The development of carbon capture and utilisation in the Netherlands

Thorsten Kuipers - 4814517

Delft University of Technology

TU Delft

accenture

The development of carbon capture and utilisation in the Netherlands

---

Master thesis submitted to Delft University of Technology

in partial fulfilment of the requirements for the degree of

Master of Science

in **Management of Technology**

Faculty of Technology, Policy and Management

by

C.W. Kuipers

Student number: 4814517

To be defended publicly in Delft on November 27th, 2023 at 16:00

Graduation Committee

First Supervisor:	Dr. ir. J.N. Quist	Energy and Industry
Second supervisor:	Dr. T. Hoppe	Organisation and Governance
Chairperson:	Dr. T. Hoppe	Organisation and Governance
Advisor:	ir. L.D. Virla Alvarado	Organisation and Governance
External supervisors:	M. Boerema	Accenture
	ir. J. Pieper	Accenture

TU Delft

accenture

Monday 20th November, 2023

Acknowledgement

I wrote this thesis as a graduation project for my Master's degree in Management of Technology, marking the culmination of my student life.

I would like to express my gratitude to Jaco Quist, Thomas Hoppe, and Luis Virla for their guidance and supervision throughout this master's thesis. The meetings and official interactions were bumpy once in a while, although helped me in shaping and refining my approach. Jaco Quist, as my primary supervisor, provided insightful feedback and supported me throughout the entire process in a collaborative and enjoyable manner. Thomas Hoppe offered insightful feedback that challenged my perspective, while Luis Virla helped me to critically assess my findings.

Furthermore, I extend my sincere thanks to Accenture for giving me the opportunity to undertake my thesis as a graduate intern. They provided me with abundant resources and a wealth of knowledge, allowing me to gain a comprehensive understanding of the company and its consulting practices. I am especially grateful to my supervisors, Marc Boerema and Jules Pieper, who guided me throughout the entire process. Our weekly meetings provided a platform for evaluating and discussing my progress, and their feedback proved invaluable. In addition to their constructive criticism.

My heartfelt gratitude goes to my friends, formal group members and fellow students. Thank you for being there during my time at the TU Delft.

C.W. Kuipers
Rotterdam, November 2023

Executive Summary

The depletion of finite fossil fuel resources, such as coal, oil, and gas, has become a global concern with significant energy security and sustainability implications. Carbon Capture and Utilization (CCU) converts CO_2 into valuable materials such as chemicals, polymers, and building materials and many other applications and offers a promising solution to reduce carbon emissions while creating valuable products and enhancing energy system flexibility. In contrast to Carbon Capture and Storage (CCS), CCU enables cost-effective carbon-dioxide removal and the production of carbon-based products. The Netherlands has set ambitious emission reduction targets in line with the Climate Agreement until 2050, focusing on five industrial clusters that can benefit from shared CO_2 resources. These clusters collaborate to reduce greenhouse gas emissions, which is critical in developing the CCU value chain. However, achieving cost-effective CCU implementation by 2050 requires substantial infrastructure and technological investment, including transportation considerations, aligning with broader CCS development efforts.

The problem is approaching the CCU development with a variety of utilisation cases and several beginning points in mind, that differ depending on the cluster and where multiple conditions for change exist. CCU implementation is complicated, and studies are scarce on how CCU implementation should be addressed, therefore it is unknown how the development of CCU in the Netherlands comes about. Therefore more study is on the CCU transition how this develops and under what conditions CCU could be implemented in the Netherlands. This resulted in the following research question:

”What are the carbon capture and utilisation niches in the Netherlands, and how to facilitate them?”

Strategic Niche Management (SNM) with supplementary insights from the Multi-Level Perspective (MLP) and Innovation systems (IS) are used in this qualitative study to analyse niche development. As a result, this thesis constructs an integrated analytical framework using the schematic MLP diagram in conjunction with IS as a foundation to analyse the inter dynamics between the landscape, the regime, and the niche. The SNM framework is employed at the niche level to give a detailed examination of niche development.

The research methodology is qualitative and comprises a combination of literature review and 14 semi-structured interviews with diverse stakeholders in the Netherlands. The data collected is subsequently subjected to thematic analysis.
The historical development of CCU has seen progress from the initial ideas in the 1990s to the establishment of significant initiatives and platforms in the 2010s and beyond. The focus has been improving CO_2 utilization, reducing emissions, and creating economic and social benefits. Initiatives on implementing full CCU value chains between industrial clusters failed due to a lack of interest in development by the clusters and decreasing financial resources. The sector continued to evolve, with new partnerships and initiatives in the Netherlands in 2023, indicating a commitment to carbon utilization for sustainable and environmental purposes. Nonetheless, the sector is gaining traction in the development of technology due to new initiatives.

Infrastructure stakeholders, with the governmental and regulatory stakeholders, are key players in the development of CCU in the Netherlands. Next to these two stakeholder groups, key players are scattered across the stakeholder map (see Figure 4.4 and Figure 4.5). Clusters are those which should be kept satisfied. Dutch Emissions Authority, Dutch Environmental Assessment Agency, Ministry of Agriculture, Nature and Food Quality, and Netherlands Enterprise Agency should be involved in the development of CCU by FutureCarbonNL and CCU Alliance. Currently, these entities are not regularly involved or not involved but are key players in the development.

The innovation system interaction unveiled the influence of climate change, geopolitical independence and circular economy of the regime and niche level initiating for change. In the Netherlands a broad variety of socio-technical regimes are related to the development of CCU. The regimes are related to electricity, fossil fuels, chemicals, heavy industry, construction, waste, agriculture, and food. All are influencing or are being influenced by the utilization niches.

As became apparent from the problem statement and the literature review, CCU technologies were expected to emerge around the industrial clusters. Nonetheless, it can be concluded that there is no specific emphasis on the clusters. Instead, it can be concluded the niches are divided into direct and indirect utilization. CO_2 gas and mineral products are related to direct utilization. Fuel, material, (animal)food, and chemical products are related to indirect utilization. In addition, it can be concluded that collaborations reflect the dynamic and evolving landscape of CCU initiatives in the Netherlands, with a particular emphasis on hydrogen, green gas, and innovative approaches to waste repurposing. Overlapping regimes, like electricity and waste and electricity and fossil fuels, emphasize the importance of cross-sector collaboration. Shared interests in food and agriculture and chemicals and fossil fuels highlight the need to diversify feedstock sources and advance sustainability. Together, the innovation system underscores the multifaceted nature of Dutch CCU innovation.

The Netherlands has the potential to become a global CCU technology provider through both direct and indirect utilization. Government commitment is crucial for CCU technology advancement. The emergence of the CCU Alliance offers opportunities for innovation, negative emissions policies, and stakeholder collaboration in direct utilization, while indirect utilization offers benefits like financial support, R&D acceleration, market expansion, and economic growth facilitated by FutureCarbonNL.

However, barriers in both direct and indirect utilization include challenges such as uncertain CO_2 supply, sustainability, stakeholder and user acceptance, policy hurdles, and governmental expertise and communication. In direct utilization, governmental structure is a specific barrier, while vision misalignment and technology integration are issues in indirect utilization. To promote CCU niches effectively, prioritizing these barriers and focusing on contextual, go-to-market, and implementation factors are crucial. This stimulation is categorized per stakeholder.

To advance, the Dutch government should develop a comprehensive CCU vision, separate from CCS, while considering the broader context of decarbonization and the circular economy. This vision should be developed internally, align with national objectives, and include a market policy to address CO_2 supply scarcity. A policy framework is needed to prevent double counting of CO_2 emissions. Different ministries should collaborate to streamline processes for faster CCU project implementation. Companies like Gasunie and Linde Gas, particularly Linde Gas, play essential roles in CCU development. Linde Gas should expand collaborative efforts with regional stakeholders and invest in research on integrating CCS and CCU networks. Gasunie should connect disparate clusters for long-term CO_2 supply flexibility. Industrial clusters should integrate CCU technologies into their production processes to bridge the gap between supply and demand. Collaboration within clusters is essential for further CCU adoption. FutureCarbonNL should align the vision of regime players with stakeholders challenging the regime through dialogues and workshops. These companies should engage communication experts to effectively communicate their CCU initiatives. They should foster open dialogues through public consultations, establish transparency in project planning, and educate their employees about CCU principles. Developing comprehensive plans for CCU technology integration into existing operations is crucial for scaling and sustainable growth.

In future research, there is a need to focus on expanding knowledge about the right pathways for stimulating CCU development and aligning it with Dutch climate and economic goals. This includes developing comprehensive Life Cycle Assessment (LCA) calculation models that consider scope 1, 2, and 3 emissions throughout the entire CCU value chain to assess CO_2 emissions and sustainability accurately. It's also important to develop models that incorporate Emissions Trading System (ETS) or carbon credits to prevent double counting of CO_2, along with regulations to support these methods. Additionally, research should address the sustainability of various CCU options along the value chain. Furthermore, future research should engage a broader range of stakeholders, including food, process technology, engineering, infrastructure, clusters, NGOs, licensors, and government divisions. As perspectives may evolve with the maturation of CCU niches and the availability of more information, ongoing research should adapt to these changes and delve deeper into the various CCU niches within the Netherlands.

This work presents a detailed examination of the development of CCU niches in the Netherlands, interdynamics between landscape elements, socio-technical regimes, and niches by merging three frameworks (SNM, MLP, IS) in one analytical framework. Several enablers, drivers, and opportunities emerged due to learning processes, network creation, and shaping of vision and expectations among actors involved in niche growth. Finally, the niches are facilitated in order for them to develop.

Keywords: Carbon capture and utilization (CCU), development, socio-technical niche, Netherlands, Strategic Niche Management (SNM), Multi-Level Perspective (MLP), Innovation system (IS), Business Models

Contents

Abbreviations

Abbreviation	Definition
ACM	Authority for Consumers and Markets
ARNL	Research Centre for Nanolithography
BIM	Building Information Modeling
CES	Cluster Energy Strategy
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture Utilization and Storage
DEI+	Demonstration Energy and Climate Innovation
EBN	Energy Management in the Netherlands
ETS	Emissions Trading System
EU	European Union
FAO	Food and Agriculture Organization
GHG	Green House Gas
HBEs	Renewable Fuel Units
IEA	International Energy Agency
LCA	Life Cycle Assessment
LTO	Dutch Federation of Agriculture and Horticulture
MLP	Multi-level Perspective
MOB	Nature Organisation Mobilisation for the Environment
MoT	Management of Technology
Mt	Megaton
NEN	Netherlands Standardization Institute
NIS	National Innovation system
NVWA	Netherlands Food and Consumer Product Safety Authority
OCAP	Organic CO_2 for assimilation by plants
OPEC	Organisation of Petroleum Exporting Countries
PBL	Netherlands Environmental Assessment Agency
PFAS	Per- and Polyfluorinated Substances
REV	Register of Energy for Transport
RIS	Regional Innovation System
RIVM	Netherlands Environmental Protection Agency
RVO	Netherlands Enterprise Agency
SAF	Sustainable Aviation Fuels
SDE++	Stimulating sustainable energy production and climate transition
SME	Small and Medium Enterprises
SNM	Strategic Niche Management
SSI	sectoral systems of innovation
TIS	Technological Innovation System
TRL	Technological Readiness level
TS	Technological systems
TNO	Applied Scientific Research
VNCI	Association of the Dutch Chemical Industry
VNPI	Netherlands Petroleum Industry Association
WLO Hoog	Prosperity and Living Environment, 'high' scenario

Glossary

Concept	Definition
Atmospheric CO_2	CO_2 derived from the atmosphere also known as synthetic
Biogenic CO_2	CO_2 derived from biological source
CO_2 sink	long-term CO_2 storage in organic material
Fossil CO_2	CO_2 derived from a fossil source

List of Figures

List of Tables

1 Introduction

Industrial CO_2 emissions account for 31% of all CO_2 emissions equivalent to 11,000 million tonnes of CO_2 (Paltsev et al., 2021). The Paris climate goals have been set to limit global warming to 1.5°C by the end of the century by peaking Green House Gas (GHG) emissions before 2025 at the latest, reduce emissions 43% by 2030 and reach carbon neutrality by 2050 ("Paris Agreement", n.d.).

The demand for industrial products will likely rise further, placing upward pressure on industrial GHG emissions. Without urgent action, the percentage of emissions from industry would climb rapidly, accounting for 45% of total CO_2 emissions (IEA, 2019). Generally, one can prevent emissions through hydrogen installation or electrification to decrease emissions. Moreover, emissions can be averted by offsetting them through an Emission Trading System (ETS), carbon credits, or tokens, which all allow for trading or accounting of emissions; these tools do not directly allow for emissions reductions. Another alternative is mitigation, which can be accomplished by increased efficiency or carbon capture, which allows for either storage or utilization.

There are limited technological options for reducing emissions in industrial operations of the "hard to abate" industry, like iron and steel, cement, oil refinery, and chemicals, where industrial decarbonisation is a challenging task (Griffiths et al., 2021). Decarbonisation is the removal or reduction of CO_2 emissions into the atmosphere. The hard-to-abate industries account for 20% of global emissions and face several variables which all contribute to the difficulty in reducing industrial emissions (Rissman et al., 2020). A visualisation is presented in Figure 1.1 on the different hard-to-abate emissions. Thereafter a categorised explanation is given:

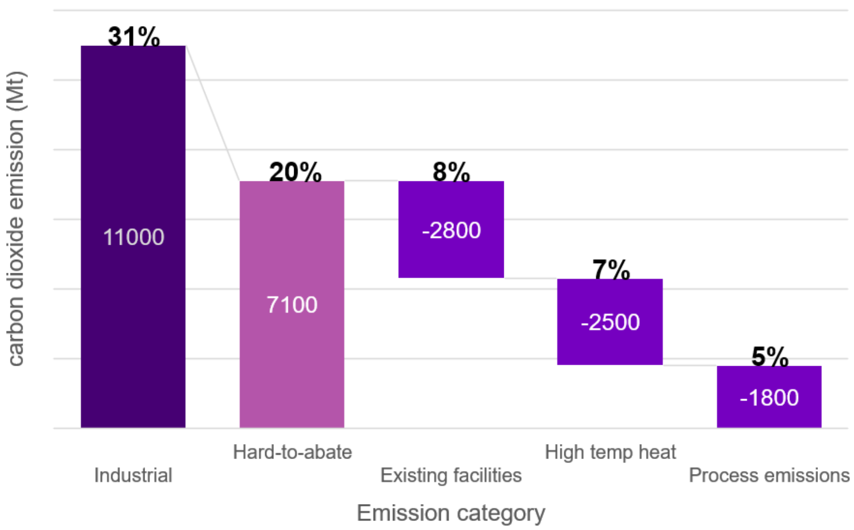

Figure 1.1: Hard to abate emissions (IEA, 2018, 2019)

Existing facilities (8%): Industrial facilities have a prolonged lifespan, up to 50 years, and have the ability to "lock in" emissions for decades. Since 2000, worldwide clinker (the major component of cement) and steel production capacity has more than quadrupled, implying that at least half of the current production capacity is less than 20 years old (IEA, 2018, 2019).
High-temperature heat (7%): Several industrial operations need high-temperature heat to run their operations. Moving from fossil to alternative fuels for operations requiring temperatures as high as 1600 degrees Celsius (°C) is challenging and costly, demanding facility changes and prohibitively expensive electrical requirements (IEA, 2019).

Process emissions (5%): Process emissions originate from chemical or physical reactions and cannot be prevented by switching to other fuels. Process emissions are a distinctive feature of cement manufacturing, accounting for 65% of emissions, although they are also significant in iron and steel, aluminium, and ammonia production (IEA, 2019).

1.1. Carbon capture

Carbon Capture technology could be a choice in the hard-to-abate industries that lead to reductions in greenhouse gas (GHG) emissions. Carbon capture eliminates 90-99% of CO_2 emissions from industrial operations by handling emissions from existing assets. Carbon capture options are at different technology readiness levels (TRL) (Hong, 2022). Some TRLs are wide, such as Industrial separation and Post-combustion capture, originating from newer and older technologies under development:

1. **Industrial separation (TRL1-9)**: are industrial technical techniques used to separate a product from contaminants or other items (de Haan et al., 2020).
2. **Post-combustion capture (TRL1-9)**: Separating CO_2 from flue gases produced from large-scale fossil fuel combustion like boilers, cement kilns, and industrial furnaces.
3. **Pre-combustion capture (TRL3-9)**: The pre-combustion capture involves syngas (a mixture of hydrogen H_2 and carbon monoxide CO) being produced from fuel reforming followed by CO_2 separation. The process net result is capturing CO_2 and hydrogen gas to be used as fuel, with water as the ultimate combustion product.
4. **Oxy-fuel combustion capture (TRL4-7)**: Burning fossil fuel in pure oxygen, leading to nitrogen-free flue gas production with only CO_2 and H_2O. The flue gas condensation leads to a pure CO_2 stream being produced and the elimination of NO_X gases.
5. **Chemical looping Combustion (TRL6)**: generate two intrinsically separated flue gas streams: a stream from the air reactor, consisting of atmospheric N2 and residual O_2, but sensibly free of CO_2; and a stream from the fuel reactor predominately containing CO_2 and H_2O with very little diluent nitrogen. The air reactor flue gas can be discharged into the atmosphere, causing minimal CO_2 pollution. The reducer exit gas contains almost all of the CO_2 generated by the system (Ishida & Jin, 1997).
6. **Direct air capture (TRL7)**: Separates CO_2 directly from the air using an engineered system (Erans et al., 2022).

The International Energy Agency (IEA) predicted that 7,6 Gt of CO_2 is currently captured per year in the energy industry from a diverse range of sources by 2050 to comply with the Paris climate goals (IEA, 2022b). In hard-to-abate industries, carbon capture is the third most important lever, after hydrogen and electrification, for emissions reduction, contributing a cumulative 27% (21 $GtCO_2$/year) of emissions by 2060. Within these industries, cement contributes a cumulative 18% of overall emissions (5 $GtCO_2$/year), iron and steel a cumulative 15% of overall emissions (10 $GtCO_2$/year), and chemicals a cumulative 38% of overall emissions (14 $GtCO_2$/year) (IEA, 2019). In 2017, the Dutch government set an ambitious aim for 2030 of lowering national CO_2 emissions by 49% compared to 1990. This necessitates 48.7 Megaton (Mt) of extra reductions over the baseline outcome of current strategies (Akerboom et al., 2021).

Although carbon capture technology implementation in the industrial sector has been limited, it has the potential to reduce industry GHG emissions (Rissman et al., 2020) significantly. After capturing the CO_2, it can follow two different pathways: storage underground, mostly empty oil fields, or utilisation by which it will be used as feedstock for other sectors or processes.

1.1.1. Storage

Carbon capture and storage (CCS) is recognised as vital to least-cost pathways and is an important bridging technology to sustainable energy for climate change mitigation. In the last couple of years, carbon storage has grown 44% year over year in capacity since 2017, as shown in Figure 1.2.

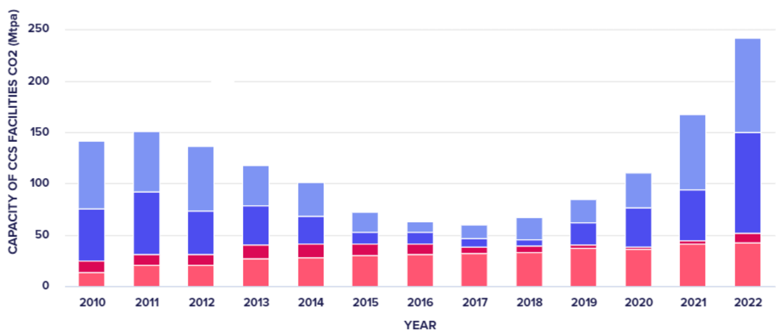

Figure 1.2: From top to bottom, the bar represents early development (light blue), advanced development (blue), in construction (red), and operational (light red)(Zapantis et al., 2022).

Most of the operational plants are located in North America, although other parts of the world like Europe, Southeast Asia and North America are developing new plants, as can be seen in Figure 1.3.

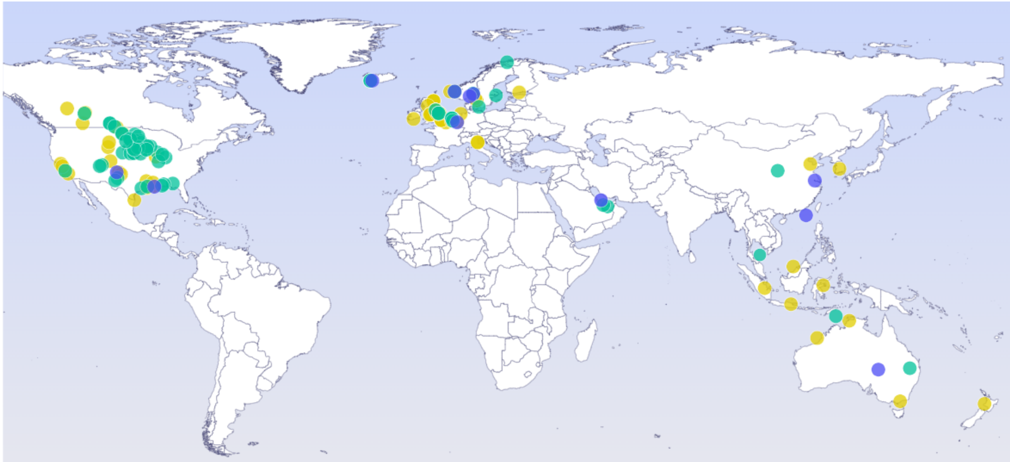

Figure 1.3: New CCS development. Yellow dots represent early development, green dots represent advanced development, and blue dots represent plants under construction (Zapantis et al., 2022).

The Dutch projected annual emission reductions in the Netherlands in 2030, based on the Dutch 2019 Climate agreement, enhances 7,2 Mt annually until 2030 as shown in Figure 1.4 (Akerboom et al., 2021).

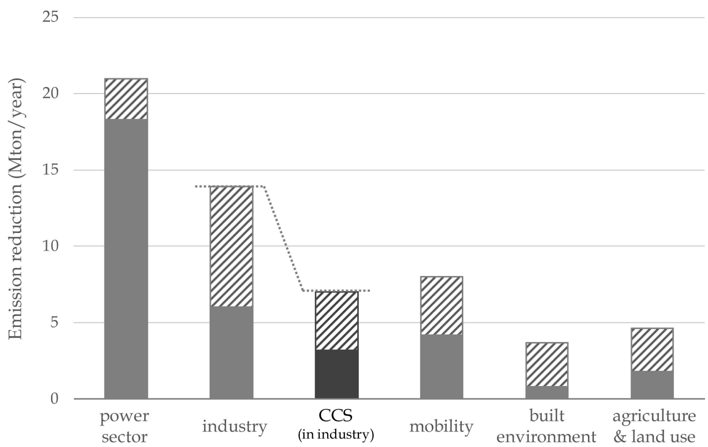

Figure 1.4: Projected annual emission reduction by CCS in the Netherlands by 2030, based on the Dutch 2019 Climate agreement, according to analysis of the Dutch Environmental Planning Agency (PBL). The Klimaatakkoord allocates the emission reduction task to five sectors of the energy economy (gray). CCS is part of industry. The hashed areas indicate the uncertainty between low and high estimates for 2030 (Akerboom et al., 2021)

In the Netherlands, Porthos, a collaboration between Port of Rotterdam, Gasunie, and Energie Beheer Nederlands (EBN), is working on a project that would transport and store CO_2 from industries in the Port of Rotterdam in empty gas fields beneath the North Sea. Several firms will catch the CO_2 that Porthos will transport and store. The enterprises will feed CO_2 to a shared pipeline that will run through the Rotterdam port region (Porthos, n.d.).

Although it can be seen as an important bridging technology, the storage may entail different risks and problems, such as:

- A smaller storage capacity than expected (Oltra et al., 2012; van Egmond & Hekkert, 2012).
- CO_2 that is stored may escape to the surface (Oltra et al., 2012; van Egmond & Hekkert, 2012).
- Long-term effects of storage in geological formations are unknown (Newell & Ilgen, 2019).
- Storage is delineated by the geographical location of the storage site (Oltra et al., 2012).
- When storing onshore, public acceptance is an issue (Oltra et al., 2012).
- Whereas in the event of deep ocean sequestration, the immediate result would be a decrease in pH, which would increase the acidity of the water and might lead to ecological imbalance (Newmark et al., 2010).

1.2. Utilisation

Resource depletion of fossil fuels, comprising coal, oil, and gas, has emerged as a pressing global concern due to their finite nature and the environmental challenges posed by their extensive use. As the globe continues to rely significantly on nonrenewable energy sources for economic growth and development, their steady depletion shown in Figure 1.5 has serious consequences for energy security, climate change, and sustainability.

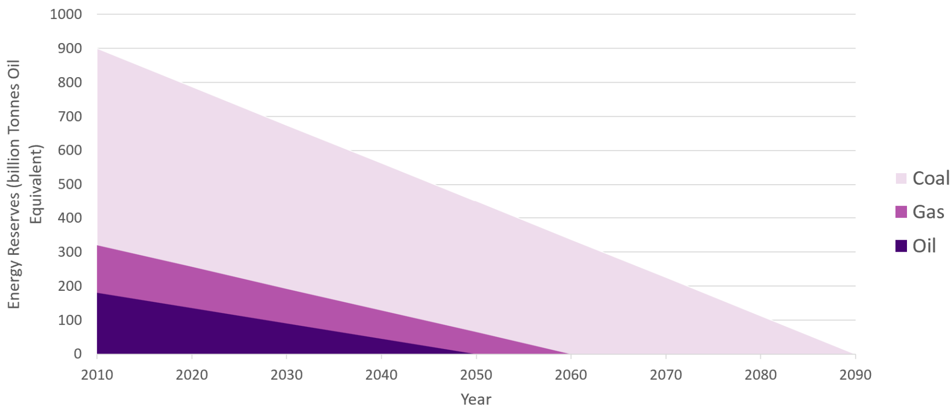

Figure 1.5: Depleting natural resource reserves (Xia, 2017)

For almost a century, fossil fuels have formed the backbone of industry and have propelled modern societies. Their extraction, refinement, and use have fuelled economic progress, transformed transportation, and raised living standards. However, the unrelenting exploitation of these resources has resulted in the buildup of greenhouse gases in the atmosphere, contributing to global warming and climate-related disasters. The need to address the depletion of fossil fuel resources has fueled initiatives to shift to renewable energy sources such as solar, wind, and hydropower. However, large-scale renewables integration poses its own set of obstacles, such as intermittency and storage issues. As a result, the world is increasingly focusing on novel technologies such as CCU to lessen the environmental impact of fossil fuel use while extending the lifespan of these valuable resources. CCU could be a viable technology to address resource depletion and climate change by capturing and converting CO_2 emissions from industrial processes and power plants into valuable goods. Rather than allowing carbon to escape into the atmosphere, where it contributes to the greenhouse effect, CCU technology converts it into valuable materials such as chemicals, polymers, and building materials and many other applications after the CO_2 has been captured as can be seen in Figure 1.6. This procedure minimises carbon emissions and opens up the possibility of using it as a resource, contributing to resource sustainability.

