a global phenomenon. This is because, in products where CO_2 emissions are deliberately reduced, the costs of reducing those emissions are internalized in the product price. Old conventional products often come from an industry that does not internalize these CO_2 costs, and consumers do not pay for them (Gillingham and Stock, 2018). The importance of this financial feasibility is also emphasized in an article by McKinsey, where the emphasis is on the fact that technologies must be financially feasible to contribute on a large scale to the net-zero goals (McKinsey, 2022b).

Because the demand for conventional concrete products is currently much higher, a second problem arises. Due to the high demand for conventional products, the industry will mainly continue to produce those products. This principle occurs in many industries worldwide and is extensively described in the literature (Gale, 1955). This is followed by the functional barrier of knowledge exchange, where the industry does not actively seek and apply the knowledge produced by the research sector on AC technology because there is little demand for products of this technology. This phenomenon is also noticeable in various industries and described in the literature under the term "demand-pull on innovation" (Costantini et al., 2015).

Next, the research showed a final functional barrier, namely guidance in the search. It is precisely this guidance that the market currently needs due to the circumstances just presented to switch from conventional to AC products. The main problem for guiding the concrete industry is that it is fragmented, making guidance difficult. The fact that the guidance of fragmented industries can cause problems is also widely described in the literature (Miozzo and Dewick, 2004). The authors of the latter research present a way to deal with this better, namely inter-organizational collaboration to tackle the larger challenges of the fragmented industry. However, it is not possible to state that this solution is also possible for the Dutch concrete industry, but it is worth further research.

The second conclusion of the study relates to the future direction of technology within the TIS. As shown, the main argument in the concrete industry for not using AC technology is that CO_2 must first be emitted in cement production to add it back in later. The problem is that more emissions always occur than can be captured afterwards. One solution to this is the development of recent years, in which other binding agents are used than cement (second-generation AC technology). The CO_2 has already been emitted for other industrial processes, creating potential residual streams that can replace new cement production. As a result, it has been shown that products that can be made with these other binding agents demonstrate negative emission results, which is the ultimate medium of reducing the amount of CO_2 in the atmosphere. The importance and potential of these negative emissions products are increasingly being recognized worldwide, particularly in the past year

(European Union, 2022; McKinsey, 2022a; PBL, 2022). Technologies currently on the market include the product CircaBuild by Carbon8 (Carbon8, n.d.), Carbstone technology by Vito (VITO, n.d.) and the production method of CarbriCrete (CarbiCrete, n.d.).

6.1.3 Personal interpretation of major findings

Throughout this research, five interesting phenomena within the concrete industry have become visible that play a significant role in the TIS. These phenomena partially contribute to the three system failures and partially cause problems apart from the system failures. While there are a lot of smaller implications, these five have an influence on a larger scale. Therefore, I would like to reflect on these findings individually in this discussion section and provide specific actions to cope with thes phenomenon.

The first interesting phenomenon in the concrete industry is the fact that there is difficulty in changing within the industry. This is partly due to everything presented in the previous sections, but I believe there is also a psychological aspect. I am convinced that the fact that the industry has existed for a very long time and that all methods are deeply rooted in habits makes it difficult to change. The fact that concrete must be structurally reliable creates a situation where old concrete compositions over 50 years old are seen as trustworthy. Because of this, new concrete compositions must first be proven and thus seem to be relatively unreliable. This is incorrect because different tests can simulate how concrete behaves over a longer period. Overall, I think there is a slight aversion to change within the industry, which slows down this transition. In my opinion, to cope with this aversion, the process of testing new concrete compositions could be improved and focused on long-term testing to remove misleading and ungrounded doubts and improve trustworthiness of innovative concrete types.

The second interesting phenomenon is the industry's high fragmentation level. During the first round of interviews, I focused on exploring the system and gaining an overview of the Dutch concrete system. However, when I conducted the second round of interviews, it quickly became clear that the overview created was too superficial. This was also confirmed by several respondents (Interview B.3 & B.4), and further explained in section 4.1.2 during the market analysis. The high level of fragmentation originates in the large number of concrete aspects that can be changed in many different ways, leading to a situation where specific innovations cannot be applied to all concrete products. Instead, each innovation must be specifically examined to see how it can be integrated into different existing concrete products (Interview A.1, A.3, B.3 & B.5). This also makes it difficult for the government to set goals and rules since different products have varying conditions that can significantly limit innovation and other interventions. In my opinion, this fragmentation requires specific customization to reach all sub-components effectively and could potentially be addressed with the proposed research in section 6.1.2 on guiding fragmented industries.

The third phenomenon within the Dutch concrete industry is the size and influence of European cement producers. As became clear in section 4.1.2, all cement used in the Netherlands is imported and many large concrete producers are subsidiaries of these European cement exporters. The first negative impact on the system is that, in several interviews, these companies were referred to as a cartel. It seems clear why this has a bad influence on the system. Secondly, several interviews explained that the concrete industry is volume-driven, meaning everyone wants to sell as much as possible to have economies of scale and make money. In addition, the requirements for concrete compositions and strengths are also designed around the principle of amounts instead of performance (Interview B.4 & B.9). This means that it is established in regulations how much cement needs to be in a concrete composition instead of how strong the concrete needs to be when tested.

Because this strongly affects cement use, there is a major contradiction in the system regarding sustainability. Currently, the largest players (cement producers) must ensure that as little cement as possible is used because cement is the biggest polluter in the concrete industry. The problem is that this is exactly the business model of the cement producers. For this reason, it is expected that cement producers will want to keep the amount of cement in concrete as high as possible for as long as possible, and will likely oppose innovations such as AC technology. Personally, I find it difficult to identify the best way to treat this party. In an ideal world, I would say that the emissions from these companies should fall more strictly under the existing ETS system, allowing alternative building materials to compete better and making sustainable choices easier. Unfortunately, this is an ideal scenario because scaling up the ETS system would make everything extremely expensive due to the internalization of CO_2 costs and solve much more of the environmental problem at once. The simplified and more achievable version of this may be to steer as much as possible towards MKI scores, so that the eventual amount of CO_2 emissions can become more important in construction processes. This will make innovations with large emission reductions more attractive, and cement producers may be more likely to adopt such alternatives.

The fourth phenomenon noticed during this research is the prominent role of contractors within the system. During the first round of interviews, it was unclear that contractors have such a crucial role within the concrete industry, as they are the connection between producer and user. Due to this realization coming in so late, contractors are actually somewhat lacking in this research. Nevertheless, it has become clear to me that contractors provide an extra set of interests in the construction process and also form an additional station for knowledge transfer about, for example, sustainable products for the end user. It is also unclear to what extent contractors determine which exact choices are made for users, making it unclear what the precise influence of contractors could be. Where it currently seems obvious that contractors want to keep user costs as low as possible, they do not benefit from sustainability because it often costs money. For example, rewarding contractors separately from outside for building sustainably could be an option. The MKI score is a very suitable tool for this, but it can be used much more to steer both end-users and contractors. I would suggest first investigating the decision power and further influence of the contractors, followed by some specific actions to improve the choices made by these contractors for sustainable products.

The final phenomenon that struck me is the generality of the policy rules and goals. This is mainly due to the fragmentation within the Dutch concrete industry, which also leads to general policy formation. As presented in section 4.1.2, the goals of the Betonakkoord are general and poorly measurable. Additionally, many (28 action perspectives) make it less specific for companies. When a government presents a smaller set of more specific alternatives, it also becomes easier for companies to implement them. On the one hand, this has to do with the fact that more specific goals are easier to pick up, and on the other hand, a smaller set of alternatives helps steer the entire industry's attention better. If there are only three possibilities, only a few early adopters are needed to try them out, so the rest see that there are possibilities before they follow. If there are, as in this case, 28, then firstly, many more early adopters are needed and secondly, there is much more doubt among parties about which options can be applied from all these different possibilities. I think the Betonakkoord is doing a really good job of working closely with the different actors and making these plans together. On the other hand, I would advise going one level deeper than the current Betonakkoord, coming up with more specific tools to improve sustainability, and just choosing some alternatives. In addition to that, goals might be more precise and more challenging together with a larger reward for sustainability.

6.2 Limitations

The limitations of this study can be divided into two parts, namely those related to the TIS methodology and those related to the data. Both will be discussed below.

6.2.1 Limitations of TIS methodology

The first limitation of the TIS method is that it takes a very broad perspective of a system, so it quickly becomes a large analysis. This ensures, on the one hand, that performing a TIS analysis takes a lot of time and, on the other hand, that the output found is also quite general about the system. As a result, the analysis may sometimes lack real specific depth, but that need not be a bad thing. After all, it provides very strong tools for a newcomer within a system to understand how the system works in relatively little time. I myself used it for about 15 weeks of research before I made the current overview and arrived at the insights I found and am only now beginning to get a handle on the nuances of the system.

The second limitation of the approach outlined in Hekkert et al. (2011) concerns the disparity in perspectives between steps 1 and 3. In step 1, the researcher explores the system independently, gaining specific knowledge of certain aspects, such as the technology involved. This results in the researcher's perspective on the system being conveyed to the reader to provide a general understanding before delving into step 3. However, when experts begin scoring features in step 3, their perspectives may differ significantly from the researcher's or they may lack knowledge of certain aspects. For instance, some experts may be unfamiliar with the technology, struggle to answer questions, or have differing opinions. There are several possible approaches to address this issue, such as presenting the findings of step 1 to the experts beforehand or allowing them to give unbiased answers. The middle way was chosen, focusing on explaining the different technologies to ensure everyone had a common understanding. Finally, there is a challenge of how to deal with answers in step 3 that are inconsistent with those in step 1. I handled these inconsistencies by adjusting scores in appendix C.

The third limitation of the TIS manual by Hekkert et al. (2011) is that the institutional building block is included as part of the actor building block in step 1, which only considers institutional actors and excludes institutional instruments. This created problems during step 4 of the research, where problematic institutional instruments identified in interviews could not be linked to the structural analysis of step 1. In addition, step 4 specifically mentions linking the findings on systemic problems back to the different structural building blocks. It feels incomplete to not discuss institutions individually in step 1 but then do this afterwards in step 4, which concerning the previous argument, also turned out like so since it caused problems. Additionally, compared to the other structural building blocks, I had less knowledge about the prevailing formal and informal institutions of the system that were not explored in step 1, which hindered my understanding and explanation of certain events.

The fourth limitation corresponds to the third one and concerns the connections of systemic problems located in step 4 with the building blocks outlined in step 1. Apart from the institutions not individually delineated in step 1, the same holds for external factors. Again systemic problems needed to be described during step 4 according to the manual, this time for external factors. Nevertheless, these could not be linked to step 1, where external factors had not yet been introduced. Notably, the absence of a created foundation in step 1 on external factors left me unclear about the scope and subdivisions. Consequently, when problems attributed to external factors emerged, it was challenging to contextualize them within the broader range of external factors. By delineating them in step 1, classifying and understanding them more deliberately would have been possible. In addition, some phenomena could not be explained or understood because they were never really looked at properly and thoroughly beforehand and thus lacked understanding.

The fifth limitation pertains to the arrangement of the five sequential steps in figure 4. The current structure of a TIS analysis is presented as a linear process that only allows forward progression. However, I have observed that between step 1 and step 3, and between step 3 and step 4, there can be iterative thought processes where the researcher can delve deeper into the system or better understand nuances, ultimately revealing the limitations of the TIS. It would be beneficial to acknowledge beforehand that the researcher may need to retrace steps to ensure accuracy or gain additional insights. Incorporating arrows in figure 4 could help clarify this process.

6.2.2 Limitations of the data

The first limitation regarding the data concerns the fact that some actor groups are missing. The interviewees represent the total TIS well, but knowledge from some specific experts would add a lot. This is somewhat logical because, in the beginning, I did not know anything about the system and invited the experts based on that. Now that I know more, I can see which pieces are still missing. The first five experts for the unstructured interviews represent the system well, but it would have been useful to have spoken to a contractor. This party turned out to play an important role in the TIS. It would also have been useful to have spoken to someone with a government background in the first round.

Regarding the structured interviews, it would have been of added value to have spoken with one or two contractors here as well. It would also have been useful to speak with a more diverse group with a government background, for example, to understand policymaking in the construction sector better. Additionally, speaking to two people involved in the Betonakkoord could have been valuable. Although many of the abovementioned conversations were almost scheduled, they did not go through, often due to planning issues. People responded late, sometimes stopped responding during email contact, or indicated they had too little time or could do it a few months later. The lesson that can be drawn from this is that experts from the industry were very willing to participate in interviews, and the research sector also wanted to participate in interviews to a large extent. Unfortunately, people from the government (except for a few respondents) seemed to have less time for interviews.

The second limitation of the data concerns the number of interviewees. Currently, the numbers from both rounds are sufficient to conduct a good analysis, but on the other hand, I also see opportunities to improve the total analysis through more interviews. I think the unstructured interviews could be increased to eight people and the structured interviews to about twenty. Although this would take more time since all the information also needs to be processed, this time can still be gained by how the structured interviews are scheduled. I have spread out the structured interviews over six weeks, which resulted in the fact that I was half analyzing the data and conducting interviews while I was actually waiting for the moment when all interviews were finished because only then the complete data analysis can really be performed. If this is planned differently, for example, by taking a timeframe of three weeks to conduct all structured interviews, then there are three extra weeks to do more data analysis.

The third limitation of the data is that the TIS technology is still very new for many actors in the system, resulting in many interviewees being relatively unfamiliar with the different possibilities. This sometimes resulted in unanswered questions, which were eventually processed in the results by removing those scores. Despite leaving some gaps in the data, it also shows that the technology is still new and unfamiliar to many different actors.

6.3 Contribution

The contributions of this study can be divided into two parts, namely those related to the TIS methodology and those related to the Dutch AC concrete system. Both will be discussed below.

6.3.1 Contribution to TIS methodology

The first addition to the TIS method is the recognition that institutions and external factors should be added as individual structural building blocks during step 1. This refers back to the first and second identified limitations of the TIS method and results in being able to refer back to them in step 4. Additionally, during step 1, the researcher is guided more in these two directions so that a better knowledge base is built and the system is better understood afterwards. Step 1 scopes the research before the researcher explores how it functions in step 3. Furthermore, step 1 is also a kind of guiding tool that actively directs the researcher to investigate how the system works so that better conversations can be held in step 3 because the researcher is well-prepared. To do this, I present a set of questions in the same style as the current building blocks that are present in the manual by Hekkert et al. (2011), which could be used in future research. I also propose a specific place within the order of the building blocks, placing institutions at 3 after the actors and before the network while placing external factors last after discussing the network. The reason for this is that institutions are part of the network and thus need to be discussed upfront, but external factors influence the network, so these need to be discussed afterwards. The questions are:

3. <u>Institutions:</u> What does the institutional landscape looks like?
   (a) Formal: What formal institutions apply to the TIS?
      i. Policy: What policy goals apply to the TIS?
      ii. Laws and Regulations: What laws and regulations apply to the TIS?
   (b) Informal: What informal institutions apply to the TIS?

5. <u>External factors:</u> What does the outside of the TIS look like?
   (a) Competing technologies: What is the development stage of competing TISs?
   (b) Geography: What larger geographical area is the TIS under study part of, and how does that affect the TIS?

The second addition to the method is the use of unstructured expert interviews as one of the data gathering methods during step 1. The researcher can get additional information besides desk and literature research by talking to experts in this phase. The information found with these other methods can also be checked. In addition, inside information can also be obtained about the system, which helps to understand why certain things happen. In my opinion, this is a great added value for later steps, and every TIS should use these unstructured interviews at an early stage.

The third addition to the method is the creation of a survey for the structured interviews, which is then reviewed with experts to fill in scores with explanations. During the conversation, the researcher and expert go through the questions and write detailed explanations in agreement with the expert, resulting in substantive text that can be easily incorporated into the results. In addition, the survey also worked well for processing the data afterwards, as everything can be easily and downloaded into Excel sheets. The explanations are directly linked to the corresponding question and score. As a result, the researcher has a perfect explanation for each score, making it easy to search for patterns and providing a good method for data analysis.

The fourth addition to the method is the accurate following of the manual by Hekkert et al. (2011). By adhering to this manual and following it as closely as possible, it was tested whether I, as a researcher, was directed in the right direction and to what extent I successfully understood the TIS better to conclude. In addition, in this way, it can also be demonstrated to what extent the manual applies to any TIS, which serves as verification of the method. In connection with this, various lessons are also learned about the precise manual applied to different cases. This exposes new improvement opportunities, as presented in the previous contributions to the method. In my opinion, this manual is a suitable tool for researchers with clear focus areas to enter and understand a system.

The fifth addition relates to the second-mentioned limitation of the TIS method in section 6.2.1. I deliberately chose to present step 1 as my perspective on the system and then leave step 3 completely to be filled in by the experts to address the presented problem for the second limitation. This means that step 3 is entirely based on the arguments of the experts and is also treated as such, allowing contradictions with step 1 to exist and be discussed later in the research. This ensures a clear separation between the information in step 1 (researcher's perspective) and step 3 (experts' perspective). If step 3 were to be filled in according to my vision of the system, but based on answers from experts, there is a danger that 4.1 and 4.2 will become a big jumble of words that all mix. It is no longer clear what the researcher's opinion is versus the experts' opinion. This can be avoided by making a clear, hard division between steps 1 and 3. I also see step 1 as a means to guide the reader of the thesis and provide a basic understanding of the system before delving into the functioning of the system in depth.

6.3.2 Contribution to the Dutch AC concrete system

The first addition to the Dutch AC TIS is the final complete overview, with the most important insight being the three central functional barriers and how they are interrelated and cause problems. I would like to focus on the finding that there is a lack of market formation for sustainable technologies. On the one hand, it could be argued that this is fairly obvious since this happens to many different sustainable innovations, but at the same time, it has been substantiated in a well-founded way through a TIS study. Additionally, the functional barrier of guidance of the search is also a valuable addition, as it is caused by a high degree of fragmentation, which may not be as obvious. Ultimately, the combination of these barriers keeps each other in balance and reinforces each other's problems. Finally, I am also of the opinion that it is likely that this conclusion applies to other TISs in the Dutch concrete industry and can be further researched to take action.

