Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Geography

Nils Oskar Tronrud

Captured Waste: Drivers and barriers to the Implementation of Carbon Capture and Storage in the Waste-to-Energy Industry

Master's thesis in Globalization and Sustainable Development
Supervisor: Markus Steen
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Abstract

This thesis explores drivers and barriers to implementing carbon capture and storage in the waste to energy industry, and how this transformation is affected by contextual factors and preconditions. Additionally, it explores the role and strategy of actors involved in the transition. It has an emphasis on place-based factors.

The study identified climate action, financing schemes and new business models that cover capital expenses and operational expenses, as well as learning outcomes as the primary drivers for CCS in WtE.

At the same time, capital expenses and operational expenses were identified as primary financial barriers, requiring policies enabling a negative emission market and adjusting the CO2 emission tariff for the sector to enable profitability of CCS in WtE. Space limitations and issues of heat integration were also major barriers.

Actors worked through networks to influence national politics, and to overcome place-based barriers.

The findings provide empirical examples of regime alignment, triple embeddedness mediation, and highlight technical and physical challenges to implementing CCS in WtE. Finally, geography was conveyed through an emphasis on place-based factors, which showed a variance between the cases.

At the general level, the findings of this thesis highlight the challenges of transforming hard-to-abate industries with CCS, and what measures actors involved are employing to increase the successfulness of these projects.

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List of Abbreviations

CAPEX	Capital expenditure
CCS	Carbon capture and storage
EU	European Union
IEA	International Energy Agency
NDC	Nationally determined contributions
OPEX	Operational expenditure
TRL	Technological Readiness Level
UN	United Nations
WtE	Waste-to-Energy

1 Introduction

Decarbonizing human activities is one of the biggest challenges facing society in the 21st century and achieving it require transitions away from unsustainable practices and production systems, also known as sustainability transitions (Markard et al., 2012).
In the field of transition studies these practices are analyzed through a system approach, which consist of three elements: actors, institutions, and technologies. The interaction between these elements consolidates what is called socio-technical systems. The land-based vehicle transportation system, for example, consists of the technologies of cars, infrastructure of roads, but also through social agreements on traffic rules and laws (see figure 1).

Transitions are, in other words, multifaceted processes. They are geographical processes in that they happen in particular places (Hansen & Coenen, 2015; Raven et al., 2012), they are social because they induce changes in behavior (O'Brien & Sygna, 2013), they are political as they require political will and commitment to accomplish (Meadowcroft, 2011), they are economic processes because they induce market changes and require resources to accomplish (Geels, 2020), and they can be technological processes when transitions involve radical new innovations (Geels, 2020).

One system undergoing a sustainable transition is the Norwegian waste management system, which is trying to reduce waste through improved habits and increase the recycling of materials to contribute to a circular economy (Mørk & Post-Melbye, 2022). Yet there will always be some waste that cannot be recycled or reused. Here waste incineration, or Waste-to-Energy (WtE), is considered the best alternative for disposal, as it lessens the need for landfills that take up space while providing energy in the form of heat and electricity (KAN, 2022). In Norway, about 26% of waste is disposed of through WtE, producing 1 million tons of greenhouse gas emissions (GHG) on average annually (Miljødirektoratet, 2022). Cutting these emissions are challenging, however. Along with industries such as the cement, steel, chemicals, and pulp industry, the WtE industry is recognized as a hard-to-abate industry (Global CCS Institute, 2023), as the industry has few options on reducing the emissions from the flue gasses produced during incineration.

A solution, however, is to introduce carbon capture and storage (CCS) as an add-on, capturing the flue gasses. Moreover, because about half of the waste incinerated in Norway is from biogenic sources (KAN, 2022; Mørk & Post-Melbye, 2022), capturing and storing these emissions lead to net negative emissions, which is a case of Carbon Dioxide Removal (CDR). CDR is deemed crucial to reduce combat climate change, and is a vital part of the UNs pathway to stay within 1.5 °C (IPCC, 2023a), in the International Energy Agency's (IEA) Net Zero Emissions by 2050 scenario (IEA, 2022a), and to the EUs strategy of becoming climate neutral by 2050 (European Comission, 2022b).

There are therefore both a need and benefits of implementing CCS in WtE. Currently, several WtE facilities in Norway are looking into this. These efforts are motivated by the pressures of climate change and the expected increase in carbon taxes in the near future, forcing the sector to adapt. Moreover, as WtE facilities are large single-point emitters, the transition is also pushed for by local and regional officials eager to meet their emission reduction targets.

1.1 Delimitation and research question

The objective of the research is twofold. First, it will employ an explorative research approach to map out drivers and barriers to implementing CCS in WtE, and whether there are variations between the cases explored due to contextual factors and preconditions. To answer this, I present the following main research question:

> *What are the drivers and barriers to implementing carbon capture and storage in the Waste-to Energy industry, and how is this transformation of the waste to energy affected by contextual factors and preconditions?*

Second, in addition to this relatively broad main research question, the thesis also attends to the following secondary research question:

> *How are actors engaging with the identified drivers and barriers, and what sort of strategies are they employing to improve the conditions for Carbon Capture and Storage in the Waste-to-Energy industry?*

These questions will be answered while situating CCS as a chain in the wider sustainability transition of the waste sector.

1.2 Theoretical proposition

This thesis will analyze three Norwegian cases pursuing CCS in WtE through employing the multi-level perspective (MLP) framework, a mid-range theory within the field of transition studies useful for explaining both stability and change in at the meso level, recognized as socio-technical systems (STSs). These systems are consolidated, maintained, and shaped by incumbent actors, who hold vested interests and core capabilities in the existing system (Geels, 2014b). The MLP operationalize STSs through socio-technical regimes, which are constructed by semi-coherent set of rules and institutions (Fuenfschilling & Truffer, 2014). Change to regimes are often induced by the interaction within and between regimes, or between regimes, niche-innovations and the sociotechnical landscape (Geels, 2018). Niche-innovations, or niches, are social or technical innovations radically different from the regime, while the sociotechnical landscape refers to broader exogenous contexts that impact regimes, but which regimes have little to no influence over, such as monetary systems or wars.

To overcome certain weaknesses within the MLP to address the RQ, the thesis borrows Geels' triple embeddedness framework (2014a) to highlight how firms engage with CCS in WtE, as well as literature underscoring the importance of the geographical level in sustainability transitions (Hansen & Coenen, 2015; Raven et al., 2012). These will be resented in section 3.3.

1.3 Signifigance of the study

Globally, waste is becoming a growing issue (Kearns, 2019). About 2.01 billion tons of waste is produced annually worldwide, and the number is set to increase to 3.4 billion tons by 2050 (Kaza et al., 2018). In a nutshell, 93 percent of waste ends up in landfills in low-income countries, 54 percent in upper-middle income countries, and 39 percent in high-income countries (Kaza et al., 2018). In the latter, 35 percent of waste is diverted to recycling and composting and 22 percent is incinerated (Kaza et al., 2018). To address this issue, several researchers highlight the immediate need for better waste management, waste reduction, resource management, and waste incineration to reduce waste accumulation in landfills world-wide (Iyamu et al., 2022; Kaza et al., 2018; Kearns, 2019; Levidow & Upham, 2017; Tang & You, 2018).

In addition to reducing landfills WtE provides energy, which reduce the dependency on conventional fossil fuels (Kearns, 2019). If coupled with CCS, a wide-spread deployment of WtE can have significant environmental benefits as the composition of waste globally is 44% biogenic (Kearns, 2019). Yet reaching this point will require trial and error to learn how to implement CCS in WtE and to lower the costs, in which the Norwegian cases can play a crucial part.

1.4 Disposition

This thesis is structured accordingly: Section 1 explains the rationale behind the research questions and the significance of the thesis.

Section 2 presents the empirical background on the evolution of waste management, CCS, and CCS in WtE.

Section 3 embeds the project in the literature of sustainable transition studies and presents the theoretical framework employed for analyzing primary and secondary data.

Section 4 discuss the methodology employed in the project and potential weaknesses in the chosen strategy.

Section 5 provides a brief overview of the three cases studied.

Section 6 presents the findings from primary and secondary data collected and analyze them.

Section 7 discuss the findings in relation to existing literature and the theoretical framework of the thesis.

Section 8 summarizes and conclude the project, reflect on the limitations of the study, and give suggestions for further research.

2 Empirical Background

This section provides an overview of the evolution of municipal waste management in Norway, which is necessary for situating CCS as a one of several efforts in making the industry sustainable. Next, the section provides a brief overview of the development of the niche CCS, before closing with a literature review of existing research of CCS in the WtE industry.

2.1 The evolution of waste management in Norway

This section will cover how waste management has developed since the 70s. Due to space limitations, the primary focus will be on the Norwegian context with allusions to the global level.

Historically, Norwegian waste was dumped in landfills, but the practice became increasingly problematized because of environmental concerns and the space they occupied (Grundt, 2015). A shift begun in 1973 when the Ministry of Environment established recycling as an important principle to avoid pollution and to preserve resources, and throughout the 70s municipalities were mandated to clear up landfills and initiate responsible waste management schemes (Grundt, 2015). Efforts increased throughout the 80s where waste was framed as 'rouge resources', sentiments intensified by the Brundland report of 1987 which recommended waste reduction, even stricter regulations on landfills, and waste incineration to abate environmental hazards while producing energy in the form of heat (Grundt, 2015). These were adopted by the Norwegian government in 1988.

Increased pressures from environmental NGOs increased public awareness on waste management, leading to a strict and ambitious policies on waste management in the 90s. The waste pyramid was established as a governing model in 1990 and were to be followed so long it was socioeconomically feasible (Grundt, 2015).

Waste incineration was subject to an incineration tariff from 1999 to stimulate an increase in recycling and reduce emissions from waste incineration, but this was removed in 2010 to even out competition between Norwegian and Swedish waste incineration plants. Doubts had also been raised regarding the effect of the tariff (Grundt, 2015).

Several initiatives were launched in the 2000s to increase public awareness and engagement with recycling, such as the non-profit foundation LOOP. Waste sorting systems for homes, industries, and recycling stations were developed to differentiate waste by type to simplify the recycling processes. This decreased the amount of waste sent to landfills or waste incineration.

Today, about a quarter of Norwegian waste is sent to incineration. There are seven big WtE facilities burning more than 100.000 tons of waste per year, and about 20 smaller facilities in Norway (Norsk Energi, n.d.). About a third of Norwegian waste is recycled, and about 17% ends up in landfills. The remainder is dealt with through various other means (see Statistics Norway, 2022).

Today, waste incineration is an important source of energy and is in viewed as critical infrastructure by some municipalities (Informant B2). Yet despite being better than landfills, waste incineration does have its environmental footprint, and the incineration of household waste alone is responsible for 5% of global GHG emissions (Hafslund Oslo Celsio, 2022). Because of its biogenic components, however, WtE facilities may become negative emitters through the implementation of Carbon capture and storage (CCS) – a sentiment highlighted by several researchers, which we will return to in section 2.3.

2.2 Global Carbon capture and storage progress and its challenges

CCS emerged in the O&G sector as a way of reducing the emissions, while providing enhanced oil recovery (EOR) (Martin-Roberts et al., 2021). It experienced optimism in to 2000s as a technical tool to combat climate change but was abandoned throughout the 2010s as projects proved difficult to materialize, leading to investment cuts and paved the way for other climate solutions.

CCS has regained its momentum in recent years, however, and is now championed by organizations such as the IEA and the UN as a crucial tool for achieving net zero (Martin-Roberts et al., 2021). The Paris agreement is viewed as an important turning point in revitalizing the CCS narrative, reiterating it from a tool to prolong the fossil industries (primarily coal power plants) to one focused on employing CCS in hydrogen production, direct air capture with CCS (DACCS), bioenergy with CCS (BECCS), and to cut emissions in hard-to-abate industries (Martin-Roberts et al., 2021).

CCS is now framed as an essential component in several plans for combatting climate change – from IPCCs (2018) emission reductions pathway to 1.5 degrees, to the EUs green deal (European Comission, n.d.), to the mitigation strategies of several countries to reach their nationally determined contributions (NDC) to the Paris Agreement (Global CCS Institute, 2023).

2.2.1 Technologically mature

The Global CCS Institute (2021b) analyzed the technological readiness level (TRL) and costs of CCS. They classified several capture technologies with TRL-9, with amine solvents and physical solvents having been widely used for several purposes (Global CCS Institute, 2021b). Likewise, on CO2 transport technologies compression, pipelines and trucks were all TRL-9.

There is little experience on shipping as CO2 transport, but due to its similarity to Liquified Petroleum Gas (LPG), they conclude it will require a similar port infrastructure and achievable without major barriers (Global CCS Institute, 2021b). Regarding injection of CO2, offshore injection from ships was given TRL-3, while conventional onshore CO2 injection from onshore facilities were given TRL-9. As for storage, depleted oil and gas fields were deemed mature, referring to eight projects currently being pursued in the north-sea (Global CCS Institute, 2021b).

Summarizing Global CCS institute’s (GCI) assessment of CCS, all elements of the CCS value chain are mature and have been in operation for decades (Global CCS Institute, 2021b), yet CCS is capital intensive, and the majority of the costs were in the capture phase where they were primarily affected by scale and partial pressure (Global CCS Institute, 2021b).

2.2.2 Lack of deployment beyond Enhanced Oil Recovery

Despite its maturity, deployment of CCS is abysmally low (Sovacool et al., 2022), and the facilities that have been build have mainly been in the context of Enhanced Oil Recovery (EOR) where CO2 is pumped down into reservoirs to increase its pressure and enabling higher levels of oil extraction (Martin-Roberts et al., 2021). In this specific context, CCS have been economically feasible because the higher O&G yields outweigh cost of CCS.

The same cannot be said for CCS in hard-to-abate industries. While there are talks of utilizing captured CO2 (CCUS) for synthetic fuels, chemicals, or building materials (IEA, 2022b), but there are currently few actual uses. There are therefore few benefits to implementing CCS in these industries beyond reducing their emissions. Coupled with CCSs high capital expenditure (CAPEX), operational expenditure (OPEX) as well as cost uncertainties (Roussanaly et al., 2021), the financial dimension is a major barrier to CCS deployment (Global CCS Institute, 2021b). This is especially the case for retrofitting existing facilities, of which there are few existing cases and studies (Roussanaly et al., 2021). The Global CCS Institute (2023) also notes the lack of carbon markets as a financial barrier for CCS, and while there have been rapid developments in this field in recent years, the world is far from reaching a common consensus on how CCS should look in current and future carbon markets.

Additionally, CCS faces technical barriers such as lack of infrastructure for transport and storage, and lack of deployment, and socio-political barriers such as lacking political commitment and regulation, and public fears of CCS and a lack of awareness regarding its usefulness (Martin-Roberts et al., 2021).

The lack of existing infrastructure for CCS value chains has been classified as a major barrier to CCS as it creates uncertainty – both out of a lack of experience, and from a business perspective (Roussanaly et al., 2020). Literature claims that actors are hesitant to commit to establishing CCS in their facilities without having anywhere to send the captured carbon, and developers are hesitant to build out CCS infrastructure without having a certainty of customers.

Collectively, the main barriers are thus the high costs of CCS and the uncertainty of how to develop CCS facilities and infrastructure.

2.2.3 Current suggestions to overcome barriers

To overcome these barriers, politicians, researchers, and stakeholders have provided several suggestions.

To overcome financial barriers for deployment, current literature emphasizes improved policies and regulations such support grants, tax or emission credits, which gives benefits for CCS adoption, and increased carbon emission tariffs, which penalize emitters and thus lower the relative cost of employing CCS in contrast to continuing conventional operations (Global CCS Institute, 2021a; Miljødirektoratet, 2023). Furthermore, the Global CCS Institute (2023) suggest facilitating carbon markets through reducing current emitter allowances, meaning the amount a firm can emit before being penalized, and reaching a common consensus on how emissions trading systems (ETS) should incorporate CCS to facilitate market formation. Special interest is paid to bioenergy with CCS (BECCS), which holds the benefits of delivering both energy and CDR (Global CCS Institute, 2023; Lefvert et al., 2022; Mørk & Post-Melbye, 2022).