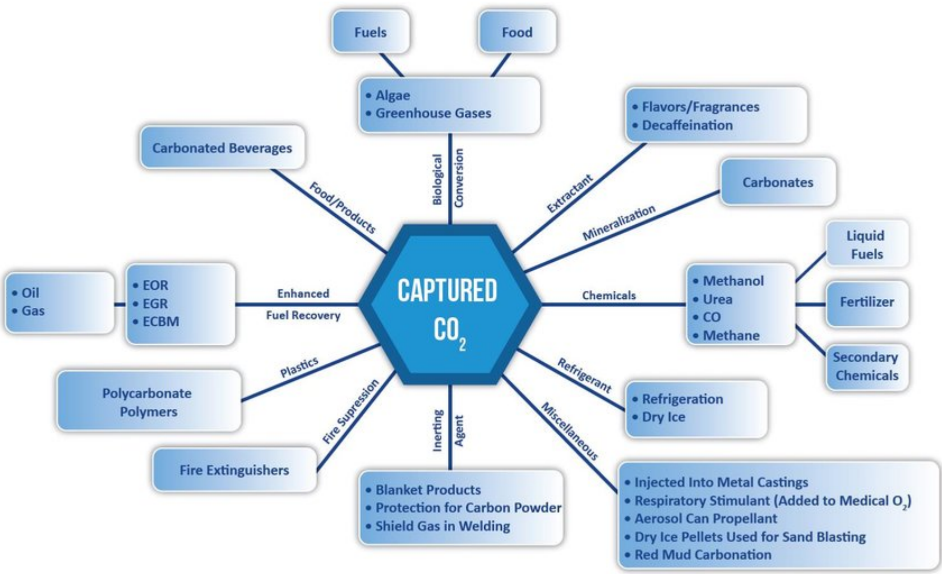

Figure 1.6: CO_2 Utilisation options (Zoi & Edesio, 2019)

CCU is gaining recognition as a means to reduce emissions while also producing valued commodities and energy system flexibility. When compared to CCS, CO_2 utilization may provide opportunities for lower-cost carbon-dioxide removal for chemical products, carbon products with lower land-use requirements than biomass-derived carbon products, and a new industry that may address environmental justice and other negative impacts associated with the production of incumbent chemicals and materials. The new industry is in the lower range expectations, expected to have a potential carbon-dioxide use of 1-2 Gt/year, compared to the existing utilization of 0.18 Gt/year.(Jackson et al., 2018; Quéré et al., 2018).

CCU is an important concept in the closure of the circular economy and has a profound impact on society's perspective regarding the disposal of CO_2. In light of this, it is essential to consider the "R-ladder," a hierarchical framework comprising stages such as refusal, rethinking, reduction, reuse, repair, refurbishment, remanufacturing, repurposing, recycling, and ultimately, recovery. Given the diminishing availability of fossil resources, the act of recovery assumes a critical role within the circularity paradigm. Notably, when confronted with resource constraints or inherent limitations in circularity, products may necessitate a recovery process involving combustion. This transformation process converts products into CO_2, with the ensuing carbon or CO_2 serving as foundational molecules for the creation of new products. Not solely combustion can be the starting point of CCU as shown in Figure 1.7, in which the circular loop for CCU is depicted. The black box within the illustration will later be explained in Section 5.3.2 by Figure 5.3.

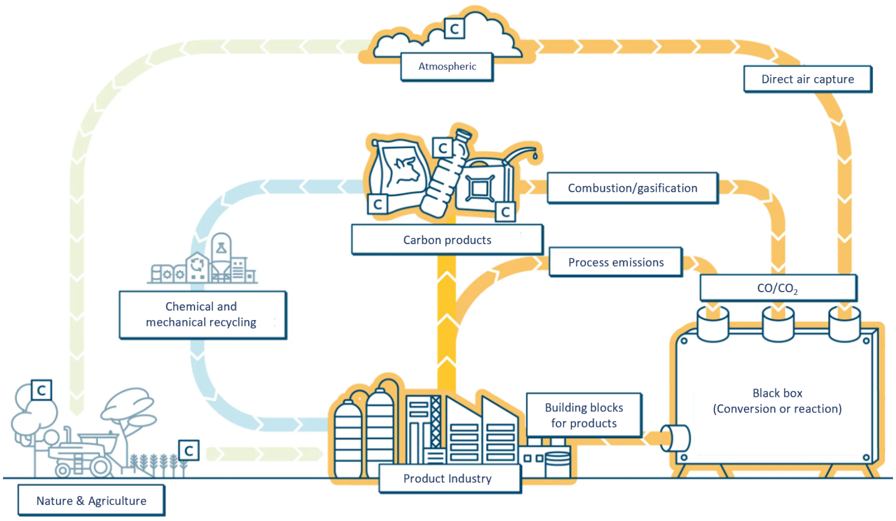

Figure 1.7: CCU circular loop (Translated and adapted from (FutureCarbonNL, 2023))

An important aspect of CCU is identifying what is done with the captured carbon dioxide. How long will the carbon dioxide be removed from the environment when the CO_2 is recycled in different products? Sick et al. (2022) introduced the difference between track 1 and track 2 CCU products, which clearly categorizes products based on the duration of CO_2 removal. It can be said that the duration that the CO_2 is stored in different products influences the importance of different niches. **Track 1** products remove CO_2 for at least 100 years if not permanently, making Track 1 products functionally similar to storing CO_2 underground via CCS, but with the benefit of using less oil in different oil-derived products. Concrete and aggregates are examples of products in which the CO_2 will be long-term stored.
The **track 2** products use or decomposition results in the release of CO_2 back into the atmosphere in less than 100 years. This CO_2 can be harvested again and used to produce products, keeping with the circular usage of carbon. Examples of products in which the CO_2 will be "short-term" stored are fuels, tires and clothes.

The Netherlands has defined a plan according to the Climate Agreement until 2050 on reducing CO_2 emissions. This plan strongly focuses on five clusters that can benefit from sharing different feedstock, such as CO_2 (Ministerie van Economische Zaken en Klimaat, 2019). These clusters are illustrated in Figure 1.8. It is up to the provinces and clusters to be proactive and initiate transition plans. The issue is that such a shift is extremely complex, and it is not clear how to approach it. As a result, it is critical to investigate how a transition to CCU should be handled and how this might be assisted in the future. All clusters have mapped their plans to reduce greenhouse gas emissions in programs. Currently, the clusters are already consulting with energy infrastructure managers on the networks needed for these plans (for electricity, gas, CO_2, hydrogen, and heat). This has led to Cluster Energy Strategies (CES). All plans are defined in the six front-runners programs (Ministerie van Economische Zaken en Klimaat, 2020). The sixth cluster is made up of companies from nine different industries that are scattered across the Netherlands.

Figure 1.8: Industrial clusters the Netherlands (van der Linden, 2019)

A specific emphasis is placed on the industrial clusters, which specialise in various aspects of the CCU value chain and are projected to play a vital role in its development but differ depending on the specific industrial cluster. Industrial cluster efforts, in general, have become a significant instrument for governments to build, promote, and strengthen economic collaboration, learning, innovation, and job creation within a specific region. Therefore, the industrial clusters are a location where the full CCU value chain emerges. A scale jump in technology and infrastructure is required for cost reduction in CCU. The cost-effective implementation of a CCU value chain is expected to be possible by 2050. This can only be achieved through investment in the industrial clusters to unroll CCU. However, to enable this, the full spectrum of the CCU value chain, shown in Figure 1.9, must be considered. Up to and including the transportation of the CCU value chain are already being considered in the development of CCS.

Figure 1.9: CCU value chain (Pieri et al., 2018)

1.3. Problem statement

This thesis will focus on the overall Dutch CCU developments and all of the aspects it has influenced and is influencing. Because of the CCU development's intricacy and infancy will touch every level of Dutch society and a multiplicity of actors in many sectors. The development is distinct from renewable energy technologies (such as solar PV or wind) in that it has multiple end-uses and is not inherently sustainable; thus, it addresses the explicit goal of sustainable development by promoting the development to a full CCU value chain.

The problem is how to approach the CCU development with a variety of utilisation cases and several beginning points in mind that differ depending on the industrial cluster and where multiple conditions for change exist. CCU implementation is complicated, and studies are scarce on how CCU implementation should be addressed. Therefore, it is unknown how the development of CCU in the Netherlands came about. Therefore, more study is on the CCU development, how this develops and under what conditions CCU could be implemented in the Netherlands. These intentions are described in ”het klimaatakkoord” on the National level in compliance with the European targets. Subsequent to the national targets, every cluster made its own plan of action to comply with the national plans. Nevertheless, it became clear that there are nationwide intentions to transition. **The desired situation** for the Netherlands is to utilise the CO_2 feedstock that comes from industries while using fewer fossil fuels by using the CO_2 feedstock instead in order to ensure a future carbon feedstock while providing a backup for depleting fossil resources.

1.4. Literature review

This section is related to the literature review that is relevant to the problem described in the previous section. The heading of the sections is carefully chosen based on the relevance of the problem statement.

1.4.1. Decarbonisation

Discussing the reduction of CO_2 emissions, the literature differentiates decarbonisation, deep decarbonisation and net-zero. Decarbonisation is the reduction of CO_2 emissions from a social and economic point of view (Sun, 2005), while deep decarbonisation is considered the reduction of CO_2 emissions annually by 42-57% by 2050 (relative to 2010), and 72-107% by 2100 (Bataille et al., 2016). Net-zero is mentioned in the literature by (Davis et al., 2018). They use net zero in the context of energy systems for decarbonisation. While reviewing the literature, I came to the conclusion that these terms are used interchangeably. Decarbonisation is also used to emphasise the need to reduce CO_2 emissions to conform to the Paris Agreement (United Nations, 2015) and the Intergovernmental Panel on Climate Change (IPCC) (P. Smith et al., 2014). Which would be described as deep decarbonisation or net zero. When discussing either deep decarbonisation, decarbonisation or net-zero in the remainder of this review, the reduction of CO_2 emissions is meant to conform to the Paris Agreement goals. All necessitate a comprehensive socio-technical transformation that includes changes in user behaviour, culture, politics, corporate strategies, infrastructure, and research (Skoczkowski et al., 2020). What is remarkable about net zero is that it emphasises the difficulty of the hard-to-decarbonise industries in this context and underscores the importance of further research in this direction. Therefore, the next section is about the hard-to-decarbonise industries.

1.4.2. Hard to decarbonise

Carbon capture can be considered to enable a smooth transition, especially in the hard-to-decarbonise industries where it is considered indispensable (Jones & Piebalgs, 2022). Therefore, some consider the technology as critical to meet the Paris Agreement goals of 2030 and 2050 (Yan et al., 2021). Others consider carbon capture as an interim solution on the way to a carbon-free future and therefore perceive carbon capture solely as an option to decrease the carbon footprint (Digmayer & Jakobs, 2017). Combining carbon capture and hydrogen seems inescapable in light of the hard-to-decarbonise industry. While the general application of hydrogen is being seen without the combination of CCUS, this is not set in stone. This implies that one should focus on eliminating fossil fuels and other factors in consideration. This may suggest that findings with a high proportion of renewable energy may not be universally applicable (Nurdiawati & Urban, 2022). This is backed by Palm and Nikoleris (2021), who argue that there is tension for the long-term strategy to support transitions away from fossil fuels while simultaneously strategising to make fossil fuels 'greener'. Roy and Schaffartzik (2021) and Xu (2021) argues that there is a paradox in the transition to renewable energies. Although China has made strides in renewable energy production, they are simultaneously expanding fossil energy production. This contradiction prevents renewable energy from threatening fossil energy's supremacy in the near future. An energy transition is considered a socio-technical transition that necessitates the co-evolution of social, economic, political, and technological variables. Procedures should be devised to speed up the transition process while recognising the old energy industry's inertia and relevance. The measures should involve the coordination of interest during the decarbonisation and the phase-out of excessive fossil fuel subsidies. This implies further research into the socio-technical variables in the hard-to-decarbonise industry. In addition, researchers have already stressed the relevance of emerging decarbonisation technologies, such as carbon capture and hydrogen. However, they do not agree with the transition of these technologies as just discussed. Therefore, research on the synergy and conflict between these technologies when combining them has not been discussed yet.

1.4.3. Industrial clusters

Clusters are a regularly mentioned definition in the literature related to the decarbonisation of industries. Bergman and Feser (2020) defined clusters as a group of business enterprises and non-business organizations, binding the clusters by buyer-supplier relationships, common technologies, buyer distribution channels or common labour pools. Delgado et al. (2016) defined industrial clusters as industries that are related by knowledge, skills, inputs, demand or other linkages that tend to be geographically concentrated. Upham et al. (2022) defined industrial clusters as large, multi-point emitters, energy consumers, and regional and national employers. Generally, a cluster in the context of this review is used to define the industries located in a similar region in relatively close proximity. The 'SuperPlaces' were only in the literature mentioned by Devine-Wright (2022) and originate from UK policy documents to emphasise the plan for a green industrial revolution. SuperPlaces were defined as geographical regions experiencing a systematic sectoral change in the manufacturing, transportation, and power generation sectors, positioned in a worldwide framework of economic competitiveness and potential UK advantage. The paper describes that superplaces combine all types of spatial imaginaries, which contain idealised spaces (industrial clusters), spatial transformations (the deployment of decarbonisation technologies) and specific places in the world (Devine-Wright, 2022). Policy documents mention two key technologies that underlie the SuperPlaces, namely hydrogen and CCUS within areas like Teesside, the Humber, Merseyside, North Wales and the North East of Scotland (Climate Change Committee, 2021; Department for Business, Energy Industrial Strategy, 2018, 2019; Department for Energy Security and Net Zero, Department for Business, Energy Industrial Strategy, 2020). Bokka and Lau (2023) were the only ones who defined industrial hub and referred to the same UK locations in Teesside and the Humber as Devine-Wright (2022). They implicate that the earlier mentioned Superplace would be a conjunction of different hubs, forming the cluster together. This is contradictory to the rest of the literature and will therefore not be taken into further consideration.

1.4.4. Carbon Capture and Utilisation

As said in the introduction, CCU could decarbonise hard-to-abate sectors and convert CO_2 into derivatives with higher energy density and economic value, such as fuels, polymers, and minerals. This has mainly described the view in which CCU is seen as a means for emissions reduction while using CO_2 as feedstock. However, the examined literature also emphasises the view in which CCU is seen as a resource security option (Bruhn et al., 2016; Kaiser et al., 2022). In general, CCU is considered an alternative for CCS as an CO_2 deducing option. This is seen as a problem for public and political support and CCU's further development and implementation. For a CCU business case to be viable, the used CO_2 must be less expensive than the traditional fossil carbon supply. Because costs are heavily influenced by the purity of the available CO_2 source and the effectiveness of the chemical process, economic feasibility is technology-dependent (Bruhn et al., 2016). A consequence is that various experts and stakeholders evaluate CCU largely in terms of its ability to contribute to climate change mitigation. As a consequence of such a framing, it has been observed that many stakeholders in the political debate, for example, in Germany, are sceptical or even negative about CCU because of its limited potential to contribute to climate change mitigation (Bruhn et al., 2016).

Last year, more work was presented on the different pathways of CO_2 utilisation (Chauvy & Weireld, 2020; Meylan et al., 2015; Philbin, 2020). Multiple studies have been conducted for techno-economic and environmental analysis of CCU, showing that CCU is technically feasible in the right places. Chauvy and Weireld (2020) concluded that the mapping and ranking of CO_2 utilization pathways could be a useful tool for prioritizing support and funding to help the development of large-scale CCU projects in Europe. Even if the available CO_2 consumption amounts are currently limited. Philbin (2020) suggests investigating the economic, technological and environmental conditions required to support CCU adoption, including the required supply chains and industrial infrastructure, such as CO_2 capture and transport capabilities and engineering plants for processing and converting CO_2. To fully use a region's CCU potential, the specifications of the various value chains must be coordinated. Understanding how to consolidate sources and the requirements, location, magnitude, and TRL of sinks can help inform the selection of capture, treatment, and transport technologies. The ability to discover the right technologies at the right scales unlocks the capacity to find the right partners (Castillo & Angelis-Dimakis, n.d.).

Pieri et al. (2018) examined the individual stages of the CCU value chain, in which the environmental and social implications of CCU value chains remain underappreciated. They addressed a few studies that analysed the environmental impact of carbon capture systems separately (using life cycle assessment) and one research that examines the system's overall environmental performance. Social impact evaluation has been largely overlooked, as has been the case with previous industrial symbiosis initiatives. However, in order to progress from the early stages of the development of a CCU value chain (opportunity identification and opportunity assessment) to the later stages (barrier removal and commercialization), a holistic view of the system that can examine the performance of all stakeholders involved and all components of sustainability must be adopted.

1.4.5. Conclusion literature review

A literature review relevant to the problem statement has been conducted.
To begin, various descriptions of decarbonisation in relation to meeting the Paris Agreement targets were examined. It became clear that net zero is emphasised in the context of hard-to-decarbonise industries.

Secondly, the hard-to-decarbonise industries are also mentioned as hard-to-abate. Carbon capture technologies will be an important lever to reduce CO_2 emissions within these industries. Research argues that there is tension for the long-term strategy to support transitions away from fossil fuels while simultaneously strategising to make fossil fuels 'greener'. This emphasises the paradox in the transition to renewable energies because some simultaneously expand fossil energy production. This contradiction prevents renewable energy from threatening fossil energy's supremacy in the near future. In addition, researchers have already stressed the relevance of emerging decarbonisation technologies, such as carbon capture and hydrogen. However, they disagree with the transition of these technologies as just discussed. Therefore, research on the synergy and conflict between these technologies when combining them has not been discussed yet.

Thirdly, it can be concluded that clusters and superplaces can be used to define geographically concentrated industries related by knowledge, skills, inputs, demand, or other linkages. Meanwhile, superplace emphasises the systematic change to decarbonise by the 2 two key technologies, CCUS and hydrogen.

Lastly, CCU technologies could be used for decarbonising hard-to-abate sectors and converting CO_2 into derivatives with higher energy density and economic value, such as fuels, polymers, and minerals. The literature emphasises the energy transition point of view and the situation in which CCU is seen as a resource security option. A consequence is that various experts and stakeholders evaluate CCU largely in terms of its ability to contribute to climate change mitigation. As a consequence of such a framing, it has been observed that many stakeholders in the political debate, for example, in Germany is sceptical or even negative about CCU because of its limited potential to contribute to climate change. Multiple studies have been conducted for techno-economic and environmental analysis of CCU, showing that CCU is technically feasible in the right places. Chauvy and Weireld (2020) concluded that the mapping and ranking of CO_2 utilization pathways could be a useful tool for prioritizing support and funding to help the development of large-scale CCU projects in Europe. Even if the available CO_2 consumption amounts are currently limited. Philbin (2020) suggests investigating the economic, technological and environmental conditions required to support CCU adoption, including supply chains and industrial infrastructure, such as CO_2 capture and transport capabilities and engineering plants for processing and converting CO_2. To fully use a region's CCU potential, the specifications of the various value chains must be coordinated. The individual stages of the CCU value chain have previously been examined, in which the environmental and social implications of CCU value chains remain underappreciated. However, in order to progress from the early stages of the development of a CCU value chain to the later stages, a holistic view of the system that can examine the performance of all stakeholders involved and all components of sustainability must be adopted.
Altogether, this can be summarized in the knowledge gaps presented in the following Section 1.4.6.

1.4.6. Overview knowledge gaps

1. The synergy and conflict between carbon capture and hydrogen technologies when combining these technologies.
2. The mapping and ranking of CO_2 utilization pathways for prioritizing support and funding to help the development of large-scale CCU projects in Europe. Even if the available CO_2 consumption amounts are currently limited.
3. Investigating the economic, technological and environmental conditions required to support CCU adoption, including the required supply chains and industrial infrastructure.
4. In order to progress from the early stages of the development of a CCU value chain (opportunity identification and opportunity assessment) to the later stages (barrier removal and commercialization), a holistic view of the system that can examine the performance of all stakeholders involved and all components of sustainability must be adopted.

1.5. Research question

The last section explained why CCU research is required and why there are theoretical flaws in analyzing such a complex transition. This section will highlight the research questions that will guide future studies. Numerous factors can play a significant role during regime shifts of the magnitude required for a CO_2 utilisation scenario. Social and technological challenges have a role. As a result, the primary Research Question (RQ) of this research is as follows:

"What are the carbon capture and utilisation niches in the Netherlands, and how to facilitate them?"

The answer to the research question can lead to policy and enterprise strategy recommendations. To answer the main research question, the following sub-questions are defined:

1. What are the CCU niches, stakeholders, and networks in the Netherlands?
2. What are the enablers, opportunities, and barriers of different CCU niches in the Netherlands?
3. How can CCU niches successfully be stimulated in the Netherlands?

1.6. Societal relevance

The rationale behind the imperative for CCU research is striking due to its profound societal significance. This technology stands as a pivotal tool in fulfilling the energy transition and circularity objectives outlined by the IEA and IPCC. It offers invaluable insights for corporations, governmental bodies, regional entities, and industrial clusters, serving as a foundational resource for crafting decarbonization plans and strategies to enhance industrial clusters' decarbonization efforts. Furthermore, CCU offers a promising avenue for the strategic allocation of captured CO_2 towards achieving the 2050 climate targets.

Additionally, a compelling perspective lies in addressing the impending resource constraints we face in the years ahead while simultaneously reducing dependence on nations with contentious records of human rights abuses. In this context, the study's contribution extends to the advancement of a circular CO_2 utilization system, aligning with the overarching goal of achieving the 2050 circularity objectives.

1.7. Relevance to MoT program

This thesis is aligned with some of the concepts taught in the Management of Technology (MoT) program, such as analysing socio-technical transitions. This concept is an integral component of the specialized track, "Emerging Technology-Based Innovation and Entrepreneurship", that I pursued during the initial phase of my second year in the MoT program. Secondly, the conclusions made in this thesis are relevant to the business context within the CCU sector. Thirdly, the complex nature of the CCU sector, in light of stakeholders, institutional context, and the multi-disciplinary nature of the research, makes it relevant for analysis with the MoT master program. This study also includes an analytical component, thoroughly analysing the obtained data via semi-structured interviews and providing valuable insights. This analysis element is also part of the MOT programme, and it requires that the problem be properly understood before a solution can be provided.

Engaging in this thesis research offers a significant opportunity to deepen my understanding of technology transition analysis. The exploration covers technical, economic, and social dimensions, providing insights into their interplay. The thesis allows me to apply theoretical frameworks and analytical tools to a real-world problem, enhancing my knowledge and expertise, as well as problem-solving skills.

Additionally, the research facilitates direct engagement with energy transition stakeholders, including policymakers and industry representatives. This interaction aids in understanding diverse perspectives and developing effective strategies for promoting the CCU developments. Conducting interviews strengthens interpersonal and management skills, offering valuable insights into decision-making processes, particularly from the policymaker's perspective.

The research will be conducted in the environment and with an interest in Accenture the Netherlands, specifically within the strategy and consulting department for utilities. Accenture can provide contacts within the sector under analysis and therefore adds benefits in the easiness of contacting stakeholders. Accenture is interested in this research because it can provide insights they can later vent to clients interested in CCU or who want to be informed about the topic.

1.8. Thesis outline

The previous chapter presented the research introduction and the literature review and discussed the rationale for the study's necessity. In Chapter 2, the theory will be decomposed, followed by a theoretical framework and exploration. Chapter 3 will discuss the methodological approach, the theoretical framework with an analysis manual, and conclude with and data collection and processing. Chapter 4 discusses the evolution of CCU and the stakeholders with its network. Chapter 5 analyses the MLP and defines the niches. Chapter 6 findings will be expanded in depth from an SNM perspective (using the analysis manual from Chapter 3) to finally identify the barriers and drivers with the internal niche obstacles. Chapter 6, a discussion about the thesis, is presented. Finally, in chapter 7, the specific conclusions of the study will be presented.

2
Theory

This section discusses relevant literature according to the problem statement and the literature gap. This section is subdivided as follows: Firstly, technological innovation systems will be discussed. Secondly, the Multi-level perspective; Thirdly, transition pathways and finalise with actor participation. These methodologies are carefully chosen based on the literature gap and should enable one to fill the gap by use of the upcoming methodologies.

2.1. Innovation systems

Innovations systems (IS) can be defined as a collection of organizations and institutions, as well as the relationships that exist between them (Edquist, 2009). There are multiple links between the various components of the IS, including those between actors and institutions. Actors may cooperate or benefit one another, yet they may also contradict one another (Edquist, 2009). Institutions can encourage actors to engage in particular activities while discouraging them from engaging in others; hence, actors are immersed in a so-called institutional environment. In the literature, technological systems are innovation systems that deal with a certain technology or product (TS). Carlsson and Stankiewicz (1995) described a technological system as a "network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology (Carlsson & Stankiewicz, 1995)." A TS is defined as an incubator for new ideas and the advancement of established technologies" (Carlsson & Stankiewicz 1991, p. 111). The contrast between innovations and existing technologies, according to the literature, is less important for incremental innovations but becomes vital when radical innovations are the topic of inquiry (Markard & Truffer, 2008).

The sectoral systems of innovation and production (SSI) approach is one theory that is making progress in this field. This is because a distinction is made between new and established products, and it is emphasized that "...because the notion of sectoral systems includes innovation and production with the related demand and market processes, one could examine separately a sectoral innovation system, a sectoral production system, and a sectoral distribution-market system for analytical purposes" (Malerba, 2007). Both TS and SSI models have an innovative component in which items or new technologies are designed, distributed, and used and a production component in which advanced products or technologies are further developed. SSI considers technologies or products (i.e., the innovation itself) to be an essential component of the system (Hughes et al., 1987; Malerba, 2007). According to Edquist (2009), the TS and IS do not perceive it that way. This should be viewed as an analytical option, according to (Markard & Truffer, 2008). Because of the complicated interplay, they propose that the innovation be viewed as a component of the system that does not fundamentally differ from other components of the system.