The second addition is the technological overview created in section 4.1.1 in combination with the term AC technology. This presents an overview of the current production methods for actively adding CO_2 in concrete production and enables these methods to be clearly identified as separate from normal concrete production where passive carbonation mainly plays a role. This overview also shows that the future of the TIS is likely to lie in concrete compositions with binders other than cement (second-generation AC technology), as these new compositions can achieve negative emissions, allowing for active CO_2 sequestration. As a final addition, this could also result in concrete engineers, by reading this thesis, gaining a better understanding of where the technology stands in the current concrete sector and broader society. This may hopefully result in the technology being further developed in a certain direction.

The third addition has been made in creating a complete overview of the concrete industry. By conducting a TIS and completing step 1, an insightful overview of the Dutch concrete industry's current status and way of working has been created. On the one hand, this can be used by someone to quickly gain insight into the structure of the system, while on the other hand, it can also be used as a basis for further research into something in the Dutch concrete industry.

In addition, I hope that my fourth and final addition to the system has been to raise awareness of AC technology among some stakeholders within the system. I have tried to clarify the possibilities of the technology for concrete production, sustainability, and the larger perspective of using CO_2 as a raw material in the hope that AC technologies can become more widely known. Among other things, as there are currently various tests related to concrete production, I hope that my activity within the system on this theme has repeated the technology enough times to make parties curious and look for applications. In my opinion, every kilogram of CO_2 that disappears from the air through this technology is a step closer to achieving the 2050 climate goals.

6.4 Further research

This section constitutes the conclusion and concretization of everything discussed in the previous chapter. Here, four specific research directions are presented based on the study's findings and further reflection on these results.

The first interesting research direction from the established research results is that of new binders to replace cement, with the main goal of producing building materials with a negative CO_2 footprint. As stated in the previous chapter, there is potential to apply negative emission AC technology in the industry. There is also a need and support for negative emissions in recent years. During the research, some existing products were found that can already be made from steel slag, but further research could discover more of these alternative binders. This could involve industrial residual streams, but also binders that can potentially be made with low CO_2 emissions.

The second interesting research direction is towards the governance of fragmented industries, potentially using the Dutch concrete industry as a case study. As previously stated, industrial systems are becoming increasingly fragmented and there is a greater need than ever for good governance on sustainability issues. On the one hand, this research identifies a suitable system with a high degree of fragmentation. On the other hand, it shows that there is indeed a need for knowledge on governing a fragmented system. A starting point could be the literature mentioned by Miozzo and Dewick (2004), for example, by testing the proposed method on the Dutch concrete industry.

The third interesting research direction could be performing a similar TIS analysis for another product mentioned in the introduction to use CO_2 as a raw material. I would advise focusing on plastic, as it is also considered a high-potential product, and I expect the application there to be easier. A similar study would pave the way for a comparative study between plastic and concrete and investigate another product to approach a complete overview of CO_2 use as a raw material. In any case, a TIS analysis of another product would contribute to the proposed perspective of stimulating the CE of CO_2.

The fourth and final interesting research direction focuses more on the methodology of the TIS analysis and specifically on improving the manual of Hekkert et al. (2011). This research has shown that adding the structural building block of institutions and the aspect of external factors to step 1 of the manual could add value. The arguments for this have been extensively discussed in the previous sections, but it could be of added value if this proposition were tested on a random TIS. If it turns out to be an addition, this could mean a development for the TIS manual.

7 Concluding remarks

At the conclusion of the research, I would like to take the time in this final chapter to make a few last remarks. I will not summarise the entire study, as it has already been described in the executive summary at the beginning of the research. However, I would like to briefly reflect on the results personally, followed by my opinion on the new perspective. Then, I will conclude with a brief personal retrospective on the research trajectory that I have undergone in the past few months.

Regarding the results of the research, I am personally satisfied. Firstly, very clear systemic problems and functional barriers have emerged from the TIS analysis, which applies to the specific AC TIS and largely applies to the Dutch concrete industry. I also believe the recommendations from chapter 5.2 and findings from chapter 6 are valuable to both the Dutch concrete system and the further research world. Lastly, the finding about the future direction of AC technology towards CO_2-negative products is also very useful, as this direction was originally the reason for which I started my research.

The potential negative emissions of AC technology align with the proposed perspective from the introduction to stimulate a circular CO_2 economy to combat the current climate problem. When I look back at this proposed perspective from the TIS research, I believe there are possibilities to build such a CO_2 utilization system. However, there are still many challenges to overcome. In principle, CO_2 can currently be used in products, but an important barrier is that obtaining high-purity CO_2 often makes the business case negative. On the other hand, it is currently visible that producers are developing technologies that use industrial exhaust gases.

In addition, the production of building materials with steel slag, for example, is strongly dependent on a residual stream from the steel industry; if that stream disappears, the product cannot be made anymore. On the other hand, a lot of that steel slag is being thrown away, which is very wasteful because potential sequestration is being discarded. Therefore, it is important for this perspective to research the possibilities per product and innovation regarding the amount of CO_2 that can be sequestered. A clear example of this has already been mentioned, such as performing a TIS analysis on the technology that uses CO_2 as a raw material for plastic production.

To conclude this research, I would like to reflect on the research process briefly. Overall, I found this research to be very educational and challenging. I mostly enjoyed working on it and received the right guidance when needed. Of course, some moments were not enjoyable, but I feel it comes with the territory. All in all, I can confidently say that writing this thesis has made me a better researcher and has definitely piqued my interest in a career in the concrete industry, with a special focus on realizing negative emissions to contribute to solving the global climate problem.

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A Unstructured expert interviews for the structural analysis

Within this appendix, all raw data from the unstructured expert interviews are presented. The interviews are given in the same order as presented in section 3.3 and represent a selection of the most important notes taken during the interviews.

A.1 Consultant Technology and Regulations at Betonhuis (Branch organization)

1. Heb ik toestemming om aantekeningen te maken gedurende dit interview en deze daarna samen met jouw functie titel + bedrijfsnaam te publiceren in het uiteindelijke document, welke ook online verspreid wordt?
   (a) Toestemming is gegeven.

A1.1 De Nederlandse betonmarkt

2. Wat is Betonhuis voor organisatie?
   (a) Betonhuis is de brancheorganisatie van betonmarkt Nederland. 80% van de betonmortelindustrie is bij ons aangesloten en 90% van de cementindustrie.
   (b) De Nederlandse betonmarkt had in 2017 een totaal volume van 13 miljoen m^3, in 2020 is dat iets gestegen tot 15 miljoen m^3. De verdeling per sector is echter hetzelfde gebleven.
3. Wat voor soorten productiemethodes zijn er voor beton?
   (a) Kant-en-klare betonproducten wordt prefab genoemd
   (b) Kant-en-klaar heeft vaak iets betere kwaliteit dan betonstort, maar is wel even duur. Het transport is duurder maar aan de andere kant zorgt binnen werken voor stabielere condities wat beter is. Daarnaast is er een herhalend proces wat de kosten drukt. Prefab heeft wel meer mensen nodig wat het ook weer duurder maakt.
   (c) Carbstone is alleen mogelijk voor heel poreus beton. Dus niet voor alle soorten beton.

A1.2 CO_2 gebruik bij betonproductie

4. Wat weet je van CO_2 gebruik bij betonproductie?
   (a) In Nederland nauwelijks, misschien 1 of 2 kleine.
   (b) CO_2 in betonmortel toevoegen versneld de uitharding, dit is onhandig en slecht voor de kwaliteit. Als beton namelijk te hard is bij het storten zorgt dit voor problemen zoals dat het minder goed uitzakt. Dit proces kan je weer vertragen door producten toe te voegen om te de uitharding te vertragen maar dat is wel weer duurder.
   (c) Bouwsnelheid is erg belangrijk. Wanneer prefab gestort is in mallen en uitgehard, moeten de kisten eraf gehaald worden. Daarom is de beginsterkte belangrijker dan eindsterkte van de producten, zodat de productie sneller door kan gaan. Dus betonproducenten kijken vooral naar de beginsterkte van beton zodat ze snel door kunnen gaan met produceren. Er is vaak ook en productiecyclus van een dag. 'S ochtends om 6 uur wordt alles voorbereidt, dan in de middag alles gestort en kan het 's nachts uitharden. De volgende dag kan dit proces weer opnieuw doorlopen worden om maximaal te produceren.
   (d) Het begint allemaal bij de opdrachtgever. Als de opdrachtgever iets duurzaams vraagt, dan krijgt hij het.
   (e) Over het algemeen moet beton binnen twee uur gestort worden.

A1.3 Onderzoek

5. Hoeveel procent van de bedrijven in de Nederlandse beton industrie hebben een eigen R&D afdeling?
   (a) Dat is absoluut waar. Voor mijn gevoel zijn dat de grotere bedrijven omdat ze budget hebben. Voor de kleinere bedrijven is dat lastiger, vooral nu in de tijden van arbeidstekort. Het is al alle hands aan dek om alles gemaakt te krijgen.
   (b) VBI, BTE-groep, Spaansen en MBI (van de straatstenen) maar ook Heidelberg (ENCI en MEBIN), Holcim en Dyckerhoff, dit zijn cementleveranciers die ook betonmortelbedrijven bezitten. Die zitten heel erg in de inframarkt. Ook de cementleveranciers. Het zijn vaak holdings met meerdere productievestigingen die dan mensen vrijmaken en kleine dingetjes onderzoeken om dat uit te rollen naar andere vestigingen. Nog geen 10 procent van de bedrijven, rond de 10 maximaal 15. Betonmortel zijn er 102 totaal maar dat zijn vooral allemaal onderdeel van een paar grote partijen.

(c) Vooral de grote partijen staan welwillend tegenover interviews.

6. Zijn er soortgelijke bedrijven als TNO in Nederland?
   (a) SGS introm (testen van beton, duurzaamheid, LCA expert), SGS search, ABT adviesbureau (actief of social media) en andere grote adviesbureaus maar daar heb ik weinig contact mee. Andere bedrijven doen alleen maar LCA's. TNO doet vooral fundamenteel onderzoek. Mensen van TU Delft werken ook bij TNO dus kruisbestuiving.
   (b) Opzoeken BRBS over gerecycled beton. 20 miljoen ton goed recyclebaar beton beschikbaar (Waarschijnlijk). BRBS recycling of BRBS.nl Ze hebben grafiekjes.
7. Kun je vertellen over de verbinding tussen onderzoek en de industrie?
   (a) De afstemming kan beter tussen gebruik en efficiëntie. Als er iets verzonnen kan worden wat compleet anders is maar wel gelijk gebruikt kan worden zou dat beter kunnen. De bouw is natuurlijk al 2000 jaar oud en de processen zijn al heel lang hetzelfde. Aannemers etc.
   (b) Betonhuis heeft wel contacten met universiteiten. We doen ook wel eens gastcolleges, iet alleen bij universiteiten maar ook bij mbo's en HBO's. Maar het zijn vooral bedrijven zelf die stagiaires aannemen voor onderzoek. Stageplekken zijn momenteel de verbinding tussen onderzoek en industrie.

A1.4 Onderwijs

8. Wat voor soort opleiding is er allemaal voor de Nederlandse beton industrie? En met name op verschillende niveaus? Wat zijn verschillende opleidingsinstituten? Hoe verloopt dit allemaal?
   (a) Het is momenteel maatschappelijk een probleem op de arbeidsmarkt en op alle niveaus staan we te springen om mensen.
   (b) Alle niveaus, LBO en MBO. Die komen meestal in de productie terecht. HBO komen op kantoor en in de werkvoorbereiding. En univeristair komen nog iets hoger in de boom met onderzoek doen etc.
   (c) Er zijn zeker opleidingen beschikbaar. Ik hoorde gister een verhaal, voorheen twee klassen met 30 mensen en nu nog maar 1 klas met 30 mensen.
9. Waarom komt het tekort?
   (a) De bouw is niet sexy. Daarnaast wil iedereen hoogopgeleid zijn en we hebben een slechte naam. Onterecht. Daar proberen we wat aan te doen. De bouw is de grootste industrie in de wereld en wordt geframed als grootste uitstoter maar zijn ook erg groot en belangrijk.
   (b) Opzoeken BRBS over gerecycled beton. 20 miljoen ton goed recyclebaar beton beschikbaar (Waarschijnlijk). BRBS recycling of BRBS.nl Ze hebben grafiekjes.

A1.5 Netwerk

10. Wat zijn partijen die betrokken worden in of samen werken met partijen binnen de betonproductie-industrie? Ik dacht nu aan transportbedrijven, brancheorganisatie, investeringsmaatschappijen.
    (a) Volgens mij geen investeringsmaatschappijen. En als ze er zijn kunnen ze niet echt wat zeggen, draait puur om geld verdienen.
    (b) Er is ook nog zoiets als subsidies voor projecten. WBSO is een voorbeeld. Daarmee wordt een deel van de loonkosten besteed aan R&D van bedrijven. Moet je van te voren aanspraak op maken.
    (c) Ook onderzoeksinstellingen kunnen gebruik maken van subsidies. En TNO is grotendeels gesubsidieerd door de overheid.

A1.6 Beleidsvoering

11. Wat zijn op nationaal gebied de belangrijkste politieke invloeden? Betonakkoord? Greendeal? Handelingsperspectieven? MVO beton netwerk?
    (a) Betonakkoord komt niet vanuit overheid maar vanuit industrie en is een afspraak/belofte aan de overheid van de hele industrie.
    (b) Ondertekenaars van betonakkoord even opzoeken en rapporteren.
    (c) Handelingsperspectieven is een handleiding van hoe het kan, en dan kan iedereen zelf kiezen welke het best toepasbaar zijn. En vanaf daar weer kijken hoe verder.
    (d) De overheid (in brede zin van het woord, van gemeenten tot en met rijksoverheid|) is voor een groot deel (ergens rond 30 tot 50%) van het Nederlands betongebruik opdrachtgever.
    (e) Handelingsperspectieven zijn opgesteld door een werkgroep vanuit het betonakkoord.
    (f) Er is ook nog een soort staal akkoord, die is iets later gestart.

(g) Aannemersbranche is zelf ook bezig met verduurzamen.
(h) Er zijn meerdere clubjes die zich inzetten voor verduurzaming van allerlei kleine subgroepen.
(i) We bekijken momenteel de handelingsperspectieven voor 2030 om te kijken per productgroep hoe de verschillende doelstellingen haalbaar zijn per tijdseenheid.
(j) De verwachting is dat er steeds minder op de bouwplaats gedaan gaat worden en steeds meer in fabrieken geproduceerd. Dan is het op de bouwplaats voornamelijk inpluggen. Dat beteketn dat alles goed op elkaar moet aansluiten, wat momenteel nog wel eens wil misgaan.

12. Hoe denk je over bepaalde vereisten in tenderprocedures om bijvoorbeeld CO_2 behandeld beton te stimuleren?
    (a) Dat gebeurd al. Er zitten heel veel haken en ogen aan. Een is, hoe eerlijk ben je met inschrijven. Beschikbaarheid van de materialen is een probleem. Hoe we het nu hebben ingericht (MVI score) zorgt ervoor dat materialen schaar zijn omdat iedereen het wil en dan worden de kosten heel hoog. Als industrie hebben we daar niks aan. Er wordt op projectniveau gekeken en niet op industrie niveau, dat schiet naar mijn mening niet op. Niet dat we gekke dingen gaan doen qua technische levensduur (dat we moeten opletten dat we niet te snel willen en daarom een verkeerde keuze maken).
    (b) De opdrachtgever bepaald wat er afgenomen wordt. Particulieren zijn wat terughoudender omdat het meer kost, overheid is wat vrijer met meer uitgeven.

A.2 Assistant professor at Delft University of Technology (Civil Engineering)

1. Do I have permission to take notes during this interview and use the answers including your job title + company name in the final document, which will be published online?
    (a) Permission is granted.

A2.1 Technology

2. I would like to discuss the topic of Carbonated Recycled Aggregates (CRA) with you. Specific topics are CO_2 uptake, important aspects of this production method and its potential. Can you elaborate on these topics?
    (a) It is hard to reach the maximum amount of CO_2 uptake with passive carbonation, therefore we try to facilitate it with active carbonation.
    (b) If Recycled Aggregates (RAs) are used in new concrete, this creates faster natural carbonation because the porosity of the entire concrete gets higher. Penetration thus goes faster.
3. I would like to discuss the topic carbon-curing Precast Concrete Products (PCPs) with you. Specific topics are CO_2 uptake, important aspects of this production method and its potential. Can you elaborate on these topics?
    (a) The maximum potential CO_2 uptake by Portland cement is 0,5 kg CO_2 per 1 kg cement.
    (b) The amount of cement used, decides how much CO_2 can be taken. On average 300 to 350 kilograms of cement is used per m^3 of concrete.
    (c) The natural carbonation process takes very long, active carbonation would increase the speed. But very unsure how much uptake.
    (d) To see how much CO_2 can be captured, Calcium oxide (CaO) is the one to watch. CaO is targeting the CO_2 so that mainly decides how much can be captured. Cement exists for 60 to 65% of CaO. 40 to 35% is a mixture of Fe_2O_2, Al_2O_3 and SiO_2, MgO. These also react with CO_2, but these do not react as well with CO_2 as CaO.
    (e) The amount of natural carbonation also depends on the form and size of precast products. If blocks are very thick, the inside cannot be reached by natural carbonation.
    (f) During the active curing process, water is added with water sprinklers on the hardening concrete and takes a minimum of 24 hours and a maximum of 28 days. Sometimes also wet towels are used on hardening concrete or it is packed in plastic so that water cannot evaporate.
4. I would like to discuss the topic of infusing CO_2 during the mixing of concrete with you. Specific topics are CO_2 uptake, important aspects of this production method and its potential. Can you elaborate on these topics?
    (a) If there is a lot of carbonation, the pH will drop below 7 and if there is reinforcement within the structure, this will start to corrode. This will also happen if reinforcement is too close to the surface of the concrete. It is thus important to see where reinforcement is applicable and where and how to carbonate concrete.
    (b) If reinforcement is in a structure, no extra carbonation is used. Next to that, reinforcements are treated with coatings of high pH values to protect them from corroding. Corrosion happens because carbonic acid is formed: H_2CO_3 or H^+CO_3. Nevertheless, Carbonated Recycled Aggregates (CRA) can be used in concrete production without a direct risk of corrosion.
    (c) Combining all three methods is possible, it would highly increase carbonation uptake. Problems are only with how to set up production processes and implement these production methods within the industry. And for example, who is delivering CO_2?