Tackling CCS deployment, requiring O&G companies to offset their emissions through CCS could speed the process rapidly, while direct funding for hard-to-abate industries can be useful for CCS implementation in new and existing facilities (Martin-Roberts et al., 2021).

Martin-Roberts et al. (2021) and Sovacool et al. (2022) argue that industrial clusters are becoming critical for decarbonization efforts employing CCS because they offer integrated transport and storage networks, tying together the emissions of hard-to-abate sectors and reducing the cost CCS projects, a notion shared by (Jordal et al., 2023) in their report on the Midt-Norge cluster that is collaborating on a shared transport and storage network for CCS.

Existing financing schemes to facilitate CCS deployment include the Norwegian Longship project, financing two full-scale CCS facilities, the EU innovation fund (European Comission, 2022a), and the US' recent IRA bill (Global CCS Institute, 2022). Their importance extends beyond just establishing capture facilities, as the projects also facilitate the creation of a transport and storage infrastructure.

In sum, current suggestions are largely concerned with lowering financial barriers through financial support schemes and market creation, and with lowering the uncertainty related to deploying CCS through clustering and state initiative on the CCS value chain. And there are signals that current strategies are working, albeit slowly. As of September 2022, Global CCS Institute (2023) reported an 44 percent increase in the total capacity of CCS projects in development over the past 12 months – concluding that the outlook for CCS has never been better. Whether these projects will materialize remains to be seen.

2.2.4 The Norwegian context of Carbon Capture and Storage

Special interest has to be given to the Norwegian context of CCS to understand why CCS is being developed there, and because it is the national context of the three cases studied in this thesis.

In the late 80s, there were considerable interest from Norwegian firms, for using the domestic abundancy of natural gas to provide cheap and reliable energy that could increase regional development and industrial growth emissions (Normann, 2017). Yet the push was met with resistance from politicians at the local level, and by environmental organizations and politicians at the national level worried about climate change (Normann, 2017).

The debate moved to the center of Norwegian politics in the 2000, when the sitting Government opposed the Parliament's proposition to build three gas plants without employing CO2 removal. The Government was dissolved over this dispute but was reelected in 2001, now with CCS as a main element in the Government's energy politics (Gassnova, n.d.). Yet due to the low energy prices in Norway, natural gas plants were not able to operate cost efficiently with CCS (Normann, 2017). To overcome this barrier, 'protected spaces' that functioned as learning arenas for CCS technologies, insulated from market pressures, were created (Normann, 2017). In 2002, the national government established a state business for environmental innovations within the natural gas industry, and in 2004 the "Gassteknologifondet" was established to finance research and development of the latter(Gassnova, n.d.). In 2005 Gassnova was established by the ministry of Oil and Energy to oversee research on CCS and manage research fundings.

With these efforts, Norway positioned itself as a pioneer in CCS research, spearheaded by the Norwegian research institute Sintef and the Norwegian University of Science and Technology (NTNU), who have achieved important scientific breakthroughs for CCS technology – especially after the establishment of the world's biggest research center for CCS in Trondheim, Norway, in 2009 (Thobroe, 2021).

The efforts of realizing natural gas plants with CCS consolidated in the plan of a full-scale CCS facility at Mongstad in 2006, but plans slowed down due to concerns regarding the safety of the amin technology used to capture CO2 (Gassnova, n.d.), before being abandoned completely. While being deemed an economic failure, the test center established at Mongstad remained and has been considered a milestone in the technological development of CO2 capture (Gassnova, n.d.).

Realizing a full-scale CCS value chain was revisited in 2015 in a feasibility study of capturing GHG emissions from single-point emitters, and in 2017 a deal was struck between Gassnova, Statoil (now Equinor), and Shell to continue the operation of the Test Center Mongstad (TCM).

CCS has been deployed in Norway for EOR since 1996, at the Sleipner field, and since 2008, at the Snøhvit field (Benjaminsen, 2019). These projects were partly encouraged by financial incentives introduced by the Norwegian Government, including an offshore emissions tax introduced in 1991 (Martin-Roberts et al., 2021).

Yet the plans to realize a full-scale CCS value chain was not finalized until the Norwegian Government presented the CCS-project "Longship" in September of 2020, ratified by the Norwegian Parliament in January of 2021. It included the Northern Lights partnership between Equinor, Shell, and Total to create a transportation and storage infrastructure for CCS, and single-point emitters, Heidelberg Materials' cement factory in Brevik and Fortum Oslo Varme's (Now Celsio's) WtE facility in Klemetsrud, that would implement CO2 capture technology (Gassnova, n.d.).

Summarized, the story of CCS in Norway has its origin in the aim to make use of domestic natural gas resources and was characterized by strong interests from both the state and O&G firms, i.e., the regime, responded to the exogenous pressure of climate change by adopting the niche CCS (Normann, 2017). After the failure to materialize this, and due to the changing global discourse on CCS, CCS in the Norwegian context later morphed into project longship, which is set to make use of the technological expertise developed in CCSs former iteration.

2.3 Carbon capture and storage solutions in the Waste-to-Energy industry

This section presents the current discussion CCS in WtE, and its relation to the wider sustainability transition that is ongoing in the waste management sector. As elaborated in the introduction, even with improved recycling schemes and waste reduction, there will always be some waste cannot be recycled (KAN, 2022). Currently, CCS is framed as the only technology allowing the decarbonization of the WtE industry. Coupled with the fact that it CCS in WtE becomes a case of CDR due to its biogenic half, the topic of CCS in WtE has attracted attention from researchers, policymakers, and the industry itself, who suggest that CCS in WtE is a viable option to achieve negative emissions (Global CCS Institute, 2021b; Hafslund Oslo Celsio, 2022; KAN, 2022; Kearns, 2019; Mørk & Post-Melbye, 2022; Roussanaly et al., 2020) without compromising other environmental impacts (Bisinella et al., 2021). CO2 from WtE facilities is also contains less sulphur than from coal plant, so there is less need for capital investment required for gas cleaning (Kearns, 2019). Despite the benefits of its application, Bisinella et al. (2021) identify no full-scale examples of CCS in WtE.

Along with the general barriers presented in section 2.2., adoption of CCS in WtE face specific barriers. Contrary to many other process industries who have excess heat available for the capture process (Eliasson et al., 2022), the WtE industry already utilizes this energy for district heating and electricity generation – with Norwegian facilities scoring a 81% energy utilization rate (Avfall Norge, 2020). When used for the capture process instead, this spells a significant loss in energy output from the WtE industry (Bisinella et al., 2021; Roussanaly et al., 2020; Wienchol et al., 2020). KAN, a Norwegian network of WtE facilities engaged in CCS, identify this as a major technical barrier to fitting CCS facilies to existing WtE facilities(KAN, 2022).

Likewise, variations in the geographical location, layout of the WtE facility, and access to space for the CCS facility complicates cost evaluations. These factors create uncertainty about capital expenses (capex) of implementing of CCS in WtE, as well as operating expenses (opex) with regards to the cost of the CCS value chain (KAN, 2022). The smaller size of WtE facilities is also considered a challenge because they will require effective capture technologies to deliver low-cost abatement (Kearns, 2019).

As the literature on CCS in WtE is limited, I find it feasible to compare it to the discourse on bioenergy with CCS (BECCS). Lefvert et al. (2022) studied the perspectives of Swedish bioenergy companies and found that while informants considered CCS and the individual components mature and ready for commercial deployment, they reported several barriers. Firstly, while all informants recognized the urgent need for action to combat climate change, most companies had focused on contributing through reducing their fossil emissions rather than adding CCS.

Secondly, all informants interviewed in the study identified financing as one of the critical factors to BECCS, and actor deemed long-term economic compensation and political support as necessary for them to implement CCS in their bioenergy facilities.

As for drivers, informants were motivated by the idea of negative emission markets and the positive effects CCS could have on the price of their products, although some informants doubted if customers would be willing to pay for this (Lefvert et al., 2022). Developments in full-scale value chain (Northern Lights project) also motivated the informants. The article also highlighted that CCS is dependent on a point-emitter to capture CO2 and is thus reliant on seeking partnerships with industries with single-point emissions to further develop the niche.

2.3.1 Current suggestions to overcome barriers

Along with the general measures to overcome barriers presented in section 2.2, actors have several suggestions. Firstly, they suggest systems of carbon trading or negative emission bonds which can be bought by firms or actors to offset their emissions to finance CCS in the WtE industry (KAN, 2022; Miljødirektoratet, 2023; Mørk & Post-Melbye, 2022). Some even suggest future markets for negative emissions could lead to new WtE facilities incorporating CCS from the get-go (Lefvert et al. 2022).

Second, they suggest revising the fossil CO2 emissions tariff in the WtE industry, arguing that it hinders their ability to implement CCS in WtE and leads waste streams to seek out markets without such tariffs (KAN, 2022).

Third, actors suggest increasing incentives for CCS in WtE to cover the gap between costs and revenues, arguing these will lead to WtE facilities implementing CCS (KAN, 2022; Mørk & Post-Melbye, 2022).

On the technical level, Wienchol et al. (2020) highlight that the need for research into capture technologies to lower energy consumption, which will lower the costs of capturing CO2. To attract support from the government and enterprises, Tang and You (2018) suggest increasing the promotion of carbon prices.

3 Theory

This chapter will present the thesis' theoretical framework. First, it will give a brief introduction into the field of transition studies which the multi-level perspective (MLP) is embedded in, followed by a detailed overview of the MLP and how it fits into this specific case study. second, I will juxtapose the MLP to other appropriate theories to discuss why the MLP was selected as the most appropriate framework for this thesis. Finally, I will discuss the critiques of the MLP, and suggest supporting theories that can abate these shortcomings, as well as help answer the specifics of my research questions.

3.1 Transition studies

Transition studies is an interdisciplinary field of research that is rooted in the tradition of system thinking (Zolfagharian et al., 2019), reflected in its primary focus on "socio-technical system as the unit of analysis, and the features of fundamental structural change as the main object of research" (Zolfagharian et al., 2019, p. 2). Socio-technical systems (STS) are systems necessary and fitted to accommodate human activity, such as water supply and sanitation, transportation, infrastructure, and energy supply systems (Markard et al., 2012). The STS of land-based road transportation shown in figure 1 is a useful example for understanding the concept.

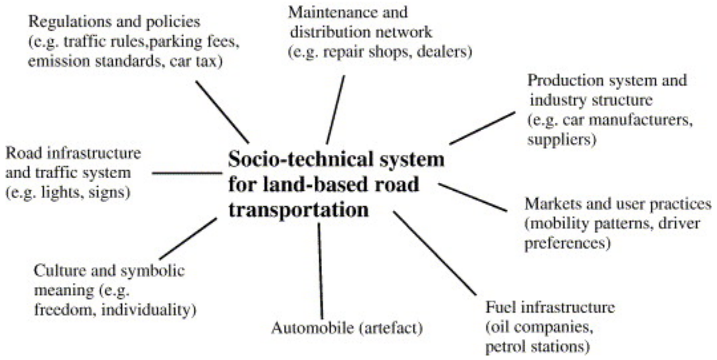

Figure 1: Socio-technical system for land-based road transportation (Geels, 2005)

As figure 1 shows, these systems consist of actors (such as firms, suppliers, and end users), institutions (such as norms and regulations), markets, physical infrastructure, as well as knowledge (Markard et al., 2012). They are, in other words, complex systems consisting of a broad variety of interrelated and dependent elements.

To accommodate this complexity, transition studies draw on insights from evolutionary economics (Nelson & Winter, 1982) and studies of the history and sociology of technology (Bijker et al., 1984; Hughes, 1987) to explain how scientific knowledge, engineering practices, and process technologies are socially embedded in the "expectations and skills of technology users, with institutional structures, and with broader infrastructures" (Kemp et al., 1998 in Markard et al. 2012:957). The emergence of the personal transportation system was for example not just a result of the invention of the automobile, but also the development of road infrastructure, traffic rules and user practices (Markard et al., 2012).

Because systems are complex, changes within systems are often incremental and characterized by path dependencies and lock-ins. For transitions to happen within systems, there thus a need for foundational shifts within one or several elements constituting the system (Markard et al., 2012), even more so in cases of rapid transitions.

3.1.1 Sustainability transition studies

In face of sustainability challenges, the field of sustainability transition studies (ST) has emerged within transition studies. Studies within the field is concerned with addressing unsustainable consumption and production patterns in socio-technical systems (Köhler et al., 2019), which are causing environmental issues such as such as rapid depletion of natural resources, air pollution and greenhouse gas emissions, environmental degradation, and loss of biodiversity (IPCC, 2023b).

These challenges can cause transitions if they lead to change within the elements of the system, such as calls from end users for environmentally friendly automobiles or cleaner electricity. Several studies within ST explore the socio-technical transition of systems adapting to or in need of change in the face of sustainability challenges (Köhler et al., 2019; Markard et al., 2012), and this study aims to add to this list.

3.1.2 The four main frameworks of transition studies

There are four well-established frameworks in transitions studies, namely transition management, strategic niche management, technological innovation systems (TIS), and the multi-level perspective (see Markard et al., 2012).

The MLP was chosen deemed most appropriate due to its focus on the interaction between the regime (WtE) and niche level (CCS), which is well suited to explore this thesis' focus on how regime actors perceive drivers and barriers to the implementation of CCS in WtE and how these interact to overcome barriers.

Strategic niche management or TIS would have been appropriate, had the thesis focused primarily on niche development.

The transition management framework could have been appropriate, had the main focus of the thesis been on how regime actors interact to impede or facilitate transition through coalitions, policies, and engagement in the transition process. While the thesis partly explores these notions, it is secondary to the primary focus on uncovering drivers and barriers to CCS in WtE. Subsequent research on CCS in WtE are encouraged to do this, however.

3.2 The Multi-level perspective framework

The MLP framework is one of the four main perspectives in transition studies and arose in the early 2000s from the works of the scholars Kemp, Schot, Rip, Geels, and Vand den Ende (see Geels, 2002) as a response to fragmented studies of change in technology and society.

The core aim of the MLP is to offer a wider explanation of socio-technical systems, and has been used to analyze both historical transitions through following the development of a niche (Berkers & Geels, 2011; Geels, 2002; Geels, 2005; Geels et al., 2016; Geels & Schot, 2007), and contemporary and future transitions involving many different and independent actors (Hynes, 2016; Moradi & Vagnoni, 2018; Morrissey et al., 2014; Nykvist & Whitmarsh, 2008; Osunmuyiwa et al., 2018; Van Bree et al., 2010).

MLP has also been used to study CCS. Geels (2014b) explores how CCS was used as a rhetorical tool by the O&G sector to maintain relevance in a low carbon future, while Lefvert et al. (2022) uses the framework to explore the how Swedish hard-to-abate industries perceive CCS.

The MLP builds on transition studies through Nelson & Winter’s (1982) concept of ‘technological regimes’ to understand inertia of established technologies, and Schumpeter’s creative destruction to understand the development of new technological paths and trajectories (Geels, 2002). In addition, it draws insights from evolutionary economics, sociology of technology, history of technology, and innovation studies (Geels, 2004). These notions all coalesce in a midrange theoretical framework useful for analyzing transitions that can explain both radical change and dynamic stability, and how these are influenced by broader contexts (Geels, 2020). To achieve this, the MLP operates with three analytical levels: a) niches, b) socio-technical regimes and c) exogenous socio-technical landscape.

As the MLP define transitions as shifts from one regime to another, the regime level is the core analytical unit of the MLP framework (Geels, 2011). I thus find it useful to explain first.

3.2.1 Socio-technical regimes

Regimes are consolidated of six dimensions (markets & user preferences, industry, science, policy, culture, and technology, see figure 2) that are oriented and coordinated by semi-coherent sets of rules, forming socio-technical systems (Geels, 2011). The term rules is used widely, and include “cognitive routines and shared beliefs, capabilities and competences, lifestyles and user practices, favorable institutional arrangements and regulations, and legally binding contracts” (Geels, 2011, p. 27). When aligned, rules create ‘dynamic stability’ across these dimensions, as illustrated in figure 2.