According to the literature, adequately delineating an IS - that is, protecting the system and the surrounding environment - is both necessary and difficult (Carlsson et al., 2002; Edquist, 2009). First, system delineation is determined by the notion selected (National Innovation System (NIS), Regional Innovation System (RIS), Sectoral Innovation System (SIS), or Technological Innovation System (TIS). Technological systems (TS) frequently span geographical and sectoral borders (Hekkert et al., 2007). Delineation must take into account the technological framework, such as a knowledge sector or a specific market (Carlsson et al., 2002). Even when viewed so broadly, system delineation remains difficult in this scenario since multiple technologies or domains of knowledge overlap and impact each other, resulting in a technology continuum rather than singular technologies. According to the literature, there are two forms of delineation:

- Descriptive delineation: System delineation is heavily influenced by the research question and the purpose of the analysis. In addition, a spatial specification is frequently given in this form of system delineation.
- Conceptual delineation: System boundaries are created here so that interactions between system elements are more important than interactions between the system and what happens outside of it.

2.2. Multi-level perspective

System innovations, such as using carbon dioxide as industrial feedstock representing a technological departure from the status quo and impacting the social environment, should be handled from a multi-layered systems perspective known as the Multi-Level Perspective (MLP). Usually, the MLP is used as a framework to analyse (socio-technical) transitions, which are characterised as large-scale changes in how social functions are fulfilled. One such societal role is the decarbonisation of the hard-to-abate industries while simultaneously providing CO_2 as a feedstock. As a result, a transition would be required for this societal function to convert to a CO_2 neutral value chain. The MLP concept describes transitions in terms of interferences between three different scales (levels): macro, meso, and micro (F. Geels & Kemp, 2000). The various levels of scale are functional rather than spatial in nature.

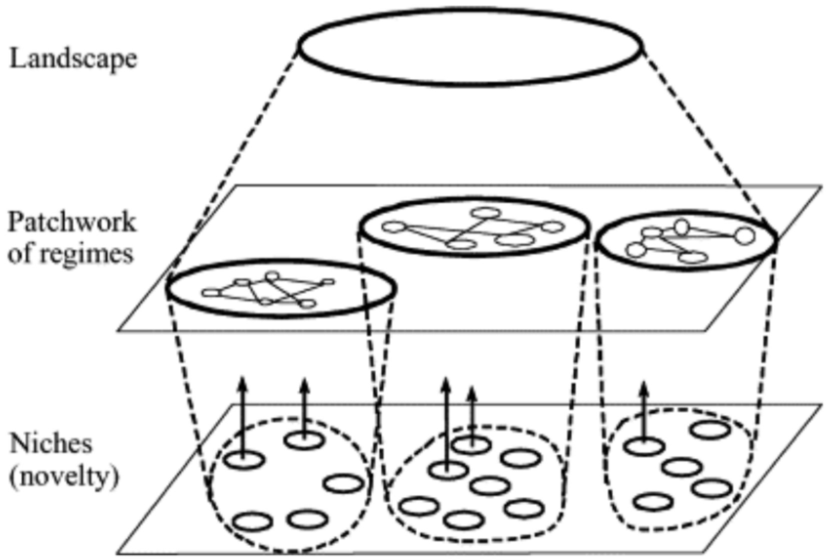

Figure 2.1: Multi-level perspective (F. W. Geels, 2002)

- Macro-level (Landscape): Landscape changes have an impact on the macro level, for example, in politics, culture, worldviews, paradigms, and macroeconomic aspects. Trends and developments produce a relatively slow undercurrent at this size level. The macroeconomic developments are external to the regimes and niches, but they impact them (Rotmans et al., 2001).
- Meso-level (Regime): Regimes are established systems in this area that are designed to execute a certain societal purpose. At this level, there is a lot of resistance to innovation since established organizations, institutions, and networks uphold existing rules, procedures, and interests (Rotmans et al., 2001). Socio-technical regimes explain the embeddedness of certain technical systems, such as fossil-based energy supply, making implementing (cleaner) alternatives difficult.
- Micro-level (Niche): At the micro level, niches emerge, frequently developed by people or groups of players open to new ideas. There is room for learning processes concerning innovations, new techniques, or behaviour at this level, and the first steps toward a change are frequently taken. The concept of niches is important in transition theory (F. W. Geels, 2002, 2004, 2005; Kemp & Rotmans, 2005; Rotmans et al., 2000) niches are places where deviant practices occur, such as niches for alternative technology, but also in the form of new initiatives and new forms of culture and governance (Rotmans et al., 2001). The variability of the selection environment enables these deviant actions (prices, preferences, standards, protection of sponsors). Here is also where radical new technological developments, such as CCU technology, live and are safeguarded.

The interaction between the three layers is key to MLP, and it all contributes to the success of new technology (Rotmans et al., 2001). Transitions always result from large-scale and small-scale processes and events (niche developments) (Sondeijker et al., 2006). Transitions will be realized only if advances at the three levels link and reinforce each other in the same direction (modulation).

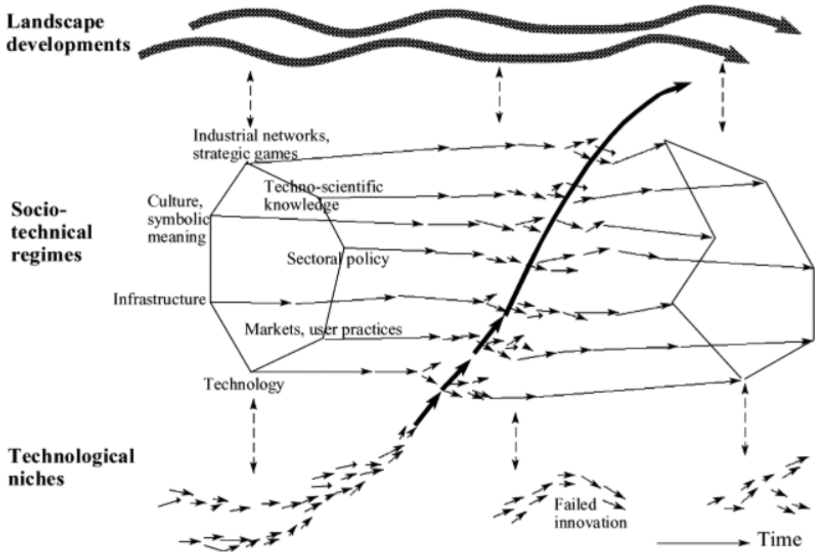

Figure 2.2: Interactions Social-technical transitions(F. W. Geels, 2002)

2.3. Combining IS and MLP framework

Markard and Truffer (2008) present a framework for technical innovation systems (TIS) that combines the multilevel view and the innovation system frameworks to explore developing innovations. These notions were formed primarily independently of one another despite the fact that they try to describe similar empirical phenomena and are built on overlapping conceptual foundations. Markard and Truffer (2008) conducted research on the basics of technological systems (TS), sectoral systems of innovation (SSI), and niches, with a focus on the IS and MLP techniques had numerous commonalities, with areas where they might reinforce each other at the empiric level of aggregation that is generally applied and the interaction they have with innovation and transition processes. Markard and Truffer (2008) state unequivocally that this unified approach should be applicable to a wide range of innovations, examining innovation dynamics at various aggregation levels. According to the authors, this combined framework would be most advantageous if it compensated for the weaknesses of both frameworks to the greatest extent possible.

A TIS is “a set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion, and utilization of variants of a new technology and/or a new product” (Markard & Truffer, 2008). The TIS under study is likely to interact with other TISs through competition or complementation. According to the authors, contrary technology may also provide advancement if it destabilizes the government. When considering fuel cells, for example, at the landscape level, factors such as power market liberalization or natural gas electricity costs can influence the TIS (and the regimes). Within a TIS, several niches are typically considered and developed. Furthermore, a TIS is more than the sum of its niches because it comprises numerous institutions that can stabilize the TIS or multiple players that are not directly involved in the niche but contribute to the TIS. Niches are essential incubations where technologies may be tested, and actors can come together and learn to work better together. Niches can also be (physical) gathering spaces for actors and technology from various TIS to exchange project specifics. TIS can expand and mature concurrently as niches evolve further (Markard & Truffer, 2008).

The proposed framework by Markard and Truffer (2008), which combines the strengths of MLP and IS, allows for the identification of CCU clusters. Something similar has been done with biogas (Markard et al., 2009). This delineation guarantees that the entire CCU innovation system may be considered and thus that all regimes related to the niches that are influential are taken into account. Markard and Truffer (2008) state that such a TIS encompasses several niches, yet it is more than the sum of the niches. This is undeniably crucial to consider when considering CCU, as there may be more than one single niche involved.

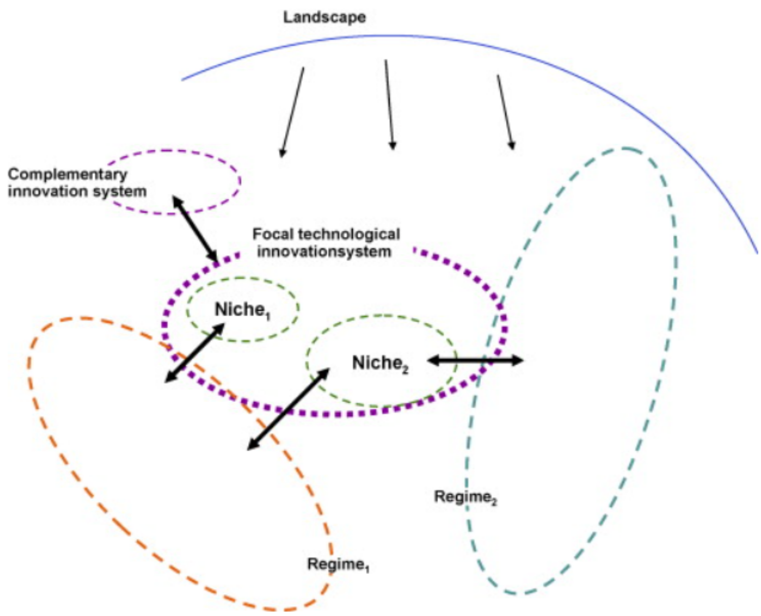

Figure 2.3: Technological innovation system and interactions with the conceptual elements of the multi-level framework (Markard & Truffer, 2008)

2.4. Strategic Niche Management

According to the preceding MLP framework, the dissemination of niche innovation necessitates interaction between niche innovation and the socio-technical landscape and socio-technical regime. To thoroughly examine diffusion, it is necessary to examine diffusion from both the external context and the niche-internal process. In this example, the strategic niche management framework supplements the MLP framework by examining the internal process of niche innovation (Turnheim & Geels, 2019).
Strategic Niche Management (SNM) is an analytical technique for micro-level examination of niche developments inside CCU niches. Such an approach is required to determine the effectiveness of the innovation system. Practical experimentation in so-called (partially) 'protected niches,' where actual consumers can profit from testing without being pressured by severe selection processes, is essential to the SNM framework. SNM academics classify the specialised internal process in the SNM framework into three properties: shielding, nurturing, and empowerment (Smith & Raven, 2012). These procedures are outlined below.

2.4.1. Shielding

Many case studies on transition reveal that sustainable innovation niches face pressure from various regime dimensions such as technology, industry, user, market, culture, and policy (F. W. Geels, 2011). To preserve innovation from numerous regime constraints, a niche as a protected space is essential (A. Smith & Raven, 2012). A. Smith and Raven (2012) define shielding as the process of protecting a nascent innovation. They categorise this mechanism as passive or active shielding. Passive shielding refers to the procedure by which the developer tests the technology in various geographical places away from the regime's operation zones until it becomes economically practical and is adopted by a small number of users (i.e., in an emerging market niche).

A. Smith and Raven (2012) goes on to say that active shielding encompasses the protective process, which includes intentional interventions and techniques from actors. Regulations on subsidies, incentives, and tariffs to promote the supply side can provide active protection from policy players. On the demand side, policy actors might apply methods such as awareness campaigns, quotas, and market segmentation. A non-policy actor (i.e., a private corporation) employs active shielding by establishing a business unit that serves as an incubator for new radical inventions that are distinct from the mainstream organisation.

2.4.2. Nurturing

A. Smith and Raven (2012) describe nurturing as an activity and process promoting niche innovation development. In this situation, the emergence of niche innovations is the consequence of a number of 'niche internal processes' as well as external events. Three of these internal niche processes are highlighted in the literature (Schot, Slob, & Hoogma, 1996; Weber et al., 1999):

1. Learning processes;
2. (actor) Network building; and
3. Articulating visions and expectations.

Each of them has underlying criteria for determining their level of efficacy in innovation pathways. The ”feedback loop,” as defined by Raven (2005) is an addition to the SNM assessment that emphasises the interdependence of the three specialised internal processes.

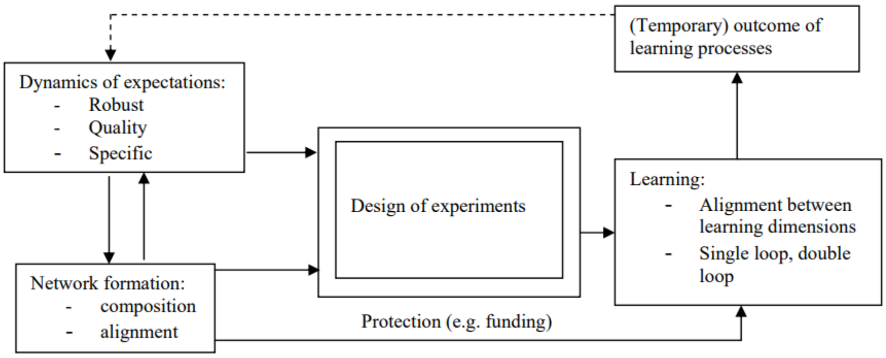

Figure 2.4: Dynamics in expectations, learning processes and network formation in relation to the design of experiments (Raven, 2005)

Actors can choose to become involved with a certain technical solution or experiment based on players' (voicing of) expectations (providers, knowledge institutions, users, and sponsors). When actors participate in such an experiment, they go through a variety of learning processes, which may cause them to change their opinions and expectations about the product or technology. New actors may become involved in experimenting based on new expectations, which may modify the network between actors, potentially leading to new alliances. These changes in (voicing of) expectations and the restructuring of actor networks may necessitate a revision of the experiment or even the beginning of whole new experiments. External developments in the Landscape, Regime, or other Niches substantially impact the niche internal processes that occur in the experiment's local surroundings. According to Raven (2005) research, external factors can substantially explain variations in views and expectations.

There are two forms of learning in the learning process: 'first-order' learning and 'second-order learning'. First-order learning is the study of the usefulness of a particular technology in achieving a given aim. First-order learning seeks to validate pre-defined goals and achieve goals within a given set of norms and regulations (Raven, 2005). First-order learning is based on a variety of criteria, such as technical infrastructure, industry advancements, environmental impact, and user experience (Hoogma et al., 2002). Second-order learning entails learning about underlying conventions and assumptions and questioning or modifying the rules (Raven, 2005). Only if both first-order and second-order learning are included in the learning process can it be termed ”sufficient” (Schot & Geels, 2008).
Expectations are considered to be effective if they are (Van der Laak et al., 2007):

1. Supported by multiple actors (Robust)
2. Specific and clear (Specific)
3. Backed by sufficient evidence (e.g. experimental learning) (Quality)

The social network is still fragile, especially in the early stages of an innovation's life cycle. Experimentation in niche markets can bring together new actors and create new social networks. When it comes to building social networks, social networks can be deemed ”Highly-Functioning” when a wide range of actor types participate, and actor alignment increases (Van der Laak et al., 2007).

2.4.3. Empowerment

According to A. Smith and Raven (2012), empowerment is the process of evaluating whether a niche will drive regime change or niche innovation will adapt to the mainstream selection environment. Empowerment, according to SNM researchers, is a political and negotiated process comprising a variety of coalitions that construct narratives to justify regime change or defend the regime (Turnheim & Geels, 2019). There are two sorts of empowerment processes: (1) fit and conform empowerment and (2) stretch and transform empowerment. The process of adapting niche innovation to be compatible with the selection environments is referred to as fit and conform empowerment. Stretch and change empowerment, on the other hand, is the process of reworking the current system to accommodate niche innovation. An overview of how shielding, nurturing and empowerment are related to the MLP is illustrated in Figure 2.5 below.

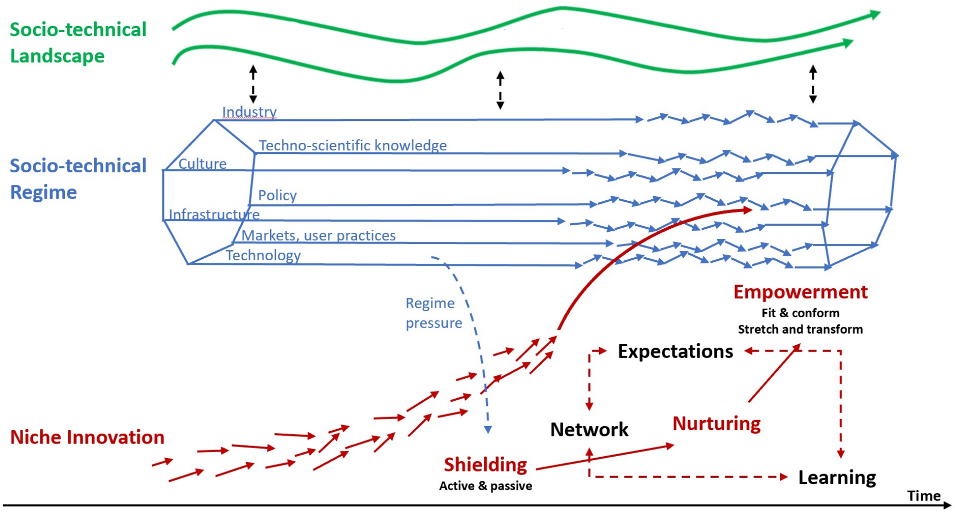

Figure 2.5: Integrated framework MLP and SNM (Adapted from (F. W. Geels, 2002; A. Smith & Raven, 2012))

2.4.4. How SNM relates to MLP

The space niches are given to claim a position inside the regime that is directly proportional to the regime's rigidity. The regime's main actors (established order) resist niche developments. The concept of "modulation" is critical here. This means that the regime must destabilize or weaken (due to the Landscape, internal regime tensions, or parallel Niche developments) to potentially create a "window of opportunities" for the niche to go through. When the interactions across layers are aligned, they reinforce one another.

- **Indirect influence:** If a destabilized or weak regime offers windows of opportunity for niche breakthrough. Pressurising landscape elements and internal regime tensions cause regime destabilization. A niche can gain internal momentum by improving price/performance, gaining support from powerful actors, enhancing the usefulness of the innovation, and so on. When a niche grows in size and velocity, it can influence the regime via bottom-up dynamics.
- **Direct influence:** These factors directly influence niche processes such as network formation and learning processes. Landscape and regime changes can also have an impact on niche development by influencing internal niche processes and niche activities. A failing regime, for example, might raise expectations and instil confidence among actors and the general public that the niche can be expanded. Furthermore, landscape elements such as education level and socio-cultural aspects may have an impact on the niche via learning and network building. Finally, the context in which a niche originates might influence niche activities, such as infrastructure and natural resource availability.

Kamp and Vanheule (2015) draw upon these internal niche processes and identified indicators related to these internal niche processes shown in Table 2.1. The MLP complements the SNM framework by providing information on the external environment in which the new innovation is being developed, resulting in these indicators.

Table 2.1: Niche process indicators (Kamp & Vanheule, 2015)

Niche process	Indicator	Analysis of
Expectations	Internal expectations	The quality, robustness and specification of expectations of the current actors in the niche.
	External expectations	The awareness and confidence level of actors outside the niche.
	Exogenous expectations	Expectations originating from developments that are external to the niche expectations: landscape and regime factors, the development and/or rise of other niches.
	Endogenous expectations	Expectations originating from learning experiences and network composition within the niche.

Network formation	Network composition	The desired network composition and network completeness.
	Quality of the sub-network	The extent to which the involved actor groups contribute to niche development.
	Network interactions	How and to which degree the network actors are interacting.
	Network alignment	The degree to which actors′ vision, expectations and strategies are in line with the niche development.
Learning processes	Technical development and infrastructure	The learning about design specifications, complementary technology and the required infrastructure needed for technology dissemination.
	Industrial development	The learning about the production and maintenance network needed to broaden technology dissemination.
	Social and environmental impact	The learning about the technology impact on safety, energy and the environment.
	Development of the user context	The learning about the end-user characteristics, their requirements, their barriers to technology adoption and the meanings they attach to new technology.
	Government policy and regulatory framework	The learning about the institutional structures and legislation that are relevant for dissemination, and the incentives they can provide to encourage adoption.
	Niche potential and analysis	The learning about the available wind resources.
	Business models	The learning about business models that enable successful market penetration.

2.4.5. SNM analysis for CCU Value chain

The activities through the whole CCU value chain are so highly complementary that one cannot be anticipated to take off without the concurrent development of another. CCU should be employed in all industries in order for this investment to be profitable. According to SNM, the simultaneous beginning of trials at each of the stages in the chain appears to be critical for the establishment of a successful CCU value chain as a whole (together, they are more than the sum of their parts). Thus, effective experimentation requires networking, expectations/experimentation, and learning inside and across different stages of production. It is critical that all components of the supply chain work well in their respective niches at the same time. Van Eijck and Romijn (2009) utilised a similar approach to analyse when studying Jatropha in Tanzania.

2.5. Conclusion

The IS theory will provide insights into the different CCU niches in the different clusters in the Netherlands. The clusters are seen as ISs, although they are more than only innovation systems since they also include production systems. SNM will be utilized to examine the sociotechnical dynamics and factors that exist within the niches. This is accomplished within the context of the MLP, which complements the SNM by offering greater insight into the external environment in which the niche develops in the Netherlands and Dutch society as a whole. As a result, these three frameworks are merged with other components that are uniquely significant for CCU in the Dutch context to provide insight into the relevant factors and how they relate to the Dutch CCU niche transition path.

3
Research design & Methodology

This chapter describes the approach utilised to conduct the proposed research. The research objective is explained in detail in the first part. The final two parts describe the research plan and the methods utilised to gather and analyse data.

3.1. Objective

As mentioned in the introduction, the primary goal of this thesis is to contribute to the body of study on the socio-technical deployment of CCU to contribute to the energy transition on the circularity of CO_2 as a feedstock of the demand side. Because multi-faced problems do not have a single strategy that can be implemented on a large scale, this research will look specifically at how the CCU landscape currently looks like, what its enablers, barriers, and opportunities are, and how these might be addressed (Grewatsch et al., 2021). CCU has recently piqued the curiosity of scientists and governments. However, there is still a lack of an overview in the Netherlands. The purpose of this thesis is to determine the current landscape and development of the CCU niches in the Netherlands. The landscape of the CCU niches is determined by its actors and surrounding actors. In addition, the thesis aims to provide stimulation measures based on strategic niche management.

3.2. Research approach

The nature of the research questions leans toward exploratory research. As defined by Sekaran and Bougie (2009, p. 43), exploratory studies are indispensable when some facts are known, but further insights are required to analyse the research area. Moreover, gaining more insight is one of the key objectives of this study, and not all of the requisite data could be extracted from existing literature. For instance, while some stakeholders may already be known. It remains unknown what their importance and contribution to the development of CCU in the Netherlands is. Furthermore, the means to effectively address barriers and how to stimulate CCU development in the Netherlands remains unknown.

A case study research approach was chosen to address these research questions. As argued by Yin (2018), a case study research approach is apt when investigating the 'whys' and 'hows' of contemporary events beyond the researcher's control. This choice aligns with our principal research question, which seeks to answer how the CCU niches in the Netherlands can be stimulated. Given this, the Netherlands has been selected as a geographical delineation to conduct the case study.

3.3. Research Design

Figure 3.1 depicts the steps that will be taken in order to answer the research questions.

In the introduction (Chapter 1), the problem is defined, and with the problem, a literature review is conducted, which results in the main research question. In Chapter 2, the theory that will be used to answer the sub-questions will be presented. This chapter (Chapter 3) discussed the research design, including the approach, methodology, data collection and processing, and the analytical framework. Figure 3.1 visualizes the (further) research structure, relating to the sub-questions, research method, data analysis methods and theory used. The next chapter (Chapter 4) presents the evolution of CCU over time and maps the stakeholders in the Netherlands. Desk research and interviews will provide data input, and the power vs. interest matrix will be used to analyse and thereby answer the first part of the first sub-question. Chapter 5 provides an overview of all the levels of the multi-level perspective in combination with the innovation system theory. Interviews will be used as data input, answering the second part of the first sub-question and the second sub-questions. In Chapter 6, the niches will be further explored by strategic niche management, interviews, and desk research, which will be used as data input, answering the third sub-question. Chapter 7 provides a discussion, which is, together with the results of Chapters 4, 5, and 6. Chapter 8 answers the main question and provides recommendations to stakeholders and suggestions for future research.