A2.2 Research

5. Which parties develop knowledge on AC technology in The Netherlands?
    (a) Some students execute tests for example here at TU Delft, which is very practical. I do not know what other universities are researching on this topic. Research centres also develop knowledge, like TNO and VITO (Belgium). There are also companies with their own research teams, but they have a conflict of interest. They will probably also keep their research and the direction they are heading to their selves.
    (b) First there is research on a proof of concept. This has started with green construction materials, sometimes also with a design perspective in mind. It is important what materials are used and whether they are environmentally friendly. Within society, concrete is used on a very large scale, and

thus a lot of unsustainabilities comes from the construction industry. The question then is: what can be done? Cement is accounting for a large part of industry emissions, so one way to optimize this is developing materials where the cement use from Portland cement (a lot of emissions) shifts to Cem iii (substantially less cement use and thus emissions). Another method to reach results was carbonation, but a problem was the corroding of reinforcement in concrete because of carbonic acid which was a thread. CO_2 dissolved within the water and that makes a very small amount of carbonic acid which corrodes. But, if CO_2 reacts faster with CaO the problem goes away because the CO_2 has become solid instead of carbonic acid. But, the final results are not sure and need to be seen in the future after the service life of the concrete. In the end, carbonation makes concrete stronger. Another green practice is after-service life. RAs are the last method, this can be used with structures with reinforcement because the carbonation process has already taken place before coming in contact with the reinforcement.

6. How can knowledge development on CO_2 use be investigated?
   (a) Look for interesting papers in The Netherlands and search for their latest work.
   (b) Look for organisations underneath who know this. Maybe create a research overview table of The Netherlands.
   (c) NWO, funding agencies, European Commission, and Rijkswaterstaat are also involved in knowledge development.
7. Are there a lot of requests from the concrete production industry on research?
   (a) Horizon projects are funded by the European Commission. Companies that do not want to pay for landfill (disposal taxes) send samples to the lab which can be tested and valorized before it will be used. We need to know the quality od composition of the RA's before we can use them.
   (b) Companies need to have a benefit, otherwise, they will not use it.

A2.3 Politics & policy

8. Have you experienced some form of influence of policy-making on concrete production research?
   (a) Within tendering processes sustainable requirements can be created. They will ask for green materials, less carbon footprint, sustainable products, green products, less energy use or specific materials.
   (b) In 2030 concrete has to be 100% circular, this means that all the resources for concrete need to be recycled. It is called betonakkoord. Concrete agreement.
   (c) Research is done in the past 20 years which has brought useful results.
   (d) Maybe add circularity score or carbon footprint score or sustainability score to projects or products.

A.3 Manager Production & Technology at Dyckerhoff Basal Betonmortel B.V. (RMC producer)

1. Heb ik toestemming om aantekeningen te maken gedurende dit interview en deze daarna samen met jouw functie titel + bedrijfsnaam te publiceren in het uiteindelijke document, welke ook online verspreid wordt?
   (a) Toestemming wordt gegeven.

A3.1 Organisatie

2. Wat doet jullie bedrijf precies?
   (a) Dyckerhoff Basal Nederland is onderdeel van Buzzi Unicem, een organisatie gevestigd in Italie. Zij zijn in 13 landen actief en hebben 10.000 werknemers. Leveren niet alleen een product maar ook beton technisch advies. Verder leveren we dus betonmortel en toeslag materiaal.
   (b) Buzzi Unicem (ons moederbedrijf) heeft een netzero plan en is hier heel hard mee aan de slag. Er is onder andere een uitgebreide roadmap te vinden.
   (c) Er zijn ook 28 handelingsperspectieven vanuit de beton branche vereniging waar mee gewerkt wordt om zo het hele systeem te verbeteren.
3. Waar komen de duurzaamheidsdoelstellingen vandaan? Internationaal? Zelf ook inbreng op Nederlands niveau?
   (a) Wij hebben invloed op de duurzaamheidsplannen, omdat we onze eigen doelstellingen en plannen moeten maken. We moeten werken aan onze eigen doelen voor kleinere carbon foorprint volgens een aantal normen. We schakelen bijvoorbeeld om naar minder gebruik van klinker en willen ook zoveel mogelijk betongranulaat toepassen. Maar we hebben ook hele andere duurzaamheidsplannen. Dit is ook ledverlichtingen. Dus zeker vanuit bovenaan (moederbedrijf) maar ook eigen maatregelen. We hebben dus ook losse dingen naast de roadmap van Buzzi Unicem.

A3.2 Algemene betonmarkt

4. Welke hoeveelheden beton worden er per keer gebruikt in de industriële betonsector?
   (a) Het soortelijk gewicht van 1 m3 beton is 2380 kilo en we hebben twee typen tuckmixers, namelijk 10 m3 en 13 m3. Daarnaast wordt alles bij ons per m3 verkocht.
   (b) Bij de productie van 1 ton cement van het type cem 1 (pure klinker) komt totaal 850 kilo CO_2 vrij.
5. Hoeveel cementproducenten zijn er in Nederland?
   (a) Er wordt hoegenaamd geen cement meer geproduceerd. Klinker fabriek in maastricht is gesloten rond 2017 en daarmee zijn er geen cementfabrieken meer in Nederland. Er zijn wel maalfabrieken in ijmuiden en Rotterdam. Dus geen brander maar een maler. Het komt er eigenlijk op neer dat alle cement wordt geimporteerd.
   (b) Cement was een x bedrag per eenheid in het afgelopen jaar en gaat komende jaar naar 1,5 keer die prijs voor een eenheid. Dit heeft te maken met energieprijzen, CO_2 rechten, etc. In het verleden hadden we stijgingen van een paar procent per jaar maar nu gaan we dus zo'n 50% omhoog. Je merkt dat dit ook wel voor innovatie en verandering in de markt zorgt. Zo kunnen we bijvoorbeeld goedkope chemicaliën inmengen om de hoeveelheid cement die we nodig hebben te verlagen.
   (c) Algemene berekeningen carboncure zijn gebaseerd op portland cement, maar als je cem 3b gebruikt (hoogovencement) dan moet je natuurlijk wel een andere berekening doen, omdat er veel hoogovenslak inzit en dat kan minder CO_2 binden.
6. Wie produceert/importeert toeslag voor betonproductie?
   (a) Toeslagmaterialen voor beton zin in Nederland voornamelijk zand en grind of graniet, dus inerte materiaal. Er zijn een aantal partijen die dit leveren, het is voornamelijk zoetwatermateriaal. Het wordt gewonnen in de stroombedding van de rivieren. In de maas zit ook heel veel grind bijvoorbeeld. Het komt met de stroom mee vanuit de ardennen. In maastricht is het vijvoorbeeld groot materiaal (80 grind /20 zand) en stroomafwaarts wordt het steeds fijner dus in Nijmegen (20 grind / 80 zand) is het steeds kleiner. Vooral uit de rivieren dus maar ook import uit Duitsland maar dat wordt steeds moeilijker. Daarom ook steeds meer materiaal wat uit de zee komt.
7. Algemene opmerking
   (a) Persoonlijk vind ik het van groot belang dat de levensduur van het beton niet ten kosten gaat van duurzaamheid, maar dat is wel wat we gaan krijgen momenteel. Er worden steeds meer dingen gemengd door het beton om duurzamer te worden, maar het wordt heir niet altijd beter van.

A3.3 Betonmortel

8. Hoe kijkt de industrie aan tegen het gebruik van CO_2 bij de productie van betonmortel?
   (a) Over enkele weken gaan we een test doen in Delft met de technologie van Carboncure, dan spuiten we CO_2 in tijdens het mengen van toeslag, cement en water. Hiermee kan je dus CO_2 kwijt.
   (b) Het inspuiten van CO_2 heeft geen effect op de verhardingstijd, zegt Carboncure. Ik denk dat het niet heel veel effect heeft op de verhardingstijd, misschien wat op de sterkte. Maar daarom gaan we dus wat tests doen.
9. Weet je toevallig of er op meer plekken in Nederland dit soort tests gedaan worden?
   (a) Weet hij niet, ziet soms wel iets via linkedin dingen voorbij komen. Maar kan niet verwachten dat zij de eerste zijn.

A3.4 Prefabbeton

10. Zijn de mix opstellingen van betonmortel hetzelfde als voor prefab productie locaties?
    (a) Prefab producenten gebruiken over het algemeen dezelfde mengers als betonmortel producenten. In Delft hebben we nog een oud model staan, die worden niet meer gemaakt omdat de meng principes zijn veranderd in de neiuwe systemen. Maar over het algemeen zijn ze zeker hetzelfde.
    (b) Het is voor de prefab industrie dus ook mogelijk om de carboncure technologie te gebruiken.

A3.5 Gerecyclede toeslag

11. Hoe wordt er vanuit de industrie gekeken naar gerecyclede toeslag? En wat als deze ook nog behandeld is met CO_2?
    (a) Beton wordt voorlopig best wel gerecycled in de Nederlandse betonindustrie, er is ongeveer 6 miljoen ton bruikbaar beton als we goed slopen en scheiden wat ook best wel gebeurt. Echter weet ik niet precies hoeveel er momenteel wordt gerecycled, dat moet ik even checken. Betonhuis weet dit ook zeker.
    (b) Wij recyclen zeker beton. Vaak wordt beton niet allemaal opgemaakt door klanten van ons. Daarom hebben wij in het midden van het land rest betoncontainers waar we ongebruikt beton in kunnen dumpen met truckmixers. Dit wordt dan hard en wordt naar een breker (betonmaler) gebracht die het dan teruggeeft als gerecycled toeslagmateriaal. Wat we ook kunnen doen als het nog niet hard is, is uitspuiten. Dan voegen we veel water toe aan het natte beton en kunnen we cement en toeslag scheiden en de dag erna hergebruiken. Echter is het cementmengsel slecht handelbaar wat het soms wat lastig maakt.
    (c) De hele industrie heeft het betonakkoord getekend, dit betekent dat iedereen zich heir ook steeds meer naar gaat gedragen. Denk aan sloopbedrijven die beter slopen voor recyclen, projectmanagers die openstaan voor gebruik van gerecycled materiaal en wij die aan de slag gaan met nieuwe technologieën om CO_2 uitstoot te verlagen. In het begin moest iedereen wennen, er is nu verandering merkbaar dat iedereen steeds meer aan het toelaten is dat Ras gebruikt worden.
    (d) Een doelstelling van ons bedrijf is dat er dit jaar 5% van de primaire invoer van toeslagmateriaal uit gerecycled beton moet komen. Ik weet niet of we dat gaan halen maar het zel ergens rond de 4% a 5% zijn. Je merkt dat verduurzaming begint dte lopen en de cirkel zich steeds meer sluit, er wordt steeds meer recyclebaar beton verzameld en verwerkt.
    (e) Voor een deel is de sterkte van beton niet heel belangrijk voor ons, er is vooral oversterkte in de lagere sterktenklassen. Daar zijn meestal de milieueisen voor de verhouding water/cement zo dat er oversterkte is/moet zijn. Maar, als we allerlei maatregelen gaan treffen in de komende jaren om minder klinker te gaan gebruiken en zo minder CO_2 uit te stoten, daan gaat beton ook minder cement bevatten omdat dat duurzamer is. Dan wordt het misschien belangrijker om potentiële kansen te vinden waarmee we minder klinker gaan gebruiken maar zelfde sterkte te hebben. Door deze focus gaat de komende jaren oversterkte minder worden verwacht ik. Door meer versnijden van product (andere substanties toevoegen dan cement) wordt oversterkte meer een onderwerp.
    (f) Ik denk dat de drie methodes van CO_2 behandeling gecombineerd kunnen worden vanuit een industrieperspectief.
12. Hoe werkt de beton sloop industrie?
    (a) 30% van het volumeprocent van toeslagmateriaal kan gerecycled beton zijn en dan moeten we echt gaan doorrekenen wat de effecten zijn op het beton. Verder is er jaarlijks 30 tot 35 miljoen ton toeslagmateriaal nodig om betonprodutie van Nederland te doen. Ik geloof dat er ongeveer 6 miljoen ton beton recyclebaar is alleen ik heb geen idee hoeveel het ook gebruikt wordt.

A3.6 Overig

13. Hoe verloopt het vervoer voor jullie betonmortel?
    (a) In feiten doen we dat zelf maar we hebben dat uitbesteed aan een bedrijf waar we een 50% belang in hebben. Voor ons is het belangrijk dat we dat uitbesteden omdat we dan kunnen focussen op de kwaliteit van het beton en dan hebben we de logistiek binnengehaald met dat externe bedrijf. Meeste partijen in de markt hebben eigen autos en doen dat zelf, we zijn daar redelijk de enige in.
14. Wat betekent de brancheorganisatie betonhuis voor jullie?
    (a) Er is een betonakkoord via betonhuis, actie ondernemen.
    (b) Betonhuis lijkt inderdaad 80 tot 90% van de markt aangesloten te hebben. Betonhuis betekent veel voor de industrie, als je er met zijn allen namelijk energie insteekt komt er ook meer energie uit. Met zijn allen wat doen en de mouwen op stropen. Zij faciliteren bijvoorbeeld berekeningen over de hele industrie.
    (c) Ik zit ook in een groep voor het betonakkoord vanuit ons bedrijf, daar zit iedereen in van de industrie (sectoren) waar we gezamenlijk werken aan het verduurzamen van de industrie.
    (d) Vroeger was het alleen transportbeton en nu alles samen, dat is zeker een toevoegde waarde.
    (e) Betonakkoord is overheid met aannemerij en toeleveranciers. Betonindustrie heeft samen afspraken gemaakt. Rijkswaterstaat, bouwend Nederland, aannemers als bam en duravermeer. En lveranciers van betonleveranciers.
    (f) Het is een akkoord met de overheid waar we ons verplichten om die prestatie te gaan leveren.
    (g) Coördinatie is goed dus vanuit overheid. Wel moeten we in 2030 al 50% van onze maatregelen genomen hebben sinds 1990, dus dat is snel en we moeten nog heel veel. We zijn met zijn allen te laat van start gegaan.
    (h) Betonaakooord ligt er al langer maar dat heeft even nodig om op gang te komen. Het begint te landen en iedereen beseft we moeten aan het werk, we moeten met zijn allen aan het werk om die doelen te realiseren.
    (i) Het is altijd lastig, het moet er eerst even liggen en dan moet het landen. Het bewustzijn begint momenteel echt op gang te komen. Ik merk het zelf, vroeger hadden we een enorm economisch aantrekkelijk project wat we altijd deden. En laatst maakte we echt de keuze, dit doen we niet meer. Het is veel te vervuilend en slecht voor onze voetafdruk. Mensen gaan echt anders denken. Beslissingen worden anders genomen, die omslag is echt aan het gebeuren. Naast het economische voordeel weegt milieu dus echt steeds meer.

A3.7 Onderzoek

15. Hoe staat de beton industrie in relatie met onderzoek?
    (a) De industrie heeft er heel veel behoefte aan, kijk maar naar de industrie hoe we nu kijken tegen verduurzaming. Het injecteren van CO_2 kwam op ons pad dus daar kijken we dan naar en pakken we op met die tests in Delft. Er wordt hard gewerkt aan verduurzaming op verschillende manieren en dat willen we dus wel. Ik weet bijvoorbeeld dat bewerken van toeslagmateriaal met CO_2 kan helpen, maar niet hoe dat precies werkt en waar te beginnen. Een organisatie die kartrekker is in onderzoek naar industrie brengen is SGS intron.
    (b) Wij worden zelden benaderd vanuit onderzoek. We hebben soms stagiaires vanuit HBO en dergelijke maar niet veel. Ik moet ook zeggen dat het hierbij voor mij belangrijk is dat ik er tijd in moet steken wat soms lastig is als het me die periode niet uitkomt. Er kan zeker veel meer verbinding komen wat ook belangrijk is voor ons als industrie denk ik.
    (c) Uit contact met universiteiten en studenten komen nieuwe ideeën en andere invloeden. Universiteiten kijken soms heel anders tegen de wereld aan en dat kan dingen anders presenteren en nieuwe ontwikkelingen veroorzaken.
    (d) Er is en klein beetje verbinding, maar deze is zeker belangrijk. Ik denk dat het misschien wel te weinig is momenteel.
    (e) Onze industrie en zeker transport beton heeft jonge mensen nodig die verder gaan met ons product. De beton technoloog is een beetje een uitstervend ras, de technisch adviseur is er steeds minder. Het is moeilijk om jonge mensen in onze industrie te trekken. Veel mensen gaan naar bijvoorbeeld grote aannemers omdat ze daar een breder plaatje krijgen qua werkzaamheden. Bij ons liggen hele mooie banen alleen zijn daar de werkzaamheden wat smaller en meer gespecialiseerd. Het is voor ons momenteel echt heel moeilijk om jonge mensen te vinden. Echte technische mensen zijn moeilijk te vinden.

A3.8 Politiek & beleid

16. Heb je enige vorm van invloed gemerkt in de afgelopen tien jaar van beleidsvorming op de productie van beton?
    (a) De Greendeal houdt in dat we in 2030 30% minder CO_2 uitstoot moeten hebben dan in 1990, hiervoor is een roadmap gemaakt. Ook vanuit ons bedrijf.
    (b) Omdat we al een langere tijd moeten verduurzamen in de Nederlandse industrie, is de klinker factor al erg laag. Er wordt momenteel veel geïnvesteerd in het afvangen van CO_2, dat gaan we na 2030 gebruiken. Een groot gedeelte hiervan gaat in de grond (CCS) en een ander deel wordt in het midden oosten omgezet naar methaan wat vervolgens weer gebruikt gaat worden.
    (c) Om beton te laten verharden heb je altijd klinker nodig, daarom moet de industrie wel een andere manier gaan vinden om CO_2 te verminderen. Je hetb gewoon altijd klinker (en dus cement) nodig.
    (d) Het bedrijf wil 48% CO_2 gaan afvangen. Het is belangrijk dat je naar Nederland kijkt, daar kunnen we nog veel.