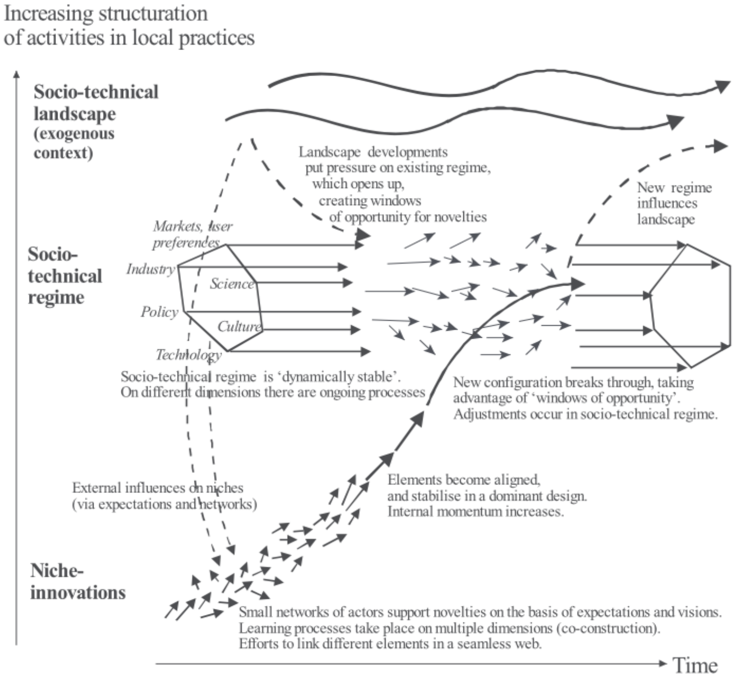

Figure 2 multi-level perspective on transitions (Geels & Schot, 2007, p. 401)

Juxtaposed to transition studies, the MLP view rules as the units creating the social embeddedness of technology. Geels (2011) note that rules both configure actors through forming a structure and empower actors to draw upon rules to shape structures, forming a 'duality of structure'. As such, rules can create a constrained environment of relative autonomy.

Change in regimes often begin as change in its sub-regimes. These may change both from within and from the outside due to landscape effects. When regimes change, they become unstable, creating 'windows of opportunity' for the diffusion of niche innovations, as illustrated in figure 3. In such cases, regimes may attempt to adopt niches to avoid becoming obsolete or be forced to change from within.

In the case of the waste management regime in Norway, for example, one may argue that the scientific evidence of climate change and environmental pollution that came about in the 70s and 80s resulted in changes in the cultural and political dimension, leading to stricter policies recycling throughout the 80s and 90s, which again paved way for the a waste management industry with a market for recycled materials, and technological advancements which increased the profitability of waste management such as district heating.

This example illustrates the interrelatedness of the dimensions constituting the regime, and how changes in one may the others. Geels (2011) refer to this notion as co-evolution, where different sub-regimes interpret and co-evolve with each other.

3.2.2 Landscape level

Geels (2002) denoted landscape as the deep structural trends, and used the metaphor of 'landscape' for its hardness and the material context of society, i.e., "the material and spatial arrangements of cities, factories, highways, and electricity infrastructures" (Geels, 2002, p. 1260).

Later iterations also refer to landscape as the broader forces that influence socio-technical regimes (Geels, 2018). These are often contextual and develop over time with little to no interference from the regime. Geels (2018) distinguishes between slow-changing trends and external shocks. The former refers to factors such as geopolitics, ideology, and spatial structures, while the latter refers to factors such as wars, economic crises, environmental disasters, and political unrest.

Previous MLP studies have used the landscape level to explain hiatus, such as in Geels et al. (2016), where the financial crisis of 2008 caused an economic downturn in the UK that severely halted decarbonizing efforts. The example illustrates the importance of timing, an important element in the MLP, reflected in its notion of 'windows of opportunity' for niche diffusion. Windows can thus be shut too, by e.g., external shocks.

Second is the interpretation and mobilization by actors, in which the regime plays a crucial part. In Germany and the UK, for example, differences in environmental values and in political and economic systems resulted in different pathways and strategies for decarbonization (see Geels et al., 2016).

In other words, the landscape refers to exogenous factors that affect the 'playing field' of regimes and niches. They can be slow-changing trends, or they can be shocks. In the case of the transition of the waste management regime, the landscape level is identified as the narrative of climate change (and the discursive struggle over suitable innovations such as wind, solar, CCS, nuclear), voiced by powerful intergovernmental actors such as the UN through the Paris Agreement and IPCCs assessments and special reports, the waste market treating waste as a commodity, and EU policies and regulations. Covid-19 and the war in Ukraine are interpreted as external shocks, because of their impact on global energy and commodity prices.

3.2.3 Niche level

Niches are "emerging social or technical innovations that differ radically from the prevailing sociotechnical system and regime but are able to gain a foothold in particular applications, geographical areas, or with the help of targeted policy support" (Geels, 2018:225). Niches are created through the work of precarious actors, and are usually developed in 'protected spaces', insulated from normal market selection in the regime (Geels, 2002). Because of a lack of stable configurations such as an appropriate infrastructure, regulation, consumer practices, reliable suppliers, and a stable configuration 'dominant design', niches are often initially fitted to work within the current regime in an attempt to break through their stable configurations (Geels, 2011).

As the empirical background stated, CCS is certainly a niche. While some would argue that has a dominant design because of the maturity of amin capture technology, CCS lacks other characteristics such as appropriate infrastructure, market, and regulation.

Gradually, however, they are stretched as wide adoption urges new functionalities, as illustrated in figure 3.

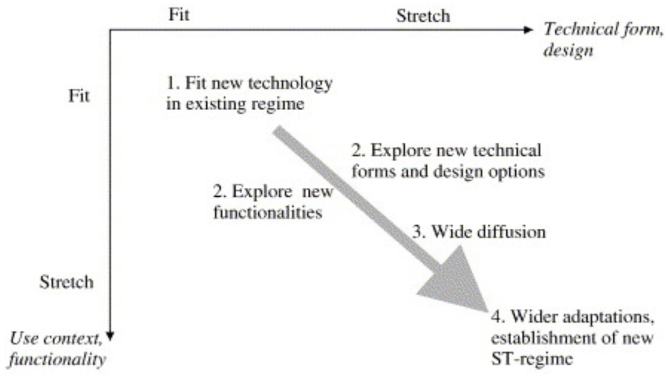

Figure 3 Fit - stretch pattern in the co-evolution of form and function (Geels, 2005)

This fit and stretch between the design and functionality of niches in the context of regimes is viewed as a co-evolution a core concept in the MLP (Geels, 2005). CCS was initially fitted to the O&G sector, which may have led to possible incompatibilities between the niche and other appliances. Whether this is the case in the waste sector will be discussed in section 7.

3.2.4 Interaction between the levels – transition pathways

The interaction between the three levels can be conceptualized in four transition pathways (Geels, 2011):

1) Substitution, where well-developed niches replace regimes during a 'window of opportunity' presented by landscape developments, or through outcompeting the regime through gaining high internal momentum.
2) Transformation, where landscape pressures prompt incumbent actors to reorientate the innovation activities towards add-on, incremental or radical niches within the regime.

3) Reconfiguration, where landscape pressures prompt regimes to adopt symbiotic niches as add-ons to solve internal challenges. Add-ons can reconfigure regimes through triggering adjustments, changing their basic architecture.
4) De-/re-alignment, where major landscape pressures disintegrate regimes. This causes a number of niche-innovations to emerge to fill its place, before a new regime is formed around a single innovation.

While most MLP studies have concentrated on the substitution pathway, the implementation of CCS in WtE can be understood as a gradual reconfiguration of the waste management regime, as landscape pressures, and perhaps opportunities, have prompted the regime to engage with CCS.

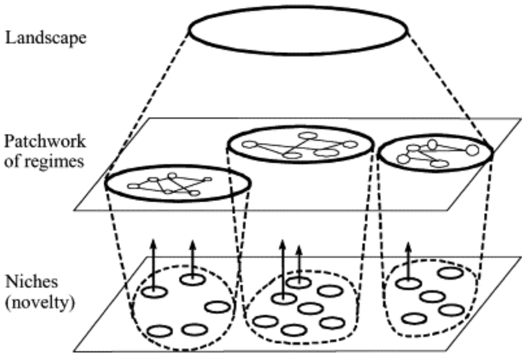

Figure 3 Multiple levels as a nested hierarchy (Geels, 2002)

Laakso et al. (2021) presents a thorough review of the reconfiguration pathway and how it has been employed in existing literature, highlighting that the pathway expands beyond the notions of adopting symbiotic niches which reconfigure the technological dimensions of a regime, but include reconfigurations in other dimensions such as political (need for regulations), and user practices. Promptly, I expect to find evidence of this in the analysis section.

3.3 Critiques of Multi-level perspective framework and supporting theories

The MLP has been subject to several critiques and reiterations since its inception. This section will discuss some of these that are of importance for this thesis and suggest supporting theories in response to MLPs shortcomings, namely the engagement of incumbent actors in transition processes, and geographical factors that create variation between the cases.

Additionally, the MLP has been criticized for an overdependence on secondary data (Geels, 2011), which has been addressed in this thesis through employing a mixed method of both primary data and secondary data collection.

3.3.1 Imcumbents as transition proponents

Transition studies in general and the MLP in specific are criticized for generalizing incumbents as opposers of change (Berggren et al., 2015; Turnheim & Sovacool, 2020) and as ‘locked-in’ to socio-technical regimes and passive to transition processes (Steen & Weaver, 2017). Similarly, Geels (2018) argues that too little attention is paid to the interaction between niches and regimes, and that there is a need for studies to address the techno-economic and business dimensions of transition processes.

The triple embeddedness framework may be employed to bring nuance to this image of incumbents, and how they interact with niches to facilitate transition processes. The framework is useful for understanding the co-evolution and bi-directional interactions between industries and their environments. The framework conceptualizes "firms-in-industries as embedded in two kinds of external environments (economic task environment and a socio-political environment) and in an 'industry regime' which mediates perceptions and actions towards both environments" (Geels, 2014a, p. 263).

Understanding this mediation process may shed light on how incumbents on the one hand are reluctant to radical change due to lock-ins and sunk investment in existing technologies, skills and people, and because of the risk associated with radical innovations (Geels, 2014a), yet may be stimulated to change from pressures from the socio-political environment and even engage in the transition discourse themselves. Their transition pathways are, however, constrained by the economic environment, constituting a triple embeddedness (see figure 4).

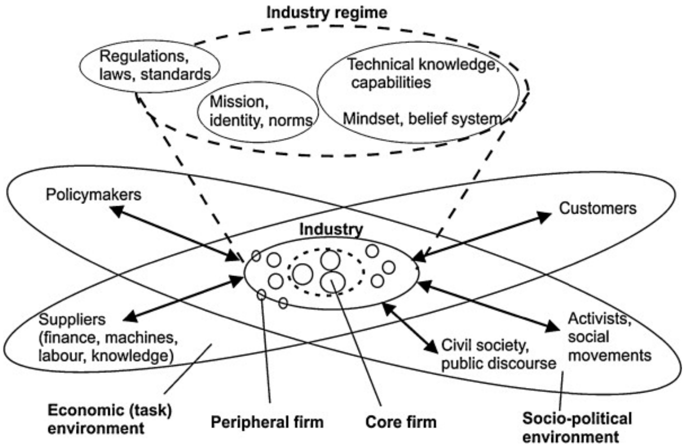

Figure 4 Triple Embeddedness Framework of industries (Geels, 2014a:266)

Broadening MLPs perception of incumbents also assists in overcoming assumed homogeneity associated with the regime-level, often neglecting institutional tensions and contradictions (Fuenfschilling & Truffer, 2014).

Relatedly, Dolata (2009) suggests the framework of transformative capacity, which highlight that new technology in itself can create pressures in transitions. The framework is useful for analyzing technology-based sectoral change through the concept sectoral adaptability, which is concerned the compatibility between sectoral structures, institutions, and actors, and new technologies. Additionally, the framework's concept of adaptive capacity can be used to highlight technical barriers in transition processes, such as demands for electricity, infrastructure, and space. These are all highly central factors in in the implementation of CCS in WtE and will be discussed in section 7.3.

3.3.2 Geography matters

Another central criticism of the MLP has been its apparent lacking emphasis on geography (Hansen & Coenen, 2015; Raven et al., 2012; Truffer et al., 2015). Raven et al. (2012) showcased how several existing MLP studies focused on the national level despite the findings of innovation studies, regional studies, and economic geographic studies all suggesting that "actors and institutions at multiple spatial levels interact to create 'spaces for innovation'" (Raven et al., 2012, p. 64), disciplines the MLP was built upon. Without a broader focus on space, it becomes very hard to explain why a niche succeeds in one place and not another.

Linking geography to the notion of embeddedness, the three cases explored in this thesis are located in different parts of Norway and are thus affected by different place-based factors. These can have a great impact on transitions (Hansen & Coenen, 2015).

Finally, all cases are located in urban municipalities with strong sustainability goals. Policy and regulation are important pull factors for sustainability transitions, and urban and regional policies tend to run ahead of national and supranational regulations in response to climate change (Hansen & Coenen, 2015). Whether this is the case in the regions examined in this study will be explored in the discussion.

In the context of this thesis, a focus on space and place-based factors are useful for understanding variances in drivers and barriers between cases. This is explored by comparing findings in the primary and secondary data across cases.

3.4 Summary of theoretical proposition

Summarized, this thesis deems it appropriate to use the MLP as a primary framework to study drivers and barriers to CCS in WtE, and how the sustainable transition of the waste management regime is affected by contextual factors and preconditions. It is assumed that this transition process follows the reconfiguration pathway, which will be discussed in section 7.

To accommodate for shortcomings in the MLP, the thesis employs the triple embeddedness framework to discuss how firm-in-industry are embedded in the socio-political and economic task environment, and how they interact with actors and institutions to create favorable positions in a transition. Dolata (2009) is employed to discuss the waste sector’s technical capacity to adopt CCS and its value chain. Finally, space and place-based factors will be discussed to highlight the centrality of geography and the impact they can on transition processes.

4 Research methodology

The following section elaborates and discuss the chosen research methodology applied to this study. It is structured accordingly: first, I will present the chosen research approach and discuss its appropriateness in relation to the research objective. Second, the data collection method will be presented. Third, the method of data analysis will be presented. Fourth, the quality of the research design will be discussed, highlighting its strengths and limitations. Fifth, research ethics will be presented and discussed.

This thesis emerged in the end of February when I conceded the quest of finding interview objects for my initial thesis proposal[1]. To make up for the lost time, I discussed with my supervisor about writing a thesis related to Sintef's captureX project, which he was working on. The project aims to develop new knowledge about drivers, opportunities and challenges for realizing large-scale CCS and CCU (SINTEF, 2021). This was a perfect fit. I had already studied the field of CCS out of personal interest. Moreover, I had a keen interest for the transition studies field, which I deemed an appropriate theoretical framework for a thesis exploring CCS. Collectively, these notions enabled good and efficient discussions with my supervisor on suitable topics and approaches for studying drivers and barriers to CCS and simplified the process of producing a new thesis proposal in a short time.

In discussion with my supervisor, I subsequently decided to study the implementation of CCS in the waste management sector – as it is one of the sectors most engaged with implementing CCS, illustrated by the ongoing project at Klemetsrud. The MLP framework was chosen as the thesis' theoretical framework due to its appropriateness for studying how the waste sector (regime) interpreted and interacted with CCS (niche).

As such, this thesis is part of Sintef's Capture X project. It has been submitted and approved by NSD (Norwegian Center for Research Data).

4.1 Research approach

Deciding on a research approach should be guided by the research objective. The objective of this project was to identify the drivers and barriers to the implementation of CCS in WtE, and to identify how this transformation is affected by contextual factors and preconditions. Additionally, as a secondary objective, the thesis explored how incumbent actors are engaging with and influencing these factors.

To satisfy the research objectives, I firstly identified the MLP as an appropriate theoretical framework. I employed a qualitative multiple-case design that used semi-structured interviews and secondary data for data collection.