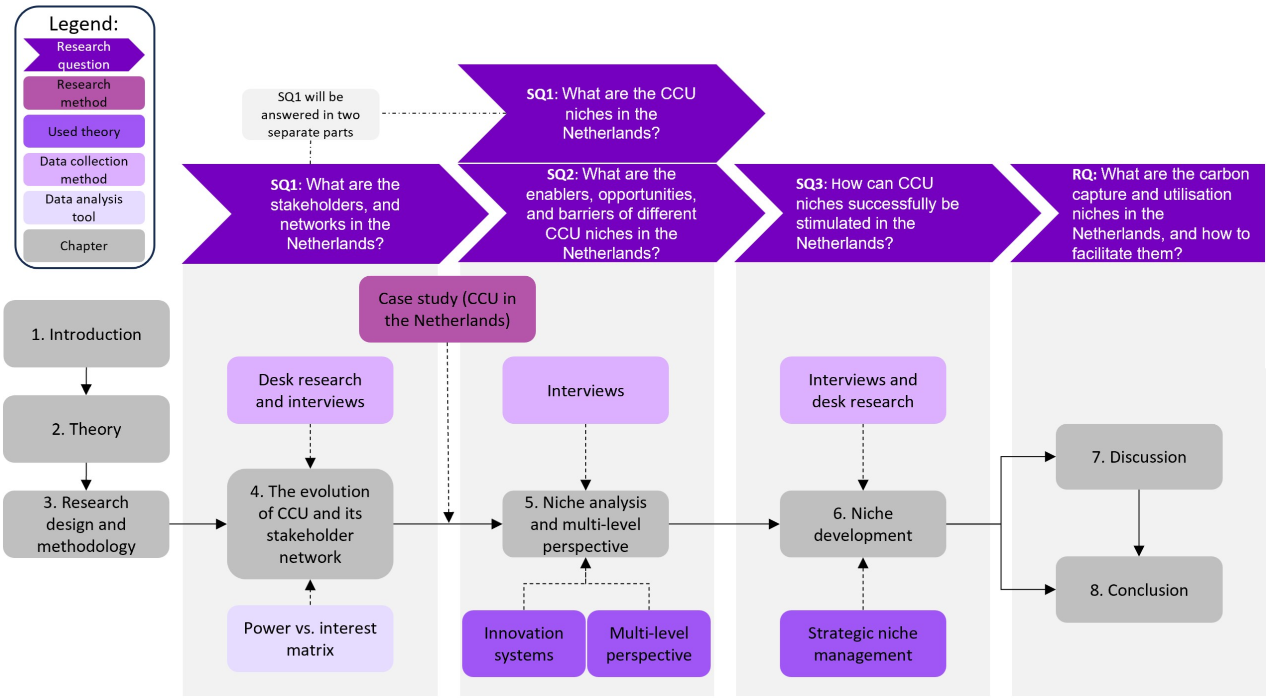

Figure 3.1: Research flow chart

3.4. Methods

The proposed thesis will examine the application of CCU in the Netherlands and how the country might strengthen its innovation system to support CCU implementation. A micro-level analysis will be employed to investigate this. A qualitative case study research approach will be used for the micro-level investigation.

3.4.1. Case study

To investigate the development of CCU in the Netherlands, a case study will be performed on the Netherlands. When conducting case studies, the generalizability of the study is frequently questioned. Therefore, this study aims to be relevant because it does not try to generalize for countries worldwide in how they implement CCU, but rather to gain an in-depth understanding of the Netherlands. A qualitative research approach is appropriate for better grasping the underlying processes and circumstances of a study topic (Sekaran & Bougie, 2010). This study aims to test present theories' assumptions; rather, the research technique should be left open to enable case-specific information and phenomena to emerge from the data.

3.4.2. Power vs. interest matrix

The power vs. interest matrix by Bryson (2004) will be used to provide insight into the actor's interest and power. It is an analytical framework in the field of stakeholder analysis and is a useful tool for assessing the relative relevance and impact of stakeholders. This matrix allows researchers to categorise stakeholders into separate quadrants based on their level of influence and interest in a specific topic, project, or organisation. Power and interest are two major factors that must be considered when examining stakeholder relations.

In this context, power refers to a stakeholder's ability to exert influence, make decisions, or enforce their will on the subject matter at issue. Control over resources, decision-making authority, and access to key individuals or organisations are all considerations. Governmental authorities, regulatory agencies, and significant investors are examples of powerful stakeholders. Interest, on the other hand, reveals how personally invested people are in the result of the issue or project. High interest suggests a significant stake in the problem, and high-interest stakeholders may include community organisations, advocacy groups, or those directly affected by the issue.

Researchers can categorise stakeholders into four distinct quadrants using the Power vs. Interest Matrix: 'Key Players' (high power and high interest), 'Subject' (low power and high interest), 'Context setter' (high power and low interest), and 'Crowd' (low power and low interest). This classification provides vital insights into the management and engagement tactics necessary for each stakeholder group, informing the development of effective stakeholder communication, involvement, and influence initiatives.

When engaging with stakeholders in organisational decision-making, policy development, or project management, the Power vs. Interest Matrix provides a structured approach to understanding the complex landscape of stakeholders in various research contexts, enhancing the ability to prioritise efforts and resources.

3.5. Analytical framework

In this section, the main points that will be used in the framework will be highlighted.

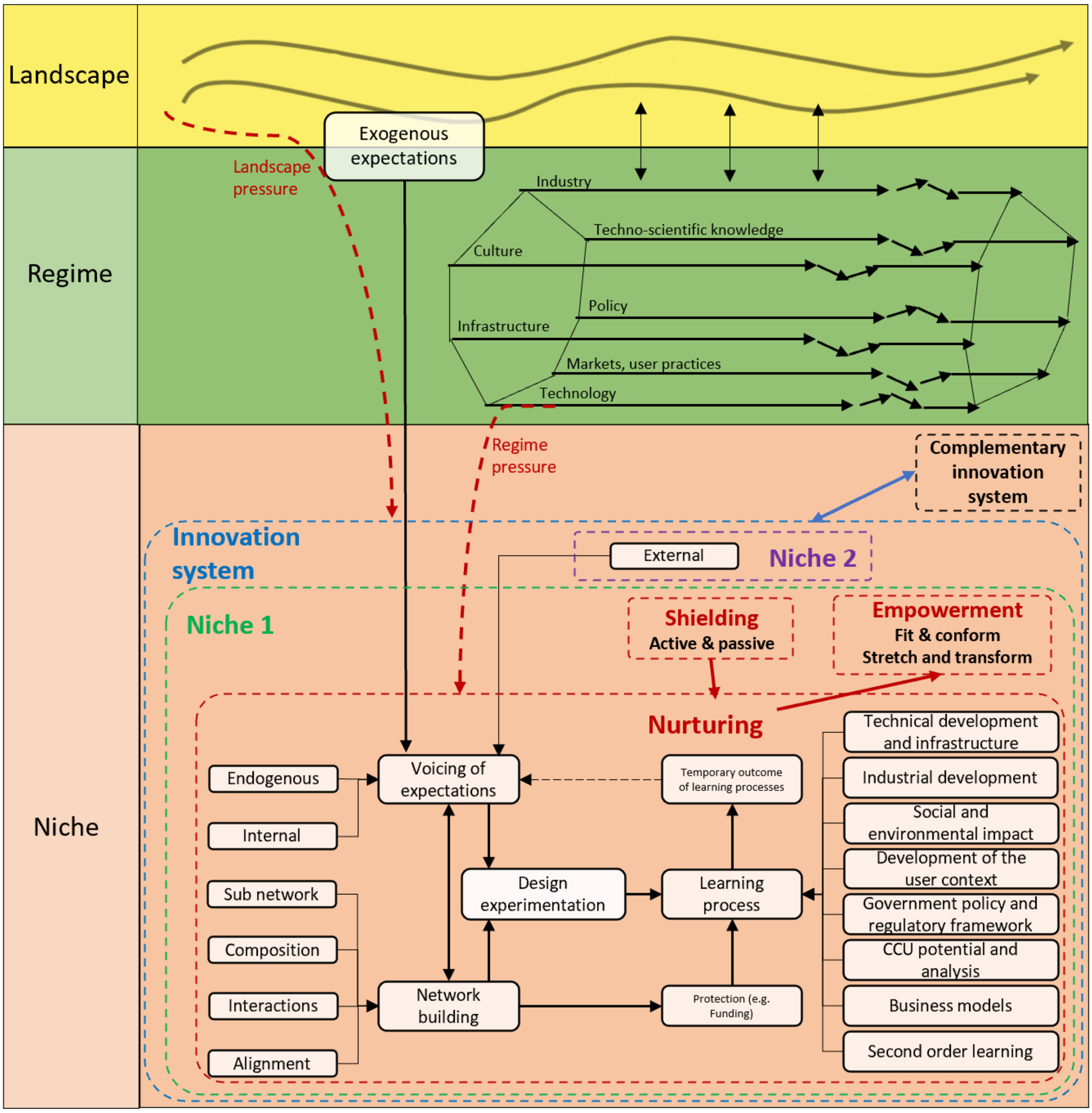

Figure 3.2: Analytical framework overview

Figure 3.2 depicts how the strategic niche indicator connects to strategic niche processes within various niches, as well as how it links to the regime and terrain. Later, The research design is illustrated in Figure 3.1. In the research phase niche analysis, a broader study of the niches is performed in relation to Figure 2.3 in the (industrial) clusters; several niches may be inside a single cluster. A more in-depth investigation is performed in the strategic niche management research stage connected to Figure 3.2 to determine how the niche might be successfully stimulated.

3.5.1. Landscape analysis

Secondary data sources and insights from interviewees will be used to explore landscape dynamics such as macroeconomic conditions, the global issue of climate change, and demographic patterns, and how these variables influence CCU niche development.

3.5.2. Regime analysis

According to F. W. Geels and Schot (2007), the sociotechnical regime will be analysed utilising three interconnected components of the regime: actors' network, regulations, and technology. First, the dynamic of the actors' network and social groupings will be investigated in this thesis. The second step is to examine changes in formal rules such as regulations and legislation. Finally, this research will examine the technical advancements in the regimes.

3.5.3. Niche analysis

The SNM section in the framework in Figure 3.2 is based on Raven (2005), with indicators extracted from Kamp and Vanheule (2015). The framework includes the second-order learning by Hoogma et al. (2002) since the learning process can only be termed as sufficient when both first- and second-order learning are included (Schot & Geels, 2008).

Table 3.1: Niche analysis overview

Niche process	**Internal niche process**	**Indicator**	**Analysis of**
Shielding	**Passive shielding**		To what extent niche developed through passive shielding.
	Active shielding		To what extent niche developed through active shielding.
Nurturing	**Expectations**	Internal expectations	Quality, robustness and specification of expectations of the current actors in the niche.
		External expectations	Awareness and confidence level of actors outside the niche.
		Exogenous expectations	Expectations originating from developments that are external to the niche expectations: landscape and regime factors, the development and/or rise of other niches.
		Endogenous expectations	Expectations originating from learning experiences and network composition within the niche.
	Network formation	Network composition	Desired network composition and network completeness.
		Quality of the subnetwork	Extent to which the involved actor groups contribute to niche development.
		Network interactions	How and to which degree the network actors are interacting.
		Network alignment	Degree to which actors' vision, expectations and strategies are in line with the niche development.
	Learning processes	Industrial development	Learning about the production and maintenance network needed to broaden technology dissemination.
		Social and environmental impact	Learning about the technology's impact on safety, energy and the environment.
		Development of the user context	Learning about the end-user characteristics, their requirements, their barriers to technology adoption and the meanings they attach to a new technology.
		Government policy and regulatory framework	Learning about the institutional structures and legislation that are relevant for dissemination, and the incentives they can provide to encourage adoption.
		Niche potential and analysis	Learning about the available wind resources.
		Business models	Learning about business models that enable successful market penetration.
		Second-order learning	Learning about the underlying norms and values related to the new technology.

Empow-ering	**Fit and con-form**		Analysis of competitiveness of CCU in the current regimes.
	Stretch and conform		Analysis of changes in regulations, laws, and incentives that is influenced by niche.

3.6. Analysis manual

The analysis manual corresponds to the research flow chart (see Figure 3.1) and the analytical framework (see Figure 3.2)

3.6.1. Approach sub-question 1

"What are the CCU niches, stakeholders, and networks in the Netherlands?"
Sub-question 1 addresses the intricacies of the stakeholder landscape in the Netherlands, including the composition of the stakeholder field, the dynamics of their relationships, and the identification of specific niches within the context of CCU development. To investigate this, a combination of desk research and interviews will be conducted.

The construction of the stakeholder field and network will draw from an array of data sources comprising extensive desk research and in-depth interviews. The Power vs. Interest Matrix by Bryson (2004), a valuable tool for assessing the impact of CCU development, will be applied to discern the relative importance of stakeholders within this expansive network. This approach was deliberately chosen to differentiate and categorize stakeholders based on their power and interest levels, thus facilitating a nuanced analysis.

Furthermore, the identification of distinct niches within the CCU landscape will be accomplished by employing the Multi-Level Perspective framework developed by F. W. Geels and Schot (2007). Interviewees will be engaged in discussions concerning the most prominent CCU options in the Netherlands, with a particular focus on eliciting their rationale behind these selections. This qualitative approach will unveil the underlying niches and help characterize their unique attributes, enabling a more comprehensive analysis of the landscape.

3.6.2. Approach sub-question 2

"What are the enablers, opportunities, and barriers of different CCU niches in the Netherlands?"

In this sub-question, the enablers that propel the development of CCU will be examined. The objective is to identify the primary driving forces behind CCU developments, which necessitates an exploration of the underlying landscape factors. To achieve this, the Multi-Level Perspective framework will be leveraged, as outlined by F. W. Geels and Schot (2007).

Simultaneously, the aim is to uncover the array of opportunities and barriers that influence CCU initiatives employing the same theoretical framework proposed by Geels (2007), complementing this analysis with insights drawn from A. Smith and Raven (2012). In shaping the investigative approach, the niche process indicators articulated by Kamp and Vanheule (2015) will be utilized. These indicators serve as a foundation for formulating interview questions, thoughtfully designed to extract comprehensive insights from participants.

The interview questions, offering a comprehensive overview, can be found in Appendix A. The opportunities and barriers identified during the study may manifest at either the regime or niche level and will be systematically categorized based on their respective niche-level implications (see Table 3.1). This nuanced classification ensures a holistic understanding of the intricate interplay of factors affecting CCU development.

3.6.3. Approach sub-question 3

"How can CCU niches successfully be stimulated in the Netherlands?"
This sub-question serves as an exploration following the previous inquiry. The incentive for stimulating measures primarily arises from insights aggregated through interviews and desk research. Drawing from the theoretical framework on learning processes as elucidated by A. Smith and Raven (2012), the aim is to extract and elucidate the underlying stimulating measures. These findings are corroborated and expanded by the existing body of desk research, which has delved into the barriers previously identified in the preceding sub-question.

3.7. Data collection and processing

3.7.1. Ethics and privacy processes

In light of this research project, the Human Research Ethics of the Delft University of Technology will be considered. To comply with the research ethics, the application will be submitted and approved before potential participants are approached to participate in the study.

Prior to conducting the interviews, a comprehensive Data Management Plan (DMP) was devised and subsequently subjected to scrutiny and approval by the Human Research Ethics Committee (HREC) at TU Delft. Additionally, participants were conscientiously provided with a consent form, as presented in Appendix A. This consent form explicitly elucidates the purpose of the interviews, namely, to contribute to answering the research question. All signed consent forms have been securely stored on the Surfdrive cloud, maintained by TU Delft.

The interviews were diligently transcribed using the Atlas.Ti tool and subsequently subjected to manual review and refinement where necessary. It is imperative to emphasize that these interviews are treated with the utmost confidentiality, and the identities of participants are anonymized. The information revealed in the transcripts will only be categorized by the relevant stakeholder type and type of organization for analytical purposes, preserving the anonymity of the individuals involved.

3.7.2. Desk research

Desk research will be conducted using journal papers, government reports, publicly available rules and regulations, online webinars, online newspapers, and company websites. Google Scholar, Scopus, and ScienceDirect will be academic search engines. Government publications such as those from the Ministry of Economic Affairs and Climate Policy, the Ministry of Infrastructure and Water Management, and the Dutch Environmental Assessment Agency offered vital data and information that will be used related to the energy transition in the Netherlands. Secondary data is also gathered from stakeholder websites (FutureCarbonNL, CCU alliance), global organisations (World Bank, IEA), consulting firms (PwC, McKinsey, Deloitte), and online webinars hosted by renewable energy communities and think-tank organisations such as TNO.

3.7.3. Semi-structured interviews

Interviews will be performed with players from a number of sectors in order to gain a complete and well-rounded perspective for answering the research questions. The interviews are designed to gather insights from important players and build a greater knowledge of the subject areas. The interviews will be semi-structured, with a set interview format. This strategy provides for better concentration and direction during the interview and improved comparability throughout interviews (Sekaran & Bougie, 2010). This is important for contrasting the attitudes and outlooks of players from various niches. Furthermore, this interview approach allows for fresh subjects of interest to be brought up for debate by the interviewees (Sekaran & Bougie, 2010). The interview plan will include key questions for all performers based on the indicators presented in the framework in Figure 3.2. Further sector-specific questions will be utilized to gain more precise information on the various industries' outlooks. In all, 15 interviews will be done throughout the industries specified. If questions are perceived as vague or additional questions are required, the interview questions can be revised. The interviews will be transcribed in order to improve the quality of the data obtained and the analysis of the data. The interviews will be transcribed and summarized; the transcription will be analyzed in the transcription software Atlas.ti n(Sekaran & Bougie, 2010).

A diverse array of experts, encompassing government officials, researchers, and professionals from start-ups to multinational companies, were engaged in this study. Notably, the selected interviewees were actively involved in various aspects, including formulating energy policies, research, company initiatives and regulatory frameworks. In total, 14 interviews were conducted with these industry experts during the months of June and August 2023. The interview questions can be found in Appendix A for reference. All interviews were conducted using Microsoft Teams as the chosen platform. The duration of these interviews ranged from 55 to 60 minutes. Only the first interview was 30 minutes due to circumstances, with participants being initially contacted through the professional networking platform, LinkedIn, and invited to partake in the research.

The lead investigator creates an interview protocol to guide the interview process and guarantee that all ethical requirements are met during the interview. Chapter 8.3.5 contains the interview methodology and questions. Table 3.2 provides an overview of the stakeholders that have been interviewed and their relation to the niches provided.

Table 3.2: Interview overview

Interviewee	Stakeholder	Related to niche
Interviewee #1	Professor at University	General
Interviewee #2	PhD-er at University	General
Interviewee #3	Manager at Institute for open innovation	Indirect
Interviewee #4	Innovation manager at branch organization	Indirect
Interviewee #5	Strategy consultant at knowledge institute	General
Interviewee #6	Policy officer at ministry of climate	General
Interviewee #7	Innovation manager at Oil and gas company	Indirect
Interviewee #8	CTO at start-up	Direct
Interviewee #9	Consultant at circular and sustainability consultant	General
Interviewee #10	Advisor at Waste incinerator	Direct
Interviewee #11	Managing director at chemical production company	Direct
Interviewee #12	CBO at start-up	General
Interviewee #13	Program manager at branch organization	Direct
Interviewee #14	R&D manager at a biochemical company	Indirect

3.7.4. Sampling strategy

Non-probability purposive sampling is commonly used in qualitative research when data is purposefully sampled from information-rich sources that might help to address the study questions (Sekaran & Bougie, 2010). Individuals in subgroups of interest are sampled using non-probability purposive sampling (Sekaran & Bougie, 2010). These subgroups will be made up of niche(s) participating in CCU developments in the Netherlands in order to acquire niche-specific information. This will be acquired in the first five interviewers, namely the exploratory interviews. Actors can then be intentionally sampled from these niche(s). During interviews, snowball sampling is used to ask interviewees if there are additional players they believe are essential for the research and should be included in the sample (Sekaran & Bougie, 2010). This will enable a thorough sample to be obtained in order to answer the study questions.

3.7.5. Data analysis

The collected interview transcripts will be analyzed using qualitative data analysis. This enables the identification and extraction of information relevant to the study objectives, as well as the exploration of data linkages. The first five interviews will be in the light of the exploration of different niches. With this data, the niche(s) will be determined and will provide information on which the following interviewees will be selected in the remaining interviews. These remaining interviews (approx. 10-15) are to gain deeper knowledge in the niches under analysis. For this process, a coding scheme will be created and implemented. The scheme will use indicators from the research questions, theory, and interview scheme to determine the type of information that should be coded. This will maintain consistency throughout the materials under consideration. The coding strategy will abductive coding, with the coding directed by indicators in the coding scheme but remaining open to any new concepts that may emerge beyond the coding scheme. A thematic coding analysis will be used to examine the codes. Themes and patterns that arise from the data must be discovered from the initial codes for this study. The initial codes are then classified based on these themes to uncover linkages within the data (Sekaran & Bougie, 2010). The coding will be done with Atlas.ti software.

The abductive coding procedure with the thematic analysis is executed by following a series of steps, which have been adapted from the methodological guidelines presented by Braun and Clarke (2006) and Vila-Henninger et al. (2022):

1. **Familiarize with data**: To become acquainted with the data, the researcher goes over the transcripts of the interviews several times in order to gain a better grasp of the data.
2. **Formulated a codebook**: An initial set of codes is established based on the theoretical background. After becoming acquainted with the data, inductive codes were also developed.
3. **Collate codes within data**: Identify elements in the data and assign a code to each one.
4. **Group code into themes**: The last stage is to look for overarching themes within the codes. This provides a more comprehensive grasp of the data's findings.
5. **Reviewing themes**: Themes will be checked for coherence to ensure that they sufficiently represent the data and answer the research questions.

6. **Defining and naming themes**: A closer look is given to how each topic should be defined and named so that it is apparent what the theme is about. It is also checked whether there are adequate sources for each theme and whether they are distinct from one another; otherwise, merging themes may be an option.
7. **Writing analysis**: The findings of the themes will be presented in a coherent story and explored in relation to the research questions in this step.

The list of pre-defined codes for thematic analysis and the final list of codes can be found in Appendix B.

3.7.6. Reliability, validity, and generalizability

The theoretical framework is built using many peer-reviewed literature sources and serves as the foundation for the interview scheme and the data collection type. This ensures the study's validity. Certain measures are introduced into the interview and coding processes to increase data gathering and analysis's reliability, replicability, and validity. The information gathered to address the research questions will come from a variety of sources. Several interviews with industry professionals from various industries will be conducted as well as document analysis of recent literature. This should allow for a fully-rounded view of the research issue to be gathered, as well as the identification of overlaps, or lack thereof, between the sectors. The semi-structured interviews will allow for greater replicability and less researcher control over the interview responses (Sekaran & Bougie, 2010). Furthermore, the interviews will be conducted in accordance with a predetermined interview plan and transcribed within one business day to ensure consistency and accuracy of the data acquired. A comprehensive coding guide will also be employed to improve consistency in the data analysis process.

Table 3.3: Internal and external validity threats with mitigation (Sekaran & Bougie, 2010; Yin, 2018)

Threat	Explanation	Mitigation
Internal validity		
Researcher subjectivity	Purposive sampling involves the researcher's judgment in selecting participants based on specific criteria. If the researcher's personal biases or preconceptions influence the selection process, it can introduce bias and compromise the objectivity of the study.	Reflexivity
Selection bias (case study)	When the selection of subjects in a study (or the likelihood that they will complete the study) results in a result that differs systematically from the characteristics of the target population, this is referred to as selection bias.	Randomized selection method, stratified sampling
Halo effect	Interviewers might form an overall positive or negative impression of the interviewee early in the conversation, leading to biased assessments of subsequent responses.	Information from different sources
Confirmation bias	Researchers might unintentionally seek or interpret information that confirms their preconceived hypotheses or expectations. To minimize this, use open-ended questions and try to approach the research with an open mind.	Acknowledge your bias, avoid echo chambers
Inadequate question clarity	If the interview questions are vague or unclear, participants may not fully understand the purpose or scope of the interview, leading to responses that do not align with the research objectives.	Use plain language, avoid ambiguity, clarify as needed, minimize clues
Lack of diversity in interviewees	If the interviewees are not representative of the population or the group you are trying to explore, the findings may lack external validity or may not generalize to a broader context.	Purposeful sampling, report limitations
Biased or leading questions	Phrasing questions in a way that implies a specific answer or assumes certain perspectives can bias participant responses and lead to an inaccurate portrayal of the explored topic.	Avoid loaded terminology, avoid double negative phrasing, use open-ended questions
Response bias	Participants may provide socially desirable responses or answers that they believe the interviewer wants to hear rather than their genuine thoughts and experiences, compromising the face validity of the data.	Guarantee anonymity and confidentiality, randomize question order
External validity		
The novelty effect	Participants' responses or behaviour may be influenced by the novelty of the intervention or experimental conditions. This may not be representative of how they would respond in a more familiar or routine context.	Pre-exposure or pilot-testing

Transfer-ability	Qualitative research often focus on in-depth exploration of specific cases or contexts, which may limit the transferability of the findings to different settings or populations. The unique characteristics of the cases or contexts understudy may not be generalizable to other situations.	Purposeful sampling
Contextual factors	Qualitative research often focus on specific contexts or cases, which may limit the generalizability of the findings to other contexts or populations. It is important for researchers to clearly describe the context and consider its influence on the findings.	Critical reflection
Limited sample size	Interviews and case studies often involve a small number of participants or cases, which may not capture the full range of variation or diversity within the population. This can limit the generalizability of the findings.	Critical reflection
Time-related factors	The findings of qualitative research conducted at a specific time may not apply to different periods. Social, cultural, or environmental factors may change over time, affecting the external validity of the results.	Replication studies
Reliability		
Interviewer bias	The interviewer's own beliefs, attitudes, or expectations can influence the questions asked, the way they are asked, and how responses are interpreted.	Recording interviews and transcriptions
Participant variability	Participants may respond differently to different interviewers or at different times, introducing variability into the data. This can be minimized by standardizing the interview process as much as possible.	Record interviews and use qualitative software,
Transcription errors	Transcription errors, such as misheard words or omissions, can introduce variability and affect the reliability of the data.	Pilot transcription, Transcription verification
Memory bias	Participants may not accurately remember events or experiences, leading to inconsistencies in their responses during different interviews.	Encourage open-ended responses

3.8. Conclusion

This chapter outlines the methodological approach adopted for this thesis. The research methodology is qualitative and comprises a combination of literature review and 14 semi-structured interviews with diverse stakeholders in the Netherlands. The data collected is subsequently subjected to thematic analysis, an established analytical technique.

This study employs a framework that integrates the IS, MLP, and SNM models. These frameworks investigate and analyze various aspects of the CCU landscape in the Netherlands. Specifically, the research explores regime developments, the emergence of CCU niches within the Dutch context, heating solutions for residential buildings in the Dutch urban environment, the maturation of the hydrogen niche, as well as the identification of barriers that both the niche and its development must address. Furthermore, the study examines the relationship between these barriers and offers insights into strategies to overcome them effectively.

For Sub-question 1, the Dutch CCU stakeholder landscape will be examined, and stakeholder composition, relationships, and niche identification will be investigated through desk research and interviews. The Power vs. Interest Matrix categorizes stakeholders by power and interest levels, while the Multi-Level Perspective framework identifies CCU niches. Sub-question 2 analyzes the enablers, opportunities, and barriers shaping CCU niches in the Netherlands. Utilizing the Multi-Level Perspective framework, guided by Geels (2007) and insights from Smith and Raven (2012), employing niche process indicators by Kamp and Vanheule (2015) to formulate interview questions. Sub-question 3, building on the prior findings, explores the measures required to stimulate CCU niches in the Netherlands. Insights from interviews and desk research inform the extraction of stimulating measures, guided by Smith and Raven's (2012) framework on learning processes. Existing research enriches the understanding of previously identified barriers.