A.4 Researcher at VITO (Commercial research center)

1. Heb ik toestemming om aantekeningen te maken gedurende dit interview en deze daarna samen met jouw functie titel + bedrijfsnaam te publiceren in het uiteindelijke document, welke ook online verspreid wordt?
   (a) Toestemming wordt gegeven.

A4.1 Prefabbeton

2. Kun je iets meer vertellen over jullie onderzoek naar CO_2 gebruik bij betonproductie?
   (a) 15 jaar geleden zijn we begonnen met onderzoek naar het gebruik van RVS staalslak in bouwblokken (carbstone project). Orbix is een Belgisch bedrijf wat staalslak (restproduct van staalproductie) inneemt en verder fijnmaalt om er nog meer staal uithalen. Alleen hadden ze dan geen restproduct meer van granulaat, wat normaal geld waard was. Dus toen was de vraag wat kunnen we met dat superfijn gemalen staalslak (poeder). Het was niet mogelijk om dat in betonproductie te gebruiken. Maar wij hebben dus carbstone ontwikkeld waar we dat poeder mengen met water, de juiste vormgeven en dat laten reageren met CO_2. Dat reageert dan met calcium mineraal en zorgt voor de sterkte.
   (b) Van staalslak wordt poeder gemaakt door het te vermalen, het poeder wordt dan gemengd met granulaat en water. Dat geeft de sterkte van een zandkasteel en als we het behandelen met CO_2 dan krijgt het een duurzame sterkte.
   (c) In carbstone blokken kan je veel meer CO_2 op laten nemen dan met betongranulaat. Dat komt omdat er dus ook veel CO_2 opgenomen kan worden door slak materiaal opzich. Hierdoor heeft carbstone dus helemaal geen cement nodig wat nog veel duurzamer is. Carbstone kan namelijk ongeveer 15% opnemen van zijn gewicht aan CO_2.
   (d) Carbstone maken is best wel moeilijk. De volledige sterkte moet namelijk komen van de reactie met CO_2. Aan de andere kant creëer je wel een eindproduct, dus de winstmarge is groter waardoor je kan werken met hogere concentratie en hogere druk (want dat is wel duurder). Daardoor wordt het weer beter produceerbaar. Granulaat is een tussenproduct dus minder winstmarge. We laten de verhoogde druk en concentratie wel steeds meer los omdat we sterktes van 140 mega pascal halen terwijl er soms maar 20 mega pascal nodig is.
   (e) Carbstone is een tijdje gebruikt in nederland, maar is nu niet meer op de markt. We zijn nu nu wel bezig met twee bedrijven in Vlaanderen. Het proces is namelijk gepatenteerd dus wij en Orbix bepalen wie er mag produceren.
   (f) Er is momenteel iemand bezig om het te produceren. Dat zijn dunne steentjes die tegen een draagmuur geplaatst wordt. Het heeft vooral een esthetische waarde. Het lijkt op een baksteen en vormt de buitenste schil. Ze zijn momenteel bezig met de opschaling.
   (g) Er is ook nog een ander berdrijf wat bezig is met mogelijke productie. Een bedrijf wat stapelblokken maakt wil ze gaan produceren met carbstone technologie. Zowat elk soort blok kan namelijk gemaaktworden met carbstone techniek, alleen wapening vormt ook een probleem. Net als bij carbonisatie via die andere technologieën.
3. Kun je me iets vertellen over het behandelen van betongranulaat (gerecycled toeslagmateriaal) met CO_2? Tijdsduur, uitvoerbaarheid, ontwikkelingsfase
   (a) Recyclen van beton gaat nu twee kanten op. Beton wordt gebroken in stukken en aan het einde van het brekingsprocess is een zeef. De grove fractie wordt momenteel gebruikt in betonproductie en de niet grove fractie in carbstone.
   (b) We zijn dus gefocust op lage druk en lage concentratie CO_2 om het betaalbaar te houden.
   (c) Op zich kan het ook maar kleine hoeveelheden opnemen, maar er zijn wel goede sterkte effecten.
   (d) Er wordt ongeveer 30 tot 40 gram CO_2 opgenomen per kilo beton. Verschil in lage en hoge druk en lage en hoge concentratie is tijd, en dit geeft een verschil van uren en niet dagen. Er is dus GEEN verschil in totale opname van CO_2. In de eerste 4 uur ligt ongeveer 20 gram vast en na 24 uur optimale hoeveelheid. Temperatuur op 60 graden zorgt ervoor dat optimale hoeveelheid opname al na 6 a 8 uur bereikt kan worden.
   (e) momenteel mag je binnen de betonstandaarden 30% van de grove granulaten vervangen met gerecycleerd materiaal. Fijne granulaat wordt minder gebruikt omdat het poreus is en veel vocht opneemt wat voor slechter beton zorgt.

A4.2 Onderzoek

4. Welke partijen ontwikkelen kennis over CO_2 gebruik tijdens betonproductie?

(a) VITO heeft vier vormen van onderzoek. De eerste is commercieel onderzoek (contractonderzoek) waarbij we voor een bedrijf onderzoek doen als zij naar ons toe komen en vragen naar een oplossing voor een probleem en dan gaan we aan de slag.
(b) Verder doen we ook onderzoek voor de claamse overheid, bijvoorbeeld recyclen van materialen en dan voor wetgeving. Dus onderzoeken doen om wetgeving te ondersteunen.
(c) Dan daarnaast investeren we zelf ook middelen in twee soorten onderzoek. Bijvoorbeeld een samenwerking met de TU Delft maar ook voor Europese commissie is dat nu gedaan met het iceberg project. Dit is onderdeel van het horizon project 2020.
(d) Dan als laatste doen we ook zelf onderzoek doen naar eigen thema's zodat het ons eigen eigendom is en we het kunnen verkopen.

5. Zijn het er meer dan universiteiten en onderzoeksbedrijven?
   (a) Er zijn universiteiten, commerciele onderzoeksbedrijven en grote bedrijven met een eigen R&D afdelingen.
6. Hoe zou je deze ontwikkelde kennis in hoeveelheden uitdrukken?
   (a) Het is gebruikelijk om te werken met Technology Readiness Levels (TRL). TRL 1 is het basis level en bij TRL 9 is het een getest systeem in een omgeving, dus markt klaar. Daartussen zitten allemaal levels, zoals proof of concept, getest in het lab etc. Vaak is de universiteit in het begin van dit level, de eerste stappen. Er is bijvoorbeeld wel onderscheid tussen TU Delft die iets verder in de TRL zitten omdat het een technische universiteit is. Fysica universiteiten zitten dan bijvoorbeeld iets vroeger omdat zij meer fysisch onderzoek doen. TNO en VITO zijn dan bijvoorbeeld weer iets verder op de schaal en uiteindelijk R&D van bedrijven maakt het af naar hoogste level. In projecten voor Europese commissie staan bijvoorbeeld doelstellingen dat je van TRL 4 naar TRL 7 moet gaan als je funding krijgt.
7. Hoe verloopt de vraag naar jullie patent bijvoorbeeld vanuit het bedrijfsleven?
   (a) Orbix, onze andere patenteigenaar, is meer op zoek om mensen dit te laten gebruiken. Ook omdat hun grondstof wordt gebruikt dus hebben ze meer een winstoogmerk.

A.5 Sustainability coordinator at Bruil (PCP and RMC producer)

1. Heb ik toestemming om aantekeningen te maken gedurende dit interview en deze daarna samen met jouw functie titel + bedrijfsnaam te publiceren in het uiteindelijke document, welke ook online verspreid wordt?
   (a) Toestemming is gegeven.

A5.1 Bedrijfsgerelateerd

2. Wat doet jullie bedrijf precies?
   (a) Ik ben verantwoordelijk voor duurzaamheidsbeleid binnen Bruil, we bestaan sinds 1906. Het is een familiebedrijf en hebben ongeveer 440 man personeel. Binnen de markt zijn ze nummer twee van droge mortels van 5 partijen. We hebben 60 vrachtwagens rijden voor transportbeton. En daarnaast doen we ook veel prefab betonproducten.
3. Hebben jullie bepaalde duurzaamheidsdoelstellingen?
   (a) Ik ben dus de duurzaamheid coördinator. We zijn afgelopen jaar wat meer zwevend geweest, omdat we een wisseling in directie hadden. Maar we hebben best wel concrete doelstellingen om onze CO_2 uitstoot te verlagen.
   (b) Een belangrijk aspect is de beïnvloedbare CO_2: dit bestaat bij ons uit fabrieken, gasverbruik, dieselverbruik etc etc. Totaal hebben we in 2021 6099 ton CO_2 uitgestoten. Daarnaast worden we gecertificeerd voor duurzaamheid, dus we moeten wel plannen maken. Dit gebeurd op een CO_2 prestatieladder waar we minimaal niveau 3 moeten halen (vind hij relatief makkelijk), anderen hebben bijvoorbeeld niveau 5. Deze certificering wordt bijvoorbeeld gebruikt bij tenderprocedures. Bruil gebruikt het niet in deze procedures maar doen het vooral voor intrinsiek motivatie om aan duurzaamheid te werken.
   (c) Zo gebruiken we bijvoorbeeld 1 miljoen liter diesel voor transport beton wat erg vervuilend is. Maar de meeste CO_2 komt uit cement, daarom willen ze inzicht op productniveau creëren.

A5.2 Algemene betonmarkt

4. Zijn er partijen, naast transport, brancheorganisatie een opdrachtgevers, die binnen de beton industrie aanwezig zijn maar niet zelf produceren?
   (a) Certificerende instellingen. SGS introm die onze mengsels certificeert. Nibe is een bedrijf wat onze LCA's en MKI-waardes certificeert, dus dat houdt het veilig. Zij keuren het goed. Mantijn van Leeuwen van Nibe is interessant en kent iedereen.

A5.3 Betonmortel

5. Hoe kijkt Bruil aan tegen het gebruik van CO_2 bij de productie van betonmortel?
   (a) Ik ken het wel maar niet heel erg goed. We gebruiken het niet maar houden het wel in de gaten.
6. Weet je toevallig of er op meer plekken in Nederland tests gedaan worden met Carboncure?
   (a) Ik weet dat het wel gebeurt maar ben er niet heel bekend mee.

A5.4 Prefab beton

7. Heb je het idee dat behandeling met CO_2 mogelijk zou zijn bij prefab beton?
   (a) Ik denk dat het wel mogelijk is. Wij hebben nu bijvoorbeeld heel veel ruimte nodig om alles 4 weken uit te laten harden in de mal. We hebben naast onze fabrieken hele grote stukken grond waar we alles neerleggen en dan moeten wachten. Als we het proces kunnen versnellen dan zou het zeker winst behalen. Klanten kunnen dan bijvoorbeeld binnen een week producten krijgen in plaats van na 8 weken.
   (b) 3D print beton doen we ook maar heeft een hoog gehalte portlandcement en veel additieven.

A5.5 Gerecyclede toeslag

8. Hoe wordt er vanuit de industrie gekeken naar gerecyclede toeslag? En wat als deze ook nog behandeld is met CO_2

(a) Bruil gebruikt granulaat (gerecycled beton), ongeveer 8%. Dat is voornamelijk vanuit eigen productie, een deel blijft over tijdens gebruik van kanaalplaten en wordt dan vermalen voor het productieproces. Ons restant beton wordt namelijk een keer per zoveel tijd gebroken en dan ligt het heir een tijd. Vervolgens wordt dat beton gebruikt gedurende een tijdje.

9. Hoe werkt de beton sloop industrie?
   (a) Er zijn vergunningen voor het inzamelen van beton en dat dan gebruiken. Er is een vergunning: verzamelen afval van derden. Al zouden we het willen, dan nog mag het niet. Er moet echt een partij zijn die dat doet onder vergunning. Die vergunning hebben we dus op een plek voor een deel.

A5.6 Overig

9. Hoe verloopt het vervoer voor jullie prefab beton?
   (a) Wij besteden het vervoer van prefabbeton uit. Alleen zijn dat mensen die altijd bij ons komen en dus zo goed als voor ons werken. Ze zijn vaker op ons bedrijf dan bij hun eigen bedrijf.
10. Wat betekent de brancheorganisatie betonhuis voor jullie?
   (a) Betonhuis is voor mij nog wat nieuw. Sessies die ik heb gehad waren wel erg goed. Veel nuttige kennisdeling en je merkt echt dat er een old-boys beton netwerk is.

A5.7 Onderzoek

11. Hoe staan jullie in relatie met onderzoek?
   (a) We hebben een eigen R&D afdeling. Sinds dit jaar een nieuw betonlab voor transportbeton.
   (b) Als we nieuwe dingen ontdekken zijn we redelijk transparant in kennisdeling, maar als er echt een doorbraak komt dan misschien wat minder. Uiteindelijk willen we ook impact maken en dat kan door kennis te delen.
   (c) We hebben onder andere contact met TNO en universiteiten. We hebben ook een innovatie afdeling, los van R&D. We hebben gesprekken met Delft, Eindhoven. We zitten niet in werkgroepen maar hebben wel contacten. Universiteiten zitten vooral in het ontdekken van nieuwe dingen en voor ons moeten we echt wel een stapje verder zitten in het proces, dus het moet iets meer uitvoerbaar zijn richting de markt. Voor ons is er een tijdlijn van ongeveer 5 tot 10 jaar implementatie, dan zit het goed.

A5.8 Opleiding

12. Hoe verloopt opleiding voor de betonindustrie?
   (a) Ik ben niet van HR maar ik kan wel mijn eigen ervaring delen. De gemiddelde leeftijd in de betonsector is rond de 50. Gemiddeld dienstverband is ook ongeveer 20 jaar, dus ook vergrijzing binnen de sector. Als jong persoon krijg je veel ruimte om te ontwikkelen en echt iets bij te dragen. Heeft ook wel te maken met het bedrijf. Ale ruimte is er, maar je moet hem wel pakken. In de fabriek wordt veel ruimte gegeven voor activiteiten van de mannen. Ruimte om te werken aan hun gezondheid, zelfontwikeling etc.

A5.9 Politiek & beleidsvoering

13. Heb je enige vorm van invloed gemerkt in de afgelopen tien jaar van beleidsvorming op de productie van beton?
   (a) We hebben zelf niet zoveel te maken met tenders, dat loopt vooral via aannemers. Maar alles in de markt gaat op prijs. Je mag duurder zijn als je duurzamer bent (MKI waarde (Milieu Kosten Indicator)). Maar vanuit de vraag van klanten draait het allemaal om geld. Binnen het bedrijf wordt niet alles door geld gedreven, maar verder daarbuiten wel. Deels ook door aandeelhouders, we zijn nou eenmaal een commerciële instelling.
   (b) Ik denk dat MKI wel een goede manier is om de sector te stimuleren. Je hoort overal wel de focus op MKI.
   (c) Er wordt op basis van grondstoffen een berekening gemaakt op milieu impact waardoor er een MKI waarde ontstaat. Er zijn rond de 40 parameters waarop elke grondstof wordt gemeten en dan komt er per product een totaalscore uit. Er is zeker potentie in dit systeem om CO_2 opname toe te voegen.

B Structured expert interviews for the functional analysis

Within this appendix, all raw data from the structured expert interviews are presented. The interviews are given in the same order as presented in section 3.3 and represent all scores and exact explanations given during the interviews.

B.1 Assistant professor at Delft University of Technology (Civil Engineering)

B1.1: Entrepreneurial activities
Not applicable to this interviewee.

B1.2: Knowledge development

1. Is the amount of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: The knowledge availability in the community is quite large. It is scientifically proven and it is something we can mimic from the natural reactions from limestone. There is a clear calculation method how it captures CO_2 during its lifetime.

2. Is the quality of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: The carbonation principle is quite obvious. Knowledge is of quality when it is replicable. There is a tension for the technology between CO_2 use and reinforcement.

3. Does the type of knowledge developed on CO_2 usage during concrete production fit with the knowledge needs of the Dutch concrete system?

Score: 4 (positive)
Explanation: The knowledge developed on CO_2 usage during concrete production will always be the right type, because it is a very simple process. Carbonation is a natural process that can be applied within concrete production. Knowledge on this process thus can be applied. .

4. Does the quality and/or quantity of knowledge development form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on a large scale?

Score: 4 (positive)
Explanation: There is a barrier in the application of the technology, the fundamental knowledge needs to be transfered to the application within the industry.

B1.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 3 (neutral)
Explanation: Not quite sure and remain neutral here. Research on the topic has started quite long ago, but then it disappeared. Now it is starting to gain some interest again, due to the environmental actions of governments.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: There is no exchange of knowledge.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 3 (neutral)
Explanation: Really dont know. There is a little exchange of knowledge. This will not be a problem if the right application is there, becuase it will find its way.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: No there are not. This research is relatively active.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: People understand how it works, it is quite simple. But, they see problems on the implementation of the technology on a lot of things. Where to get CO_2, how to use it, will is cost more.

B1.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 2 (negative)
Explanation: There is a clear vision on CO_2 reduction, but not for this specific technology. The vision on the entire picture is missing, where is CO_2 taken from, where to implement it.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 2 (negative)
Explanation: Same as last question.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: Positive for precast industries (doable). For others it is difficult.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: x
Explanation: Not sure.

5. Are these goals regarded as reliable and doable?

Score: x
Explanation: Related to last question.

5. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 2 (negative)
Explanation: I do not think it is sufficient. There are uncertainties, and if we want to move forward these need to become clear. Technical development, where to apply.

B1.5: Formation of markets
Not applicable to this interviewee.

B1.6: Mobilization of resources
Not applicable to this interviewee.

B1.7: Counteracting resistance to change
Not applicable to this interviewee.

B.2 Researcher at VITO (Research centre)

B2.1: Entrepreneurial activities
Not applicable to this interviewee.

B2.2: Knowledge development

1. Is the amount of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: Kennisontwikkeling is goed, maar die kennis kan nog meer opgepakt worden door de markt die het toepast.

2. Is the quality of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: Geen verdere toelichting nodig.

3. Does the type of knowledge developed on CO_2 usage during concrete production fit with the knowledge needs of the Dutch concrete system?