Qualitative studies are suitable when the objective is to deepen an understanding for a topic or a phenomenon. According to Cope and Hay (2021), qualitative research produce contextual and personal explanations for a topic that generate new insight into people's

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[1] Initial plan was to explore the interaction between public policies for energy transition and foreign renewable energy companies in Indonesian. It proved too difficult to get interviews with such companies, and software issues made other approaches such as an extensive document analysis unfeasible.

experiences, which may be used to craft new theories about the human condition, the production of meaning, and human-environment relations. This is because, as social beings, humans construct their world on information from various sources; from our culture and environment, to our everyday practices, preferences and needs (Cope & Hay, 2021). Qualitative methods are thus useful when studying socio-technical systems, which is concerned with the social embeddedness of technology, and thereby an appropriate method in a study employing the MLP.

Next, qualitative research designs can be based on one or multiple cases. Yin (2014) deems single case studies as most appropriate when cases pose a critical test of a concept or theory, while Baxter (2021), argues that "multiple-case studies provide a broader base for exploring theoretical concepts and explanations of phenomena" (Baxter, 2021, p. 117). Moreover, analyzing similar cases across space allows for comparative analysis that reveals similarities and differences between them, and allows for triangulation between the cases. Depending on whether the cases share a mutual context or not, multiple-case designs can explore each case independently, or embed them in a mutual context (Yin, 2014).

I found a research design based on multiple-case study to be the most appropriate for answering the research question. This approach provided a broader approach for exploring theoretical concepts as cases explored in this thesis had both shared and place-specific contexts.

Qualitative research may be conducted through several methods, but Cope and Hay (2021) splits them into two overarching methods. First are oral methods, such as in interviews, focus groups, and participant observation. Second is text-based methods, which is analyzing written sources of data from journals, newspapers, historical documents and so forth. These two methods are by no means exclusive to one another, and studies often uses a mix of the two to collect data.

4.2 Data collection

This thesis uses both primary and secondary data. The primary data was collected through semi-structured interviews between March and April 2023.

Semi-structured interviews are usually conducted accordingly; the researcher prepares some predetermined open-ended questions and themes that they want to explore, but maintain a flexibility through the questions are asked, how much emphasis is given to them(Dunn, 2021). The informant may also diverge the conversation as they see fit (Tjora, 2017). Such a design allows both the researcher and the interviewee to place emphasis on topics viewed as central to them and the research question.

Three interviews were conducted with firms implementing CCS, three were conducted with a representative of the municipality in which the WtE facility was located, and three expert interviews were conducted. All but one of the interviews were conducted digitally using Microsoft Teams. All interviews were recorded and later transcribed and coded using Nvivo. Secondary sources were collected through various channels such as scientific journals, company websites, public white papers, news articles, and special reports by NGOs, such as the UN, GCI, and Zero.

4.2.1 Sampling cases & participants

As the primary data collected through interviews serve as the foundation of the research project, sampling is one of the most essential steps in a successful qualitative study. For this project, the first level of selection was to select the cases to include. Stratford and Bradshaw (2021) argues that case selection should be based on the question: "what is this case a case of?" (Flyvberg, 1998, p. 8). Subsequently, potential cases were identified through a rigorous review of the topic of CCS in the WtE sector and later narrowed down to three cases chosen for their similarity as projects in WtE facilities actively engaged in CCS and located in a Norwegian city.

The next stage was the selection of participants. According to Stratford and Bradshaw (2021), this selection should be deeply rooted in preliminary research that identifies central actors. Second, selection should be appropriated to the research methodology. In this research project employing semi-structured interviews, limitations such as time and cost appropriates a smaller sample size of around ten participants. These limitation necessitates knowledgeable participants that will provide significant insight to the cases (Stratford & Bradshaw, 2021), and who are in close proximity and/or involvement in the cases, or who holds expert knowledge on the research topic.

All three cases are CCS projects carried out by the respective WtE facility with strong collaboration or support from their respective municipality. Based on the aforementioned sampling logic, it was deemed appropriate to sample one participant from the WtE facility and one from their respective municipality for each case. In addition, three expert interviews were carried out to triangulate the data. These represented Gassnova, Sintef, and ZERO.

Some of the relevant participants were sampled through the snowball method, in which contact information is provided by others. Others were sampled through reaching out to the communications department in the organization, while providing a thorough description of research motives to ensure a viable informant.

The table below provides an overview of all participants, what kind of actor they are, and how they are coded in the analysis. Letters are used to highlight positionality of participants, which is useful to distinguish between the cases.

Actor	Coded in analysis
Representative from Bergen municipality's climate agency	Informant B1
Representative from Bir	Informant B2
Representative from Oslo municipality's climate agency	Informant O1
Representative from Celsio	Informant O2
Representative from Trondheim municipality's climate and environmental agency	Informant T1
Representative from Statkraft Varme	Informant T2
Researcher from Gassnova	Informant E1
Representative from Sintef	Informant E2
Representative from Zero	Informant E3

4.2.2 Conducting semi-structured interviews

As stated, semi-structured interviews were used to collect primary data for this thesis. The preparation for the interview process was done accordingly:

First, I created a semi-structure interview guide with open-ended questions based on extensive research into the topics of waste management, CCS, and CCS in WtE to get an understanding of what kinds of questions would be relevant. These questions were guided by the research questions and the theoretical framework that shaped the foundation of the research project. The result was a set of questions exploring different dimensions (environmental, technical, political, social, economic & geographic) that the actors could perceive as motivating or obstructing the implementing CCS in WtE. Additionally, to survey for how actors engaged with drivers and barriers, they were asked how they worked to improve these dimensions and whether they collaborated with others to overcome barriers.

In preparation for each individual interview, the specific case and actors were researched to tweak the interview guide to ensure optimization of data collection. The latter was important in order to identify contextual factors and preconditions for each case.

The length of interviews averaged about 45 minutes, with the shortest lasting 35 minutes and the longest 58 minutes.

The chosen strategy worked quite well to answer the research questions, and informants gave in-depth answers to most questions. As such, the interview guide was successful at collecting data to answer the research question. It proved especially useful to prepare for each case, as this allowed me to address specific place-based challenges during the interviews, such as the lack of space for the CCS facility in Trondheim, for example.

There were two minor exceptions, however. The interview guide was not a great fit for the expert interviews with informant E1 and E2. While these held considerable knowledge on the technical dimension of CCS and provided insightful data on how geography can affect the latter, they were reluctant to give insights into the remaining dimensions. Additionally, as experts, they were not themselves engaged in overcoming barriers to implement CCS in WtE, so these questions could have been dropped.

Reflecting on this notion, I could have created a secondary interview guide for these interviews to save time during the interviews. Yet because the interviews were semi-structured, the impact of this was limited, as i could shift emphasis to the dimensions the informants were comfortable addressing during the interview. The examples were thus a valuable learning insight into how do conduct primary data collection using semi-structured interviews.

4.2.3 Collecting secondary sources

The thesis also used secondary data such as reports, news articles, scientific articles, and public documents. Secondary data was collected through two means; 1) through a keyword search in google scholar and 2), through identifying central actors engaging in the topic and subsequently seek out their published reports etc.

These had two main uses in the thesis. Firstly, secondary data on waste management regime, CCS and CCS in WtE provided an overview of general and specific themes in the current literature, which proved useful when designing the research approach and preparing for interviews. Second and relatedly, secondary data was used to triangulate the findings of the primary data collection and to strengthen the credibility of the analysis of this thesis.

4.3 Analysis method

The analysis of the primary and secondary data collected for this thesis was done accordingly: First, I transcribe the interviews and uploaded them to Nvivo for coding, a software useful when doing qualitative analyses. Second, the interviews were coded using inductive coding, a technique useful to avoid the researcher's bias affecting the coding process (Bryman, 2016). Third, the initial codes were interpreted and sorted into themes juxtaposing theory and patterns in the empirical findings. Identified themes were then situated against existing research and interpreted in relation to the theoretical framework. The process produced a thematic analysis, which is a common approach in qualitative research methods employing both primary and secondary data (Bryman, 2016).

The codes were spread across four top codes: Drivers, barriers, landscape level, and actor strategies for overcoming barriers. Drivers and barriers were categorized within the top-codes based on different dimensions relating to the theory; political, social, economic, environment, geographic, technical (as well as 'learning outcome' for drivers). The actor strategy top-code was split into two child codes: collaborations, and suggestions for improved policies and frameworks. These categories are reflected in the subsections of section 6.

Overall, the method employed for the analysis was a good strategy for ensuring that codes corresponded to the what the informants said, avoiding researcher's bias, while the process of sorting codes into themes based on existing literature and theory produced themes ensured they were compatible with the latter. A weakness of this method, however, was that it was very time consuming – which led to less time in finishing the final sections of this thesis.

4.4 Quality of research approach

To test the strength of the research approach, I find it useful to reflect on how it fits with well-established evaluative criteria in qualitative research. Different scholars propose different criteria for ensuring the quality of the research design. Lincoln and Guba (1985) propose four evaluative criteria that ensures trustworthiness in qualitative studies: credibility, transferability, dependability, and confirmability. Building on Lincoln and Guba's criteria, Bryman (2016) proposes three central criteria for the evaluation of research in social sciences; reliability, replication, and validity.

Reliability, relating to dependability, is concerned with the consistency of findings and that they can be replicated. Ensuring reliability in qualitative research requires transparency in how samples are selected, how interviews are carried out, and in the research objective (Bryman, 2016). As qualitative studies are often conducted in specific temporal, spatial, political, regulatory, cultural, and financial contexts, they are near impossible to fully replicate – as these contextual factors develop unevenly over time. This have led some scholars argue that only quantitative research is replicable (Leppink, 2017).

From this point of view, this thesis is not replicable. After the end of the data collection, for example, the construction of Celsio's CCS plant at Klemetsrud was put on halt (Valderhaug, 2023). Conducting the interview after this could have yielded different responses. The success or failure of future CCS projects will also impact the cultural context CCS, and the trust investors are willing to put in the technology.

Other scholars argue that while exact replication is not possible, conceptual and methodological replication is (Dennis & Valacich, 2015). So long as the inherent goals, concepts and methodological framework remains the same, variation in participants and context does not disqualify replication and the subsequent concepts and outcomes of the research should be the same. (Polit & Beck, 2010). From this point of view, this project is possible to replicate, because I have provided sufficient details to do so. As qualitative research is unstructured and reliant on the researcher's ingenuity, a true replication is nearly impossible, however (Bryman, 2016).

Bryman (2016) operates with five types of validity, but only three were deemed relevant for this specific research design. The first is measurement validity, which is whether a measurement really reflects the concept it is supposed to. This includes selecting an appropriate size and variety of samples. This thesis ensured measurement validity through constructing the research design narrow enough to satisfy a small sample size and selected samples though a thorough selection process to satisfy variety. I acknowledge that the selection process for this thesis was simplified by the limited number of WtE facilities engaged in CCS. Additionally, one may assume that the the small sample size produced less variance than a large sample size. This was overcome, however, by triangulating the primary data with secondary data.

Second is internal validity, which deals with whether one can trust the findings presented in the research. A determiner for internal validity is whether the researcher has been able to present a causal connection between variables. Transparency is another factor ensuring internal validity in qualitative research because researcher wields power over data selection processes, what data is deemed important, and how it is interpreted. This is especially important in a thesis employing semi-structured interviews as they often begin with open-ended questions before gradually narrowing down to the heart of the research question, yet leaves very little transparency in the decision-making of this process (Bryman, 2016).

This study has increased internal validity through triangulation between primary and secondary data, and by being transparent in how the research question was approached and how the process of collecting data went, as well as cementing the research process in a theoretical framework.

Third is external validity, which refers to the degree in which the findings have applicability in other contexts, i.e., their level of generalization. Many argue that the findings of qualitative research are not generalizable. And this is true if talking of statistical generalization, meaning to draw conclusions on for example the behavior of a population based on a representative sample, which is not possible due to the small sample size of qualitative studies - especially in case studies where the samples have been carefully selected (Bryman, 2016; Yin, 2014). Yet statistical generalization this is not the goal of qualitative case studies anyway. On the contrary, case studies can be used for analytical generalization, which is achieved through using empirical cases to test the theoretical reasoning of a theory and theoretical proposition (Yin, 2014).

In this thesis, analytical generalization is achieved through creating an initial research design based on the MLP, that is then tested through analyzing the empirical data collected through three case studies. Such a process allows the researchers to draw generalizations beyond the specific case studies. The conclusions of this thesis can be generalized to the degree that it highlights the challenge of transformation in hard-to-abate industries generally, and what measures actors involved are employing to increase the successfulness of these projects.

4.5 Ethical considerations

Ethical considerations are a crucial part of conducting qualitative research to ensure the credibility of the research. Some researchers argue that research should always have a purpose extending beyond the researcher's sphere and contribute to the improvement of society by proposing improvements to existing practices or highlight problems with existing ones (Ingierd, 2018), suggesting that the researcher should always ask themselves the questions 'what is the purpose and value of this research, and what may it be used for?'. While such normative attitudes to research can be useful reflections, they also run the risk of producing biased research rooted in the researcher's preconceived condition of what should be done to improve society (Yin, 2014). Openness to contrary evidence is one of the key qualities to abate such a bias (Yin, 2014).

Reflecting on this, I acknowledge that my interest in technical solutions such as CCS that can decarbonize human activity while allowing us to maintain a similar lifestyle can be viewed as a preconceived condition – and is partly what has led me to engage in this research topic. Yet I argue that these notions do not dismiss the value of this research, as CCS is widely considered a necessity to combat climate change.

As a qualitative case study involving human subjects, another ethical consideration is the protection of participants (Yin, 2014). As participation can have consequences for participants, special considerations are required. To protect the participants in this study, I gained informed consent from all participants and stated that their participation is inherently voluntary. Second, I have ensured the anonymity of participants through the use of encrypted software for conducting interviews and data storage.

The need to specify cases and small size of actors engaged in implementing CCS in WtE offered certain challenges to anonymity, however, which the research design tackled accordingly: the position and personal information of participants was anonymized, while the firms and organizations that they represent were not. In such a scenario transparency and communication with participants on anonymity is key to secure consent and avoid a scenario where participants withdraw their interview.

I have achieved this through providing an information letter to participants in advance of interviews and repeating what I intend to use the data for at the beginning of every interview, as well as asking for informed consent – both notions deemed crucial by Bryman (2016) to ensure that participants know what they consent to. As such, there is a clear risk of tracing participants, but this has been clearly communicated and accepted by participants.

A final ethical consideration is translation. All interviews were conducted in the first language of the interviewer and informants, Norwegian. To reduce the impact of subconscious reinterpretations of the primary data, the interviews were not translated until they were coded and sorted into themes. Still, translation may reduce the trustworthiness of the research. Another consideration is whether the interviewer is able to translate the semantic meaning of what the informant stated (Qoyyimah, 2023). A positive effect of translation is that it becomes even harder to identify informants, however.

5 Brief presentation of cases

This section provides a brief overview of the three cases explored in this thesis. This is done to improve the reader's understanding of the cases, which is helpful for interpreting the findings of this thesis. The map below provides an overview of the geographical location of each case explored in the study.

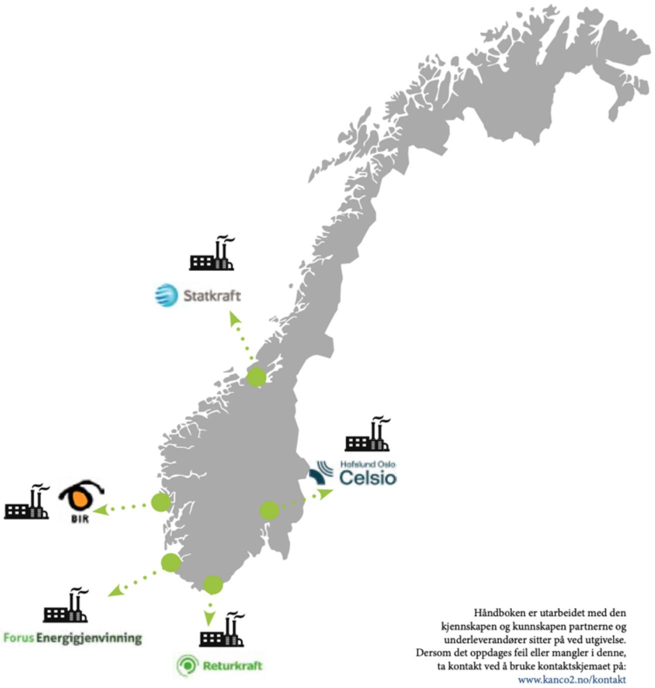

Figure 5 map of WtE facilities engaged in CCS (KAN, 2022, p. 3)

5.1 BIR (Bergen)

The municipality of Bergen is located in the far west of Norway, and is Norway's second largest city with 267 117 inhabitants (Statistics Norway, 2023).