Nevertheless, it is imperative to recognize the inherent limitations of this research. These limitations encompass several aspects, including the primary focus on the Netherlands, the potential presence of biases in the interview sample, and the utilization of qualitative methods, which, by their nature, may not provide a fully comprehensive perspective on the broader energy transition landscape. Furthermore, given the study's specific concentration on the Netherlands and its unique energy transition context, characterized by well-established gas infrastructure and specific cultural and legal factors, the degree of generalizability of the research findings to other countries remains constrained.

4
The Evolution of CCU and Its Stakeholder Network

An overview of the historical development is given to understand the context in which the stakeholders operate. This gives insights into who the stakeholders are and what network they operate in. Thereafter, the stakeholders and the groups they belong to will be extensively discussed. This will be done in the context of the stakeholders' network and their power and interest in developing CCU in the Netherlands.

4.1. Historical development

The historical development of carbon utilization represents a significant trajectory in addressing climate change and transitioning to a sustainable low-carbon economy. This overview highlights key milestones and discoveries that have shaped our understanding and approach to carbon utilization throughout history.

(1990s) Supplying CO_2 from industry to greenhouse horticulture more efficiently emerged in the mid-1990s in the western part of the Netherlands. After all, they require a lot of CO_2 to get their crops to grow well. Until then, greenhouse horticulture got most of their CO_2 from burning natural gas in their heating boilers. Heat is not required in the summer and will be destroyed. The only option was to purchase liquid CO_2. This was made available by the industry and was transported by tanker. However, compressing, liquefying, and transporting are costly and energy-intensive. Furthermore, road haulage is a significant disadvantage. It took over ten years to make CO_2 from industry by tanks to greenhouse horticulture a reality.

(2000s) Since the turn of the millennium, significant advancements have been made in developing and scaling up various carbon utilization technologies worldwide. Carbon mineralization, for instance, presents a promising pathway where CO_2 is chemically transformed into stable mineral forms, such as carbonate minerals, through processes like mineral carbonation. This approach offers the advantage of permanently sequestering CO_2 while utilizing it in an environmentally friendly manner. Another avenue of carbon utilization involves the conversion of CO_2 into valuable commodities, such as chemicals and fuels. Innovative processes, including electrochemical reduction and catalytic conversion, promise to transform CO_2 into economically viable products, contributing to establishing a circular carbon economy (IEA, 2022a).

Focusing on the Netherlands again, during the 2000s, the Shell refinery in Pernis had been identified as a viable supplier. The government was given a usable pipeline used for natural gas transport, and a distribution network and compressor station were constructed. This is how OCAP came to be, providing the first CO_2 to horticulturists in 2005. However, it quickly became clear that the demand for environmentally acceptable, economical CO_2 was so enormous that OCAP had just one problem: there wasn't enough on the market. The Shell refinery's capacity was insufficient. And every defect resulted in serious issues for the horticulturists. OCAP would not find a second source until 2010. Since 2011, Alco Energy's bio-ethanol plant has also supplied CO_2 to the greenhouse horticulture sector via OCAP. However, even with two sources, supply security is insufficient.

(2010s) In recent years, the commercialization of carbon utilization technologies has gained momentum. Both startups and established companies have been actively working on scaling up and optimizing CCU pathways. This can also be highlighted by venture capital investments in CCU start-ups, which have been illustrated in Figure 4.1. Governments and international organizations have recognized the significance of carbon utilization, providing financial support and policy incentives to foster its deployment and market penetration (IEA, 2022a).

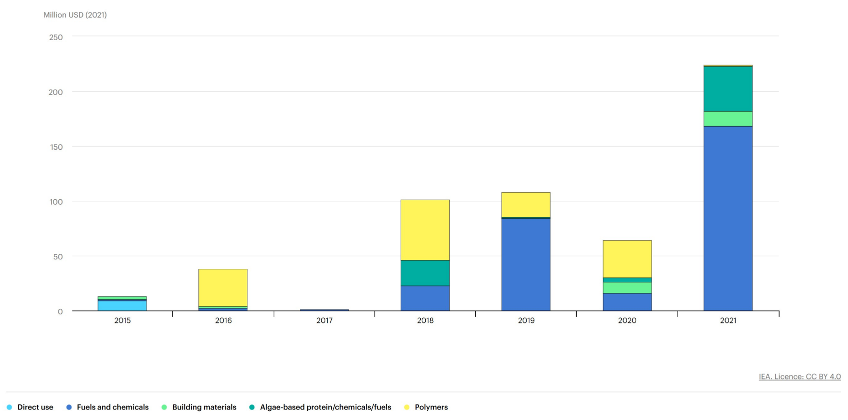

Figure 4.1: Venture capital investments in CCU start-ups 2015-2021 (IEA, 2022a)

(2016-2020) In 2016, 26 partners, shown in Appendix C, Table 8.10, initially formed the CO_2 Smart Grid. The CO_2 Smart Grid platform came before the CO_2 Smart Use platform. They collaborated on a thorough feasibility analysis of the potential of a smart grid for energy in the western part of the Netherlands. They began working on the business case with CO_2 Smart Use in order to set up a national and international CCU economy. A smart grid/smart usage network is a network of resources, infrastructure, and customers that use CO_2 as a raw material. In 2017, the partners started a pre-feasibility study, which showed that the Netherlands presents a viable market for CCU, estimated at 1.7 Mt/year within the next decade. There is a robust demand for greenhouse agriculture, particularly in the western region, accounting for 1.2 Mt. The immediate future holds promise in mineralisation, with even greater potential in the medium term within the chemical sector. The unique CO_2 Smart Grid, a global anomaly, stands poised to significantly drive R&D, employment, and knowledge advancement in the CCUS domain. The dynamic interplay between CCS and CCU demonstrates substantial synergies in knowledge, quantities, and supply security (Mirella, 2022).

The inception of the subsequent studies hinged on two key aspects: technology assessment and Life Cycle Analysis. The technology evaluation aimed to determine the technical feasibility of implementing a CO_2 Smart Grid and identify potential hurdles. The assessment, conducted by a consortium of 26 partners, concluded that the physical network deployment posed no insurmountable technical barriers. However, a substantial challenge remains in establishing a connection between the Amsterdam port and Tata Steel IJmuiden, spanning approximately 30 kilometers. While CO_2 storage is intricate, the primary challenge is locating suitable storage sites. Additionally, the research underscores the need to explore novel applications for CO_2 and reframe its role as a valuable raw material. (Mirella, 2022).

The Life Cycle Analysis (LCA) conducted by the 26 partners aimed to assess the emissions reduction potential of using CO_2 as a raw material compared to conventional methods. The analysis revealed a substantial net emissions reduction of approximately 85-105% across various applications when CO_2 is utilized. The efficacy of emissions reduction in methanol production depends on the type of hydrogen feedstock, with cleaner energy sources yielding better results. The LCA study indicates that CCS capacity is projected to exceed the market demand for CCU in the next decade. (Mirella, 2022). The Social Cost-benefit Analysis, based on technology assessment and Life Cycle Assessment, highlights the CO_2 Smart Grid as a socially viable investment in line with the current Climate Policy, specifically the 'high' scenario in the WLO Hoog (Prosperity and Living Environment, 'high' scenario) report. Its estimated market volume of approximately 3.3 Mt (as of June 2018) underscores its potential impact. Affordable green hydrogen is essential for chemical applications, especially those involving methanol. It's crucial to note that only biogenic CO_2) aligns with the Paris Climate Agreement and offers potential for reuse within the climate policy framework, supported by a robust social cost-benefit analysis. The collaboration between CCU and CCS holds promise for substantial synergies. (Mirella, 2022).

Finally, on the initiative of the mayor of Rotterdam and with the approval of the partners, a study into the economic consequences of CO_2 Smart Grid was conducted. The study provided a complete solution to the question of which of the CO_2 Smart Grid's direct and indirect economic consequences (employment, external effects, etc.) can be expected, which showed that the construction of the Smart Grid could lead to the creation of approximately 470 additional working years, along with an additional 80 employment opportunities during the management phase, encompassing both the grid and the capture processes. Envisioning the implementation of the CO_2 Smart Grid, a notable surge in employment is anticipated, ranging between 5,000 to 15,000 jobs, with around 200-400 positions dedicated to research and development (R&D). It's important to note that the absence of the CO_2 Smart Grid would result in the loss of many of these jobs, especially in industries such as greenhouse agriculture, which hinges on the availability of CO_2 for its viability (Mirella, 2022).

(2021) According to Mirella (2022), in 2021, the course changed considerably, and website visits decreased, as did the turnout at CCU activities. Newsletters about members within the CCU collaboration still attracted attention, but events were visited less often, according to their analysis, especially in the second half of 2021. Simultaneously, the CCU alliance was founded and requested a policy framework from the Dutch government on how to coop with CCU and give perspective to this form of CO_2 handling.

Furthermore, Tata Steel has disclosed a modification in its strategy pertaining to carbon utilization. Initially, the corporation had intended to initiate a venture to capture CO_2 emissions emanating from its blast furnaces in Ijmuiden, with subsequent transportation and storage of this captured CO_2 in a subterranean gas reservoir located beneath the North Sea. However, a significant shift in these plans transpired when Tata Steel shifted its focus towards the recycling of the captured CO_2 to advance the principles of a circular carbon economy, primarily through the production of blue hydrogen (Tata Steel, 2021).

(2022) In 2022, all Dutch industrial clusters were interviewed to see if there was a way to expand the collaboration beyond increasing the CO_2 smart use platform. However, the clusters were more focused on regional CCU developments and propositions. All this, in combination with decreasing financial resources to finance the CO_2 smart use, made it inevitable to stop the activities with CO_2 Smart Use (Mirella, 2022).

Furthermore, Tata Steel underwent a noteworthy alteration in its CO_2 mitigation strategies. With the aspiration of establishing itself as the inaugural CO_2-neutral steel manufacturing facility, the company made a strategic decision to deviate from its prior CCU initiatives. Instead, they shifted their focus toward utilising green hydrogen and green electricity as the primary energy sources to power their industrial plant (Tata Steel, 2022).

(2023) As of 2023, FutureCarbonNL, a partnership of Dutch universities, knowledge institutions, industry, SMEs and start-ups, have gathered to build a world-leading carbon technology sector in the Netherlands. They focus on research, development, demonstration and marketing of technologies that can convert CO_2 into usable products.

4.2. Stakeholders

As described in the previous paragraph, the development of CCU in the Netherlands is very early, influencing the power and interest of the stakeholders in their network. A stakeholder influence diagram is useful for illustrating how different stakeholders' (power and interests) influence each other and for identifying the most influential or central stakeholder(s). According to Bryson (2004), this is critical for conducting research and understanding the challenges (related to the development of CCU in the Netherlands) between stakeholders.

The power/interest grid assists in determining which players' interests and power bases are relevant for a meaningful assessment. A high power level shows stakeholders have significant resources to alter the CCU development. A high level of interest shows that stakeholders are invested in the issue's outcome, often due to reliance on the decision. A stakeholder can be classified into four quadrants based on these two axes presented in Figure 4.2. Stakeholders from the "crowd" are required to monitor with minimal effort. "Subjects" require more work to be informed. "Context setters" are supposed to be kept happy by being handled with care and providing their needs. The "key players" ought to be managed closely due to their high power and interest (Bryson, 2004).

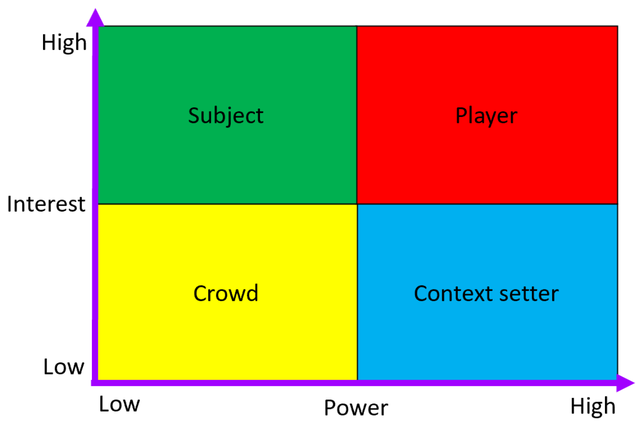

Figure 4.2: Power interest grid (Colours adapted from (Bryson, 2004))

Figure 4.3 shows a simplified presentation of the situation regarding stakeholder groups. The border colours of the presented stakeholder group correspond with the colours presented in the power interest grid. An explanation for the different powers and interests of the stakeholder groups can be found in Appendix D, Table 8.11.

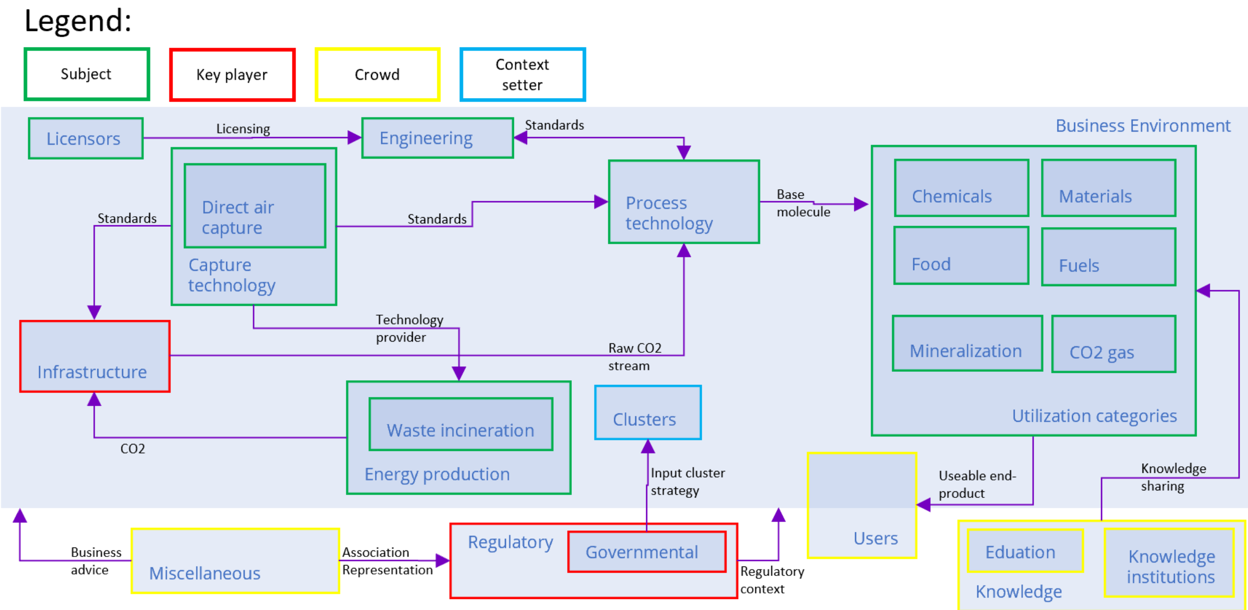

Figure 4.3: Stakeholder groups network diagram

Figure 4.3 shows that governmental entities control the next steps in developing CCU in the Netherlands. Companies can develop technologies to some point. However, their power is limited depending on the context the government creates and CCU in the larger energy transition and circular economy. Infrastructure development is already high in power due to the limited network available to develop different initiatives. Smaller, off-grid initiatives are already emerging. However, a sustained supply of CO_2 can not always be guaranteed. Clusters are the places where the first full value chain development of CCU emerges.

The stakeholder groups shown in Figure 4.3 are split into two more detailed maps Figure 4.4 and Figure 4.5 and provide a visual overview of the different stakeholders' power, interest and influence on other stakeholders. A more detailed explanation per stakeholder can be found in Appendix D, in Table 8.11. The remainder of this section will discuss the stakeholders that deviate in power or interest from the corresponding stakeholder group and other interesting insights.

Within Figure 4.4, many key players are represented within the chemicals sector because several pathways to use CO_2 are via chemical conversion. CO_2 gas sector is not among the high power stakeholders because the direct use of CO_2 doesn't need the investments in development as is seen with the other CO_2 utilisation categories. BASF, Deep Branch, and Westlake are considered more powerful than the other companies in the materials, food, and mineralisation categories. This is because of their involvement in developing CCU over different TRL technologies within the FutureCarbonNL collaboration. Similarly, Photanol, Albermarle, and Twence, from the process technology and waste incineration categories, have a high power and interest. The stakeholders within the infrastructure are both key players. They differ based on the current CO_2 infrastructure provided by Linde gas in the western part of the Netherlands for horticulture and Gasunie in their contribution to develop CCU with their infrastructure side of the development actively. Like the other key players in the different stakeholder groups, these stakeholders are actively pursuing the development of CCU in the Netherlands. In addition, the key players in the field are generally the larger companies and multinationals. This is a consequence of their budget to lobby (Interviewee #11). However, this should be carefully considered, as they are much more drawn towards considering the maintenance of the industry rather than taking an innovative side into perspective as the start-up can do (interviewee #8). Unlike the problem statement and findings from the literature review, the clusters don't have as much interest as expected because these industrial clusters have other options to decrease their emissions (Mirella, 2022).

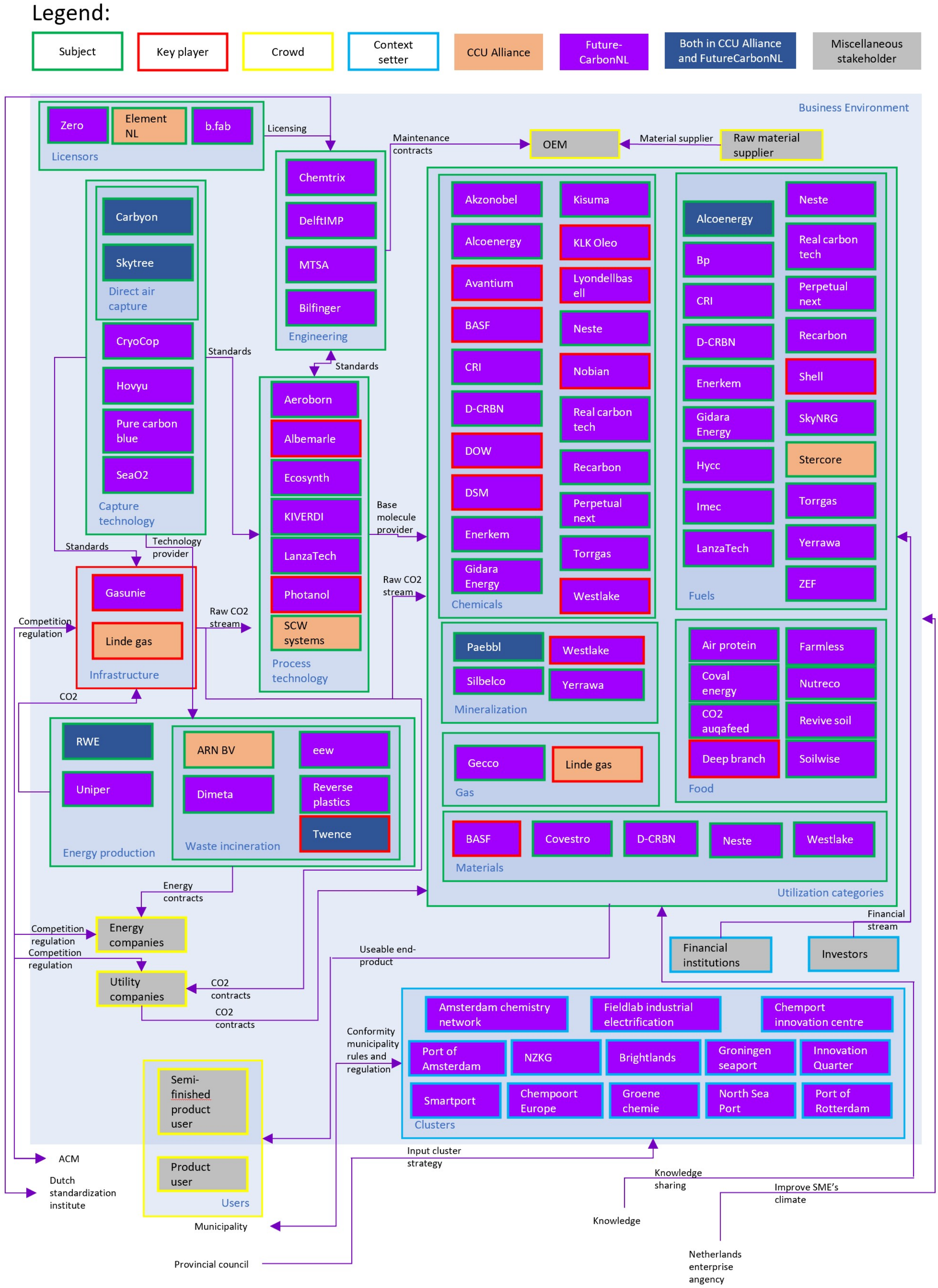

Figure 4.4: Stakeholder network part 1 (business environment)

In Figure 4.5, a representation of the different stakeholders in the knowledge, government and miscellaneous groups is given. In the government section, the Dutch Environmental Assessment Agency is a key player in the field. This entity's planning practices are essential in assessing CCU's role in the energy transition and the circular economy, but they are not currently involved. Nonetheless, this entity should continuously be involved in developing CCU in the Netherlands as the Ministry of Infrastructure and Water Management and the Ministry of Economic Affairs and Climate Policy are in the FutureCarbonNL collaboration (Interviewee #9). The Ministry of Agriculture, Nature and Quality is essential in the policy development towards the food production related to CCU. However, they are not involved in the development. The Netherlands enterprise agency is a key player that actively tries to improve SME climate, and at times, they are involved in the development but are essential for the companies that are currently piloting, testing or want to scale production (Interviewee #8). All the key players in the knowledge group, such as TNO, TU Delft and the Institute for Sustainable Process Technology, are actively involved in developing the FutureCarbonNL plans. This means the stakeholders actively have a say in the process.

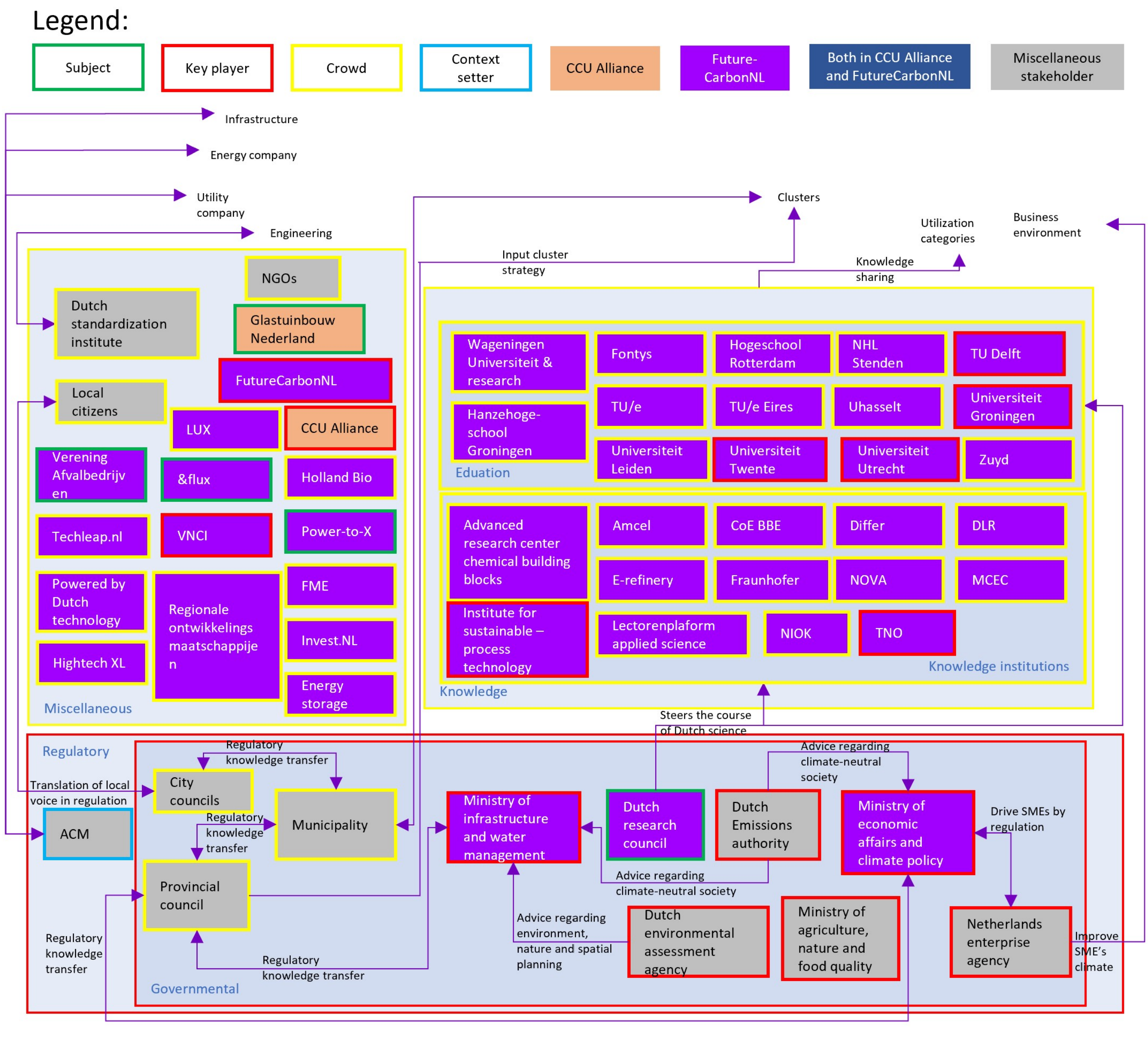

Figure 4.5: Stakeholder network part 2 (Knowledge, government and miscellaneous)

4.3. Main findings

In this concluding section, we will encapsulate the key takeaways from this chapter. The historical development of CCU has seen progress from the initial ideas in the 1990s to the establishment of significant initiatives and platforms in the 2010s and beyond. The focus has been improving CO_2 utilization, reducing emissions, and creating economic and social benefits. Initiatives on implementing full CCU value chains between industrial clusters failed due to a lack of interest in development by the clusters and decreasing financial resources. The sector continued to evolve, with new partnerships and initiatives in the Netherlands in 2023, indicating a commitment to carbon utilization for sustainable and environmental purposes. Therefore, it can be concluded that initiatives were made in the past but failed due to reduced interest and finances. The change in plans by Tata Steel shows a quickly changing decarbonization plan by this industry. Nonetheless, the sector is gaining traction to develop the technology due to new initiatives. Nonetheless, clusters are the places where the first full value chain development of CCU emerges.