Score: 4 (positive)
Explanation: Geen verdere toelichting nodig.

4. Does the quality and/or quantity of knowledge development form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on a large scale?

Score: 3 (neutral)
Explanation: Het hangt er vanaf welk deel van het systeem je bekijkt. Bijvoorbeeld CO_2 wordt momenteel in processen gebruikt in hoge puurheid wat heel duur is. Daarom gaan we nu bijvoorbeeld onderzoeken of we het carbonatie process kunnen laten plaatsvinden op basis van uitlaatgassen.

B2.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 3 (neutral)
Explanation: Voor vlaanderen is het nu aan het starten, betonproducenten beginnen nu in aanraking te komen met de technologie.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Hier is nog wel werk. Betonproducenten beginnen pas net door te hebben wat de technologien zijn, dus laat staan dat de aannemers en projectontwikkelaars dit al weten.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 4 (positive)
Explanation: Het bedrijf wat gestart is met Carboncure is natuurlijk ook in belgie, die technologie komt uit canada. Er zijn ook veel lokale initiatieven, in elk land zijn er wel initiatieven.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Er zijn momenteel een aantal grote bedrijven die frontrunner zijn en veel ontwikkelen. Dit is wel hoe het altijd gaat met nieuwe technologien, er zijn een aantal voorlopers en daarna volgende kleinere minder innovatieve spelers.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Je kan zo'n proces niet forceren. Daar moet op worden ingezet de komende jaren. Er moet duidelijk gecommuniceerd worden over de moeilijkheden, maar de situatie nu is logisch.

B2.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 2 (negative)
Explanation: Er wordt in vlaanderen niet echt gestuurd. De twee grote aandachtspunten zijn CO_2 vermindering en het verminderen van bouwmaterialen. Er is dus niet zo'n specifieke focus op hoe we dat gaan doen. Het gaat voornamelijk over cementvervangers maar niet echt deze technologie.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 4 (positive)
Explanation: Vanuit onderzoekskant wel. Er zijn veel intiatieven om naar 0 CO_2 uitstoot te komen maar dat is wel ambitieus. Vanuit onderzoek is er wel visie maar in de praktijk zal een overheid ook meer moeten sturen.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 5 (very positive)
Explanation: Het bewerken van betongranulaat en technologien als carboncure zie ik wel doorgroeien. Carbstone noem ik niet als beton, maar dat gaat wel concurrentie vormen voor de betonindustrie. Waarschijnlijk zullen we steeds meer beton gaan vervangen met andere bouwmaterialen. Kijk maar naar stonecycling me hun biobased tiles.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 3 (neutral)
Explanation: Kan ik niet beantwoorden, dat is specifiek voor Nederland

5. Are these goals regarded as reliable and doable?

Score: 3 (neutral)
Explanation: Kan ik niet beantwoorden, dat is specifiek voor Nederland

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 3 (neutral)
Explanation: Ik heb het idee dat architecten snel denken aan hout als duurzaam materiaal en niet aan beton. Degene die aan duurzaamheid denken, gaan vaak naar biobased. Ik heb het idee dat beton een imago probleem heeft op dat vlak als erg slecht. Er moeten ook duidelijke normen komen.

B2.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 3 (neutral)
Explanation: Het is moeilijk te zeggen, gaat afhangen van met wie je praat. Het gaat ook afhangen van het beleid, de technologie gaat er wel zijn. Het gaat waarschijnlijk duurder zijn, dus het gaat afhangen van hoe CO_2 uitstoot geprijsd gaat worden. Als de EU verder gaat en hun doelstellingen effectief willen halen en hun wetgeving aanpassen dat kan het. Hangt af van de acties, kan richting 1 gaan en richting 5 in de komende jaren.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 3 (neutral)
Explanation: Onzekerheid zorgt ervoor of bedrijven dit wel of niet gaan gebruiken. Als wetgeving duidelijker wordt zullen bedrijven het sneller toepassen.

B2.6: Mobilization of resources
Not applicable to this interviewee.

B2.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 3 (neutral)
Explanation: Niet bij de producenten maar wel bij de gebruiker. Het is een industrie die al heel lang bestaat en op dezelfde manier werkt. De oude productie manier is vertrouwd en nieuwe technologien gebruiken zorgt voor onzekerheid over levensduur. Als iets in elkaar stort dan is de aannemer verantwoordelijk. Dus misschien moet er ook naar overheden en verzekeringsmaatschappijen gekeken worden. Een idee is dat de dragende dingen zoals balken met de oude conventionele beton geproduceerd worden en de niet dragende dingen met nieuwe technologien. Als die stuk gaan is het minder erg.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Hetzelfde als de vorige vraag.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Als je naar de standaard betonnormen kijkt niet. Het gaat afhangen van wat er wordt voorgeschreven. Dit zin geen wetten die in steen gebeiteld staan, maar het is wel een standaard. De score geldt voor een bredere blik dan alleen vergunningsprocedures.

B.3 Senior consultant at TNO (Research centre)

B3.1: Entrepreneurial activities
Not applicable to this interviewee.

B3.2: Knowledge development

1. Is the amount of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 2 (negative)
Explanation: We zitten in Nederland op het spoor dat we produceren met zo min mogelijk uitstoot terwijl dat in het buitenland (bijvoorbeeld belgie) meer gericht is op afvangen en terugstoppen in producten. Verder hebben we in Nederland geen cementproductie meer, maar hebben we wel weer veel diverse bindmiddelen ontwikkeling. Dus weinig ontwikkeling, maar is ook niet erg want het is een Europese markt.

2. Is the quality of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: Nogmaals benadrukt dat het een vrij Europese markt is waar we het over hebben met Europese regelgeving, waardoor nieuwe producten toepasbaar zijn in de Nederlandse regelgeving.

3. Does the type of knowledge developed on CO_2 usage during concrete production fit with the knowledge needs of the Dutch concrete system?

Score: 4 (positive)
Explanation: De Nederlandse beton industrie is erg versnipperd. Er zijn veel diverse toepassingen welke allemaal andere eisen en voorwaarden hebben. Wanneer er bijvoorbeeld een nieuw bindmiddel is, vindt dat op een natuurlijk manier zijn weg naar de markt waar het de beste toepassing heeft(product-market-fit). Dit is iets wat redelijk vanzelf gebeurd in de markt.

4. Does the quality and/or quantity of knowledge development form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on a large scale?

Score: 2 (negative)
Explanation: Het is niet te veel maar ik kan me voorstellen dat het voor sommige partijen wel te veel lijkt. Als je weinig kennis hebt over de markt kan je je verwonderen over de grote hoeveelheid innovaties. Soms ook oude technologien in een nieuw jasje (mooie marketing). We hebben in Nederland een heel mooi systeem als je wil afwijken van de huidige regels. Iedereen mag afwijken van de normen, mits je bewijst dat het voldoet aan het bouwbesluit. De wet en regelgeving kost bedrijven geld, maar is wel weer een vorm van beschermingen voor de gebruikers/maatschappij .

B3.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 4 (positive)
Explanation: Er is een spanning tussen industrie en wetenschap. Industrie wil niets delen en wetenschap (publiek geld) moet delen. Er zit een verschil tussen belangen, de industrie wil meestel iets verdienen met de verkoop van producten. Ze hebben er geen belang bij om kennis over hun productie methodes te delen met het oog op concurrentie. Daarnaast heeft TNO voor 30% inkomsten uit publiek geld en die kennis moet openbaar gemaakt worden. Het ligt er dus aan waar het door betaald is en of het gepubliceerd wordt. Uiteindelijk heeft TNO een belangrijke natuurlijk rol om hier tussen te werken en te adviseren.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 4 (positive)
Explanation: De grotere aannemers hebben zelf R&D teams, betontechnologen etc. Die kunnen dus goed levelen met betonproducenten en daarbij kennis uitwisselen.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 4 (positive)
Explanation: Op Europees niveau (en dus internationaal) is er zeker uitwisseling. Er is alleen natuurlijk geen top-down organisatie. Het is eigenlijk gewoon een groot netwerk, en iedereen heeft zijn eigen internationale netwerk. Dit is wel persoons afhankelijk, er zijn geen Nederland gebnden KPI's. Het is niet geborgen in bepaalde dingen, het moet echt zelf actief gedaan worden (papers lezen, naar congressen gaan etc.)

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Nee, partijen weten elkaar te vinden en alles werkt in principe. De vraag is wel of er voldoende funding is, met meer geld kun je meer doen. Maar dat is een andere discussie.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Er mist soms opvolging op experimenten in de werkelijkheid. Hier is dan bijvoorbeeld geen budget voor. Als het misgaat wordt dat ook niet altijd gecommuniceerd.

B3.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 4 (positive)
Explanation: Dan kan je het beste naar het betonakkoord kijken. Daarin staat hoe er voor 2030 bepaalde resultaten behaald kunnen worden. Er staat in de handelingsperspectieven 1 manier van deze technologie, maar er zijn er 28. Dit geeft mooi aan hoe versnipperd de industrie eigenlijk is. Betonakkoord richt zich op resultaat van hele sector, de hoofdlijnen. Voor bedrijven is het fijn dat er geen hele specifieke regels zijn zodat bedrijven zelf kunnen experimenteren. Uiteindelijk geeft het betonakkoord iedereen die wil de mogelijkheid om mee te doen (publiek en privaat).

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 3 (neutral)
Explanation: Een visie dus niet, want de doelen zijn gesteld maar niet de manier waarop. 28 handelingsperspectieven, en de bedrijven mogen zelf kiezen hoe ze die invullen. Als bedrijven een idee hebben kunnen ze die zelf in de markt zetten. Maar, hierdoor gaat innovatie langzaam in de sector. Want: heb je 5 opties, dan verdeel je alle middelen uit de sector daarover en is het kiezen. Dan blijft er veel over per optie. Wanneer er 28 zijn en de middelen worden verdeeld blijft er maar weinig over. Weinig middelen is langzaam gaan. Het hangt echt af van je gezichtspunt.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: De vraag is of je het neerlegt bij de cementproducenten of betonproducenten. Het aantal cementproducenten in Europa is zeer overzichtelijk en ik verwacht dat de CO_2 uitstoot bij hen komt te liggen. Daarom ondernemen zij actie en ligt die keus waarschijnlijk niet bij Nederland. Onder andere door het Europese systeem van emissie rechten zal het dus bij de cementproducenten komen te liggen. Conclusie, het is een Europese markt dus daar zou het vandaan moeten komen. Referentie aan geopolymeren, dat zijn ook europese spelers. Negatief omdat ik geen cementproductie en dus ook geen CO_2 productie zie in Nederland.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: Hiermee kom je uit bij de algemene beleidsregels. Grondstofakkoord, klimaatdoelstellingen van Parijs, verschillende transitie agendas en natuurlijk betonakkoord. Deze zijn allemaal wat abstracter, maar betonakkoord specifiek voor beton industrie. Voor CO_2 gebruik zijn ze duidelijk, want staat in de handelingsperspectieven.

5. Are these goals regarded as reliable and doable?

Score: x
Explanation: Lastig in te schatten, dat moet aan bedrijfsleven gevraagd worden.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 4 (positive)
Explanation: Terugverwijzend naar het betonakkoord, hier is een groot aantal actoren in betrokken die hierover lang overlegd hebben. Dus dat zal zeker goed zijn.

B3.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 3 (neutral)
Explanation: De potentiele marktomvang van CO_2 is natuurlijk heel groot, want er wordt heel veel geproduceerd waar CO_2 vrij komt. Ik weet alleen niet aan welke technologien de cementproducenten allemaal denken. Het is sterk afhankelijk van waar partijen voor kiezen. Er is dus weer geen eenduidige route die belopen kan worden. Ik verwacht dat verschillende partijen anders gaan kiezen. De vraag blijft wat kost het, hoeveel concurrentie is er. Het is een goede start dat er veel marktpotentieel is, maar succes hangt van heel veel meer af.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Nee het vormt geen barriere. In principe zijn er geen belemmeringen voor het Nederlandse betonsysteem.

B3.6: Mobilization of resources
Not applicable to this interviewee.

B3.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 2 (negative)
Explanation: Er zijn natuurlijk belangen. Sommige partijen hebben belangen en die zullen ze waarschijnlijk beschermen. Ze zullen niet tegen innovatie zijn, maar ze verdedigen wel hun belangen. Kleine spelers zijn in principe vrij om CO_2 zelf toe te voegen bij betonproductie, maar dan moeten ze dat zelf trekken. Ligt er ook helemaal aan wat de andere opties zijn. Belangrijk: we leven niet op een eiland, er is een sterke dynamiek. Geen weerstand, maar logisch dat ze belangen beschermen.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Geldt exact hetzelfde voor bij de vorige vraag. Ik verwacht geen weerstand, maar wel een hoop vragen. Hangt van de partij af die de projecten draait of ze die vragen kunnen beantwoorden.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: We hebben in Nederland het bouwbesluit, waardoor we er vanuit kunnen gaan dan constructies veilig zijn en wat de effecten van bouwmaterialen zijn. Er zijn dus niet bepaalde regels die innovatie tegenhouden, maar met de handelingsperspectieven is het wel weer heel breed. Er zal dus een deel van de bedrijven zijn wat afvalt omdat het niet aan de regels kan voldoen. Naar mijn mening zijn die regels er niet voor niks en beschermt het ook. Vanuit publiek belang is het heel goed dat die regels er zijn, maar vanuit privaat belang kan het soms vertragen.

B.4 R&D Manager at Bruil (PCP producer)

B4.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Primair ligt de focus op reductie van uitstoot die afkomstig is uit primaire grondstoffen. Dat geldt voor de betonindustrie, niet voor de cementindustrie.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Zelfde uitleg als vorige vraag. De norm voor beton gaat uit van samenstellingseisen, niet van prestatie eisen. Het is een wens om naar prestatie eisen te gaan.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ik zie initiatieven die van toepassing zijn.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: (4 positive)
Explanation: Dat is juist de uitdaging. De industrie van reststromen verwerken is op labaratorium schaal veel makkelijker dan het in het groot te gaan doen.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Het is business as usual, tot er nieuwe mogelijkheden voor handen zijn. Dat is met name een glijdende schaal. Stap voor stap kleine aanpassingen.

B4.2: Knowledge development

1. Is the amount of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 3 (neutral)
Explanation: Het is heel erg gefragmenteerd als industrie, iedereen is bezig maar doet het op eigen houtje. Het is ook niet samen met de cementindustrie.

2. Is the quality of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 2 (negative)
Explanation: Te weinig. Zie het vorige antwoord.

3. Does the type of knowledge developed on CO_2 usage during concrete production fit with the knowledge needs of the Dutch concrete system?

Score: 4 (positive)
Explanation: De kennis die er is is wel van toepassing.

4. Does the quality and/or quantity of knowledge development form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on a large scale?

Score: 3 (neutral)
Explanation: We zitten er midden in, dus je kan moeilijk van een barriere spreken. Het is nog een uitdaging.

B4.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 4 (positive)
Explanation: Er is de betonvereniging en de Technische Universiteiten, daar zijn wel banden. Ook de onderzoeksinstituten.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: De gebruikers hebben een achterstand.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 2 (negative)
Explanation: Elk land vaart zijn eigen koers.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Er zijn voldoende platforms en de branchevereniging. Mits je het wil natuurlijk, er zijn veel individuele partijen en je moet het wel willen.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Zelfde als de vorige vraag.

B4.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 4 (positive)
Explanation: Bij ons bedrijf wel. Er zijn natuurlijk CO_2 doelstellingen op landelijk als Europees niveau. Het gaat de hele tijd over het saldo wat je achteraf aan het eindproduct ziet.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 3 (neutral)
Explanation: Er zijn visies, maar die zijn niet eenduidig. De Nederlandse industrie is erg versplinterd.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 3 (neutral)
Explanation: Ik zie daar geen hele grote bijdrage, maar toch wel wat.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: Niet op technologische gebied. Het is versplinterd en iedereen heeft zo zijn eigen koers.

5. Are these goals regarded as reliable and doable?

Score: 2 (negative)
Explanation: We hebben geen industrie brede doelen. Het zijn allemaal individuele doelen. Per individueel zou die uitvoerbaar moeten zijn. Ik hoop ook dat onze doelen uitvoerbaar zijn.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 2 (negative)
Explanation: Terugverwijzend naar eerdere vragen over versplintering industrie, eigen doelen en visies etc. etc.

B4.5: Formation of markets
Not applicable to this interviewee.

B4.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Verwachting van niet. Er zijn sowieso erg weinig personele middelen beschikbaar. Dit zorgt er ook voor dat de mensen die het zouden kunnen niet beschikbaar zijn om het te doen omdat zij andere taken moeten overnemen.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Geen verdere toelichting nodig.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Verwachting van niet. Als je naar het inzamelen en selecteren van reststromen kijkt is dat wel een problem, dat is gewoon heel lastig zoals eerder ook vermeld. Moet nog opgezet worden.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Zelfde verhaal als vorige vraag.

B4.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 2 (negative)
Explanation: Dat geloof ik niet.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Er zit een bedrijfseconomische component aan van het management van bedrijven omdat daar investeringen aan genoodzaakt zijn. Bij veel initiatieven moet niet alleen de technologie aangepast worden maar ook de marktbenadering en de productiefaciliteit.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Binnen de bestaande vergunningsprocedures kan het gedaan worden.

B.5 Consultant Technology and Regulations at Betonhuis (Branch organization)

B5.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Verder geen toevoegingen.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Feitelijk kan een technologie zoals carboncure overal, maar technologien zoals carbstone hebben een poreuze structuur nodig.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: De meeste innovaties zijn al gedaan. Innovaties worden al heel veel gebruikt. Carbstone is voor bepaalde producten te gebruiken, maar carboncure staat nog in de kinderschoenen. Dat zal zich wel ontwikkelen.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 4 (positive)
Explanation: Heel veel producten zijn maatwerk, dat maakt het lastig om grootschalige productie in te richten. De meeste proberen de productie natuurlijk op zo'n groot mogelijke schaal te maken omdat dat zo efficient mogelijk is. De betonindustrie is erg groot, met ieder zijn eigen uitdagingen. Maar investeringen moeten wel terugverdient kunnen worden en hoe snel is de vraag.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 3 (neutral)
Explanation: De betonindustrie is erg breed met een aantal grote bedrijven, zij hebben ruimte om te ontwikkelen. Kleine partijen hebben hier niet de mensen en ruimte voor en zijn allang blij dat ze hun productie halen. De grote partijen kunnen hierbij wel ontwikkelen maar gaan die opgedane kennis natuurlijk niet delen omdat ze daarmee een voordeel ten opzichte van de rest hebben (concurrentie voordeel). Hierdoor is branch brede uitrol lastig. CO_2 gebruik is momenteel een voordeel, dus daar maken ze gebruik van. Voor de kleine dus wel, voor de grote niet.