Its WtE plant is managed by BIR, and emitted 260.000 tons of fossil and biogenic CO2 in 2021 (BIR, 2022a). The plant is owned 80% by Bergen municipality, with the remanding 20% split between the neighboring municipalities (cite interview). The plant is Bergen's largest point emission, making up a third of the municipality's emissions (Fossen, 2022b). CCS in the plant has been a political priority since 2016 when the municipality set a target to implement it by 2025, and its success is crucial for Bergen's plan of reaching net-zero by 2030 (Fossen, 2020).

BIR received the results of two feasibility studies in September 2022 showcasing that CCS is feasible, and BIR is opting for a strategy of installing a modular CCS plant capable of capturing 100.000 tons of CO2 annually (Fossen, 2022a).

With some 50 minutes travel from BIRs WtE plant to the Øygarden facility, the injection plant of the Northern Lights project where captured CO2 is received and injected into the well 2.500 meters under the seabed (equinor, 2023) is in close proximity.

5.2 Celsio, Klemetsrud (Oslo)

Located in the south-east of Norway, Oslo is Norway’s largest city with 1 064 235 inhabitants (Statistics Norway, 2023). The municipality has multiple WtE plants, but its biggest is the Klemetsrud plant which is the largest single-point emitter in Oslo with 17% of the region’s direct GHG emissions (KlimaOslo, 2023). It provides 20% of all heating in Oslo through its district heating system (Hafslund Oslo Celsio, 2022).

The plant is managed by Celsio, which is owned 60% by Hafslund, 20% by Infranode, and 20% by HitecVision (Hafslund Oslo Celsio, 2022). Hafslund is fully owned by Oslo municipality, while the two other owners are private equity firms.

According to one informant, CCS in the facility has been a political priority for the municipality since 2015.

The CCS facility is currently under construction and is estimated to capture 400.000 tons of CO2 annually, of which half is of fossil origin and the other half is of biogenic (Hafslund Oslo Celsio, 2022). The project is part of the longship project, receiving 3.4 billion NOK in investment grant and operating cost support (CCS Norway, 2022). Its planned value chain is also part of the Longship project. CO2 will be transported by trucks to an intermediate storage in the Oslo docks, before being collected by ships and transported to the Øygarden facility for injection into the storage site.

5.3 Statkraft Varme (Trondheim)

The municipality of Trondheim is located in the region known as mid Norway, and is Norway’s fourth largest city with 194 860 inhabitants (Statistics Norway, 2023). The Municipality’s WtE plant, Heimdal Varmesentral, is managed and fully owned by Statkraft Varme, which is a business unit within Statkraft. The heat provided from the facility covers about 30% of Trondheim’s heat demand, but has an annual CO2 emission of 240.000 tons of which 67% are of biogenic origin (Jordal et al., 2023). The fossil portion of these emissions make up 25% of Trondheim’s total emissions and one of its biggest single-point emitters (Statkraft Varme, n.d.).

Cutting these emissions have been a political priority for Trondheim municipality since its climate plan from 2017 which specified the dependence of CCS at Heimdal Varmesentral for reaching their target of a 80% reduction in GHG emissions by 2030, measured against 1991 emissions (Trondheim Kommune, 2017).

Geographically, Trondheim is located far away from Øygarden. Statkraft Varme has conducted feasibility studies for their planned facility, but is waiting with advancing their plans.

5.4 Collective emissions

If all cases were to successfully implement CCS, they would collectively capture about 700.000 tons of CO2. In 2021, Norway emitted 49,3 million tons of CO2 (Øvrebø, 2022), making their contribution quite substantial.

6 Findings and analysis

This section presents the findings of the primary and secondary data collected and explain and evaluate them in relation to the theoretical framework. The section is split into three subsections. Drivers, barriers, and how actors are engaging with the latter.

Due to the MLPs focus on stability and instability in regimes, I find it useful to begin the analysis by evaluating the drivers to implementing CCS in WtE, as these can be understood as factors pushing for change in the sector. Then, I will present the barriers to elaborate on what is obstructing change to happen. These may be viewed as factors maintaining stability, as we will discuss in section 7. Finally, the section will close with a presentation of how actors are engaging with barriers and what sort of strategies they are employing to overcome them.

Because the primary research question guiding this thesis is to understand drivers and barriers to implementing CCS in the WtE industry specifically, some general points have been neglected in the analysis to give more space to address the research questions thoroughly.

6.1 Drivers

This section focuses on presenting findings that can be categorized as drivers for CCS in WtE. These have been categorized into several groups.

6.1.1 Climate action

Environmental, political, and social drivers coalesce in what can be viewed as the importance of climate action. All informants acknowledged the immediate need of decarbonizing society to fight climate change.

Statistics show that climate change has become the most important issue for Norwegian constituents (Fosby Livgard, 2019), and near half of all Norwegians are very concerned for climate change (Gregersen, 2023). In Bergen, a poll from 2021 found that 53% of constituents saw it as very important for Bergen to reach net zero by 2030 (Prestegården, 2022). In Oslo, a poll from 2022 found that 70% of constituents viewed it as very or pretty important that Oslo reached its target of a 95% GHG reduction by 2030. In Trondheim, a poll from 2021 found that 69% of constituent agreed that Trondheim should take a national leading position in fighting climate change (Opinion, 2021).These statistics show that there is a high social support for climate action in the three regions, which was claimed by all informants too.

Politically, climate has been a key area of focus for Norwegian municipalities since 2009 when the Norwegian government revised the Planning and Building Act, mandating municipalities and counties to contribute to an environmentally friendly energy transition and to a reduction of GHG emissions (Regjeringen, n.d.).

All informants representing the municipalities studied identified the WtE facilities as significant single-point emitters in their region and stated that cutting these emissions as essential to reach their regional climate goals (Informant B1, O1, T1).

All municipalities also reported wide-spread social acceptance for CCS in WtE, although informant B1 and T1 acknowledged they were uncertain if acceptance would remain high if the cost of CCS had to be borne by constituents through increasing the annual waste tariff for households. Additionally, informant B1 noted that other climate measures were more important to constituents than CCS, such as recycling.

Environmentally, informants highlighted clear a benefit to CCS in WtE: its biogenic emissions, averaging about 50% of the plants' total emissions. Additionally, informant T2 and E2 noted that due to strict regulations on the contents of emission in the waste management industry, their emissions are very clean of other hazardous compounds and thus suitable for CCS.

6.1.1.1 Carbon capture necessary to decarbonize waste sector

Moreover, as a hard-to-abate industry, informants claimed CCS to be the only solution capable of bringing the sector's emissions to zero: "In the waste management sector, emissions have remained flat … we are meeting drastically higher demands for reuse and recycling, but this will not be enough. So, we view CCS as necessary" (Informant B1). B1 also claimed that as we succeed with decarbonizing other sectors, hard-to-abate industries, and WtE especially with its negative emissions, will become even more important users of CCS.

T2 added that while there are several measures needed to improve the waste management sector, such as tighter restrictions on plastics to simplify recycling, and improved methods of waste separation, there is also an environmental and a business dimension to recycling:

"If you look at it from both in terms of economics and in terms of carbon footprint, which is a consequence of increased recycling and everything related, is it perhaps better to just let it burn and use CCS instead? Say for instance this computer mouse, how much carbon are you emitting by recycling it, against putting it into an oven and burning it?" (Informant T2).

Their statements situate CCS in WtE as a necessary final step in the sustainability transition of the waste management regime. Coupled with its several environmental benefits, and suitableness with regional and national political aims for emission reductions, it is evident why CCS is highly interesting in the WtE industry. Informant O1 also highlighted environmental organizations such as Bellona and Zero as important instigators for CCS in WtE.

6.1.1.2 Landscape level

Looking beyond national boundaries, informants viewed EU as a major driver for CCS in WtE. As an EEA member Norway is part of EUs inner market but its membership is contingent on adoption of EU-policies in several policy-areas (Stortinget, 2023). Additionally, the newly announced 'Green Alliance' between Norway and the EU aimed at strengthening collaboration on climate action, environmental protection, and energy and industrial transition sends a clear signal. Several informants also noted the EU's plan for negative emission bonds as a driver, anticipating similar schemes to be adopted in Norway.

UN reports on climate change was also deemed as important by most informants. Informant B1 believed that the UNs communication on climate change has been the foundation of national and regional climate politics. E2 believed that the UN reports have been important to give nations a direction on combating climate change. Informant O1 argued that CCS would likely not have survived after its failed ‘moonlanding’ without the UN repeatedly emphasizing its importance in their reports. Their statements may suggest that while the UN narrative does not directly address the waste management regime, it has the effect of delegitimizing unsustainable practices and legitimizing the adoption of technical niches such as CCS to decarbonize human activities.

Collectively, these forces have the effect of making the niche of CCS more lucrative to adopt by the waste management regime and implement into the WtE facilities, a notion that will be discussed in the next section.

6.1.2 Place-specific drivers

Narrowing in on the cases, there were also place-based factors that made CCS in WtE more favorable.

In Bergen, informant B1 and B2 noted that the proximity to Øygarden is a big advantage for them as they do not have to establish intermittent storage, nor use sea-based transport in their value-chain – substantially reducing the cost and complexity of their transport infrastructure (Informant B2).

In Oslo, regional politics have been an even bigger driver than the other municipalities, as the local government has gone beyond the role of a supporter and facilitator. As informant O1 stated:

> “This has been something that the entire city Government stands behind, and that he City Council has blessed. There is a broad political majority behind it in Oslo. And this commitment has for a large part been spearheaded by the Governing Mayor himself. So, this has a strong political focus in Oslo and has been a very important part of Oslo's climate strategy”. (Informant O1).

This was also confirmed by informant O2, stating the importance of support from politicians, Norwegian NGOs, LO and NHO, and others, in Klemetsrud becoming part of the Longship project. A third contextual driver in Oslo is the size of the facility, enabling a value chain consolidated solely of their capture plant – in contrast with Trondheim, for example.

In Trondheim, T2 noted that Statkraft, the owner for Statkraft Varme, has ambitions of becoming carbon neutral by 2040. Cutting the emissions from their WtE facility is thus a high priority. Moreover, the informant also noted that there were expectations from the municipality that the WtE firm contributes to net zero efforts. This pressure may be especially important in Trondheim, where the municipality has no ownership over the WtE facility. A similar notion was expressed by informant B2, who claimed that most working within the waste sector was motivated by contributing to improving waste management.

One may view these statements as evidence of pressure within the regime of adopting CCS to improve the environmental performance of the waste sector.

Secondly, the Midt-Norge cluster can be classified as a regional driver because regional collaboration reduces the risk and uncertainty related to large infrastructure projects such as the value chain of CCS is.

The regional variance in the drivers is an important finding because it helps explain why the CCS is still considered an alternative by the different regional actors despite their shared and place-based barriers.

6.1.3 Prospects of new business models drivers

Interestingly, despite the fact that financing CCS is viewed as a major barrier, informants also view CCS in WtE as a potentially new business model. This is primarily due to the expectancy of increased CO2 emission tariffs, making CCS cheaper in the long run, and through selling negative emissions. All informants were positive to the latter, with several actively engaged in lobbyism and collaborations to materialize such a system, which will be presented in section 6.3.

Informant E1 also noted that as CCS becomes more widely adopted, businesses without CCS may become obsolete because of consumer preferences, while informant B2 added that businesses not using CCS may be perceived negatively in the future. Whether such notions will affect the waste sector remains to be seen.

From such an angle, the reconfiguration pathway of the waste management regime may be viewed from the economic task environment, despite the legal framework creating a market is not in place yet.

6.1.4 Financial support schemes as driver

Financial support schemes were also identified as a driver for implementing CCS in WtE.

For Celsio, financial support from the state through the Longship project was decisive for the project. Informant O1 added that “the state is covering all costs tied to transport and storage of CO2 over a ten-year period, which makes CCS much more commercially attractive”.

While there is no certainty, informants representing Bergen and Trondheim were motivated by the Longship project and hopeful of future financial schemes that could enable CCS in their WtE facilities too: “When Norway has used close to 20 billion NOK to establish, then it’s clear that it’s important that other projects come afterwards” (Informant T2). At the same time, informant T2 thought the national government should do more to facilitate CCS projects in Norway but recognized that “there is a growing consciousness and willingness to discuss that sort of frameworks are needed for CCS to succeed in different Norwegian industries” (Informant T2). This willingness has actively been lobbied for through various channels, to be discussed in section 6.3.

6.1.5 Learning outcome as a driver

Learning outcome is identified as the last major driver, as it was deemed as a substantial motivation for engagement from all informants. The driver is directly related to the technology dimension of CCS (see figure 3).

Informant T2 noted that the learning outcome from CCS projects in WtE was crucial:

> “I think the importance of more facilities being built is that the learning curve gets steeper we learn more, and it is important that we build more facilities so that we gain experience around regulation processes, emissions, technology, value chain - every bit, actually… That we gain more experience on the synergy of research and development, us as actors, public authorities… learning on all those areas are important for future facilities, because then they will be able to do it more efficient

> than we did, right? Because then we have learned. So, I think the learning outcome is the most important with what we are doing". (Informant T2).

Relating this statement to the theory, it showcases the active engagement of an incumbent actor to reorientate their activities towards radical innovations, such as CCS. The motivation behind their engagement will bill be discussed in section 7.

The previous statement also repeats the of the novelty of CCS technology. Although all informants agree that the amin capture technology is mature, fitting CCS to existing facilities is challenging and that there is need for more knowledge to enable widespread diffusion of CCS in hard-to-abate industries.

This has been a core aim of Gassnova's activities, as they have a mandate to ensure benefits realization from the projects they monitor and support. Informant E1 defined benefits realization in CCS as:

> "To generate learning, so that subsequent projects can learn from this and get motivated, so that we initiate full-scale. It is also clear that Norwegian value creation is a part of the picture, in addition to climate change – we have Norwegian technology suppliers, we have Norwegian industries that will become more competitive once they can capture CO2, hopefully. So, there is a clear element of "what's in it for us", so also the development of business opportunities, I believe". (Informant E1).

Their quote also sheds light on the underlying motivation for CCS in the Norwegian context. It is arguably motivated by the hopes of gaining comparative advantages in a future market through technological expertise and know-how.

As financing CCS projects are part of the Government's strategy to generate research and development of CCS, learning outcome as a driver is thus not necessarily specific to the context of CCS in WtE - but it can be said to be the raison d'être for the Klemetsrud project. As noted by informant O2, prior pilots in 2019 and 2021 were important in their decision to proceed to greenlight the project at Klemetsrud – thus confirming the link between learning and

The dynamics of CCS development in Norway is interesting, because it is an example of state-led niche development, as elaborated in section 2.

6.1.6 Summary of drivers

To summarize, several different drivers have been identified.

First is climate action, composed of environmental, political, and social drivers that urge for action to combat climate change. These were held by all informants. Climate action was complemented by statements on the necessity of CCS in WtE and arguments for the synergy between CCS and WtE.

Next were two categories of financial drivers. First were new business models, which included the avoidance of CO2 tariffs and ideas of new business models through the sale of negative emission bonds. Second was financial support schemes. Klemetsrud has already received support, and this was viewed as a driver by the other cases who were hopeful of also doing so.

The third and final group identified as drivers were learning outcomes, which had two dimensions to it. On the one hand, participating in the development of CCS was a motivation for WtE firms, while financing CCS in WtE firms with the benefit of generating learning was a motivation for Gassnova.