Embarking on the power interest matrix integrated stakeholder network map, it can be concluded that the infrastructure stakeholders, with the governmental and regulatory stakeholders, are key players in the development of CCU in the Netherlands. Next to these two stakeholder groups, key players are scattered across the stakeholder map. Clusters are those which should be kept satisfied. Dutch Emissions Authority, Dutch Environmental Assessment Agency, Ministry of Agriculture, Nature and Food Quality, and Netherlands Enterprise Agency should be involved in the development of CCU by FutureCarbonNL and CCU Alliance. Currently, these entities are not regularly involved or not involved but are key players in the development.

5
Niche analysis and Multi-level perspective

5.1. Socio-technical landscape

The socio-technical context influences the development and adoption of new technologies. This chapter explores the intricate network of social, cultural, economic, and political forces that shape the interaction between technology and society. By evaluating the socio-technical landscape, a deeper understanding of how societal values, institutional structures, and actor interactions impact technological transitions can be gained. This analysis aims to uncover the intricate mechanisms that drive technical advancement and its broader societal implications. The following paragraphs are devoted to how climate change, international dependence, and the raw material transition impact the macro level.

5.1.1. Climate change

The first important landscape component that can be identified is the growing worry in the Netherlands about global warming. As global temperatures rise, the repercussions of global warming become more visible all around the world. Concerns and attention for this problem are simply and swiftly conveyed due to the global connection provided through media access. Activist platforms encourage citizens, businesses, and governments to contribute, as everyone must have a role in resolving the situation. There is a greater awareness of the carbon impact and the need to achieve CO_2 neutrality. 2016, the Paris Agreement was developed to set targets for Europe's commitment to resolving the climate catastrophe. Furthermore, numerous nations reached their own accords in order to accomplish these targets. In 2019, the Netherlands established a climate agreement with several enterprises and corporations to reduce CO_2 emissions by 49% in the Netherlands (Ministerie van Economische Zaken en Klimaat, 2019). Furthermore, the agreement aims to make all buildings in the Netherlands totally CO_2-neutral by 2050. Furthermore, buildings should be totally separated and rely on a sustainable energy source, with no use of natural gas by 2050, according to (Ministerie van Economische Zaken en Klimaat, 2019). This landscape aspect has an impact on most existing socio-technical regimes since it forces the market to include sustainable solutions and satisfy climate targets.

Politics has increasingly moved to the development of policies and regulations that significantly impact the development of climate mitigation technologies and, therefore, CCU technologies. The government in the Netherlands established incentives, mandates, or financial support for CCU projects as they work to reduce greenhouse gas emissions and combat climate change. These actions can help establish a more favourable environment for developing and deploying CCU technology (Ministerie van Algemene Zaken, 2023; Ministerie van Economische Zaken en Klimaat, 2019). While industries are looking to decarbonize their operations, they are considering investing in CCU to mitigate emissions and achieve environmental goals. Demand for CCU products, such as carbon-negative materials or synthetic fuels, has the potential to spur innovation and investment in CCU development. Therefore, there will be an expanding market demand for CCU technologies that are driven by the urgency to address climate change and reduce greenhouse gas emissions (Ministerie van Economische Zaken en Klimaat, 2019, p.109-112). Consequently, this influences the availability of funding and investment for CCU projects; governments, philanthropic organizations, and private investors can allocate more resources to support the development and commercialization of CCU technologies, recognizing their potential to contribute to climate change mitigation (VNCI, n.d.-a).

Due to climate change, the European Union aims to protect nature and bio-diversity by reducing nitrogen decomposition in ”Natura 2000 sites”, which have been appointed with the goal to improve and safeguard the bio-diversity throughout Europe (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2022). Nitrogen decomposition is caused by the release of reactive nitrogen compounds, namely ammonia (NH3), nitrates, and various nitrogen oxides, referred to as NO_X. These are released in, e.g. agriculture and combustion processes in the industry in the form of ammonia (NH3), a colourless gas with a strong odour (RIVM, n.d.-b). This causes conflict with the current excessive nitrogen decomposition in the Netherlands. This is influencing the development of infrastructure for CO_2 transport in the port of Rotterdam. Nature Organisation Mobilisation for the Environment (MOB) filed an appeal against Porthos's use of the building exemption in November 2021. With the building exemption in effect at the time, no permit was required or could be obtained for the nitrogen emissions produced during construction. The Council of State concluded in an interim judgement on November 2, 2022, that the building exemption is no longer valid since it violates European nature conservation law (Fraters, 2023). On the 16th of August 2023, the Council of State decided that the development of infrastructure is allowed to proceed with a delay of almost a year.

Most interviewees do not specifically mention climate change as a driver for the CCU sector. Nevertheless, three interviewees (Interviewee #3, #7, and #8) explicitly mentioned how climate change is affecting CCU, led by the following exemplary quote:

"For me, the climate agreement is leading. So, basically, the energy transition and the carbon transition that we want to achieve in the Netherlands." (#7, 2023)

Interviewee #4 was the only one disagreeing with the perspective on climate change and questioned this as the motive behind the CCU development, asserting that the development of CCU relies solely on the resource transition.

"This is not about climate change at all. This is about the resource transition, not the energy transition." (#4, 2023)

5.1.2. International dependency

The second landscape component can be divided into two events that gave the notion of international dependence. The Netherlands, as an open and increasingly globalised economy, relies on raw material and resource imports to support its industries and meet domestic demand. The different events will be explained in the following paragraphs. First, the blockage of the Suez Canal will be discussed, as Covid-19, and thereafter, the Russia/Ukraine war.

5.1.2.1 Suez Canal blockage

The Suez Canal was closed for six days in March 2021 due to the Ever Given, a container ship that ran aground in the canal. Because the obstacle happened south of the stretch of the canal with two channels, additional ships were unable to circumvent Ever Given. The canal obstruction had a substantial detrimental influence on trade between Europe, Asia, and the Middle East because it was one of the world's busiest commercial routes. Maritime and logistics experts warned that the incident would almost certainly cause delivery delays for clients all across the world. On March 28, at least 369 ships were awaiting passage through the canal. This averted an estimated $9.6 billion in commerce. Because of this, the worldwide supply system was interrupted, and oil and petrol prices skyrocketed. This was the first encounter of Europe's and the Netherlands' reliance on resources from other regions of the world.

It emphasised the risks of reliance on certain trade routes, the need for transportation diversification, and the need to increase domestic production. The tragedy prompted the Netherlands to reevaluate its raw material supply chains and implement measures to increase resilience, reduce reliance on imports, and assure a more secure and sustainable supply of vital resources.

"And the geopolitical independence, yes, I think it kind of started with the Suez channel." (#4, 2023)

5.1.2.2 Covid-19 pandemic

Disruptions in global supply networks have been one prominent result of the pandemic. Lockdown measures, travel restrictions, and temporary manufacturing closures in many regions of the world have caused delays and shortages in raw material supply. As a major trading nation, the Netherlands witnessed disruptions in the supply of vital materials such as metals, minerals, and chemicals, affecting industries like manufacturing, construction, and technology. As a result, many products' prices have continued to grow, resulting in substantial inflation. Overall, the economic outlook has shifted substantially in a short period of time (De Nederlandse Bank, 2022).

Furthermore, the pandemic has highlighted the importance of diversifying supply sources. Many countries, like the Netherlands, relied largely on a few main suppliers of critical raw commodities. However, when those suppliers were subjected to major disruptions as a result of the pandemic, it resulted in shortages and price variations. This has caused the Netherlands to reevaluate its supply chains and look for other sources in order to minimise the risk of future interruptions. To assure a steady supply of raw materials, the emphasis has turned to constructing more resilient and diverse supply networks (De Nederlandse Bank, 2022).

The Covid-19 crisis has also accelerated the demand for increasing local raw material production. The Netherlands understands the need to minimise its reliance on imports by encouraging indigenous extraction and processing of vital resources. This includes attempts to build local mining, recycling, and circular economy skills. By increasing domestic production and decreasing reliance on foreign sources, the Netherlands hopes to improve supply security and reduce vulnerability to global disturbances (European Circular Economy Stakeholder Platform, 2023).
Interviewee #4 was very elaborate on the geopolitical independence and mentioned this 5 different times.

”Yes, and Covid-19 of course too. Just look at those raw materials for medicines. India went into lockdown. And then it was suddenly like, we can’t make paracetamol anymore later. Yes, so that’s why the willingness to accelerate geopolitical independence has accelerated.” (#4, 2023)

5.1.2.3 Russia/Ukraine war

On February 24, 2022, the Russian army launched an invasion and invaded Ukraine. The Dutch government joined NATO partners in strongly condemning Russia and Belarus, imposing harsh penalties to hamper Russia’s capacity to finance this conflict.
Shortly after the commencement of the Ukrainian war, the Dutch parliament set the goal of reducing Russian energy imports to the maximum extent feasible, as soon as possible, in order to stop contributing to Russia’s war fund. Fossil fuel exports accounted for more than 60% of Russia’s government revenue. As a result, the Dutch government has been working hard to stimulate the development of alternative energy sources, save energy, hasten the energy transition, and limit energy price increases whenever possible (Ministerie van Economische Zaken en Klimaat, 2023).

As a result, the increase in energy prices comes on top of the significant price hikes observed in the previous year. Initially, this was primarily due to the quick rebound of demand following the COVID-19 crisis, to which supply did not adapt adequately (De Nederlandse Bank, 2022).

”And issues like geopolitical conflicts also come into play. Look at what’s happening with Ukraine and Putin and oil. These are actually alternatives to oil. So when Putin attacked Ukraine, everyone realized that we needed to become much more independent. So, these kinds of general trends also help.” (#4, 2023)

Interviewee #4 further emphasised from a forward-looking perspective the potential danger of Iran and China in the government’s willingness to become geopolitical independent.

”And now they also see the downpour with China and Iran. So I think that has also been an acceleration for the Net Zero Industry Act, the critical raw material Act and therefore again those wishes to be more geopolitically independent.” (#4, 2023)

5.1.3. Circular economy

The last landscape factor is the circular economy. The circular economy represents a paradigm shift in resource management underpinned by waste reduction, resource efficiency, and material recycling. The Netherlands has created a detailed National Circular Economy Strategy that defines the country’s aim and road map for attaining a circular economy by 2050 to comply with the Paris Agreements. The strategy is divided into four parts (Ministerie van Infrastructuur en Waterstaat, 2022):

- **Biomass and Food**: The country’s goal is to eliminate food waste, promote sustainable agriculture practices, and develop circular food systems that reduce resource use and waste.
- **Plastics**: The policy calls for steps to minimise plastic consumption, improve recycling infrastructure, and promote recyclable and biodegradable materials.
- **Manufacturing**: The Netherlands wants to encourage companies to use circular production methods and to promote product design for durability, repairability, and recyclability.
- **Construction and Demolition**: The plan focuses on circular practises in the construction sector, such as reusing building materials, designing for disassembly, and developing circular building standards.

These government policies and regulations are increasingly reflecting a commitment to circular economy principles. These policies encompass a wide array of measures, such as waste reduction targets, extended producer responsibility, and incentives for eco-design and product longevity. The Netherlands, for instance, has taken significant steps to promote the circular economy, including the implementation of a comprehensive Circular Economy Program in which CCU is the closing technology of the circular chain (Interviewee #4).

Moreover, the business landscape is also evolving in response to the circular economy's imperatives. Companies are recognizing that adopting circular practices can enhance their competitiveness, reduce costs, and open new revenue streams. There is a growing realization that sustainability and circularity are no longer merely ethical considerations but are central to a business's long-term viability (World Economic Form, 2023).

As a result, increased efforts to create a fully circular economy are gaining prominence as a response to the environmental and economic challenges posed by linear models. It is driven by a confluence of factors, including environmental concerns, governmental policies, and corporate initiatives. This paradigm shift towards circularity holds the potential to transform not only economic and production systems but also the way society conceives of resource utilization, waste, and sustainability. The circular economy, with its commitment to resource efficiency and regeneration, emerges as a compelling strategy to shape a more sustainable future.

> *"Without this, without CCU, we will not have circularity and, in fact, no net zero society."* (#7, 2023)

Interviewees #3, #4 and #5 had similar statements to this perspective. Interviewee #4 added one reason why there won't be a net zero society without CCU:

> *"CCU, we're not doing much about CCU yet. It is a final piece of the circular economy. You know, we already have hydrogen. We already have chemical recycling; we already have recycling. A lot is going on with bio-based, not much is going on with CCU yet, because yes, it is fairly new."* (#4, 2023)

In light of the final piece of the circular economy, interviewees #4 and #5 call the development of CCU a resource transition.

5.1.4. International CCU developments

International developments on CCU influencing the developments within the Netherlands. Project in various TRLs can influence the Dutch market. Therefore, all international projects are presented in Appendix F, in Table 8.15. What is seen in the international projects are the high amount of European project, indicating high efforts in European context, especially in Germany, Spain, France, and Sweden. The projects cover a broad range of applications, from traditional industries like cement production to emerging technologies such as graphene production and algae cultivation. In addition, a quarter of the 92 projects are related to methanol production through various TRL. 10% is related to hydrogen production, 15% is related to cement production, another 10% is related to fuels in general. This shows that about 45% of the projects is related to some kind of fuel development. Therefore, it is likely that the production of fuels from CO_2 is influenced by projects outside the Netherlands. Belgium has a significant number of projects across various categories. Some projects are already producing, while others are in planning or early development stages. Operation dates range from the current year to as far as 2030. This can influence the Dutch developments substantially, while the projects focus on very specific applications in contrary to some collaborations within the Netherlands, collaborating on similar technologies and preconditions, such as policy, and supply security. In addition, multinational stakeholders in the Dutch stakeholders network are represented in the international field as well.

5.2. Regime analysis

The key socio-technical regimes in the CCU sector are detailed in this section. As simply mentioned in Section 2.2, socio-technical regimes are the current routines and actions carried out by all groups that have an impact on the technological environment. The engineering community, scientists, policymakers, users, and other special-interest organisations are among these groups (F. W. Geels & Schot, 2007). The socio-technical regimes remain largely stable but receive gradual advances as a result of system players' activity (F. W. Geels et al., 2017). The macro level refers to the system's overall landscape developments. Socio-technical system players do not directly drive developments at this level but rather exert pressure on existing regimes to conform to the changing environment (F. W. Geels & Schot, 2007).

5.2.1. Electricity

In the Netherlands, the power business is a multidimensional sector with numerous organisations, agencies, and networks. It includes energy utilities (e.g., Eneco, Vattenfall), grid operators (e.g., TenneT, Alliander), and renewable energy developers at the organisational level. These organisations are in charge of different components of the power supply chain, such as generation, transmission, distribution, and retail. The industry is subject to extensive regulation and oversight on an institutional level. Regulatory agencies such as the Authority for Consumers and Markets (ACM) and the Ministry of Economic Affairs and Climate Policy set the rules, pricing, and regulations controlling the electricity market. Their job is critical in maintaining fair competition, dependable operations, and compliance with sustainability objectives. The networks of the electrical business are critical for the reliable transmission and distribution of electricity. Extensive regional and international cooperation, such as the North Sea Wind Power Hub, helps to integrate renewable energy sources and cross-border electricity commerce. These networks are critical to the stability and sustainability of the power grid. The Dutch electrical business is at a crossroads, marked by rapid transformations, revolutionary policy efforts, and lofty sustainability targets.

The Dutch electrical sector is undergoing a significant and diverse transformation in the context of the global responsibility to mitigate climate change and cut greenhouse gas emissions. This evolution is inextricably related to a broader energy transition, which aspires to transform the nation's energy-producing landscape and stimulate innovation, improve energy efficiency, and secure long-term energy security (S&P Global, 2023). The stakeholders related to the electricity regime are those within the energy production category in Figure 4.4, RWE, Uniper, Twence, and eew.

5.2.2. Fossil fuel

In the Netherlands, the fuels industry consists of a variety of organisations, institutions, and networks that shape the production and distribution of fuels. It includes major oil and gas firms (e.g., Royal Dutch Shell, ExxonMobil) and fuel distributors involved in many areas of the fuel supply chain, from discovery and refining to distribution. The sector functions institutionally within a framework of regulatory control and governance. The Netherlands Petroleum Industry Association (VNPI) advocates the fuels industry's interests to regulators and policymakers. In addition, the Dutch Emission Authority supervises the Register of Energy for Transport (REV) Renewable Fuel Units (HBEs) for companies that supply fuels for transport. Furthermore, government entities such as the Dutch Ministry of Economic Affairs and Climate Policy establish energy policies and regulations that affect the operations of the business (Nederlandse Emissie authoriteit, 2022).

The fuels business is linked to global oil and gas supply networks, which are affected by international organisations such as OPEC (Organisation of Petroleum Exporting Countries). Research institutions and industry organisations contribute to the fuel sector's innovation and sustainability efforts to address environmental and economic concerns (Organization of the Petroleum Exporting Countries, 2005). Like many other European countries, the Netherlands has been aggressively seeking policies and methods to reduce its dependency on fossil fuels and move to cleaner, more sustainable energy sources. Environmental concerns, climate change mitigation aims, and a commitment to meeting international agreements such as the Paris Agreement are driving this move (interviewee #5). As with other EU member states, it has implemented various policies to encourage biofuel use. To minimise greenhouse gas emissions, these policies include blending targets for biofuels with conventional fuels such as petrol and diesel. The Netherlands has put in place carbon pricing measures such as the ETS, which caps emissions and requires businesses to purchase permits for their emissions. This stimulates emission reductions and the shift to cleaner energy sources (European Commission, n.d.), which is in line with the vision of interviewee #7. The stakeholders related to the fossil fuel regime are those within the fuel category in Figure 4.4, Shel, Bp, ZEF.

"CCU has to compete with biofuels" (#7, 2023)

5.2.3. Chemicals

The Dutch chemical sector has historically been critical to economic prosperity. The Dutch chemical sector has remained competitive in the global market due to its strategic position, excellent infrastructure, talented workforce, and strong focus on innovation and sustainability (Deloitte & VNCI, 2012). As is been confirmed by one of the interviewees:

"When considering CCU in the context of chemicals, the petrochemical industry plays a significant role in the Netherlands, and there is a desire to maintain a portion of it locally." (#1, 2023)

The sector is quite diverse, with segments such as petrochemicals, speciality chemicals, polymers, and pharmaceuticals. The Dutch chemicals industry is diversified with several organisations, institutions, and networks. At the organisational level, it consists of chemical manufacturing businesses such as AkzoNobel, DSM, and LyondellBasell. These companies manufacture a diverse range of chemicals, including speciality chemicals and petrochemicals (interviewee #4).

Institutionally, the chemicals sector is supervised by organisations such as the Netherlands Environmental Protection Agency (RIVM) and the European Chemicals Agency (ECHA). These organisations are in charge of establishing chemical safety and environmental effects guidelines. Industry-specific organizations like the Association of the Dutch Chemical Industry (VNCI) play a crucial role in advocating for the sector's interests and connecting the sector.

Furthermore, the Dutch Ministry of Infrastructure and Water Management is active in chemical safety and environmental protection (European Chemicals Agency, n.d.; Ministerie van Infrastructuur en Waterstaat, 2023; RIVM, n.d.-a; VNCI, n.d.-b). The stakeholders related to the chemicals regime are those within the chemical category in Figure 4.4, BASF, DOW, Kisuma, Neste, and Nobian.

"But let's say there is a lot of knowledge about petrochemical processes. That was the main reason coming in." (#8, 2023)

5.2.4. Agriculture

The Netherlands is a global leader in production and technology. Dutch horticultural products, including flowers, plants, and vegetables, are highly sought after in international markets. The sector has a strong export orientation, with a significant portion of its produce being sold abroad. Meso-level dynamics in Dutch horticulture are marked by the presence of distinct horticultural clusters and agglomerations. These clusters consist of specialized regions where various crops are cultivated, benefiting from local expertise, infrastructure, and supply chain networks. For example, the Westland region is renowned for its greenhouse cultivation. The stakeholders related to the agriculture regime is Glastuinbouw Nederland in Figure 4.4 other stakeholders of the argiculture regime are not represented within the CCU stakeholder network.

"When fossil CO_2 *is used in greenhouse horticulture, it ends up back in the atmosphere, which is not in line with our long-term emission reduction goals to achieve zero* CO_2 *emissions. This could potentially be replaced by atmospheric* CO_2 *or biogenic* CO_2 *since these are not permanently stored. However, this poses other issues, such as the limited availability of biogenic* CO_2 *and the high energy costs associated with extracting atmospheric* CO_2*."* (#2, 2023)

5.2.5. Food industry

The Dutch food industry functions within a well-defined institutional framework. Regulatory authorities such as the Netherlands Food and Consumer Product Safety Authority (NVWA) and the Ministry of Agriculture, Nature, and Food Quality play critical roles in establishing and implementing food safety standards, assuring product quality, and monitoring compliance with relevant rules. Furthermore, industry organisations such as the Dutch Federation of Agriculture and Horticulture (LTO Nederland) fight for the sector's interests and work with government agencies to create agricultural policies. Environmental sustainability is a major concern, and the government seeks to implement regulations that promote sustainable agriculture practises through numerous ministries (interviewee #13)(Nederlandse Voedsel- en Warenauthoriteit, 2023).

Within the food sector, networks are essential for knowledge sharing, research, and innovation. Wageningen University & Research stands out as a prominent institution fostering collaboration and research in agriculture and food sciences. As exemplified by the Royal Agrifirm Group, farmer cooperatives facilitate resource-sharing and market access for agricultural producers, promoting collaboration and sustainable practices. International collaborations with organizations like the Food and Agriculture Organization (FAO) extend the Netherlands' reach in the global food community. These networks contribute to the sector's resilience and innovation (Food and Agriculture Organization of the United Nations, n.d.). The stakeholders related to the food regime are those within the food category in Figure 4.4, Air protein, Deep branch, Farmless, and Soilwise.

5.2.6. Energy intensive industry

The Netherlands' heavy industry and manufacturing sector encompass a wide range of organizations, institutions, and networks. At the organizational level, it includes companies engaged in steel production (e.g., Tata Steel). Institutionally, the sector is subject to government regulations and policy oversight. Regulatory bodies such as the Netherlands Enterprise Agency (RVO) and the Ministry of Economic Affairs and Climate Policy influence industry policies and sustainability initiatives.

Networks within the heavy industry and manufacturing sector benefit from collaborative research centres and innovation hubs. For example, the Smart Industry program promotes digitalization and innovation within the sector. These networks facilitate technological advancements and sustainability initiatives in heavy industry and manufacturing. The Dutch heavy and manufacturing sector was grappling with transformative pressures arising from environmental sustainability imperatives, technological advancements, and shifts in global economic trends (Ministerie van Economische Zaken en Klimaat, 2021). The stakeholders related to the energy-intensive regime are those within the materials category in Figure 4.4 such as Neste, Westlake, and Covestro.

5.2.7. Construction

The construction sector in the Netherlands, including concrete manufacturing and brick production, operates within a regulatory framework that addresses environmental and quality standards. Regulatory bodies such as the Netherlands Enterprise Agency (RVO) and the Ministry of Economic Affairs and Climate Policy significantly shape industry policies and sustainability initiatives. They set standards related to energy efficiency, emissions reduction, and environmental impact. The sector is also subject to building codes and standards established by organizations like the Netherlands Organization for Applied Scientific Research (TNO) and the Netherlands Standardization Institute (NEN). These standards ensure the quality and safety of construction materials and practices. Environmental sustainability is a key concern, and policies related to circular construction and reducing the carbon footprint of construction materials, including concrete and bricks, are becoming increasingly important.

Collaboration and knowledge-sharing networks are instrumental in advancing innovation within the construction sector. Research institutions, including Delft University of Technology and Eindhoven University of Technology, conduct construction materials and processes research. These institutions collaborate with industry stakeholders and government agencies to drive construction technology and sustainability advancements. Industry associations such as Bouwend Nederland and the Dutch Concrete Association (Betonvereniging) serve as platforms for collaboration, best practices sharing, and advocacy for the sector's interests. These networks foster cooperation among manufacturers, contractors, and architects, ensuring that industry advancements are effectively disseminated and implemented (interviewee #8).

Technological innovation is a cornerstone of the Dutch construction sector, particularly in manufacturing concrete and bricks. Research and development efforts focus on producing more sustainable construction materials. For example, a growing emphasis is on developing low-carbon concrete by reducing cement content and incorporating alternative binders like fly ash and slag (Eurpean Commission, 2021). The stakeholders related to the construction regime are those within the mineralization category in Figure 4.4, Yerrawa, Paebbl, Sibelco and Westlake.

"We have also observed that the route of permanent CO_2 *storage can be interesting, even in the Netherlands, focusing on alkaline waste streams, for instance. There are waste incineration plants, for example, where* CO_2 *can be easily captured and permanently stored to be utilized in the construction sector. These are options that I find interesting in any case, in my opinion."* (#2, 2023)

5.2.8. Waste management

The Netherlands' waste management sector encompasses various organizations, institutions, and networks responsible for waste collection, recycling, and disposal. At the organizational level, it includes waste collection companies (e.g., Renewi), recycling facilities, and waste-to-energy plants (e.g., AVR). These organizations are responsible for various aspects of waste management, from collection and sorting to recycling and energy recovery.

Institutionally, the sector operates within a regulatory framework governed by the Dutch government, particularly the Ministry of Infrastructure and Water Management. This ministry sets waste management policies and regulations, ensuring proper waste disposal, recycling, and environmental protection. Additionally, waste management practices are influenced by EU directives and international agreements aimed at waste reduction and recycling. Networks within the waste management sector are essential for efficient waste collection and recycling.

Collaboration among waste management companies, local municipalities, and recycling organizations ensures that waste is managed effectively. Research institutions like Wageningen University & Research contribute to waste management innovation and sustainability initiatives, seeking to improve waste reduction and recycling practices (Interviewee #10) (European Environment Agency, 2023). The stakeholders related to the waste regime are those within the waste incineration category in Figure 4.4. The regime overlaps with the electricity regime and has players such as ARN BV, eew, reverse plastics, and Twence.