B5.2: Knowledge development

1. Is the amount of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: Ook hier weer, de grote partijen doen het werk.

2. Is the quality of knowledge development on CO_2 usage during concrete production sufficient for the Dutch concrete system?

Score: 4 (positive)
Explanation: Het Nederlandse kwaliteit systeem vraagt dat je dingen aantoont. Daardoor moet het onderzoek zorgen dat de kwaliteit van de producten die geleverd worden van kwaliteit zijn. Een soort slot op de deur dus.

3. Does the type of knowledge developed on CO_2 usage during concrete production fit with the knowledge needs of the Dutch concrete system?

Score: 3 (neutral)
Explanation: Ja, maar we doen er te weinig mee. Dat heeft met investeringen te maken maar ook met de vraag uit de markt (aannemers). Opdrachtgevers willen wel, maar aannemers zitten er tussen die andere belangen hebben.

4. Does the quality and/or quantity of knowledge development form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on a large scale?

Score: 2 (negative)
Explanation: Mogelijkheden zijn er, het is alleen de vraag hoe graag we dit willen.

B5.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: De kennis is er allemaal wel, maar door de grote bouwvraag hebben we de tijd niet om er mee aan de slag te gaan. Daarnaast moet er wel ruimte zijn om die investeringen te doen, het is allemaal erg complex. De fabrieken zitten vol, het personeel wat die aanpassingen moet doen is er ook niet want iedereen zit te springen om mensen.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: De mensen zijn vooral te druk met productie, maar niet met het installeren van nieuwe technologien. Daarnaast zijn ze bezig met andere dingen die met milieu te maken hebben zoals rapporteren over hun uitstoot. Hij is er dus eigenlijk niet of nauwelijks. Ergens tussen 1 en 2 in.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 2 (negative)
Explanation: We zijn hier niet mee bezig omdat het allemaal te druk is en te weinig mensen, zelfde argumentatie als hiervoor.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: De capaciteit om die kennis te brengen is er wel, maar om het te halen schiet het te kort. Weer door tijdgebrek argument. Iedereen zit in hetzelfde spanningsveld, we willen wel maar we kunnen het niet. Je moet kiezen wat het makkelijkst is of het meeste oplevert.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: als het zo gesteld wordt wel, conclusie is een beetje te lezen in al deze toelichtingen. Er is gewoon te veel werk, te weinig mensen en te weinig tijd.

B5.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 1 (very negative)
Explanation: De doelen zijn wel bekend maar de manier om daar te komen zijn per bedrijf/product anders. Dat maakt het lastig.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 2 (negative)
Explanation: Weer negatief, maar iets minder. Er is geen duidelijk visie, maar er wordt wel over nagedacht. Ook omdat we niet weten hoe streng er gekeken gaat worden naar CO_2 uitstoot en opname.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: De bedrijven die ermee bezig zijn zien er wel wat in. Voor de ene industrie is het natuurlijk beter toepasbaar dan voor de ander.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: Alles is erop gericht om de hoeveelheid uitstoot per product te minimaliseren, CO_2 erin stoppen is daarbij niet echt bekend. Een andere vraag is, wil hij (de klant) ervoor betalen?

5. Are these goals regarded as reliable and doable?

Score: 3 (neutral)
Explanation: Ja en nee. Ja ze zijn haalbaar maar op de termijn die is gesteld is de vraag. We zijn begonnen, maar klimaatneutraal in 2030 wordt nog een hele uitdaging.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 2 (negative)
Explanation: Nee, een opdrachtgever, aannemer en producent hebben weldegenlijk andere belangen zoals eerder gezegd. Er is zeker een spanningsveld tussen die drie.

B5.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 4 (positive)
Explanation: Wanneer de cementindustrie CO_2 gaat afvangen en nuttig gebruiken kan dat een erg groot voordeel zijn. Als je het naar een andere keten moet brengen kan dat voor problemen zorgen. Daarnaast wordt er nu al getest op CO_2 afvangen omdat er heel erg veel vrijkomt. Bij de bron afvangen is dan het makkelijkst.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: In het ene product beter toepasbaar dan het andere, maar over het algemeen dus wel potentie door zelfde argument als vorige vraag.

B5.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 1 (very negative)
Explanation: Momenteel niet, maar je weet niet wat er gaat gebeuren door bijvoorbeeld stikstof vergunningen etc. Wanneer er minder werk is zou er personeel beschikbaar kunnen komen om te vergroenen, maar dan moeten zij wel behouden worden voor de industrie en niet ergens anders heen gaan. Algemeen dus heel veel personeelstekort.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Er worden redelijk veel subsidies gegeven aan de industrie, maar de vraag is of het goed terecht komt. De opdrachtgever is bereid om meer te betalen, maar de vraag is of dit bij de producenten terecht komt.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Nee er zijn niet echt beperkingen.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: De huidige transport lijnen van cement zijn al aanwezig, dus dan zou daar ook CO_2 bij kunnen in principe.

B5.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 3 (neutral)
Explanation: Ja en nee, dus kanttekening. De industrie wil natuurlijk voor een deel zijn marktaandeel beschermen waardoor sommige technologien bijvoorbeeld geprobeerd vertraagd te zullen worden.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Waarom zou je dit niet willen?

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Nee die is er niet.

B.6 Director at Martens Groep (PCP producer)

B6.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 5 (very positive)
Explanation: Ik merk dat de hele keten naar aanleiding van duurzaamheid gaat handelen, dus iedereen staat open voor het gebruik van dit soort technologien.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 5 (very positive)
Explanation: Voldoende actoren zijn er in mijn optiek om dat te realiseren.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 5 (very positive)
Explanation: In zijn algemeenheid wordt er zeer veel geexperimeenteerd binnen de industrie, dus ook met CO_2 gebruik.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 5 (very positive)
Explanation: Alleen grootschalige productie kan een substantiele bijdrage leveren aan het oplossen van klimaatproblemen.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 1 (very negative)
Explanation: Teveel experimenteren in de praktijk bestaat in mijn optiek niet. Universitair onderzoek doet heel veel onderzoek maar in de praktijk moet het gewoon toepasbaar gemaakt worden, daar kom je achter door experimenteren.

B6.2: Knowledge development
Not applicable to this interviewee.

B6.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 5 (very positive)
Explanation: Onlangs is iemand van ons naar Gent gegaan, op uitnodiging van een onderzoeksintelling, om daar te kijken naar een opstelling voor dergelijke technologie (uitharding door CO_2).

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 3 (neutral)
Explanation: Voor ons is het nog niet eens duidelijk wat we kunnen met de verschillende technologien en hoe het gaat doorwerken, dus we kunnen er nog niks over communiceren. Dus voor nu is het voldoende, want er is niks te vertellen.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 4 (positive)
Explanation: Het voorbeeld over Gent is hier een mooi voorbeeld van.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Er zijn weinig problemen, jij doet bijvoorbeeld ook weer onderzoek nu dus dat laat zien dat er wel degelijk uitwisseling is.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 1 (very negative)
Explanation: Geen verdere uitleg.

B6.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 2 (negative)
Explanation: Zelf absoluut nog geen idee hoe de toepasbaarheid zich zou moeten ontwikkelen.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 5 (very positive)
Explanation: Dat wel, van een labaratorium setting zal het door moeten ontwikkelen naar een markt waar het als oplossing voor een probleem gebruikt kan worden.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: De verwachtingen zijn hooggestemd omdat we alle opties momenteel moeten onderzoeken, maar of het realiseerbaar is is nog maar de vraag.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 1 (very negative)
Explanation: Ik ben er blij om dat deze doelen er niet zijn, omdat ze zich daar niet mee moeten bemoeien. Middelen voorschriften zijn niet goed namelijk, bijvoorbeeld een MKI score dient een hoger doel dan 1 oplossing. MKI stuurt dus breder dan een enkel middel.

5. Are these goals regarded as reliable and doable?

Score: 3 (neutral)
Explanation: Die doelen zijn er niet.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 5 (very positive)
Explanation: Het hoger belang (aandacht voor de planeet) is momenteel erg breed gedeeld waardoor er veel vrijheid is om dergelijke veranderingen aan te gaan.

B6.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 3 (neutral)
Explanation: Geen idee, omdat de bruikbaarheid en toepasbaarheid nog onduidelijk is.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 1 (very negative)
Explanation: Nee, want er zijn partijen genoeg die gaan experimenteren. Wanneer er een partij is die dit tot een succes maakt zullen er anderen volgen.

B6.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 5 (very positive)
Explanation: Als er kansen zijn dan zijn er ook mensen.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 5 (very positive)
Explanation: Als de kansen er liggen dan komt dat geld ook wel.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Bijvoorbeeld de container bij de testopstelling in gent, als iemand daar in staat is diegene na een korte tijd dood. CO_2 is dus best gevaarlijk.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 5 (very positive)
Explanation: Als de problemen aan de kant van de technologie overkoombaar zijn is de fysieke infrastructuur van het Nederlandse betonsysteem verder geen probleem.

B6.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 1 (very negative)
Explanation: In vergelijking met het buitenland is die er zeker niet. Nederlands is namelijk een vrij opereerend land en is vrij voor verandering.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Bij mij zijn er absolute zorgen. Als mensen het risico lopen om dood te gaan ben ik negatief. Als duidelijk is dat de nadelen te verhelpen zijn zou ik het andere uiterste antwoorden. Er zijn behoorlijk wat zorgen.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Dit is zo nieuw dat ik geen idee heb of het per definitie verboden is of dat er nog nooit iemand over nagedacht heeft om het te verbieden.

B.7 Manager Production & Technology at Dyckerhoff Basal Betonmortel B.V. (RMC producer)

B7.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Industrie heeft een collectief belang hieraan te werken

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Overheid is grote opdrachtgever.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: De industrie moet een hogere prioriteit geven aan innoveren in gebruik van CO_2

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 3 (neutral)
Explanation: Industrie is best wel afwachtend mede door het garanderen van levensduur van het geleverde product

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Geen verdere toelichting.

B7.2: Knowledge development
Not applicable to this interviewee.

B7.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Geen verdere toelichting.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 3 (neutral)
Explanation: Kennis is bij de producenten onvoldoende om gebruikers te informeren hierover

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: x
Explanation: Geen kennis hierover.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: x
Explanation: onvoldoende ervaringen

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Onvoldoende kennis vormt een belemmering bij kennsoverdracht.

B7.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 2 (negative)
Explanation: Te weinig op dit moment. Wel benoemd in de handelingsperspectieven maar niet gekwantificeerd.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 2 (negative)
Explanation: onvoldoende ervaringen en onduidelijk wat het oplevert

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: Momenteel nog onduidelijk wat het oplevert

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: alleen benoemd als handelingsperspectief

5. Are these goals regarded as reliable and doable?

Score: 4 (positive)
Explanation: Industrie heeft de intentie deze doelen uitvoerbaar te maken.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 4 (positive)
Explanation: De intentie is zeker aanwezig.

B7.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 4 (positive)
Explanation: Wanneer toepasbaar is er een groot marktpotentie

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Geen verdere toelichting.

B7.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Grote vraag naar betontechnologisch geschoold personeel

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Geen verdere toelichting.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Geen verdere toelichting.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Landelijke dekking moet realiseerbaar zijn

B7.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 1 (very negative)
Explanation: Nieuwe ontwikkelingen worden niet meer gezien als bedreigingen

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 1 (very negative)
Explanation: Gezien als kansen

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Geen verdere toelichting.

B.8 Technical Sales Consultant at Edilteco Benelux (CO_2 technology distributor)

B8.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Die zijn er zeker. Er zijn zowel in Nederland als in Belgie zijn er enorm veel betoncentrales. Dus er zijn zat kansen. Beton is ook wereldwijd heel erg veel gebruikt.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Hetzelfde antwoord als de vorige vraag.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ja. Ik vergelijk dat met Belgie, Nederland is sowieso een veel innovatiever land. Ook qua bouwcultuur. De zoektocht die bedrijven in Nederland houden naar nieuwe productiemethoden is veel meer gericht. In Nederland krijg ik vragen over het product, in Belgie moet ik op zoek naar mensen.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 4 (positive)
Explanation: Een betoncentrale werkt in een bepaald gebied, een prefab producent (bestratingsmateriaal etc) die draaien gigantische productie. Zelfs ook voor over de landsgrenzen. Wanneer je op grote schaal produceerd, dan merk je ook veel meer het effect van die cement bezuiniging. Een paar % cement reductie op 400.000 m3 beton in een jaar scheelt natuurlijk gigantisch dan in kosten en milieu besparing.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: We merken natuurlijk dat er een grootschalige verandering is in materiaalgebruik etc. Maar het is denk ik niet te veel, we moeten namelijk wel. Men wil vooruit in gebruik van materiaal en milieu. Misschien is er wel te weinig innovatie zelfs. Ook daar is Nederland weer voor op belgie.

B8.2: Knowledge development
Not applicable to this interviewee.

B8.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Ik denk dat er een bepaald voorbehoud is uit de industrie, zij reageren vanuit een economisch belang. De wetenschap redeneert vanuit een wetenschappelijke hoek. Die twee moeten elkaar zien te vinden en overtuigen. Ik merk dat de industrie vooral wil weten wat het opbrengt. Ze zitten niet altijd op een lijn. De wetenschap moet soms ook snappen dat de industrie vanuit een ander perspectief handelen.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 4 (positive)
Explanation: Je merkt dat aannemers, projectleiders etc vragen aan de leveranciers waaraan aantoonbaar is dat er een betere ecologisch resultaat behaald is. Dus daar komt zeker druk naar de industrie om te verbeteren. Dus de vraag is er zeker. Op dat moment zegt de industrie dat ze mee meoten in die trend en het moeten gaan proberen. Als een wetenschapper erover begint dan denkt de industrie dat gaat me geld kosten, als de gebruiker vraagt naar CO_2 gebruik denkt de producent dit gaat me geld opleveren.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 4 (positive)
Explanation: Ja, zeker. Dat heeft te maken met het feit dat je niet altijd vind in eigen land wat je zoekt. Een mooi voobreeld is van ons (Edilteco) wij zochten technologie en hebben die in Canada gevonden. Nu distributeren wij het in de Benelux.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Er gaat gewoon heel veel tijd overheen, maar dat is niet perse een probleem. Iedereen wil weten wat de kosten/beten voor zijn of haar bedrif is. Ik zou dat geen probleem durven noemen.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Nee. Dat vormt momenteel geen probleem.Het zijn heel veel mensen, heel veel bedrijven die op termijn moeten gaan omschakelen. Dat is net als dat we van fossiele brandstof naar elektrisch rijden moeten. Het is een heel log schip wat van koers moet wisselen. Dat is volop bezig. Het gaat ook heel snel, als je ziet de ontwikkeling is aan het versnellen de afgelopen tijd. Op beurzen ziet het er allemaal al heel anders uit dan 5 of 10 jaar geleden.

B8.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 4 (positive)
Explanation: Ik denk het wel en ook daar staat Nederland er ook verder in dan Belgie. Dus daar is weldegenlijk een visie over. Men weet heel goed waar men naartoe wil over een x aantal jaar.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 4 (positive)
Explanation: Moeilijk om voor mij te beantwoorden maar wat ik merk is van wel. De bereidheid om te innoveren is er zeker. Daarnaast zijn de middelen ook zeker aanwezig. Iedereen is zich er van bewust dat het echt moet. Economie speelt daar een belangrijke rol in. Men heeft vaak het economische doel voor ogen. Innoveren moet opbrengen.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: Ook die schat ik positief in. Er wordt heel actief geinnoveerd momenteel. Dat gaat verder dan wat wij doen. Je kan het vergelijken met autoproducenten. Alleen maar vasthouden aan brandstoffen is niet meer de weg vooruit. Hetzelfde is voor cementproducenten, zij zien de afzet van cement verkleinen en zijn ook actief bezig om hun marktaandeel te beschermen.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: Ik zeg heel duidelijk ja. Er is gewoon veel beleid op dit gebied. Uit die hoek zeker. Ook uit de hoek van Europa komt daarbij druk.

5. Are these goals regarded as reliable and doable?

Score: 4 (positive)
Explanation: Betrouwbaar zijn we in Belgie soms iets meer sceptisch over dan in Nederland, is het uitvoerbaar dat absoluut.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 4 (positive)
Explanation: Men is het er niet over eens dat dit de enige oplossing is. Het is een van de oplossigen, maar ik ben er zeker van dat er op termijn betere oplossingen ontwikkeld gaan worden. Bijvoorbeeld als je kijkt naar het gebruik van het soort beton dat men in de states gebruikt. De oplossing is beter in Amerika omdat ze daar Portland cement gebruiken, maar hie gebruiken we andere samenstellingen (die een stuk duurzamer zijn) maar minder goed reageren met CO_2 via carboncure systemen.

B8.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 4 (positive)
Explanation: De huidige is weinig, de toekomstige is er zeker. Als je kijkt naar de dekking van beton producenten die is enorm, als iedereen erin meegaat dan is die marktomvang zeker gewaarborgd.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Terugwijzend naar het vorige antwoord.

B8.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ik kan niet zeggen dat er krapte is op de arbeidsmarkt, maar er is wel heel gespecialiseerd personeel in betontechnologen. Dus dat betekent wel dat ze die kunnen vinden. Gaat het genoeg zijn is dan de vraag, maar als je technologisch wil ontwikkelen zullen daar toch ook mensen voor moeten gevonden worden.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Dat denk ik wel.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: De beschikbaarheid van het CO_2 zelf. Daar worden wij nu mee geconfronteerd. We halen die weg bij chemische processen en als die stil komen te liggen door grondstof schaarste hebben wij geen CO_2 meer en kunnen we ook onze technologie niet meer gebruiken. Er wordt CO_2 van hele hoge puurheid gevraagd en dat is kostbaar.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ja absoluut. Ik zie hele mooie moderne bedrijven met veel potentieel wat dat betreft.