6.2 Barriers

Identified barriers revolve around three main themes, costs/financing, regulation/policy, and integration/operation. These are partly overlapping but have been split into main groups: 1) barriers related to establishing the CCS facilities, and 2) barrier to operating the CCS facilities.

6.2.1 Barriers to establishing CCS in WtE facilities

Three main barriers were identified in relation to establishing CCS in WtE facilities: costs, space limitations, heat integration, construction challenges, and challenges to establishing the CCS value chain.

6.2.1.1 In need of financial support

The cost of establishing CCS (CAPEX) was the largest single barrier to CCS in WtE, according to informants. Neither Bergen nor Trondheim has progressed their plans past feasibility studies. According to the informants, a main reason for this is lack of financial support.

Informant T2 noted that they were dependent on the national government for financial support to materialize their project. Likewise, informant B2 believed too little attention was paid to the cost of establishing CCS:

> "…you need a business model that can work in the long term. With the tariffs that are planned to come, the orders of magnitude planned to come, the CCS in WtE is expected to be profitable before 2030. But that is on the operation costs, not on the cost of establishing the facility. Establishing the facility is very expensive. That we expect CCS to be profitable when operating does not mean that we will be able to establish a facility, because that is so expensive".

The informant added: "if we do not receive any assistance, it would be dramatic for us. It will affect us so much that full capture will be simply impossible".

Their arguments were supported by informant E2, who when asked about costs in CCS stated: "well, that may well be the same question as to why are there not more existing projects? It probably has to do with the costs. It's simply cheaper to emit than to capture emissions. And then society have to make demands".

Their points situate CCS as an expensive technical solution which at the current moment is economically unfeasible to install without financial support, which is a typical niche characteristic.

The cost barrier was overcome in the case of Celsio's facility at Klemetsrud. They receive financial support through the Longship project and private equity firms. When interviewed informant O2 reported that construction was ongoing, but that its costs have increased due to external shocks in the landscape. When asked about the reports of budget overruns in their project, informant O2 stated:

“As everyone else constructing industrial projects now, we are very affected by high prices for energy and raw materials...First you had Covid with all its delays and now you have Ukraine” (Informant O2).

Recent developments led Celsio to pause the project in April, as it was suffering financially form a combination of inflation, unstable international relations, and the weakness of the Norwegian currency that increased the costs of the project dramatically (Valderhaug, 2023).

Representative O1 also noted that the repeated pattern of cost overruns for infrastructure projects in recent years, saying:

> “Construction costs in Norway have been much talked about… we have seen the major cost overruns of both the Follobanen and the new municipal water supply – simply because the market is under extreme pressure… It is a little bit unexplainable why the costs of large infrastructure projects are so much higher here than they are in our neighboring countries, for example”.

These notions confirm the impact of landscape factors on financing the establishment of CCS in WtE, thus exacerbating existing uncertainties on its costs related to the novelty of CCS. Collectively, this constitutes a massive barrier.

6.2.1.2 Integration to existing facilities

Second to costs, and specific to the context of the WtE industry, informant highlight the integration to existing facilities as a major barrier. This was challenge both due to a lack of available space and due to technical challenges.

6.2.1.2.1 Occupies limited space

The challenge of space limitations was repeated by all firm and municipality informants. In Bergen, space limitation in the industrial area may create financial and socio-political issues. According to informant B2, there are already struggles over space in the industrial area in Rådal:

> “In the area where our facility is located, people are already screaming for space. So, it’s clearly a challenge, but at the same time we think it’s solvable. But it’s of course just talks of money … We have already confirmed that we can’t build a CCS facility on the area we already own, so we have to acquire more property, and that affects some of our neighbors. And it is clear that at one point or another, if we do not come to an agreement with any of our neighbors, then the municipality has been quite clear that they will regulate this so that there will be space for a CCS facility.
>
> But in such a way that there is, in a way, an issue of expropriation, a process which potentially becomes a last resort. But we want to come to an amicable solution with the potential areas that may be relevant. We want to find a good solution for both parties instead of expropriation. Because it is clear that expropriation, then time also passes” (Informant B2).

Additionally, despite there being high social acceptance of CCS in Bergen according to informant B1 and B2, local news stories report that neighbors are skeptical of the plans due to the impact an expansion of the industrial area may have on the neighboring forest and sports facilities (Fossen, 2020). Space limitations thus create both physical, financial, social, and political barriers in Bergen. For these reasons, however, the statement also suggests that CCS in WtE has a very high political priority in Bergen.

Similar clinches were reported in Trondheim, where the planned facility will have to either be built on an area allotted for a future ice hockey rink by the municipality, or through relocating neighboring firms. According to informant T1, this issue was lifted politically, and local politicians decided on matter of principle to go with the relocation strategy.

Likewise in Oslo, space limitations meant they had to remove 40 meters of rock and do some 'swaps and buyout', which has been more challenging and time-consuming than expected, according to informant O2, and created moments of uncertainty.

Relating space limitations to the theory, the constraints imposed by a lack of space is identified as a barrier to the reconfiguration pathway of the waste management regime. As stated by informants, the need of space for CCS was not considered when the WtE facilities were constructed, which are now creating both physical, financial, social, and political barriers to its deployment – which take time and effort to overcome and create uncertainties for the projects.

6.2.1.2.2Requires efficient heat integration

Heat integration was the second biggest barrier with integration to existing facilities, which is a technical challenge. Because the capture process requires a lot of thermal heat, informant T2 noted recycling of low- and high-pressure heat from the capture process as imperative to designing integrations that minimize the need for added energy.

In Bergen, informant B2 agreed that heat integration was a major barrier and added another dimension to it:

> "What you actually do with a capture plant, and those that have district heating, is that you supply a lot of electricity for the heating and cooling processes in the capture process. Then you actually get a lot of the energy you supplied as electricity back as district heating. And that's top notch in winter when it's cold outside, then we need to put more heat into the district heating system than what our system produces. But it is clear that for at least half of the year, or perhaps more than that, we do not have the need for heat but for electricity, and it is clear that we will lose that opportunity. So… the energy problem, is very central to us." (Informant B2).

The loss of electricity, deemed a high-quality energy carrier, thus lessens the flexible output of the WtE facility. In Bergen, the WtE facility is categorized as critical infrastructure due to its output of electricity and district heating (Informant B2). To lessen the impact and loss of energy output, informant B2 stated that they would opt for partial capture. Energy output was a concern by Oslo Muncipality too, where informant O1 hoped CCS would not impact the Klemetsrud facility's district heat production too much.

Their statements were backed up by the expert informants. Informant E2 noted energy efficient integration of CCS as one of the priorities with further technological development.

The concern about energy reveals that WtE firms are not only needed for managing waste, but also for their energy output. As such, WtE can be framed as multi-sectoral – as they are both waste managers and energy producers.

6.2.1.3 Need for added energy

In Oslo, they need to build two new transformer stations to supply enough electricity for the capture process. Informant O2 views this as a barrier because it has created uncertainty in their project as these stations would not be ready until 2027, one year after the planned completion of the project.

The informant also noted concerns with access to electricity, as this have recently been prevalent struggle for several Norwegian industrial projects. Placing these in theoretical perspective, the ongoing transition of the WtE regime is affected by the ongoing struggles of the Norwegian electricity production system, which is facing challenges in meeting a growing demand.

The challenges related to integrating CCS to existing WtE facilities reveal interesting notions about the technical synergy between the two, which will be discussed in section 7.

6.2.1.3.1 Construction challenging

Finally, a third challenge to integration is that the WtE facility has to be able to run as normal during and after the construction of CCS, deemed a considerable technical challenge by informant O2, noting: "the technical challenges are often in the interface between, for example, capture facilities and WtE facilities – that integration is a challenge, because the normal WtE plant must be operated at 100% all the time" (Informant O2).

Construction challenges are also affected by uncertainty. As informant E3 noted:

> "Because CCS has to be tailored for the facility, costs that may arise can be uncertain. We see that there have been budget overruns at both Nordcem and Klemetsrud, because you have to try and fail, both at the technology, but also with the physical building process." (Informant E3).

The statement underscores the argument that CCS is still a niche in need for further development for heat integration, and deployment experience to improve estimates of cost and the building process.

6.2.1.4 Factors complicating the creation of CCS value chains

Leaping to the next segment of the CCS value chain, scale and geography creates barriers to the transportation and storage of CCS. Informant E2 noted that a general challenge to CCS in WtE facilities in Norway is their relatively small sizes and that they are spread out, both factors increasing the costs per ton CO2 and discourage actors from implementing CCS (Informant E2). The issue of scale scrutinizes the proposed reconfiguration pathway of CCS in WtE, because a better strategy could be to centralize WtE, which will be discussed in section 7.

Another barrier in the value chain is the lack of existing infrastructure, discouraging industries from engaging themselves in CCS:

> "When CO2 capture and storage is established, you need infrastructure. You need transport links, you need local storage and intermediate storage near the industry

> or industrial clusters, and you need transport and permanent storage. And many industries see this as difficult today because there are very few players in the picture, and are afraid of being such a first mover, because then you will have to take a lot of the costs, as for local intermittent storage, for example" (Informant E1).

These concerns were also reflected in the cases. In Trondheim, informant T1 and T2 highlighted the CCS value chain as the biggest barrier. Due to geography and relatively low emissions, it is not feasible to establish a value chain solely for Statkraft Varme's WtE facility. To overcome this barrier, multiple industries in the region are collaborating on a shared transport infrastructure through the CCS Midt-Norge Cluster (Jordal et al., 2023), an example of regime actor agency that lowers risks, uncertainties, and costs in CCS that will be discussed in section 6.3.

Yet such a solution will require a high degree of coordination between the multiple actors, which can be challenging and time-consuming. Moreover, Jordal et al. (2023) noted that all CCS projects planned in the cluster will need some financial support from the authorities, yet the likelihood of this in the near future is debatable. According to informant E3, there is currently a lack of willingness in the national authorities to finance any further CCS projects before seeing the developments of the Longship project. Informant E1 elaborates that this may be due to the infancy of the Longship project, but that new models of financial support are being planned out. The scarcity of financial support available is thus also a barrier to the value chain.

In Oslo, informant O2 noted that the complexity of CCS projects also impacted their planned infrastructure, which had done be altered due to the time it took advance the project:

> "We had a deal with Oslo Dock about where our dock terminal was supposed to be, but then they have made new priorities over the years … the extra years it took for us to draw a funding decision … so they moved us … and that makes our dock terminal from being a green Field, where there is no existing infrastructure, to a brown field, where there is existing infrastructure. And that is both a positive and a negative … creates some challenges, some opportunities, but it also means that we have to redo our plans after project start" (Informant O2).

Additionally, the financial support frame for the Klemetsrud facility of 10 years put restrictions on the value chain: "even if a pipeline perhaps would pay off in the long run, it will not pay off in ten years. Then it's more flexible with trucks" (informant O2).

Aggregating these notions within the MLP, the novelty of CCS - and the fact that no existing value chains as extensive as the one planned in the Longship project - leads to uncertainties that take considerable time and effort to work through, which in and of itself create new uncertainties.

6.2.2 Barriers to operating CCS in WtE

Informants also highlight several barriers to operating CCS in WtE facilities. These do of course also act as barriers for establishing CCS in WtE facilities. Here informants noted three main issues: issues with CO2 tariffs, the lack of a market for negative emissions, and the issue of waste as a commodity. These issues are all tied together, as I shall elaborate.

At the current moment, CO2 tariffs were too low to trigger the adoption of CCS. And while several informants stated that future increases in CO2 tariffs will make CCS profitable, they also stated deep uncertainties about when these tariffs will increase. Not knowing when something will start paying off is a massive barrier to implementing CCS in WtE, according to the informants.

Relatedly, while most informants listed the potential of a future market for negative emissions as a driver for CCS in WtE, as such a market is yet to exist there are currently no incentives to capturing biogenic emissions. As explained by informant B2:

> "For the time being, as we view it, there are no economic incentives to capturing biogenic CO2, because there have been no renumeration for it. There has only been a tariff for fossil emissions, which you avoid when capturing the CO2, but no negative tariff, as we call it, when you capture biogenic CO2. So, when we've looked at the financial side of operations, capturing the biogenic CO2 will be even more challenging than the fossil CO2" (Informant B2).

Informant B2 related this to the question of political preconditions for CCS in WtE, that there is a lack of clear incentives for CCS today, adding: "I think it's strange, given the time we're in, with one report after the other on the climate and what we have to do, that the government is not more engaged and do more to support the projects that can deploy CCS" (Informant B2).

Finally, commercial waste is traded as a commodity through a reverse auction market, which creates challenges related to both increased CO2 tariffs and the implementation of CCS:

> "As both household waste and commercial waste is going into the facility, and it is approximately 50-50, we can only add 50% of the cost of CCS to the fee, while the other 50% goes to the business exposed to competition.
>
> What we see there is no willingness from the customers (industry) to pay that cost, because waste is traded as a commodity via markets and stock exchanges, or agents, and they find the cheapest way. Already today, a lot of waste is transported from Bergen to Sweden, and probably even more in the Østland region, to incineration plants in Sweden, which has a much lower gate fee, or reception cost. If we were to add a fee for CCS to our customers, then a lot more would just be transported to Sweden, because the willingness to pay is not there" (Informant B2).

These statements suggest there is a lack of appropriate regulation that can enable WtE firms to cover the OPEX of CCS. Informants made several suggestions to improving these factors, such as changes to where the CO2 tariff should be applied. These points will be presented in section 6.3.2.

6.2.3 Summary of barriers

To summarize barriers, some patterns emerge. First, informants recognize both the CAPEX and OPEX of CCS to be too high for the WtE sector to cover alone, hinting to a clear dependency on the national level to provide financial schemes to cover both, which informant criticize the lack of.

Second, there are two main challenges to fitting CCS to existing facilities. The first is the need for space, which in two of the cases is exacerbated by struggles for space. The second is the need for heat integration. As providers of both district heating and electricity, CCS would steal away valuable energy from the latter. It thus requires efficient integration to lower the amount of energy required for the CCS process, as well as to return some of the energy put into the process.

Barriers to operating CCS in WtE were mainly within the domain of OPEX, and informants pointed to three factors complicating this: issues with CO2 tariffs, the lack of a market for negative emissions, and the issue of waste as a commodity. To abate this, informants suggest several policy changes, which will be discussed in the next section.

6.3 Regime actor agency

One of the core contributions of this thesis is to analyze how regime actors are using their agency to shape the implementation of CCS in WtE. These dynamics are crucial to highlight when studying sustainability transitions in which the regime engaged in adopting a niche. At the core of this is how informants are responding to drivers and barriers, and what strategies they employ to overcome barriers and improve drivers. Some of these strategies have been alluded to in the former sections, and they will be explored thoroughly here. Networks and suggestions were often interrelated, as actors use their networks to strengthen their voice.

6.3.1 Networks of collaboration

To materialize the implementation of CCS in WtE, several actors are collaborating through different channels. These collaborations range from concerning CCS in WtE specifically, such as the KAN network, to general network collaborations on climate change strategies, such as the Metropolitan Network for Climate (storbynettverket for klima), a network consisting of the Norwegian cities Bergen, Oslo, Trondheim and Stavanger (Oseland et al., 2021). Figure 5 below is an illustration of actors mentioned in this thesis, and who they are collaborating with.