5.3. Niches

This section will discuss niches that emerge within the innovation system and provide an overview of the system interactions.

5.3.1. Industrial clusters

As apparent from the problem statement and the literature review, CCU technologies are expected to emerge around the industrial clusters. Most industrial cluster plans involve CCU deployment, as can be read in Section 1.2. However, the particular plans are unknown. The most concrete plan includes establishing a CO_2 network and connection to CCS in the North Sea and the need for a transition from CCS to CCU to occur in the clusters starting in 2030. The demand side of the scope remains unknown, as noted in the Rotterdam clusters for CCU implementation.

As a first step, an arrangement has been made for all the stakeholders, in Figure 4.4 and Figure 4.5, this stakeholder map will be used as a starting point for the remainder of this chapter.
Figure 5.1 shows all the stakeholders defined in Chapter 4. In this illustration, the colours the stakeholders are given are based on the clusters in which they are located. An overview of the colours related to the stakeholders is presented in the legend in Figure 5.1.

In general, it can be seen that there is no specific emphasis on clusters since more than half of the stakeholders are located abroad or not related to a specific cluster, even when solely taking the business environment into account. When only taking the business perspective into account, only 43 out of 73 stakeholders are related to a specific cluster, and 30 stakeholders are either not related to a cluster(14) or located in a foreign country(16). 16 stakeholders are related to the Rotterdam cluster, 14 stakeholders to the Amsterdam cluster, 7 stakeholders to the Delftzijl cluster, 6 stakeholders to the Chemelot cluster, and 2 stakeholders to the Zeeland cluster.

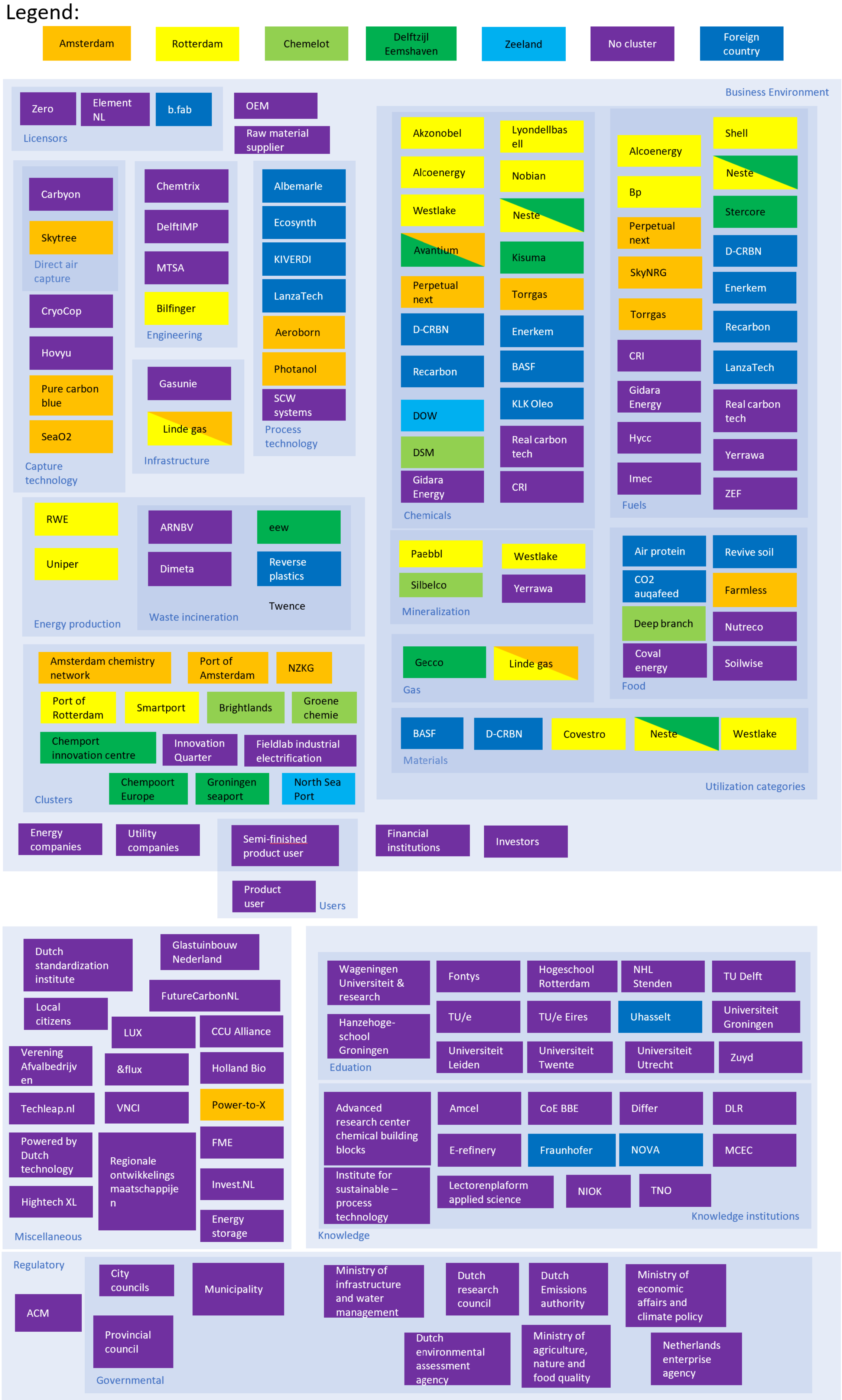

Figure 5.1: Stakeholder allocation map

5.3.2. Socio-technical niches

Derived from the theory, niches are defined as places where deviant practices occur, such as niches for alternative technology, but also in the form of new initiatives and new forms of culture and governance. Within the CCU development in the Netherlands, the identification of the niche(s) will be determined around the following use cases:

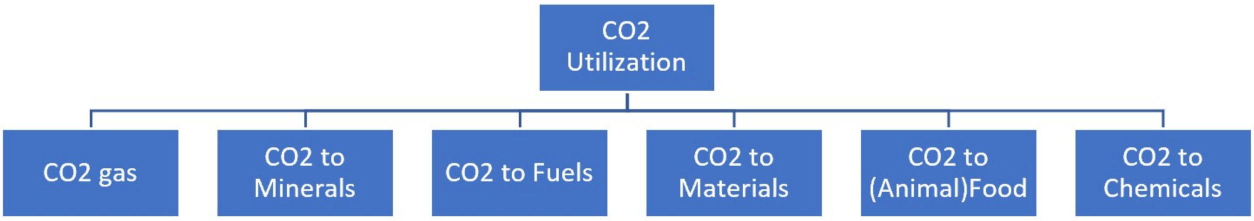

Figure 5.2: CO_2 use cases

As seen in Figure 5.2, the CO_2 can be used for different applications. Illustration Figure 5.3 depicts the full conversion chain starting at the carbon source to the final product that can be made. The last step represents the niches linked to the different end products. It can be seen that the conversion of CO_2 in platform chemicals determines whether or not CO_2 is directly or indirectly utilized.

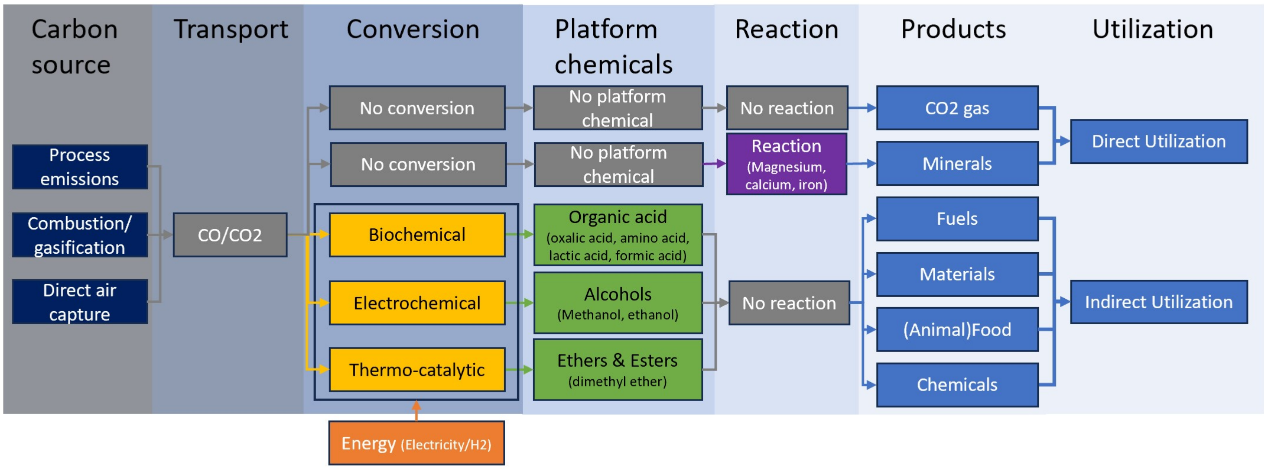

Figure 5.3: Carbon conversion chain (Adapted from factsheet FutureCarbonNL (FutureCarbonNL, 2023))

The indirect utilization is mainly represented in the FutureCarbonNL collaboration due to their strong focus on the conversion to platform chemicals shown in Figure 5.3. Therefore, the mineralization of CO_2 has been rejected from the collaboration.

> *"It was decided not to include mineralization in FutureCarbonNL, as there was a separate proposal specifically addressing concrete and aggregates. However, mineralization remains relevant to the topic of CO_2 utilization."* (#1, 2023)

This was the first initiation to differ between the later defined direct and indirect utilization niche, confirmed by interviewee #4:

> *"mineralization is actually direct use"* (#4, 2023)

5.3.3. Stakeholder collaborations

In Figure 5.4, an overview is given of all the stakeholders' collaborations.

Figure 5.4: Stakeholders collaborating within the stakeholder field

In **Collaboration 1**, as illustrated in Figure 5.4, brings together stakeholders from various segments of the value chain. Two notable outliers within this collaboration are Stercore, a green gas producer, and Alcoenergy, which engages in bio-ethanol production, corn oil extraction, and electricity generation for internal consumption.

Moving to **Collaboration 2**, it constitutes a consortium focused on repurposing waste materials to generate proteins for human and animal consumption. This consortium maintains a connection with FutureCarbonNL to monitor sector-specific developments. However, it is noteworthy that most participating companies are located abroad, rendering them of limited relevance to the Dutch context.

Collaboration 3, the most extensive collaboration, focuses on the complete spectrum of indirect utilization products. It boasts the broadest array of stakeholders and uniquely involves collaboration with a Dutch ministry as part of the Growth Fund application process. The National Growth Fund is a government investment fund in the Netherlands aimed at strengthening the sustainable earning capacity of the country. It achieves this by collaborating with project initiators to invest in endeavours that foster long-term economic growth (Rijksoverheid, n.d.). The depicted companies are leading participants in the FutureCarbonNL movement and are actively engaged in the application process for the Growth Fund. Other entities associated with FutureCarbonNL have opted to observe ongoing developments and are, therefore, not featured in this selection.

Collaboration 4 comprises two distinct cluster entities, namely the Port of Rotterdam and Amsterdam. This collaboration exhibits a strong focus on transportation and contributes to the CO_2 supply to the OCAP network through Linde Gas. Additionally, Gidara Energy has designated the Port of Amsterdam as a site for developing a Bio-methanol plant.

Collaboration 5 closely monitors developments by leveraging FutureCarbonNL; however, both participating companies are located overseas, rendering them less pertinent to developments within the Netherlands.

Collaboration 6 is dedicated to advancing hydrogen production within different clusters.

Lastly, **Collaboration 7** centres its efforts on waste-to-fuel production through the development of flexible feedstock technology. Collaborations 6 and 7 also maintain connections with FutureCarbonNL to stay abreast of sectoral advancements.

5.3.4. Innovation system

Figure 5.5 shows the niches, regimes, and landscape described in this chapter, which are brought into the context of the innovation system of CCU in the Netherlands. Climate change, international dependency, and circular economy are the landscape factors influencing the CCU innovation system and the complementary CCS innovation system by stabilizing or destabilizing pressures. The two-sided arrows illustrate that eight regimes influence and are influenced by the direct and indirect utilization niches. Furthermore, the regimes overlap with the CCU innovation system as well as with other regimes. This is because certain regime actors are stakeholders within the innovation system and the overlapping regime. For visibility, not all connections are made in the illustration, but actors within different regimes have connections with multiple aspects of the value chain. The CCS innovation system is complementary to the CCU innovation system as the first two steps of the value chain, capture and transportation, are covered in this innovation system.

The electricity regime and waste regime overlap over environmental sustainability, resource efficiency, and energy supply. The effective management of waste in electricity production can contribute to a more sustainable and resilient energy system while addressing environmental concerns related to waste disposal (e.g. Twence). Fossil fuels produce a substantial part of the electricity. Therefore, the electricity and fossil fuel regimes overlap over environmental concerns and regulatory policies as the world seeks to address climate change and move toward more sustainable energy systems. Alcoenergy is one of the stakeholders challenging both regimes as it produces both biofuels and electricity. The food and agriculture regimes overlap over the production of food as agriculture takes an important place in food production. The chemicals and fossil fuels regimes overlap over the feedstock, diversifying feedstock sources to reduce environmental impacts and dependence on fossil fuels. The production of hydrocarbon is exemplary of the shared feedstock when using CCU for fuel and chemical production. Enerkem is one of the stakeholders serving both regimes by producing ethanol and methanol.

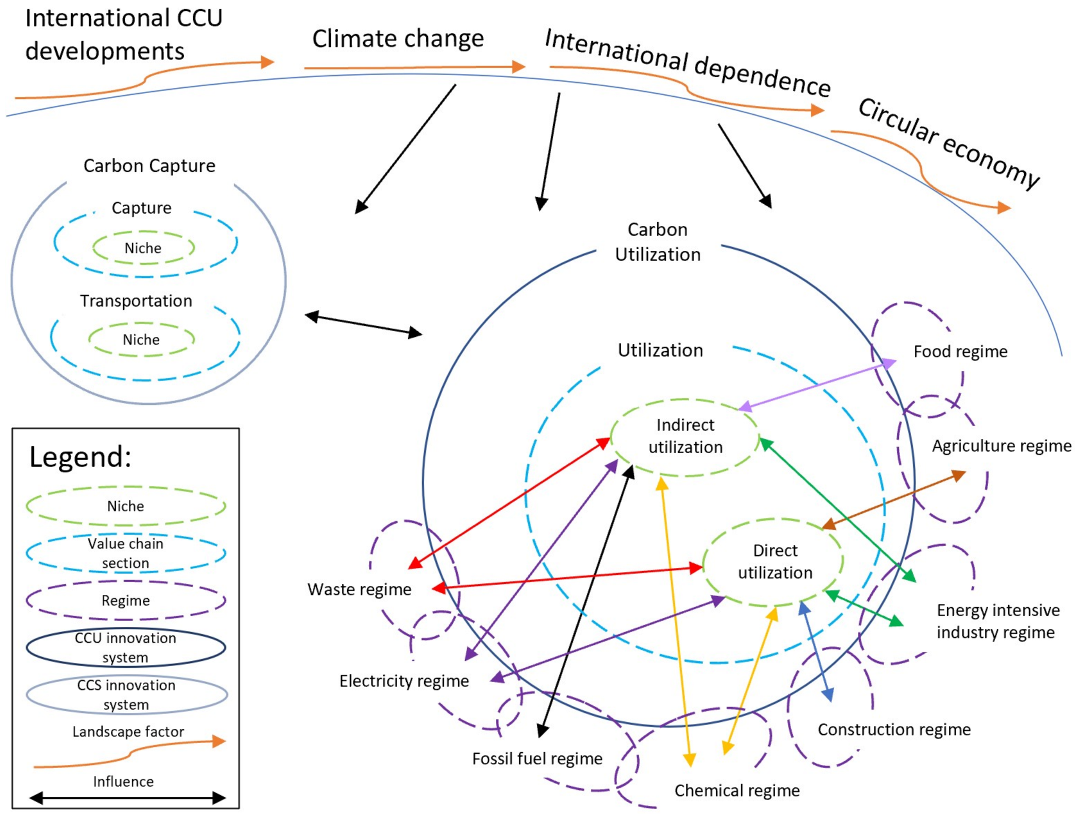

Figure 5.5: Innovation system interactions (Adapted from (Markard & Truffer, 2008)

5.4. Main findings

The three landscape factors uncovered are climate change, geopolitical independence, circular economy, and the international CCU developments especially Europe pressing on the niches and regimes to initiate change by stabilizing and destabilizing.Various socio-technical regimes are related to the development of CCU in the Netherlands. The regimes are related to electricity, fossil fuels, chemicals, energy-intensive industries, construction, waste, agriculture, and food. All are influencing or are being influenced by the utilization niches. Several regimes have corresponding stakeholders, such as electricity and waste regime, fossil fuels and electricity, food and agriculture, and chemicals and fossil fuels.

As became apparent from the problem statement and the literature review, CCU technologies were expected to emerge around the industrial clusters. Nonetheless, it can be concluded that there is no specific emphasis on the clusters since only 43 out of 73 of the stakeholders are affiliated with one of the clusters. At the same time, 16 stakeholders are located in the Rotterdam cluster and 14 in the Amsterdam cluster, respectively, around 20% of the stakeholders in the business environment. Instead, it can be concluded the niches are divided into direct and indirect utilization. CO_2 gas and mineral products are related to direct utilization. Fuel, material, (animal)food, and chemical products are related to indirect utilization.

It can be concluded that collaborations reflect the dynamic and evolving landscape of CCU initiatives in the Netherlands, with a particular emphasis on hydrogen, green gas, and innovative approaches to waste repurposing. Collaboration 3 stands out as the most extensive, with governmental involvement, demonstrating the commitment to long-term economic growth through CCU endeavours. However, international participation is also notable in these initiatives, emphasizing the global dimension of CCU research and development.

The innovation system shows that eight regimes impact and are impacted by the niches, revealing a complex interplay. The CCS innovation system complements CCU by managing the initial value chain stages. Overlapping regimes, like electricity and waste and electricity and fossil fuels, emphasize the importance of cross-sector collaboration. Shared interests in food and agriculture and chemicals and fossil fuels highlight the need to diversify feedstock sources and advance sustainability. Together, the innovation system underscores the multifaceted nature of Dutch CCU innovation.

6
Niche development

This chapter aims to analyse niche processes using Strategic Niche Management ideas and offer barriers and opportunities based on findings from niche development analysis. The analysis is based mainly on information gathered through semi-structured interviews with several actors in CCU niches in the Netherlands.

6.1. Nurturing

6.1.1. Social network formation

Referring back to Figure 5.4, different collaborations have been presented. In general, these different collaborations are related to either the direct or indirect utilization niche, presented in Table 6.1.

Table 6.1: Collaboration, product, niche relation

Collaboration	Collaborative focus	Niche relation	Product relation	Specific end-products
1	Full value chain with direct air capture	Direct	Gas, minerals, fuels	CO_2, construction filler material, green gas, ethanol
2	Protein production	Indirect	(Animal)food	Proteins, soil fertilizer
3	Chemicals and conversion	Indirect	Chemicals, food, materials, fuels, minerals	Ethanol, methanol, hydrogen, proteins, polymers, bio-fuel, building materials
4	Clusters and methanol	Indirect	Chemicals, fuels	Methanol, ethanol, hydrogen
5	Process technology	Indirect	Fuels	Syngas, hydrogen
6	Hydrogen and clusters	Indirect	Fuels	Hydrogen
7	Waste-to-fuel	Indirect	Fuels	Hydrogen, methanol, ethanol

The establishment of various collaborations primarily centres around the concept of indirect utilization. While the first collaboration exclusively concentrates on direct utilization, a more in-depth analysis reveals that most collaborations are product-oriented, particularly concerning hydrogen production. These collaborations, numbered 3, 4, 5, 6, and 7, are strongly associated with fuel-related products.

Collaboration 2, on the other hand, focuses on producing proteins derived from CO_2, with potential applications in both animal feed and human consumption. In contrast, Collaboration 3 boasts the broadest array of end-products, with most stakeholders aligning with the chemical industry due to its focus on the requisite conversion methods integral to indirect utilization.

Collaborations 4, 5, 6, and 7, although relatively small in scale, provide valuable insights into the current network development and the overarching hydrogen focus of the collaboration. Notwithstanding their modest scale, these collaborative efforts collectively underscore a prevailing trend toward hydrogen development, with a primary emphasis on electrochemical conversion method.

6.1.1.1 Direct and indirect utilization

The government's perceived unreliability as a business partner poses a significant impediment to its potential contributions to the advancement of CCU for both direct and indirect utilization. Furthermore, there exists a misalignment between the European Union's vision for the CCU strategy and the perspectives of other key stakeholders. These stakeholders advocate for a separation of the strategy, contending that its current concentration on addressing hard-to-abate industries hinders CCU progress, detracting from the emphasis on fostering the circular economy.

6.1.1.2 Direct utilization

Companies specializing in direct utilization are concerned about their ability to access the indirect utilization network due to its pronounced emphasis on hydrogen-related initiatives. Despite these concerns, they remain optimistic about gleaning valuable insights from the stakeholders engaged in indirect utilization. While their collaborative efforts exhibit a cooperative spirit, it is noteworthy that startups in this domain encounter challenges in attracting a lead investor to support their developmental endeavours.

6.1.1.3 Indirect utilization

In general, stakeholders concur on the overarching principle of inclusivity within the network, aiming to encompass all pertinent stakeholders. Nonetheless, some perceive certain areas, such as infrastructure and the demand side, as being underrepresented. An entity notably absent from the current network is Sebik, and the subsequent developmental phase is expected to incorporate additional actors, including NGOs, provincial bodies, and municipal entities.

Recognizing the need for heightened innovation, it is proposed that SMEs be integrated into the network to bolster their capacity for innovative endeavours. The broad spectrum of businesses represented in the network can render interactions complex, but the network's ability to convene meetings several times a week proves advantageous for stakeholders. However, collaboration among fuel producers is constrained by the rigidity of their established procedures.

Despite the network's representatives primarily focusing on R&D, it is widely perceived as having a strategic character. Owing to the diverse range of CCU initiatives, the network comprises stakeholders with disparate interests and objectives.

This diversity is reflected in the varying visions within the network, where some emphasize stimulating a circular economy while others prioritize optimizing the existing system. These differing visions can be attributed to variations in the participants' backgrounds and affiliations within the current system.
In Appendix E, Table 8.12, the stakeholders related to network formation are shown.

6.1.2. Articulation of vision and expectations

6.1.2.1 Direct and indirect utilization

Stakeholders across both direct and indirect utilization domains express concerns regarding the impact of a scarcity of affordable energy on the competitiveness of production costs when compared to the United States and China. This challenge is further compounded by apprehensions about the availability of sustainable green CO_2. Implementing the Inflation Reduction Act by the Biden administration in the United States has stimulated CCU production, providing U.S.-based facilities with a competitive edge and diminishing prospects for large-scale production in the Netherlands.

A significant challenge stems from the government's lack of a comprehensive vision for the role of CO_2 in the broader decarbonization strategy and the CO_2 supply chain. This absence of a cohesive government strategy has created uncertainty and deterred investments in the sector. Looking towards the long term, expectations centre on constraints in CO_2 supply, attributed to the gradual depletion of fossil resources, intensified competition for CO_2 across various applications, and limited availability of viable CO_2 sources.

In the broader context, stakeholders exhibit varying expectations regarding niche development, with a prevailing pessimistic outlook in the short term but a more optimistic perspective in the long term. Long-term expectations are buoyed by the potential for feasible, long-term CO_2 storage through mineralization technology, thus diversifying the array of available CCU options. However, short-term concerns persist due to anticipated constraints in CO_2 supply, linked to CCS developments in the Netherlands and the government's perceived lack of comprehensive planning for market development policies. Nevertheless, DAC units are expected to facilitate off-grid CO_2 provision for small to medium-scale applications.

6.1.2.2 Direct utilization

Solely related to direct utilization, the dynamics of these expectations are marked by a degree of ambiguity, exemplified by the case of CO_2 smart grid development in the western part of the Netherlands. As one stakeholder noted, "But the direction in which it needs to go, in our opinion, has not changed drastically. Namely, that CCU was simply one of the components necessary to make the industry more sustainable." This observation underscores the notion that despite certain setbacks, the fundamental expectations regarding the development of CCU remain largely unchanged.

6.1.2.3 Indirect utilization

Broadly, stakeholders expect that CCU technologies are poised for development within the Netherlands. This optimism is grounded in the nation's established knowledge base and production culture conducive to technological advancements. However, the anticipation of large-scale CCU implementation may remain elusive, counterbalancing this positive outlook primarily due to the constraints of limited access to green CO_2 sources.

Instead, the emphasis is shifting towards strategic volumes aimed at securing geopolitical independence, underpinning the nation's role as a stabilizing force in the global context of resource independence. Concurrently, applying oxygen binding in the production of materials is anticipated to enhance cost-effectiveness. Oxygen-carbon binding mechanisms play a crucial role in reducing excessive energy consumption, as they necessitate the separation of carbon and oxygen bonds before single carbon molecules can be employed in the construction of products, presenting a sustainable alternative to conventional oil-derived products in contemporary society.
In Appendix E, Table 8.13, the stakeholders related to the visions and expectations are shown.

6.1.3. Learning processes

6.1.3.1 Direct and indirect utilization

Environmental impact

Related to the environmental impact, the following three aspects must be considered. Firstly, the origin of the CO_2 source. Secondly, The duration of the CO_2 storage in the product. Thirdly, How the energy that is used is produced green. In addition, the complex environmental considerations surrounding CCU in terms of carbon stream question the true sustainability of CCU. However, the importance of CCU does not solely rely on the sustainability of the technology but also the circularity as it is the closure of the circular economy. Notably, when confronted with resource constraints or inherent limitations in circularity, products may require a carbon recovery process(Combustion) to become circular. Nonetheless, the three environmental aspects are important to take into consideration.

Technology adoption

Technology adoption comprises several barriers. Firstly, technology is seen as a barrier as it needs a fair amount of development. This should involve designing the CCU networks in which the origin of the CO_2 should be considered. Secondly, the stakeholder and end-user awareness is important. Nonetheless, different initiatives were already undertaken to enable stakeholder awareness (e.g. informative meetings, lectures, using communication experts to bring these difficult messages, writing position papers, and internal master classes). Thirdly, high costs are associated with CCU projects. therefore, there is a reluctance to adopt costly technologies and integration into industrial processes. Fourthly, the need for high-quality CO_2 feedstock in CCU applications hampers adoption, particularly in greenhouses and product manufacturing. Lastly, the industry is cautious about operating within an uncertain market environment.