B8.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 3 (neutral)
Explanation: Weerstand niet, gezonde interesse/vragen over de technologie. Ze zijn voorzichtig maar staan er wel voor open. Weerstand klinkt negatief.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Nee, dit leeft momenteel heel erg.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: De keuringsinstanties, het moet allemaal in orde zijn. Er is wel veel contact tussen die instanties. Er is geen weerstand maar er is een gezonde communicatie, alles moet voldoende wetenschappelijk onderbouwd zijn. Die voorzichtigheid is goed, het is te gevaarlijk om foute veronderstellingen te maken.

B.9 Head Business Office at Hoco Beton BV (PCP producer)

B9.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Op zich hebben we het betonakkoord, maar het moet uit meerdere partijen komen. Zoals een ENCI, betonindustrie, andere partijen komen. In principe hebben we nu alleen het bijmengen van betongranulaat. En daar werkt de norm ook nog tegen.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Ik zie weinig initiatieven voorbij komen, alleen wat afvalstromen die worden aangeboden. Weinig samenhang. Iedereen is er in gedachten mee bezig, alleen komt er weinig van de grond. Ik denk dat het ligt aan kennis.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Zelfde als vorige vraag, gebrek aan innovatie. Ligt aan kennis.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 3 (neutral)
Explanation: De betonindustrie is volume gestuurd. Wat negatief is voor CO_2 reductie. Men probeert zoveel mogelijk volume te draaien om daarmee winst te behalen. De mal kan ook iets complexer, bijvoorbeeld beton weghalen waar dat niet nodig is, maar dan wordt er minder geproduceerd. De cementproducent wil maximaal verkopen, de toeslagmateriaal wil max verkopen, en prefab in principe ook. Elk geproduceerd product dekt de indirecte kosten, dat wordt terugverdient met volume. Minder volume per product betekent dus meer producten verkopen. Er is een omslag merkbaar, iets minder volume gestuurd iets meer omzet gedreven. Is iets beter, in feite zou dat over CO_2 gebruik moeten gaan. Neutraal omdat het dus ook negatieve gevolgen heeft.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Versnipperdheid is zeker aanwezig. Misschien moeten er wat meer dingen wettelijk opgelegd worden, bijvoorbeeld secundaire grondstoffen. Nu mag je betongranulaat toevoegen, misschien moet iedereen dat el gewoon verplicht doen (en dat het behandeld is me CO_2). Over het algemeen een idee dat het te veel is.

B9.2: Knowledge development

Not applicable to this interviewee.

B9.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Kan meer.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Er wordt naar milieucertificaten nauwelijks gevraagd. Opdrachtgevers moeten er naar streven dat er een gebouw wordt neergezet met zo weinig mogelijk CO_2 uitstoot, maar hier wordt niet echt naar gekeken. ISO en breeam komen afentoe langs maar dan ben je er al. Op dit moment is het meer imago, maar als puntje bij paaltje komt wordt er vaak voor de goedkoopste gekozen.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 1 (very negative)
Explanation: Ik kan zo geen voorbeeld geven. Een voorbeeld uit Italie wat ik opgevangen heb. Daarnaast belgie daar halen we grondstoffen vandaan.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: De betonvereniging doet zijn best. Het komt maar heel moeizaam van de grond. Economische triggers kunnen een verklaring zijn. Het levert geen plus en geen min op, of er nou iets aan gedaan wordt of niet.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Over het algemeen is er dus geen prikkel om wel of niet actie te ondernemen. Dit pusht dus ook niemand om actief kennis uit te wisselen en actie te ondernemen.

B9.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 4 (positive)
Explanation: Akkoord 2030 uitstoot halveren is er wel, dus die visie is er. Maar echt veranderen zie je niet. Het is zoeken naar de bestaande methodes om dit ook te realiseren. Nu leggen we dingen vast qua uitstoot en lijkt het alsof het beter gaat, maar eigenlijk hebben we het alleen maar beter gerapporteerd.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 2 (negative)
Explanation: Die manier is nog niet gevonden. Ook weinig sturing.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: In feite positief, ik verwacht wel dat er iemand opstaat met een oplossing. Ik verwacht dat als de druk hoog genoeg wordt dat er een oplossing komt.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 3 (neutral)
Explanation: De wil is er, maar uitvoering blijft uit. Er is meer bewustwording en er worden meer afvalstromen aangeboden als toeslag materiaal maar of het beter is daar twijfel ik aan.

5. Are these goals regarded as reliable and doable?

Score: 2 (negative)
Explanation: Antwoord is gegeven bij de vorige vraag.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: x
Explanation: Geen idee of de partijen er hetzelfde over denken.

B9.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 3 (neutral)
Explanation: Nog niet heel bekend met de technologie dus ook geen idee.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Als dit de oplossing is voor het probleem dat is er zeker een grote potentie.

B9.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Het ontbreekt in de sector aan kennis en mankracht.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: In feite wel, iedereen krijgt te maken met hetzelfde. Investeren is niet het probleem. Het zal wel kostprijs verhogend werken.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Geen verdere uitleg.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Er gaat in de toekomst schaarste ontstaan op de beschikbaarheid van materialen, maar de infrastructuur is zeker goed.

B9.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 2 (negative)
Explanation: Nee geen weerstand. De markt staat zeker open voor vernieuwing, het is meer onwetendheid.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Zelfde antwoord als net.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: De normen moeten aangepast worden op de toepassing van CO_2. Daarnaast met granulaat, daar zit een limiet aan van hoeveel er gebruikt mag worden. Over het algemeen is dat een traag proces.

B.10 Senior Advisor Bridges and Viaducts at Rijkswaterstaat (Executive organization of Ministry)

B10.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Als je naar het hele scala aan bedrijven kijkt wat aan Rijkswaterstaat levert, is dat heel erg breed. Ik weet niet of dat genoeg is. Er is heel veel gebeurd in die hele industrie de afgelopen jaren geen toename en afname. Stikstofcrisis onder andere. Er was een enorme onzekere afname volume door Rijkswaterstaat, hierdoor is bijvoorbeeld spanbeton (marktleider in prefabliggers) gestopt. Daardoor is de continuiteit van de betonindustrie niet gewaarborgd. De markt zit te springen om een innovatie die door de rijksoverheid gestimuleerd wordt.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: RMC producenten hebben veel minder last gehad van die onzekerheid, woningbouw en dergelijke zijn meer doorgegaan omdat ze minder last hadden van stikstof probleem. Daar zit innovatiekracht. Dat zou een van de segmenten kunnen zijn die hierin succesvol kunnen zijn. Rijkswaterstaat is dus niet de enige partij (opdrachtgever). Rijkswaterstaat heeft wel meer ambitieuze plannen.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Zij willen wel, maar hebben ook met regelgeving te maken. Zodra je binnen regelgeving blijft kan je het zo toepassen. Als je er buiten komt, wordt het lastig. We willen als Rijkswaterstaat gewoon gevalideerde producten. Onze standaard van 100 jaar bruikbaarheid is daarbij belangrijk. Er is een innovatieloket waarbij we partijen de ruimte bieden om die innovaties toe te passen. Bedrijven willen wel maar moeten uiteindelijk door de validatie trechter heen. Marktpartijen moeten een jaarlijks dalende MKI score hebben.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 2 (negative)
Explanation: Beton is best wel lastig spul. We zeggen bijvoorbeeld tegen betonmortel centrales ga duurzaam produceren maar ze zijn wel afhankelijk van de cementindustrie. De cementindustrie is daarin ook niet heel makkelijk (toch een soort monopoliepositie). Dus macht bij cementindustrie. Er is wel besef dat ze wel moeten. We doen het in Nederland natuurlijk al erg goed met CEM 3 ipv portland cement. Focus op innovatie, geopolymeren en betongranulaat. Goed georganiseerd.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: Geen verdere uitleg.

B10.2: Knowledge development
Not applicable to this interviewee.

B10.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 4 (positive)
Explanation: Als Rijkswaterstaat hebben we veel contact met de TU Delft en TNO en dergelijken. Het is zich goed aan het ontwikkelen. Dus de uitwisseling van kennis daarin is goed, geeft een voorbeeld van samenwerking in Delft tussen onderwijs, onderzoek en markt.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Nog niet bekend bij Rijkswaterstaat met deze techologien, dus nee.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 2 (negative)
Explanation: Zelfde antwoord als de vorige vraag.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Technologie nog niet bekend dus valt ook weinig over uit te wisselen dan.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 2 (negative)
Explanation: In Nederland hebben we een heel open systeem van uitwissleing van kennis omdat we beseffen dat we alleen maar verder komen als we samenwerken.

B10.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 4 (positive)
Explanation: We hebben hoge verwachtingen van alles wat positief bijdraagt. We hebben vertrouwen in de Nederlandse innovatiekracht. Alleen moet het beginnen en geholpen worden.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

5. Are these goals regarded as reliable and doable?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

B10.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: x
Explanation: Ik kan deze vraag niet beantwoorden.

B10.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Overal is hetzelfde probleem aanwezig. Erg weinig mensen in de hele industrie. Zeker op specifieke kennis zoals betontechnologen en onderzoekers.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Er is nooit genoeg natuurlijk, meer geld zorgt altij voor meer onderzoek. Er ligt wel veel geld op de plank om dit probleem op te lossen. Er is veel geld beschikbaar alleen is het niet helemaal duidelijk hoe het bereikt kan worden. Het is er dus wel, maar misschien is het de vraag hoe het gevonden kan worden.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Ik denk dat we in Nederland een vrij goed systeem hebben qua transport.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Zelfde antwoord als vorige vraag.

B10.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 4 (positive)
Explanation: Er is altijd weerstand. Iets nieuws roept weerstand op. Je hebt koplopers nodig om nieuwe dingen populair te maken zodat ze opgenomen worden. Verwijzend naar de standaard innovatiecurve.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Zelfde antwoord als de vorige vraag.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ja dat is er ook. Zit in datzelfde systeem, we zijn nog niet ingericht op nieuwe regels en dergelijken. Dit is de grootste belemmering voor al die dingen waar we mee bezig zijn, regelgeving. Het komt ergens natuurlijk ook ten goede, maar er zit een enorme traagheid in dat proces.

B.11 Senior Technical Advisor Concrete Technology at Rijkswaterstaat (Executive organization of Ministry)

B11.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Er zijn er weinig, wij hebben het nog niet aangeboden gekregen dmv pilots.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Er zijn er voldoende die het kunnen doen, maar het wordt nog niet gebruikt. Probleem is wel dat CO_2 bij zowel uitstoot als gebruik dicht bij elkaar moet zitten. Dus er zit een gat tussen cementproductie buiten Nederland en betonproductie in Nederland.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: 2 (negative)
Explanation: Ze zijn meer in CO_2 arm beton. Dus focus op zo min mogelijk uitstoten, minder cement geopolymeren. In Nederland geloven we momenteel niet zo veel in het idee van CO_2 afvangen.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 2 (negative)
Explanation: Binnen de afname van dragend beton, wat wij veel doen, kan CO_2 niet gebruikt worden door corrosie. Wanneer er wapening in beton zit willen we gewoon absoluut geen CO_2 in ons beton, omdat de passiveringslaag dan wegvalt als de ph onder 9 zakt.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 3 (neutral)
Explanation: Er is geen barriere omdat er eigenlijk niet met CO_2 wordt geexperimenteerd in dragende betonconstructies.

B11.2: Knowledge development
Not applicable to this interviewee.

B11.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Je ziet wel eens dat onderzoek uit de wetenschap niet aansluit bij de werkelijkheid om dat er niet goed gecommuniceerd wordt. Het kan beter.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Ik heb bijvoorbeeld niks aangeboden gekregen. Daarnaast wordt het gewoon niet gezien in de industrie als de methode om het probleem op te lossen, dus meer CO_2 verminderen.

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 2 (negative)
Explanation: We zijn wel van op de hoogte dat er het een en ander gebeurd. Nederland wordt niet gezien als strategisch doel.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Het idee is dat het niet goed is voor bepaalde toepassingen. We geloven ook niet dat CO_2 uitstoot afvangen de oplossing is voor het probleem. Daarom gebeurd het ook niet.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Zelfde toelichting als de vorige vraag.

B11.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 2 (negative)
Explanation: Nee, binnen Rijkswaterstaat geloven we dus niet heel erg in CO_2 afvangen. Ook is het zo dat constructief beton afvalt door wapening, waardoor het ook minder aantrekkelijk wordt voor niet constructief beton. Andere oplossingen die wel in constructief beton kunnen hebben dan natuurlijk een groter potentieel.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 2 (negative)
Explanation: Zie antwoord op vorige vraag.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: Zie antwoord op vorige vraag.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: Zie antwoord op vorige vraag.

5. Are these goals regarded as reliable and doable?

Score: 2 (negative)
Explanation: Doelen zijn er niet, zie vorige vraag.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 2 (negative)
Explanation: Rijkswaterstaat is er niet voor. Andere partijen zien wel kansen, maar dat heeft ook te maken met de cement industrie die wil blijven bestaan. Rijkswaterstaat bekijkt vanuit de samenleving en ziet dan dat andere oplossingen meer potentieel hebben om de CO_2 probleem op te lossen..

B11.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 2 (negative)
Explanation: Het kan gewoon niet gebruikt worden in constructief beton, daardoor valt er een groot gedeelte van de markt af waardoor andere potentiele innovaties al direct een grote voorsprong hebben en dus relevanter zijn in het oplossen van het probleem.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Zelfde antwoord als net.

B11.6: Mobilization of resources
Not applicable to this interviewee.

B11.7: Counteracting resistance to change
Not applicable to this interviewee.

B.12 Senior Policy Advisor Building Regulations at Ministry (Interior and Kingdom Relations)

B12.1: Entrepreneurial activities

1. Are there enough relevant and diverse actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: x
Explanation: Ik ken wel veel initiatieven om co2 te verminderen, onder andere m.b.t. minder energieverbruik in de productie maar ook minder grondstofverbruik in de sector. Ik ken geen initiatieven om CO_2 daadwerkelijk te gebruiken tijdens de productie.

2. Are there sufficient industrial actors within the Dutch concrete system for CO_2 usage during concrete production?

Score: x
Explanation: Zelfde antwoord als vorige vraag.

3. Do the industrial actors in the Dutch concrete system innovate sufficiently with regard to CO_2 usage during concrete production?

Score: x
Explanation: Zelfde antwoord als vorige vraag.

4. Do the industrial actors in the Dutch concrete system focus sufficiently on large-scale production?

Score: 4 (positive)
Explanation: Er zijn wel veel grote betonproducenten in Nederland.

5. Does the level of experimentation and production by entrepreneurs form a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: x
Explanation: Ik weet het niet. Ik weet dat partijen bezig zijn met andere mengsels en minder uitstoot, maar dat is anders dan CO_2 gebruik.

B12.2: Knowledge development
Not applicable to this interviewee.

B12.3: Knowledge exchange

1. Is there enough knowledge exchange between science and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 2 (negative)
Explanation: Ik denk van niet. We hebben contact met Betonhuis en Betonakkoord en we krijgen wel vragen over van alles. We krijgen dan vragen, hoe kunnen we er voor zorgen dat we aan de bouwregels voldoen. Ik heb het idee dat deze twee groepen heel veel langs elkaar heen spreken.

2. Is there enough knowledge exchange between users and industry on CO_2 usage during concrete production, within the Dutch concrete system?

Score: 3 (neutral)
Explanation: Een belangrijk aspect is de nationale milieu database . Twee belangrijke dingen: constructieve veiligheid (70-80k) en aantonen dat je product duurzamer is door in de Nationale Milieu Database te komen (paar duizend euro voor een LCA).

3. Is there sufficient knowledge exchange on CO_2 usage during concrete production across geographical borders?

Score: 3 (neutral)
Explanation: Wat ik in Europa zie is dat de betonorganisaties internationaal ook goede netwerken hebben, maar ik weet niet of dit dan ook specifiek voor CO_2 gebruik als grondstof geldt.

4. Are there problematic parts of the Dutch concrete system regarding knowledge exchange on CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Ik heb hier geen antwoord op.

5. Is knowledge exchange forming a barrier for the Dutch concrete system to implement CO_2 usage during concrete production on an industry-wide scale?

Score: 4 (positive)
Explanation: Ik denk het wel. We hebben pas geleden nog een gesprek gehad met Betonhuis en twee vertegenwoordigers van de NEN betoncommissie. Dat ging specifiek over betonsamenstellingen etc. Daar zijn ervaringen uitgewisseld. Maar het kan zeker beter dus.

B12.4: Guidance of the search

1. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of growth?

Score: 4 (positive)
Explanation: Het betonakkoord heeft wel ambities. Er is wel een visie vanuit betonakkoord om CO_2 te verlagen, CO_2 gebruik is daar in principe onderdeel van.

2. Is there a clear vision on how the Dutch industry and market of CO_2 usage during concrete production should develop in terms of technological design?

Score: 4 (positive)
Explanation: Dat is nog heel erg divers. Dat zie je wel vaker bij nieuwe technologien, er moet iets ontstaan. Men is zoekende en heeft ideeen. Het moet nog uitkristaliseren.

3. What are the expectations regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 3 (neutral)
Explanation: Over CO_2 gebruikt durf ik dat niet te zeggen, dus doe maar neutraal.

4. Are there clear policy goals regarding the technological field of CO_2 usage during Dutch concrete production?

Score: 2 (negative)
Explanation: Ik ben ze niet tegengekomen.

5. Are these goals regarded as reliable and doable?

Score: 2 (negative)
Explanation: In lijn met de vorige vraag.

6. Are the visions and expectations of actors involved in this transition sufficiently aligned to reduce uncertainties?

Score: 2 (negative)
Explanation: Ik denk het niet, dat is nog zoekende. Er wordt te weinig gecoordineerd.