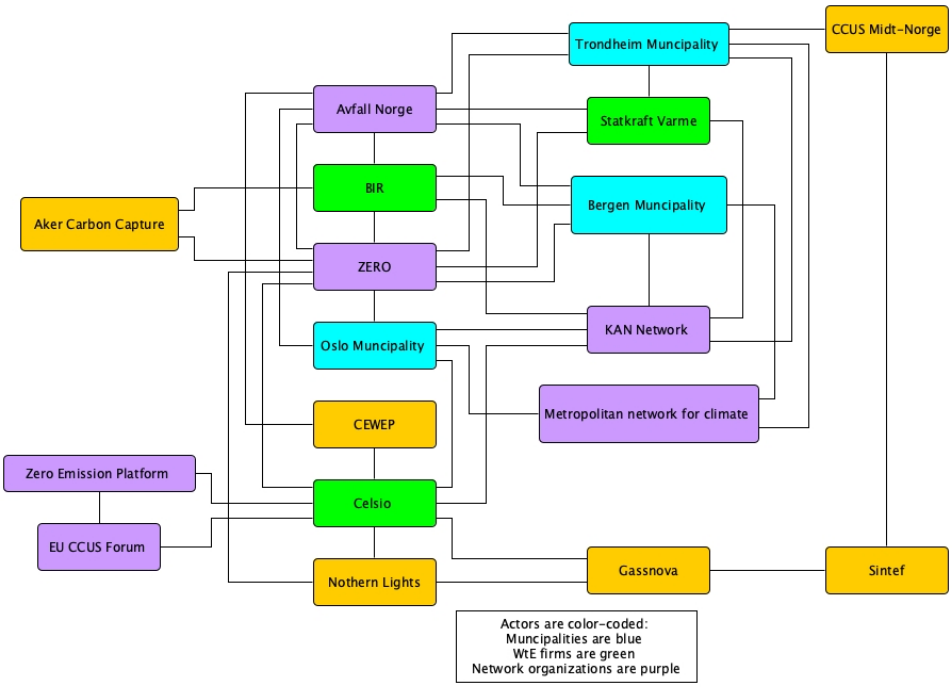

Figure 6 actor networks based on data collection. Map is not exhaustive and should not be taken as an actual illustration of an actor network for CCS in WtE

All informants highlighted collaboration as crucial for overcoming barriers, and as an asset to strengthen their advocacy on CCS. All WtE firms participating in the study are collaborating through the KAN network. Its importance was expressed by all firm informants, and it has two main benefits according to informant B2:

> “First is the share of knowledge. Both by sharing knowledge and know-how, and knowledge sharing through having joint projects so that not everyone has to solve the same problems but that we can share the work.
>
> Second is that we can communicate this together externally. And stand together with a stronger voice, and think in particular about the political, and about the framework around CCS, in relation to identifying and communicating the challenges, or the bottlenecks that may be underlying. So that’s very, very important” (Informant B2).

Similarly, the municipalities participating in the study are collaborating through the metropolitan network for climate. CCS in WtE was one of their six focus areas, and they deemed it as vital to cutting the emissions of the waste industry as not all waste can be recycled (Oseland et al., 2021). Additionally, they argued that CCS in WtE would have a double environmental effect because of the partly biogenic composition of the resource base. This network was brought up by all municipality informants as vital for looking at the possibility of integrating CCS into their waste management facilities (Informant B1, O1, & T1). A main reason for this was because it allowed for joint communication towards the national government of the need for CCS in WtE. All municipalities were also closely collaborating with their respective WtE facilities to support the implementation of CCS through for example meeting to discuss specific challenges and how the municipality could help accommodate these.

The organizations Bellona, Zero and Avfall Norge were also identified as important actors. Both Bellona and Zero has long-running expertise on CCS and was deemed as an important communicator by Informant O1. Avfall Norge, being the trade association for the Norwegian waste sector, has extensive competence on the waste sector and its challenges, yet the organization was not mentioned in any of the nine interviews.

6.3.1.1 Case specific collaborations

In Bergen, BIR have invited several CCS and CCUS actors to test their technologies on their flue gasses, of which Aker Carbon Capture was the best candidate – offering a modular capture solution fit for BIR’s needs in terms of heat integration.

In Oslo, Celsio has collaborated with several actors, most importantly Northern Lights and Gassnova on their current project at Klemetsrud. According to informant O2, Celsio (previously Fortum) have also been actively influencing the European level through CEWEP (Confederation of European Waste-to-Energy Plants) and EUs EU CCUS forum, and the Zero Emissions Platform, which has put CCS in WtE higher on the European agenda. This, in turn, has also put CCS higher on the Norwegian agenda – echoed by informant E3 which stated that Norwegian firms and politicians pay extra attention when the EU puts something on its agenda. Informant O2 acknowledged that much of their focus on the EU was out of hopes of securing financing for their CCS project at Klemetsrud, but that it morphed into an important network of collaboration partners. Celsio has in some regard created a type of feedback loop. When urging European partners to put CCS on their agenda, this has in turn motivated Norwegian actors to do so as well.

In Trondheim, Statkraft Varme is collaborating in regional clusters to overcome infrastructural barriers (Informant T1, T2 & E2). Due to its distance to the Longship project's storage site, and the fragmentation of single-point emitters in the region, the region of Mid-Norway will likely have to develop a shared infrastructure – which they are currently exploring through the Midt-Norge Cluster presented previously in section 2.2 & 6.1.1. Informant E1 added that such a strategy helps abate the barrier of being a 'first mover', as first movers have to cover large costs, for example for intermittent storage, that would be beneficial to share between several actors.

The three cases have thus employed both shared and different strategies of collaboration to overcome barriers to CCS in WtE and contextual factors and preconditions. The Municipalities have collaborated together with their respective WtE facilities to gain insight into the challenges and opportunities facing them and collaborated between each other to voice suggestions for policies and frameworks, which is the focus of section 6.3.2. The same can be said for the KAN network, with the added benefit of increasing the efficiency of knowledge production through sharing tasks between its members.

Additionally, owing to distinct place-based challenges, each case has explored different strategies.

6.3.2 Suggestions for improving policies and supporting frameworks

Informants had several suggestions for improving policies and supporting frameworks for CCS in WtE that they are actively promoting – both through collaborations and alone. Summarized, they called for improved policies and frameworks that 1) finance CCS projects and their construction, 2) provide incentives for implementing CCS, 3) reward negative emissions and 4), adjust CO2 emission tariffs in the waste sector.

6.3.2.1 Policies to reduce uncertainties and provide funding

Several informants called for increased support from the state. Here there were several suggestions. At the general level, informant E3 called for political commitment to CCS through policies and frameworks that ensure predictability. Specifically, they suggested setting national targets for CO2 storage capacity that would be financed through a scheme called 'karbonretur', where O&G companies are obligated to capture and store CO2 relative to their emissions. Such a policy would have the benefit of easing the uncertainties on storage that are identified as barriers to the implementation of CCS in WtE. Similarly, another strategy could be to place the burden of the CCS infrastructure on the government:

> "Generally, one could say that there are calls from industrial players for the government to take responsibility for the infrastructure of CCS in the long run, similar to how it has been done with electricity, water, and sewage" (Informant E1).

These sentiments underscore the novelty of CCS and the need for support in overcoming transport and storage barriers.

There were also suggestions to support the establishment of CCS in WtE. Informants representing Bergen and Trondheim called for increased financial support schemes as both cases are reliant on state financing to advance their CCS projects beyond feasibility studies, and BIR argued that the recent hiatus at Klemetsrud showed the complexity of CCS and the need for more projects to be financed (Øystese, 2023). These actors have also pushed for this through the KAN network, who argued for policies supporting the whole course of the project planning phase (KAN, 2022).

Additionally, KAN suggest implementing temporary incentives covering the gap between the cost and revenue of CCS in WtE to facilitate a swift diffusion (KAN, 2022). The same sentiment was voiced in the recent recommendations of the Norwegian Environment Agency (Miljødirektoratet) from March 2023, which stated that current CO2 emission tariffs are too low to unlock CCS in WtE, and that uncertainties regarding future prices and the lack framework for CCS of biogenic CO2 were severe barriers (Miljødirektoratet, 2023).The agency suggested a reverse tariff that would mirror the CO2 emissions tariff, with a 10 year government guarantee, to facilitate the adoption of CCS in WtE (Miljødirektoratet, 2023). Informant O1, O2 and B2 all alluded to these recommendations in their interviews to underscore their calls for improved incentives. Similar suggestions have been pushed for by the municipalities through the metropolitan network for climate (informant T1) and by Zero (informant E3).

Informants also believed that a free market for negative emissions could become a new business model for WtE facilities, that could enable projects to become profitable (Informant E3). Informant O1 acknowledged that negative emissions from CCS is more expensive than those from e.g., reforestation, but that these could be sold at a higher price because CCS with geological storage of CO2 has a higher degree of permanence.

Informants suggested to either create a national marketplace of negative emissions, or to adapt the coming EU ETS which are set to be implemented by 2028 (Informant O2). The focus on creating a market for negative emissions can be viewed as a way of abating some of the costs of adopting CCS in WtE.

Finally, the informants problematized how the CO2 emission tariff affected the waste sector (informant B1, B2, O1, O2, T1, T2, E3). As of now, WtE facilities have to pay 238 NOK for every ton of CO2 released (Wergeland et al., 2023), which according to the industry is impeding them from implementing CCS (BIR, 2022b) and leads to a loss in market competition as Sweden does not have the same tariff for their WtE industry (Wergeland et al., 2023), meaning they can offer a lower gate fee for waste disposal.

Informant B2 and T2 suggested that the tariff should instead be put in the design and production phase of the product life cycle, and not disposal, as this impedes their ability to handle the waste. Informant E3 agreed, stating that the current tariff severely affects the waste sector, and complicates the financing of CCS in WtE. The KAN network have also called for measures to avoid waste being sent out of Norway (KAN, 2022).

Interestingly, at the same time, informants viewed increased CO2 emission tariffs as a trigger for CCS (informant O1, T2, E1, E2, E3).

6.3.3 Summarizing regime actor agency

Collectively, informants were found to engage with drivers and barriers through two modes: calls for improved policies and supporting frameworks, and through networks of collaboration. These two modes were often interrelated, as networks jointly worked to improve policies and supporting frameworks. Additionally, collaboration was deemed essential by informants to overcome challenges in establishing a CCS value chain in Trondheim.

7 Discussion

This section will examine and discuss the findings presented in section 6 in comparison to the empirical background and theoretical framework encapsulating this thesis to answer the following research questions:

> *What are the drivers and barriers to implementing carbon capture and storage in the Waste-to Energy industry, and how is this transformation of the waste to energy affected by contextual factors and preconditions?*
>
> *How are actors engaging with the identified drivers and barriers, and what sort of strategies are they employing to improve the conditions for Carbon Capture and Storage in the Waste-to-Energy industry?*

From a theoretical perspective, this thesis situates the in the MLP as an interaction between WtE and CCS as a niche-regime interaction similar to the reconfiguration pathway, and one which is heavily characterized by the involvement of regime actors to overcome contextual factors and preconditions affecting the transformation.

Beyond stating that CCS is dependent on the point-source of incumbent industries capture CO2 (Lefvert et al., 2022), existing literature has neglected to highlight how regime actors are interacting with the niche level and working to create favorable conditions for the adoption of CCS. These interactions are crucial to understand why change is happening in the waste regime. For the sake of flow and relatedness, these notions will be interweaved into the following sections, rather than to be presented alone.

I have constructed a simplistic illustration of the three analytical levels based on the empirical background and findings presented in section 6:

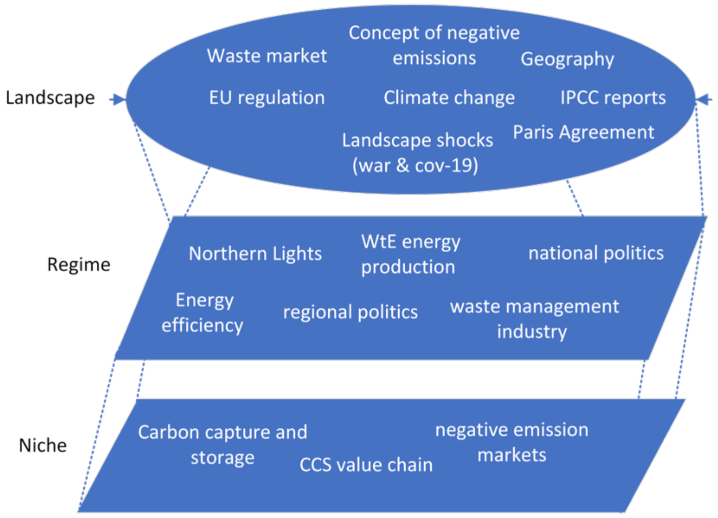

Figure 7 Schematic representation of components affecting CCS in the Waste sector. Examples are not conclusive but show components identified in the analysis.

Due to space limitations, key findings will be presented and discussed in the following sections, and summarized in section 8.

7.1 Regime interpretation of CCS

This section attempts to merge drivers and barriers to provide a full picture of how regime actors interpret CCS. This is useful because it allows for comparisons and provides a theoretical understanding of barriers and drivers.

7.2 Regime allignment through co-evolution

The analysis showcased a push for climate action within several sub-regimes. If relating these to MLPs sub-regimes, drivers can be understood as processes of regime alignment (figure 5). In the case of climate action, the socio-cultural regime and the political regime were most prominent.

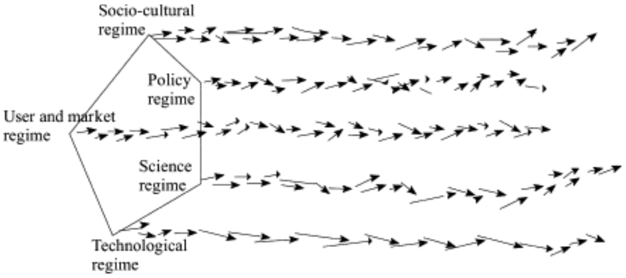

Figure 8 Alignment of ongoing processes in a socio-technical regime (Geels, 2004:912)

The socio-cultural regime was identified by the broad social acceptance for climate solutions and concern for climate change, while the political regime was visible in the engagement of the local government in all cases.

The science regime can be viewed as the bedrock, which legitimize CCS in WtE as a necessary strategy for combating climate change. This sentiment was repeated by both regime actors and at the landscape level (EU and UN) illustrated the benefits of CCS in WtE.

The above-mentioned sentiments coincide with the industry regime’s perception of CCS as the only solution to decarbonizing WtE, yet their ability to operate CCS is limited by misalignments in the political, and user and market sub-regimes, discussed in section 7.2.1.

The technology regime also views CCS as symbiotic to WtE, but that there are some barriers that need to be overcome to improve heat integration and energy efficiency, discussed in section 7.3.

7.2.1 Improving regime misalignments

The political push for CCS in WtE was interpreted as greater at the local level than at national level. Relating this notion to Hansen and Coenen (2015) argument that regional urban policies often run ahead of national policies, one can argue that there is a misalignment between the political levels. An explanation here could be that the regional level is more reactive to voter preferences than the national level. Another reason could be that reducing emissions from WtE facilities is more urgent for the host municipality than to the national level, i.e., proximity.

Political misalignments were illustrated by the several regulatory barriers identified at the national level, such as a lack of financial support schemes and regulation facilitating negative emission markets. Similar to studies in the empirical background, All informants believed CCS in WtE was contingent on financial support by the national government to cover CAPEX – similar to the findings of (Lefvert et al., 2022). BIR criticized the current strategy of funding only the facility at Klemetsrud, believing a broader funding scheme would be a better strategy to demonstrate CCS in WtE. Similarly, informant B2 found it strange that not more projects were funded, given international reports on climate change.

Regime actors employed several strategies to address these political misalignments, but a shared strategy by all case informants and zero was to gather in networks. Through the KAN network, WtE firms voice financial, technical, and regulatory concerns. Likewise, municipalities promote CCS in WtE through the Metropolitan Network for Climate (Oseland et al., 2021).

Relatedly, informants revealed several shortcomings in the user and market sub-regime, with is interrelated with the political regime as constructing the market is viewed as a political endeavor. There were three main concerns: 1) CO2 tariffs, 2) no market for negative emissions, and 3) the commodity market for waste. Collectively, these would have to be improved to ensure OPEX, according to informants.

I find it useful to analyze these concerns from the triple embeddedness framework, as they could be viewed as a way of aligning the economic task environment of the industry with CCS. The economic (task) environment of consumers and suppliers is shaped by selection criteria (Geels, 2014a). In the waste sector, these translate to how low of a price the ability to cover the expenses of conventional operations with CCS, as well as being able to offer competitive bids in the reverse auctions of the waste market. To achieve this post CCS, the industry is contingent on supportive policies. From this view, the engagement from firm-in-industries can be viewed as an approach to improve the economic task environment of CCS in WtE through influencing the socio-political environment to draft favorable policies and regulations (Geels, 2014a).