B12.5: Formation of markets

1. Is the current and expected future market size of CO_2 usage during Dutch concrete production sufficient?

Score: 3 (neutral)
Explanation: Weet ik niet.

2. Does the current and expected market size form a barrier for the Dutch concrete system to implement CO_2 usage in concrete production on an industry-wide scale?

Score: 3 (neutral)
Explanation: Zelfde antwoord als vorige vraag.

B12.6: Mobilization of resources

1. Are there sufficient human resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ik denk dat het wel binnen de bestaande structuur kan. Kijk momenteel is er natuurlijk overal personeelstekort, maar ik denk wel dat er in de industrie voldoende personeel is om dit op te pakken.

2. Are there sufficient financial resources in the Dutch concrete system to enable an increase of CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ik denk het wel, het is natuurlijk een grote industrie dus daar is wel geld beschikbaar. Er zijn ook subsidies beschikbaar maar ook banken luisteren wel naar een goed plan. Dus ik ben daar wel positief over.

3. Are there expected physical resource constraints for the Dutch concrete system that may hamper the diffusion of technology on CO_2 usage during concrete production?

Score: 3 (neutral)
Explanation: Het lastige is dat ik de technologie niet goed genoeg ken om het te kunnen beoordelen. Gevoelsmatig moet dat toch wel kunnen binnen de bestaande structuur.

4. Is the physical infrastructure of the Dutch concrete system developed well enough to support the diffusion of technology on CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Ik denk het wel, bedrijven bestaan lang zijn professioneel.

B12.7: Counteracting resistance to change

1. Is there resistance in the Dutch concrete system towards the usage of new technologies during concrete production?

Score: 4 (positive)
Explanation: Ik denk dat er altijd wel weerstand is. Als iets nieuw is zijn we kritisch. Als het om beton gaat is er brandveiligheid en constructieve veiligheid. Er kunnen natuurlijk ook slachtoffers vallen als dingen niet goed gaan. Mensen moeten echt met bewijs komen dat dingen goed zijn, dat is dan natuurlijk ook wel ook wel een investering in het laten testen van dit nieuwe product. Verder zal de prijs ook een belangrijke factor zijn voor afnemers.

2. Is there resistance in the Dutch concrete system towards the set up of projects for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Bij het aanpassen van beton en nieuwe mengsels komt in gesprekken naar voren dat de industrie een aantal barrieres door moet. Zo is het bijvoorbeeld testen voor constructieve sterkte, in de nationale milieu database komen. Maar dat is voor mij makkelijk omdat ik in de materie zit. Er zijn gewoon bepaalde eisen en normen omdat we echt met belangrijke dingen werken. Je moet voldoen aan de bouwvoorwaarden constructieve veiligheid en de milieuprestatie kunnen aantonen. Er moet bewezen worden dat alles klopt.

3. Is there resistance in the Dutch concrete system towards permit procedures for CO_2 usage during concrete production?

Score: 4 (positive)
Explanation: Deels het antwoord op de vorige vraag. Constructieve veiligheid heeft extra aandacht van bouw en woning toezicht. Als er nieuwe betonsoorten komen zullen ze er kritisch naar kijken en testrapporten willen zien. Er zijn richtlijnen waarop je nieuwe soorten beton kunt laten testen bij TNO. Het is een traject waarin je tijd en geld moet investeren. Het hoeft natuurlijk niet voor elk gebouw opnieuw. Als je met jouw betonsoort een test hebt ondergaan en je maakt het mengsel gewoon opnieuw hoef je niet elke keer opnieuw die testen te doen.

C Tables with cleaned scores of the structured expert interviews

Within this appendix, the given scores by the experts are cleaned and presented in an overview. It is important to mention that these are not the exact scores given by the interviewees as presented in appendix B, but these are the cleaned results which are used for the final analysis. The cleaning process exists of removing scores when interviewees mentioned they were unable to answer the question and changing scores when interviewees were contradicting their own scores with the given explanation. While cleaning and deciding the final score, the given explanation in words gained preference over the actually given score since the explanation gives more context. All of the adjustments are briefly described and clarified here for completeness and transparency.

C.1 Entrepreneurial activities

For the first functionality, the score for the fifth question is turned around. A low score for this question is positive for the system and a high score is negative, so in order to use the scores in the final calculation these need to be turned around as follows: 1 = 5, 2 = 4 and 3 remains 3. In addition to that, the twelfth interviewee did not answer any of the given questions for this functionality. Also, some scores have been adjusted based on the given explanation. For the first question, the scores of interviewees 7, 8 and 9 were increased by one point. For the second question, the score of interviewee 8 was increased by one point. For the third question, the score of interviewee 7 was decreased by one point. For the fourth question, the scores of interviewees 4 and 5 were turned around from 4 to 2 since they were interpreted in reverse by the interviewees. For the fifth question, the score of interviewee 11 was increased by one point.

Table 15: Score table for functionality 1.

	Q1	Q2	Q3	Q4	Q5*	Average score
1. University (Delft University of Technology)	-	-	-	-	-	-
2. Research centre (VITO)	-	-	-	-	-	-
3. Research centre (TNO)	-	-	-	-	-	-
4. R&D team of concrete producer (Bruil)	2	2	4	2	4	2.8
5. Branche organization (Betonhuis)	4	4	4	2	3	3.4
6. PCP producer (Martens groep)	5	5	5	5	5	5.0
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	5	4	2	3	2	3.2
8. CO_2 usage technology (Edilteco Benelux)	5	5	4	4	4	4.4
9. Concrete production (Hoco Beton BV)	3	2	2	3	2	2.4
10. Executive organization of Ministry (Rijkswaterstaat)	2	4	3	2	4	3.0
11. Executive organization of Ministry (Rijkswaterstaat)	2	4	2	2	4	2.8
12. Ministry (Interior and Kingdom Relations)	x	x	x	x	x	x
Average	3.5	3.8	3.3	2.9	3.5	3.4

* This column represents a question where a positive reaction has a negative effect on the system and vice versa. The respondent's answer is therefore translated from appendix B to the right Likert score.

C.2 Knowledge development

For the second functionality, no particularities are present except for the score for the fourth question being turned around. A low score for this question is positive for the system and a high score is negative, so in order to use the scores in the final calculation these need to be turned around as follows: 1 = 5, 2 = 4 and 3 remains 3. Also, some scores have been adjusted based on the given explanation. For the third question, the score of interviewee 5 was increased by one point. For the fourth question, the score of interviewee 1 was decreased by one point.

Table 16: Score table for functionality 2.

	Q1	**Q2**	**Q3**	**Q4***	**Average score**
1. University (Delft University of Technology)	4	4	4	3	3.8
2. Research centre (VITO)	4	4	4	3	3.8
3. Research centre (TNO)	2	4	4	3	3.0
4. R&D team of concrete producer (Bruil)	3	2	4	3	3.0
5. Branche organization (Betonhuis)	4	4	4	4	4.0
6. PCP producer (Martens groep)	-	-	-	-	-
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	-	-	-	-	-
8. CO_2 usage technology (Edilteco Benelux)	-	-	-	-	-
9. Concrete production (Hoco Beton BV)	-	-	-	-	-
10. Executive organization of Ministry (Rijkswaterstaat)	-	-	-	-	-
11. Executive organization of Ministry (Rijkswaterstaat)	-	-	-	-	-
12. Ministry (Interior and Kingdom Relations)	-	-	-	-	-
Average	3.4	3.6	4.0	3.4	3.6

* This column represents a question where a positive reaction has a negative effect on the system and vice versa. The respondent's answer is therefore translated from appendix B to the right Likert score.

C.3 Knowledge exchange

For the third functionality some interviewees did not know the answer to some specific questions, these questions are therefore filled in with an 'x' mark and will not be taken in the calculation of the final scores. This does not mean that all scores from that interviewee for the functionality will be left out, but only that specific value. Next to that, the scores for the fourth and fifth questions are turned around. A low score for these questions is positive for the system and a high score is negative, so in order to use the scores in the final calculation these need to be turned around as followed: 1 = 5, 2 = 4 and 3 remains 3. Also, some scores have been adjusted based on the given explanation. For the first question, the score of interviewee 6 was decreased by one point. For the second question, the scores of interviewees 3, 6 and 7 were decreased by one point. For the third question, the scores of interviewees 4 and 9 were increased by one point. For the fifth question, the scores of interviewees 6 and 8 were decreased by one point.

Table 17: Score table for functionality 3.

	Q1	Q2	Q3	Q4*	Q5*	Average score
1. University (Delft University of Technology)	x	2	x	4	2	2.7
2. Research centre (VITO)	3	2	4	4	2	3.0
3. Research centre (TNO)	4	3	4	4	2	3.4
4. R&D team of concrete producer (Bruil)	4	2	3	4	4	3.4
5. Branche organization (Betonhuis)	2	2	2	2	2	2.0
6. PCP producer (Martens groep)	4	2	4	4	4	3.6
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	2	2	x	x	2	2.0
8. CO_2 usage technology (Edilteco Benelux)	2	4	4	3	3	3.2
9. Concrete production (Hoco Beton BV)	2	2	2	2	2	2.0
10. Executive organization of Ministry (Rijkswaterstaat)	4	2	2	2	4	2.8
11. Executive organization of Ministry (Rijkswaterstaat)	2	2	2	2	2	2.0
12. Ministry (Interior and Kingdom Relations)	2	3	3	x	2	2.5
Average	2.8	2.3	3.0	3.1	2.6	2.7

* This column represents a question where a positive reaction has a negative effect on the system and vice versa. The respondent's answer is therefore translated from appendix B to the right Likert score.

C.4 Guidance of the search

For the fourth functionality some interviewees did not know the answer to some specific questions, these questions are therefore filled in with an 'x' mark and will not be taken in the calculation of the final scores. This does not mean that all scores from that interviewee for the functionality will be left out, but only that specific value. Next to that, one interviewee could only give the answer to one of the six questions. This then scores the entire functionality based on one question which is not desired, so that particular functionality score is left out completely. Also, some scores have been adjusted based on the given explanation. For the first question, the scores of interviewees 3, 4 and 9 were decreased by one point. For the second question, the scores of interviewees 3 and 4 were decreased by one point while the score of interviewee 12 was turned around from 4 to 2 because the question was answered in reverse. For the third question, the score of interviewee 2 was decreased by one point. For the fourth question, the score of interviewee 3 was decreased by one point. For the fifth question, the score of interviewee 8 was decreased by one point. For the sixth question, the score of interviewee 2 was decreased by one point.

Table 18: Score table for functionality 4.

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Average score**
1. University (Delft University of Technology)	2	2	4	x	x	2	2.5
2. Research centre (VITO)	2	4	4	x	x	2	3.0
3. Research centre (TNO)	3	2	2	3	x	4	2.8
4. R&D team of concrete producer (Bruil)	3	2	3	2	2	2	2.3
5. Branche organization (Betonhuis)	1	2	4	2	3	2	2.3
6. PCP producer (Martens groep)	2	4	4	1	2	5	3.0
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	2	2	2	2	4	4	2.7
8. CO_2 usage technology (Edilteco Benelux)	4	4	4	4	3	3	3.7
9. Concrete production (Hoco Beton BV)	3	2	4	3	2	x	2.8
10. Executive organization of Ministry (Rijkswaterstaat)	x	x	4	x	x	x	4.0
11. Executive organization of Ministry (Rijkswaterstaat)	2	2	2	2	2	2	2.0
12. Ministry (Interior and Kingdom Relations)	4	2	x	2	2	2	2.4
Average	2.5	2.5	3.4	2.3	2.5	2.8	2.8

C.5 Formation of markets

For the fifth functionality, one interviewee did not know the answer to one specific question, this question is therefore filled in with an 'x' mark and will not be taken in the calculation of the final scores. This does not mean that all scores from that interviewee for the functionality will be left out, but only that specific value. Another interviewee did not have an answer to both questions so the complete value is left out of the calculation. Next to that, the scores for the second question are turned around. A low score for this question is positive for the system and a high score is negative, so in order to use the score in the final calculation it needs to be turned around as followed: 1 = 5, 2 = 4 and 3 remains 3. Also, some scores have been adjusted based on the given explanation. For the first question, the scores of interviewees 5, 6, 7 and 11 were decreased by one point. For the second question, the scores of interviewees 2, 5, 6 and 11 were decreased by one point.

Table 19: Score table for functionality 5.

	Q1	**Q2***	**Average score**
1. University (Delft University of Technology)	-	-	-
2. Research centre (VITO)	3	2	2.5
3. Research centre (TNO)	3	4	3.5
4. R&D team of concrete producer (Bruil)	-	-	-
5. Branche organization (Betonhuis)	3	3	3.0
6. PCP producer (Martens groep)	2	4	3.0
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	3	4	3.5
8. CO_2 usage technology (Edilteco Benelux)	3	4	3.5
9. Concrete production (Hoco Beton BV)	x	2	2.0
10. Executive organization of Ministry (Rijkswaterstaat)	x	x	x
11. Executive organization of Ministry (Rijkswaterstaat)	1	1	1.0
12. Ministry (Interior and Kingdom Relations)	x	x	x
Average	2.6	3.0	2.8

* This column represents a question where a positive reaction has a negative effect on the system and vice versa. The respondent's answer is therefore translated from appendix B to the right Likert score.

C.6 Mobilization of resources

For the sixth functionality, no particularities are present except for the score for the third question being turned around. A low score for this question is positive for the system and a high score is negative, so in order to use the score in the final calculation these need to be turned around as follows: 1 = 5, 2 = 4 and 3 remains 3. Also, some scores have been adjusted based on the given explanation. For the first question, the scores of interviewees 3, 4 and 9 were decreased by one point. For the second question, the score of interviewee 6 was decreased by one point. For the second question, the score of interviewee 6 was decreased by one point. For the fourth question, the score of interviewee 4 was increased by one point and the score of interviewee 6 was decreased by one point.

Table 20: Score table for functionality 6.

	Q1	**Q2**	**Q3***	**Q4**	**Average score**
1. University (Delft University of Technology)	-	-	-	-	-
2. Research centre (VITO)	-	-	-	-	-
3. Research centre (TNO)	-	-	-	-	-
4. R&D team of concrete producer (Bruil)	2	4	3	3	3.0
5. Branche organization (Betonhuis)	1	4	4	4	3.3
6. PCP producer (Martens groep)	4	4	2	4	3.5
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	2	4	2	4	3.0
8. CO_2 usage technology (Edilteco Benelux)	4	4	2	4	3.5
9. Concrete production (Hoco Beton BV)	2	4	4	4	3.5
10. Executive organization of Ministry (Rijkswaterstaat)	2	4	4	4	3.5
11. Executive organization of Ministry (Rijkswaterstaat)	-	-	-	-	-
12. Ministry (Interior and Kingdom Relations)	4	4	3	4	3.8
Average	2.6	4.0	3.0	3.9	3.4

* This column represents a question where a positive reaction has a negative effect on the system and vice versa. The respondent's answer is therefore translated from appendix B to the right Likert score.

C.7 Counteracting resistance to change

For the seventh functionality, one interviewee did not know the answer to a specific question, this question is therefore filled in with an 'x' mark and will not be taken in the calculation of the final scores. This does not mean that all scores from that interviewee for the functionality will be left out, but only that specific value. Next to that, the scores for the first, second and third questions are turned around. A low score for these questions is positive for the system and a high score is negative, so in order to use the scores in the final calculation these need to be turned around as follows: 1 = 5, 2 = 4 and 3 remains 3. Also, one score has been adjusted based on the given explanation. For the first question, the score of interviewee eight was increased by one point.

Table 21: Score table for functionality 7.

	Q1*	**Q2***	**Q3***	**Average score**
1. University (Delft University of Technology)	-	-	-	-
2. Research centre (VITO)	3	3	2	2.7
3. Research centre (TNO)	4	4	4	4.0
4. R&D team of concrete producer (Bruil)	4	3	3	3.3
5. Branche organization (Betonhuis)	3	4	4	3.7
6. PCP producer (Martens groep)	5	2	x	3.5
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	5	5	4	4.7
8. CO_2 usage technology (Edilteco Benelux)	4	4	4	4.0
9. Concrete production (Hoco Beton BV)	4	4	3	3.7
10. Executive organization of Ministry (Rijkswaterstaat)	2	2	2	2.0
11. Executive organization of Ministry (Rijkswaterstaat)	-	-	-	-
12. Ministry (Interior and Kingdom Relations)	2	2	2	2.0
Average	3.6	3.3	3.1	3.4

* This column represents a question where a positive reaction negatively influences the system and vice versa. Therefore, the respondent's answer is translated from appendix B to the right Likert score.

C.8 All average interviewee scores per functionality

Table 22: Specific functionalities asked per interviewee.

	F1: Entrepreneurial activities	F2: Knowledge development	F3: Knowledge exchange	F4: Guidance of the search	F5: Formation of markets	F6: Mobilization of resources	F7: Counteracting resistance to change
1. University (Delft University of Technology)	-	3.5	3.3	2.5	-	-	-
2. Research centre (VITO)	-	3.8	3.0	3.5	3.0	-	2.7
3. Research centre (TNO)	-	3.5	3.6	3.4	3.5	-	4.0
4. R&D team of concrete producer (Bruil)	3.2	3.0	3.2	2.7	-	2.8	3.3
5. Branche organization (Betonhuis)	3.8	3.8	2.0	2.3	4.0	3.3	3.7
6. PCP producer (Martens groep)	5.0	-	4.2	3.3	5.0	4.3	3.5
7. RMC producer (Dyckerhoff Basal Betonmortel B.V.)	3.6	-	2.3	2.7	4.0	3.5	4.7
8. CO_2 usage technology (Edilteco Benelux)	4.0	-	3.4	4.0	4.0	3.5	3.7
9. Concrete production (Hoco Beton BV)	2.2	-	1.8	3.0	2.0	3.5	3.7
10. Executive organization of Ministry (Rijkswaterstaat)	3.0	-	2.8	4.0	x	3.0	2.0
11. Executive organization of Ministry (Rijkswaterstaat)	2.6	-	2.0	2.0	2.0	-	-
12. Ministry (Interior and Kingdom Relations)	4.0	-	2.5	2.8	x	3.8	2.0
Average	3.5	3.5	2.8	3.0	3.4	3.4	3.3