The municipalities are supportive of these changes, which may be due to their own benefits of CCS in WtE.

One of the most stated suggestions to improve the economic task environment was to establish negative emissions market, as these would commodify CCS in WtE and offer alternative business models. An alternative suggestion was for the public sector to renumerate biogenic CCS. This can be interpreted as an expansion of the protective space of CCS.

Interestingly, informants gave some conflicting statements on CO2 tariffs. On the one hand they think that increased tariffs are needed for actors to consider implementing CCS. At the same time, they criticize the way it is applied to the waste sector, suggesting the regime is uncertain of how to interpret these new notions into their activities.

7.2.2 Summarising regime allignment

Collectively, the alignment of the different sub-regimes can be interpreted as an case of co-evolution (Geels, 2011), where sub-regimes influence each other to create a new and stable configuration that incorporates CCS. As reflected by the misalignment of the political regime, this process is ongoing.

In relation to the reconfiguration pathway, the discussion above reveal that CCS is not only a technical reconfiguration of WtE, but a wider reconfiguration of the waste management regime as a whole including new practices, new regulations, changes to energy output. This repeats current theoretical presentations of the reconfiguration pathway as multi-dimensional (Laakso et al., 2021).

7.3 Effects of landscape level

The landscape level is identified to have both positive and negative effects on CCS in WtE. Some informants stressed the importance of UN and IPCCs reports on climate change in shaping the discourse on climate change and legitimizing CCS. These sentiments have been translated by sub-regimes, as illustrated by the importance of climate action.

The landscape has also had negative effects. At Klemetsrud, Informant O2 named several landscape effects that have increased CAPEX. Covid-19 and the war in Ukraine are interpreted as external shock affecting global energy and commodity prices, while national monetary conditions such as inflation and the weak Norwegian currency was identified as dramatically affecting the price of the Klemetsrud project (Valderhaug, 2023). Informant O1 also stated the general tendency of industrial projects to have budget overruns in Norway, without being able to elaborate why. Collectively, these notions expand on the current literature by highlighting the significance the landscape level has on the transition. Here one can draw parallels to UKs green energy transition presented in section 3, where the financial crisis of 2009 severely hampered private and public investments (Geels et al., 2016).

7.4 Technical challenges to CCS - adaptive capacity

Existing literature has identified several technical barriers in the adaptive capacity of the WtE regime, such as energy efficiency (Roussanaly et al., 2020; Tang & You, 2018). This thesis expands upon the existing understanding of these by discussing what informant statements reveal about the adaptive capacity (Dolata, 2009) of the WtE sector to incorporate new technology and infrastructure. Although regime actors interpreted CCS as mature, there were several uncertainties in how CCS technologies should be implemented effectively. These were reflected in several barriers, most notably heat integration, space limitations, and value chain.

7.4.1 Heat integration

Informant B2 highlighted the crucial role of WtE facilities as energy producers, demarking the multi-sectorial nature of WtE as both a means of treating waste and producing energy. Informants thus identified it as crucial to ensure heat integration and energy efficiency of CCS in WtE. One understanding of this is that CCS is not yet fully technically compatible with WtE, as it hampers one of the sector’s primary services. Related to the reconfiguration pathway, this point scrutinizes the assumed symbiosis between CCS and WtE. It also speaks of the adaptive capacity of the WtE sector, as the two are not fully symbiotic yet.

This also constitutes a crucial regime-niche interaction. As stated by informant E2, improving the energy efficiency is a primary concern in CCS research, and partly driven by its interaction with WtE.

BIR has overcome this barrier by close collaboration with Aker Carbon Capture, and plan to opt for partial capture through installing a modular facility. Not only does this allow them to retain more of the energy, but the standardized module has a lower CAPEX than full-scale. I interpret this as a regime-niche interaction, benefiting both parties.

7.4.2 Space limitations

Space limitations was not identified in the existing literature but was deemed a substantial barrier by all cases. Informants reported that space for CCS was not considered when the WtE facilities were built. As a physical barrier, space can be viewed as a notion on WtEs adaptive capacity because it is not fit expand.

Additionally, as seen in Bergen and Trondheim, the lack of space also created financial, social, and political barriers to the deployment of CCS as local constituents and firms may oppose it in the near future. This reveals an interesting dynamic about the socio-cultural regime: there may be widespread social support for CCS so long as it does not affect people personally - a ‘not in my backyard’ attitude. Here one can draw parallels to other ongoing transitions in Norway such as the deployment of wind-power.

Informant B2 also suggested that if there would be a conflict of interest over space, then the municipality would expropriate the area to secure CCS in WtE. This reflects the political nature of CCS, and how important it is perceived by the local government in reaching their climate goals. Similarly, informant O1 and O2 stated that the local government had been essential to materialize the project at Klemetsrud. This thesis thus views local politics as a significant driver for CCS in WtE.

7.4.3 Value chain

Similar to existing literature, establishing a value chain for CCS was seen as a major barrier, for several reasons. At the general level, informants stated that the main challenge to the value chain was the considerable costs of constructing and operating it, which will require building out considerable infrastructure for docks and intermittent storage. This discouraged actors because they do not want to bear the costs of being a ‘first mover’. At the same time, actors were motivated by the Longship project because it is taking a step as a ‘first mover’. Moreover, informant E1 stated that some industrial actors are calling for the national government to take responsibility for a establishing the CCS infrastructure, similar to how it has been done within the water and sewage sectors. Again, this marks an example of the political regime being tasked to solve barriers to CCS.

Specific to CCS in WtE, informants stressed scale and geography. WtE facilities are often small and spread out, both factors increasing the price per ton of CO2 collected. The empirical background stressed the importance of efficient capture technologies to make up for scale (Tang & You, 2018), yet this notion was not explicitly brought up in the interviews. To overcome this barrier, actors in Trondheim are collaborating in the Midt-Norge cluster to create a shared infrastructure, which existing literature stresses as a vital strategy for CCS deployment (Martin-Roberts et al., 2021; Sovacool et al., 2022).

Unlike Trondheim, Bergen has the advantage of being close to the planned CO2 injection site at Øygarden. This simplifies their value chain, which the informants interpret as a driver for CCS in WtE.

Finally, the time it took for Klemetsrud to overcome challenges in the value chain increased the timeframe of CCS projects, which exacerbated existing uncertainties and costs (Informant O2). The effect of time on CCS projects has not been identified in existing literature and is thus a significant finding.

Collectively, statements on the CCS value chain support the existing literature by identifying it as a major barrier – but that this can be partially abated by favorable geography. Geography thus has thus led to variance between the cases. In Trondheim, it is the largest barrier, while in Bergen its proximity to Øygarden is considered a driver.

7.5 Learning outcome

Two important theoretical notions emerge from the learning outcome driver. Firstly, it constitutes a niche-regime interaction, where the regime is collecting technical knowledge on how CCS fits with WtE through adopting it as an add-on (Geels, 2011). This is a typical characteristic of the reconfiguration pathway.

Using the triple embeddedness framework, one can discuss the motivations behind doing so from the perspective of the waste industry. The push for CCS in WtE is exogenous through the socio-political environment, specifically the push by municipalities, local politicians, and landscape pressures. However, it is also endogenous in the form of the industry regime's mindset and cognitive frames, as well as values. These are illustrated in informant T2's statement on the firm's mission to become net neutral by 2040 and their willingness to engage with CCS, and informant B2's statement that most working in the industry did so out of the will to solve waste challenges.

This is a significant finding, because it emphasizes that the WtE firms are not solely motivated by improving their economic task environment in expectancy of their sector's transition, but that they want to actively participate in this transition. Similar notions were not identified in the empirical background, thus constituting a significant finding.

8 Conclusion

This thesis has examined the ongoing transition of the waste sector from the perspective of two research questions, presented in section 1.1. To answer these, the thesis employed a qualitative multiple case study. It has collected both primary data from nine interviews and incorporated secondary data to triangulate findings. Findings were analyzed and discussed in light of theory and empirical background. This has enabled the identification of several drivers and barriers in the implementation of CCS in WtE, and elaborated on how the transition of the sector is affected by contextual factors and preconditions.

Summarized, key drivers identified were 1) climate action, which functioned as a motivation for both firms and municipalities to engage in CCS in WtE, 2) financing schemes and new business models that cover the costs of CAPEX and OPEX, and 3), learning outcomes, which was concerned with the benefit CCS projects in WtE could have for niche development.

Key barriers identified were 1) cost of CAPEX, which informants stated required supportive policies and framework to overcome, 2) cost of OPEX, which required changes in CO2 emission tariffs, the creation of a negative emissions market, and a restructuring of the waste market to tackle, 3) space limitations, which exacerbate other barriers, 4) heat integration, which is specifically required in the WtE industry to ensure its function as a provider of energy, and 5) challenges complicating CCS in WtE such as time and need of electricity.

Additionally, the thesis set out to shed light on the role and strategies of actors engaged in the transition. Summarized, they engaged through forming networks to strengthen their influence on national politics, as well as to share learning about the challenges of implementing CCS in WtE. In Trondheim, informants stated the Midt-Norge cluster as crucial to overcome challenges in establishing a CCS value chain infrastructure.

Broadly, however, actors used these networks to suggest favorable policies and frameworks. These had two main goals: to increase national government financing for CCS deployment, and to improve the economic dimension of CCS operation through modifying the CO2 emission tariff to in the waste sector and create a market for negative emissions.

Aggregating the findings to this thesis to the theoretical level, the thesis provides an empirical example of a regime alignment process, where the political and market sub-regimes are lagging behind changes in the other sub-regimes and impeding the transition process.

The triple embeddedness framework illustrates how actors use agency to improve their economic task environment to accommodate for shifts in the regime’s values and priorities, as well as in the socio-political environment. Dolata’s (2009) concept of adaptive capacity was employed used to highlight technical and physical challenges of implementing CCS in WtE, most notably the issue of heat integration and space limitations.

Finally, geography was conveyed through an emphasis on place-based factors, which showed a variance between the cases. This was apparent in the value chain, which was not a major concern in Bergen due to its proximity to the injection site at Øygarden, but was the largest barrier in Trondheim due to its distance to the latter and lack of easy access to dock for shipping. An interesting finding of this thesis is that these factors translated into different priorities, reflected in Statkraft Varme's engagement in the Midt-Norge cluster. For Klemetsrud in Oslo, the proximity to the national government is assumed to be a place-based driver, but I interpret the findings to be too weak to verify this.

The thesis has explored these research questions through the MLP and adopted similar concepts to cover its weaknesses in this specific research project. In a sense, this project has therefore tested the applicableness of the framework.

Some conclusions can be drawn from the findings of this thesis:

First, there are both drivers and barriers to implementing CCS in WtE, and overcoming these will require increased efforts within the political and economic dimensions, as well as to continue the technological development of CCS to reduce costs and energy in the capture process.

Second, at the general level, the findings of this thesis highlight the challenges of transforming hard-to-abate industries with CCS, and what measures actors involved are employing to increase the successfulness of these projects.

Finally, the evidence suggests that geography has a great impact on sustainable transitions, underscoring the need for increased attention to it in transition studies.

8.1 Limitations of study

Although this thesis has supplemented existing research on the implementation of CCS in WtE and the role and strategies of actors in this transition process, there are some limitations worth addressing.

Firstly, reflecting back on this thesis, it was perhaps too ambitious to answer two big RQ from the perspective of several theoretical angles. The aim of doing so was to highlight the complexity of transitions, and to accommodate the neglect of the agency of incumbent actors in transition studies. A narrower research approach would perhaps have yielded deeper understandings than those presented in this section, however.

Secondly, I chose the MLP as the theoretical framework for this thesis. As a process theory, MLP has a complex ontology - which can be challenging to combine with a comparative method employed in this thesis (Geels, 2011). As this was my first study employing the MLP, opting for a single case study or modifying the theoretical framework could have yielded clearer results by simplifying the analysis and discussion.

Despite these limitations, I still believe the findings of this thesis to be significant and useful for the WtE industry, and a contribution to the sustainability transitions literature.

8.2 Suggestions for further research

This thesis placed a heavy emphasis on the role of the national government to enact policies and frameworks to overcome several barriers to CCS in WtE. Further research should therefore explore how the national government interpret CCS in WtE, its drivers and barriers, and what kind of role it plays in addressing these. Such a study could benefit from employing the transition management framework.

Moreover, future studies should explore the prospects of negative emission markets, as these were identified as key to cover the OPEX of CCS in the future – as well as provide significant incentives for the adoption of CCS in industries containing biogenic emissions.

Research should keep a close eye on potential socio-cultural issues that may arise due to the space limitations identified in Bergen and Trondheim.

Finally, overcome challenge of scale and fragmentation of WtE plants, as well as unfavorable geography, a strategy could be to centralize WtE facilities. Centralization would have several benefits, such as establishing intermittent storage and shipping docks from the get-go, as well as allowing for bigger volumes which would lead to economics of scale. Future research should conduct a life-cycle analysis of the costs and benefits of doing so, and how this would impact existing WtE facilities. A last notion to consider in such a study is what do use all the district heating a centralized facility would produce.

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Appendices

Interview guide master thesis

Venue: Organization: Position/Role:

1. Hvem er du?
    a. Kan du fortelle meg litt om bedriften?
    b. Din rolle i bedriften?
2. Dere ser på CCS som en løsning for å kutte utslipp. Hvor starta dette?
    a. Hvor er dere nå i dette arbeidet?
    b. Hva har vært drivkraften bak dette arbeidet?
    c. Hvordan finansierer dere dette?
3. Hvis vi tar for oss utviklingen til karbonfangst, hvordan tolker dere forutsetningene for å benytte denne teknologien i Norge i dag?
    a. Tekniske forutsetninger (fangst, frakt og laging) – modenhet?
        i. Noen spesifikke utfordringer for dere knyttet til dette?
        ii. Noen fordeler her, i deres tilfelle?
    b. Politiske forutsetninger (politiske prioriteringer, virkemidler og regelverk)
        i. Hvor viktig har politikk fra nasjonalt nivå vært for denne satsingen?
        ii. Hva med regionalt nivå?
        iii. Internasjonalt samarbeid og deklarasjoner, slik som FNs bærekraftmål og EUs green deal
    c. Kulturelle forutsetninger, slik som sosial aksept eller press fra samfunnet i for eksempel media.
        i. Hvordan jobbes det med å skape sosial aksept?
        ii. Er det press fra samfunnet om å få til dette?
        iii. Herunder har det jo også blitt foreslått å finansiere karbonfangst gjennom å øke avfallsavgiften i byene. Tror dere dette er realistisk?
    d. Økonomiske forutsetninger, hvordan påvirker dette bedriftens økonomi?
        i. Positive økonomiske effekter? – lønnsomhet?
4. Hvilke utfordringer møter dere spesifikt med å benytte karbonfangst?
    a. Geografiske utfordringer
    b. Plass en utfordring?
    c. Risiko innbundet med implementering, hvordan håndterer dere dette?

        i. Usikkerhet i verdikjede, kostnad og effektivitet?

5. Noe som har gått igjen i litteraturen er prislappen og størrelsen på infrastrukturen bygget opp rundt transport og lagring. Hvordan håndterer dere dette i deres tilfelle?
    a. Samarbeider dere med andre lokale eller regionale på dette for å dele kostnadene, kanskje?
    b. Hva med mellomlagre?
    c. Generelt sett – er man avhengig av andre aktører for å realisere CCS?
6. Hvordan samarbeider dere med kommune, andre bedrifter osv.?
    a. Hvor viktig er dette for at CCS skal bli en suksess?
7. Er det noen andre tiltak dere tror kan være vel så viktige i deres bedrift for å kutte utslipp?
    a. Resirkulering, skape sirkulære kretsverk?
8. Hvor viktige tror dere et prosjekt som dette vil være for videre implementering av karbonfangst i norske industrier?
    a. I europeisk og global skala, da?

Takk for tiden din, har du noe mer du vil legge til?

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