Technology adoption is also related to stakeholder knowledge and end-users. Currently, many stakeholders and all end-users do not know what CCU is. Related to the stakeholders, the definition of CCU is important. Because of many different backgrounds, the definition changes accordingly. It became apparent that the community doesn't want the production in their backyard as they don't know what CCU comprises. Lastly, introducing a novel CCU product to the market is difficult as industry and social acceptance are scarce.

Policy and governmental development

In the current political landscape, CCU initiatives are not fully supported, which is related to the availability of knowledge about CCU. In addition, existing policies do not adequately accommodate innovative CCU approaches. It is seen that the unique aspects of CCU technologies and products are not adequately addressed. For example, the lack of regulation does not prevent double CO_2 counting. Therefore, stakeholders think taxpayer money for CCU projects is not efficiently allocated, leading to alternative market-driven approaches.

Stimulating policies, like subsidies, blending requirements for indirect utilization, and taxes on fossil products, are seen as ways for technology dissemination. This includes adopting scope 3 emissions in the ETS, which is seen as enabling market models.

Within the government, the lack of in-house experts at the government is seen as a barrier to making system-level decisions. This dearth of internal expertise contributes to a deficiency in strategic vision, subsequently heightening the intricacy faced by policymakers and economic affairs officials to grasp the complexities and timeframes involved. In addition, A commitment of the government is essential to de-risk companies. Regrettably, this consistency has been lacking, thereby diminishing the government's reputation as a reliable business partner. An additional complication arises from the variations in the administrative systems within different governmental departments of the Netherlands and their impact on funding flexibility.

Business models

Promoting business models can be enabled by shifting away from fossil resources, which catalyzes advancing CCU initiatives. Similarly, the capital held by companies associated with the fossil industry has the potential to accelerate CCU endeavours, thus raising questions about the involvement of incumbent companies in this transition. These entities, on the one hand, reap benefits from the industry's existing state yet actively engaged in the development of improved or novel product and production methodologies. This novel approach incorporates oxygen binding, as illustrated in Section 6.1.2.3. While enhancing existing methods may demand increased energy input, it aligns with the interests of the current regime.

CCU projects at the Mid-TRL encounter financial challenges, underscoring the necessity of resolving them to facilitate their success. The presence of well-defined documentation, rules, and standards within the CCU domain is pivotal for enabling effective project implementation. Furthermore, assigning value to CO_2 sequestration in products and materials, commonly called mineralization, and establishing a connection between negative emissions and ETS are critical elements of the CCU landscape.

Engaging end-markets in CCU initiatives is advantageous, as it enhances awareness and public perception and empowers end-market participants to wield their bargaining influence effectively. Policy stability is a linchpin for viable business models in this domain, given its capacity to mitigate uncertainty and foster long-term planning.

To surmount the multifaceted technical and commercial challenges in CCU, seamless collaboration between policy, regulation, and industry is essential, creating a unified front capable of overcoming these obstacles. An essential aspect of infrastructural development lies in the quality of CO_2, which must surpass the standards applied to CO_2 used in CCS. Presently, this quality disparity impedes the local development of CCU applications, exemplified by the availability of the OCAP network, which offers opportunities for the advancement of CCU applications.

6.1.3.2 Direct utilization

In the context of direct utilization, stakeholders have gained valuable insights, notably in understanding the inhibiting role of the governmental structure in the development of CCU. The fragmentation of responsibilities across various government ministries presents a formidable challenge, as it complicates the alignment of all relevant stakeholders. Consequently, the government's reliability as a business partner is perceived as questionable within this realm.

Additionally, emerging startups operating within this niche have acquired essential project management skills, particularly in the domain of handling large-scale projects and the associated administrative intricacies. This experiential learning underscores their adaptability and capacity to navigate the complexities inherent to project administration.

The CCU Alliance stands as a robust and influential driver in the realm of project development and the pursuit of negative emissions goals within the CCU landscape. Section 6.2.2 will elaborate on the CCU Aliance as driving factor in direct utilization.

6.1.3.3 Indirect utilization

In the realm of indirect utilization, a pivotal consideration pertains to the quantum of energy necessary for CO_2 conversion, with a specific emphasis on the energy source's environmentally friendly and sustainable nature. This emphasis arises from the inherent energy intensity of the conversion processes employed in indirect utilization. Consequently, the viability of these applications hinges on the precondition that the energy supply in the Netherlands is not only entirely green but also in surplus.

Perceiving the CCU industry as a complex endeavour involves integrating CCU initiatives into preexisting industrial networks. This complexity is further compounded by the influential presence of established industry players, adding layers of intricacy to the entire process.
FutureCarbonNL plays a central and dynamic role in propelling the growth and advancement of CCU technologies within the Netherlands. As dedicated to the growth fund, it channels resources, expertise, and support toward the development and maturation of CCU initiatives. Section 6.2.2 will elaborate on FutureCarbonNL as a driving factor in indirect utilization.
In Appendix E, Table 8.14, the stakeholders are shown related to all learned aspects.

6.2. Barriers and opportunities

6.2.1. Barriers

6.2.1.1 Direct and indirect utilization

Uncertain CO2 supply

The uncertainty surrounding CO_2 supply stems from governmental oversight. While the EU offers an overarching vision that combines CCUS, there is a compelling need to differentiate between CCU and CCS strategies. It is imperative to maintain a nuanced perspective on the pivotal role of CCU within the broader decarbonization strategy and has to be communicated by the Dutch government.

Moreover, the absence of well-defined market policy development further exacerbates the challenge of ensuring a stable and predictable CO_2 supply. In the short term, the landscape is complicated by CCS developments and the government's lack of comprehensive planning, resulting in an uncertain CO_2 supply outlook. In the long term, factors such as the depletion of fossil resources, the diverse range of CO_2 utilization products, and the limited availability of viable CO_2 sources collectively contribute to the challenge of securing a certain and reliable CO_2 supply.

True sustainability of CCU

The sustainability of CCU is commonly accepted; however, a more comprehensive evaluation is imperative. While CCU inherently embodies principles of circularity and sustainability through establishing a carbon cycle, it is vital to scrutinize the sustainability of the entire value chain.

To ensure a sustainable CCU process, several critical aspects must be considered. First and foremost, the energy utilized in CCU processes should be sourced from green and renewable sources, minimizing the carbon footprint associated with energy production. Secondly, the origin of the CO_2 source is of paramount importance. While CO_2 from fossil sources perpetuates carbon-intensive processes, biogenic and atmospheric CO_2 can potentially facilitate negative emissions, contributing positively to the carbon cycle. This highlights the necessity of addressing sustainability concerns at the outset of the value chain. In addition, incorporating Scope 3 emissions in LCA calculations is essential to gain insights into the sustainability of the entire value chain, focusing on the culmination of the process. Lastly, to prevent double-counting of CO_2 emissions and ensure transparency and accuracy, stringent regulatory frameworks must be established. This should be complemented by the development of robust modeling methodologies that facilitate clear boundary setting within the CCU system. This delineates the beneficiaries of CO_2 emissions avoidance and those responsible for bearing the associated costs.

Stakeholder and user acceptance

Gaining stakeholder and user acceptance for CCU technologies is challenging, primarily due to financial considerations. Many potential users are hesitant to pay more for CCU-related products or services, especially when traditional alternatives are perceived as cost-effective. This reluctance is often rooted in the limited knowledge and understanding of what CCU entails among stakeholders and end-users.

User acceptance is further complicated by the Not in My Backyard sentiments, which can significantly impede the implementation of CCU projects. Localized concerns related to environmental impacts, land use, and other factors often lead to resistance from communities and stakeholders.

On the stakeholder front, another hurdle lies in the perceived high costs associated with CCU technology development and project implementation. The substantial initial investment required for CCU initiatives can deter stakeholders from supporting these projects.

Policy

The policy serves as a substantial barrier, with a notable absence of policy stability. Companies encounter difficulties in establishing their business models due to the uncertainty surrounding existing policies. Furthermore, these policies often do not adequately accommodate innovative CCU approaches, which can result in perpetuating solutions that are less sustainable in the long term compared to more innovative alternatives.

An additional imperative lies in establishing the linkage between CO_2 storage in products, the concept of negative emissions, and the ETS. This linkage is crucial to incentivize solutions that store CO_2 over extended periods, contributing to long-term sustainability and environmental goals.

Governmental expertise and communication

Governmental expertise and effective communication are critical barriers that necessitate attention. To overcome the intricate technical and commercial challenges, there is a compelling need for seamless collaboration among government entities, regulatory bodies, and industry stakeholders. This collaboration is indispensable for navigating the complexities of implementing policies and regulations.

Another significant challenge arises from the variations in administrative systems across different governmental departments in the Netherlands, impacting the flexibility of funding mechanisms. These discrepancies can hinder the efficient allocation of resources and impede the progress of initiatives addressing pressing issues.

Furthermore, there is a pressing requirement for policymakers and economic affairs officials to gain a comprehensive understanding of the intricacies and timeframes involved in addressing these challenges. Their ability to grasp these nuances is pivotal in formulating effective strategies and policies that can lead to successful outcomes.

6.2.1.2 Direct utilization

Governmental structure

In direct utilization, the prevailing governmental structure poses a significant impediment to the advancement of CCU. The sector encounters challenges associated with the involvement of multiple ministries, rendering it difficult to achieve alignment among all relevant stakeholders. This complexity is not mirrored in indirect utilization, where various ministries exhibit a more proactive, direct, and coordinated engagement in CCU development.

6.2.1.3 Indirect utilization

Vision misalignment

There is a misalignment of vision within the indirect utilization network, as it does not prioritize either the promotion of a circular economy or the optimization of the existing one. This is because of different actors acting in either regime or as new technology providers serving different interests of stakeholders.

Integration

Integrating CCU initiatives into existing industrial networks involves the strategic incorporation of CCU technologies into the preexisting infrastructure and operations of industrial sectors. It requires both development of new aspects of the value chain and modification of existing processes at companies.

6.2.2. Opportunities

6.2.2.1 Direct and indirect utilization

International technology provider

In a broader international context, these opportunities offer a spectrum of possibilities for the Netherlands to harness its abundant knowledge and resources for the development and scaling of innovative technologies. The resultant technologies can not only address domestic needs but also be exported to foreign countries, providing a viable business model that significantly contributes to the Dutch economy. This strategy of technological development and international commercialization forms a powerful synergy, utilizing the nation's expertise and resources to foster economic growth and global recognition in the field of CCU.

The ongoing development of pilot and demonstration-level tests is yet another avenue through which opportunities unfold. These initiatives provide a unique testing ground for emerging CCU technologies, enabling them to evolve and mature into scalable solutions with international market potential. The Netherlands, with its proactive stance in fostering such developments, is poised to become a frontrunner in the global CCU landscape. This position not only underscores the nation's commitment to innovation but also enhances its prominence on the international stage as a hub for CCU technology advancement.

Furthermore, the confluence of a receptive market, a supportive hinterland, and an abundance of knowledge within the Netherlands presents a compelling opportunity for companies to nurture and refine their CCU technologies. This favorable environment offers the ideal conditions for research, development, and commercialization of CCU solutions, making the Netherlands an attractive destination for businesses seeking to make meaningful contributions to carbon reduction efforts and the circular economy.

In response to the growing global demand for negative emissions, the Netherlands is primed to seize a significant opportunity. Technologies focused on capturing and utilizing atmospheric and biogenic CO_2 emissions can not only cater to the local market but also be exported to foreign countries with similar environmental imperatives. This expansion of CCU technologies into international markets positions Dutch companies as leaders in the quest for negative emissions, a role that aligns with the global sustainability agenda and further solidifies the Netherlands' reputation as an innovative and eco-conscious nation.

The timing of current developments within the Netherlands provides companies with a distinct competitive advantage in the international arena. By being at the forefront of CCU technology development and implementation, Dutch firms can position themselves as technology providers, ensuring their relevance in the dynamic landscape of carbon reduction and circular economy solutions worldwide.

Government commitment

The commitment by the Dutch government to phase out fossil resources would stand as a pivotal opportunity in the realm of CCU product development. By initiating this shift away from fossil fuels, the government is effectively catalyzing the demand for alternative carbon feedstocks, a demand that CCU technologies are well-positioned to fulfil. This transition not only addresses environmental concerns but also promotes the transition to a circular economy, where waste is minimized and valuable resources are continually recycled and reused. It is through the development of CCU products that the Dutch economy can capitalize on this opportunity, paving the way for a sustainable, resource-efficient, and circular economic model.

Furthermore, the ETS and the SDE++ introduce valuable financing opportunities for emerging and more ambitious CCU technologies. These mechanisms not only incentivize the development and adoption of sustainable technologies but also alleviate some of the financial risks associated with pioneering ventures in CCU.

6.2.2.2 Direct utilization

The emergence of the CCU Alliance presents a unique and promising opportunity for the Netherlands in the development of CCU technologies, as well as the advancement of negative emissions policies and projects. The CCU Alliance acts as a collaborative ecosystem that brings together key stakeholders, including industry leaders, research institutions, government agencies, and environmental advocates. This ecosystem facilitates dialogue, knowledge sharing, and collaboration, thereby nurturing a supportive environment for CCU development.

The alliance serves as an innovation catalyst, inspiring the creation of novel CCU technologies and solutions. The shared expertise and resources within the alliance enable Dutch companies and research organizations to accelerate their innovation efforts, resulting in a faster and more efficient development process. The CCU Alliance is a strong advocate for favorable policies related to CCU and negative emissions. By leveraging its collective influence, the alliance can actively engage with policymakers and promote the development of policies that support CCU initiatives. This advocacy creates a more conducive regulatory environment for CCU projects. CCU technologies promoted by the alliance play a pivotal role in reducing carbon emissions and achieving negative emissions.

6.2.2.3 Indirect utilization

FutureCarbonNL represents a significant driver and a promising opportunity for the development of CCU technologies in the Netherlands. As a growth fund focused on advancing innovative and sustainable solutions, FutureCarbonNL plays a pivotal role in catalyzing the growth and commercialization of CCU initiatives. When succeeding it provides much-needed financial support to companies and organizations involved in CCU research and development. This funding not only facilitates the advancement of existing projects but also encourages new and innovative solutions in the field of carbon capture and utilization. With the backing of FutureCarbonNL, Dutch companies and research institutions are well-positioned to accelerate their research and development efforts in CCU technologies. This support enables them to explore new ideas, refine existing processes, and create groundbreaking innovations. Their involvement in CCU projects opens up new avenues for market expansion. The financial resources and support provided by the growth fund empower Dutch businesses to bring their CCU technologies to market more rapidly, thereby capturing domestic and international opportunities.

As FutureCarbonNL supports CCU projects within the Netherlands, it contributes to enhancing the international visibility and reputation of Dutch CCU expertise. The growth fund's investments underscore the nation's commitment to sustainability and innovation, making Dutch companies more appealing to global markets and collaborators. The growth fund's involvement not only fosters the development of CCU technologies but also fuels economic growth within the Netherlands. As CCU solutions mature and reach the market, they generate employment opportunities and drive economic activity, strengthening the nation's position as a leader in sustainable technology. Its support fosters a thriving innovation ecosystem for CCU. This ecosystem brings together researchers, entrepreneurs, policymakers, and investors, fostering collaboration and knowledge exchange. It is within this ecosystem that groundbreaking CCU technologies are born, nurtured, and propelled to success.

6.3. How can the barriers be overcome

Overall, the SNM processes have not performed well. Multiple barriers related to all types of internal niche processes have been presented. In this section, a proposal will be given on how to stimulate the niches according to the different barriers that have been presented by prioritising them. The priority lies at the contextual factors. Contextual factors aim to tackle the nuturing barriers to create a stable business environment. Once this is achieved, attention shifts to go-to-market barriers that hinder business model development, followed by implementation barriers obstructing project execution.

6.3.1. Direct and indirect utilization

6.3.1.1 Contextual factors

In the midst of the numerous barriers, a significant issue that emerges pertains to commitment barriers between the government and companies within the sector. Companies demonstrate their willingness to commit to specific boundary conditions in order to achieve various climate and sustainability objectives. In return, these companies anticipate a reciprocal commitment from the government. The challenge lies in the inconsistency of government actions, which results in a constantly shifting regulatory and contextual landscape for these companies. In tandem with this barrier, developing a coherent government vision holds substantial importance. This is because a well-defined government vision plays a crucial role in shaping the contextual framework for the sector, which, in turn, can have a profound impact on addressing these commitment barriers. The vision and stability are closely related to the in-house expertise the government holds. Therefore, the relation between the three barriers is visualised in Figure 6.1. These barriers will be discussed more elaborately in the remainder of this section, and the other barriers will be uncovered.

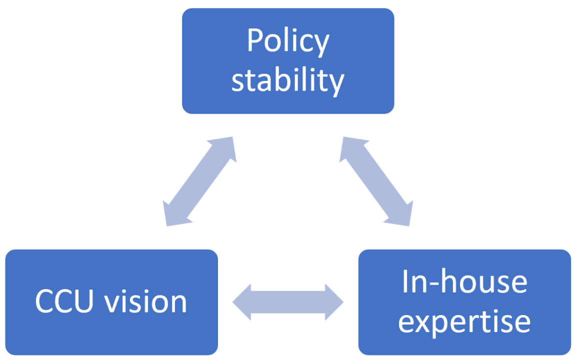

Figure 6.1: Relation contextual factors (Policy stability, CCU vision, in-house expertise

Policy stability

In the context of CCU development, policy instability has emerged as a substantial barrier to progress. The lack of policy stability creates challenges for companies seeking to establish viable business models within the CCU sector. This instability not only hampers investment but also perpetuates solutions that may be less sustainable in the long term compared to more innovative and environmentally friendly alternatives (IRENA, 2022).

CCU vision

The policy stability is connected to the overarching vision towards CCU technologies and the pivotal role of CCU within the broader decarbonization strategy as a vision towards CCU will enable stable policy. Therefore, a long-term vision is needed to tackle both barriers. This vision should harmonize with broader sustainability and environmental goals, effectively positioning CCU as a key contributor to climate and circular economy targets. For the government to create a vision towards CCU in the broader decarbonisation context. This vision will also enable long-term CO_2 supply. To secure a certain and reliable CO_2 supply over the long term, the government should develop a clear, long-term strategy. This strategy should consider factors such as the depletion of fossil resources, the variety of CO_2 utilization products, and the limited availability of viable CO_2 sources. By proactively addressing these challenges, a more stable and reliable supply of CO_2 can be assured.

In-house expertise

However, to create a vision, the ministry in-house expertise should also be improved to create this broader vision. More and more vision development is done by external advisory, and easy shifts in policy direction seem to be tough. Currently, the expenditure on external advisory services has never been so far above the norm (Rijksoverheid, 2023). To tackle the expertise barrier stemming from external advisory services, ministries can increase their number of permanent employees with expertise related to circularity and energy transition. In this way, they can manage their knowledge more stringent towards CCU.

True sustainability of CCU

Moreover, establishing stringent regulatory frameworks is necessary to prevent double-counting of CO_2 emissions and ential how to include scope 3 emission. These regulations promote transparency and accuracy in assessing the environmental impact of CCU processes. Developing robust modelling methodologies is equally important. These methodologies aid in clearly defining the boundaries of the CCU system, ensuring accurate allocation of responsibilities and costs associated with CO_2 emissions avoidance. This contributes to the policy stability the businesses are asking for.

Uncertain CO2 supply chain

In the short term, it is essential to address immediate challenges by addressing the landscape complexities arising from CCS developments and the government's limited planning. Here, policymakers can provide short-term solutions that offer supply stability while focusing on long-term objectives.

There is a pressing need for well-defined market policy development that ensures a stable and predictable CO_2 supply. Policymakers should formulate clear policies that align with the long-term vision for CO_2 utilization and how a stable supply can be ensured for market developments. This will help provide a conducive environment for businesses and investors, ultimately enhancing supply stability.

6.3.1.2 Go-to-market factors

Stakeholder and user acceptance

To mitigate the challenge stemming from limited knowledge and understanding of CCU, a comprehensive awareness campaign is essential. Stakeholders and end-users need to be educated about the benefits and principles of CCU. This can be achieved through informative meetings, workshops, seminars, and the utilization of communication experts to convey complex information in an understandable manner, of which stakeholders have already undertaken several initiatives. Pieri et al. (2023) shown that such items are relatively well known and accepted. Respondents in the United Kingdom backed policymakers and industry promotion of CO_2-derived products, government sponsorship of such schemes, and enterprises that use captured CO_2 in their products. The product category appears to influence people's readiness to use and acquire CO_2-derived items, with our respondents more likely to use CO_2-derived fuels than food or beverages, indicating sensitivity to health-related hazards. Respondents were also more likely to purchase a CO_2-derived product if it was less expensive or more environmentally friendly.

Addressing Not in My Backyard sentiments requires proactive community engagement. Open dialogues, public consultations, and transparency in project planning are crucial. Demonstrating the environmental and economic benefits of CCU can help alleviate concerns and gain local support (Petrova, 2016).

Governmental communication

To tackle the governmental communication barrier administrative systems among government departments, cross-departmental communication has to be improved or a working group could be established. This collaborative body would serve as a forum for knowledge sharing and alignment of policies and regulations related to CCU. Academic experts could participate in these discussions to provide insights and bridge knowledge gaps.

6.3.2. Direct utilization

6.3.2.1 Go-to-market factors

Governmental structure

Encourage increased coordination and collaboration among the multiple ministries involved in CCU. Establish interagency working groups or task forces that bring together representatives from these ministries to streamline decision-making and align strategies.

Moreover, a CCU advisory council composed of experts can be created, industry representatives, and government officials from relevant ministries. This council can provide guidance, share insights, and ensure a unified approach to CCU development.

6.3.3. Indirect utilization

6.3.3.1 Contextual factors

Vision misalignment

Facilitate dialogues and workshops involving all stakeholders within the indirect utilization network. Encourage open discussions to identify and understand the diverse interests and priorities of stakeholders. Foster collaboration among stakeholders with the goal of finding common ground and shared objectives related to CCU and circular economy promotion or optimization of the existing one. Ensure that policies and regulations are aligned with the shared vision for indirect utilization. Integrate circular economy principles into relevant policies to provide a clear regulatory framework for CCU initiatives. Create incentives and mechanisms that promote and reward adherence to the circular economy vision.

6.3.3.2 Implementation factors

Integration

Integrating CCU initiatives into existing industrial networks can be challenging, as it involves modifying existing operations and infrastructure. A thorough assessment of the existing industrial network to identify areas where CCU technologies can be integrated and the development of a detailed plan that outlines the specific technologies to be incorporated and the modifications required. The consideration of CCU technologies that align with the industry's objectives and can be integrated with the existing infrastructure.

Pilot CCU projects can be used within willing industrial sectors to demonstrate the feasibility and benefits of integration. The pilot projects can facilitate data collection, measuring performance, and showcasing success stories to other industries.

6.4. Main findings

Collaboration 1 focuses on direct utilization, while collaborations 3, 4, 5, 6, and 7 prioritize fuel-related products, especially hydrogen. Collaboration 3, in particular, features a wide range of end-products and strong connections with the chemical industry, emphasizing conversion methods for indirect utilization. These collaborations indicate the early stages of network formation. Social network development in both direct and indirect utilization highlights challenges related to government reliability, differing stakeholder visions regarding CCU strategy, and alignment with European Union goals and the circular economy. Social network development in direct utilization underscores tensions with indirect utilization networks, potential for collaborative learning and cooperation, and challenges faced by startups in securing investment. Social network development in indirect utilization emphasizes inclusivity, SME integration, the benefits of frequent meetings, collaboration challenges among fuel producers, and diverse stakeholder interests within the CCU network.

Expectations in both direct and indirect CO_2 utilization reveal the complex dynamics of the sector, influenced by government policies, energy costs, CO_2 supply constraints, and technological innovations. Stakeholders hold diverse short-term and long-term outlooks, balancing optimism for the future with immediate concerns, notably related to CO_2 supply and government planning. The sector's trajectory is shaped by policy, technology, and market forces. In direct utilization, stakeholders consistently emphasize the importance of CCU for industry sustainability. In indirect utilization, optimism for CCU technology development is prominent despite challenges accessing green CO_2 sources for large-scale implementation. The strategic shift toward resource security and the potential of oxygen-binding mechanisms for cost-effectiveness and sustainability are also highlighted.

Learning processes in both direct and indirect CO_2 utilization emphasize crucial environmental factors: CO_2 source origins, product storage duration, and the role of green energy. They highlight CCU's role in promoting circularity and adaptability in resource-constrained settings. Identified barriers to CCU adoption include technology development, stakeholder awareness, cost considerations, CO_2 feedstock quality, market uncertainty, and the need for a clear CCU definition. Addressing these barriers requires government support, adaptive policies, business model evolution, and financial challenge resolution. Well-defined documentation, standards, and stakeholder collaboration drive CCU progress. In direct utilization, challenges arise from governmental structure, fragmentation, and the need for project management skills among startups. The CCU Alliance is pivotal in project development and achieving negative emissions goals in direct CCU. In indirect utilization, challenges relate to energy requirements, sustainability, integration into existing industrial networks, and FutureCarbonNL's leadership in advancing CCU technologies in the Netherlands.

In exploring opportunities for direct and indirect utilization, the Netherlands can establish itself as a global CCU technology provider. Government commitment plays a pivotal role in advancing CCU technology. For direct utilization, the emergence of the CCU Alliance offers an opportunity to drive innovation, negative emissions policies, and stakeholder collaboration, creating a conducive environment for CCU. For indirect utilization, opportunities include financial support, accelerated R&D, market expansion, international reputation enhancement, economic growth, job creation, and fostering an innovation ecosystem facilitated by FutureCarbonNL.

Barriers in both direct and indirect utilization encompass uncertain CO_2 supply, CCU sustainability, stakeholder and user acceptance, policy challenges, and governmental expertise and communication. A specific barrier in direct utilization relates to governmental structure, while barriers in indirect utilization involve vision misalignment and CCU technology integration. Prioritizing barriers is essential to stimulate CCU niches effectively. Therefore, focusing on contextual factors, go-to-market, and implementation factors is critical. An overview of stimulation measures is presented in Figure 6.2.

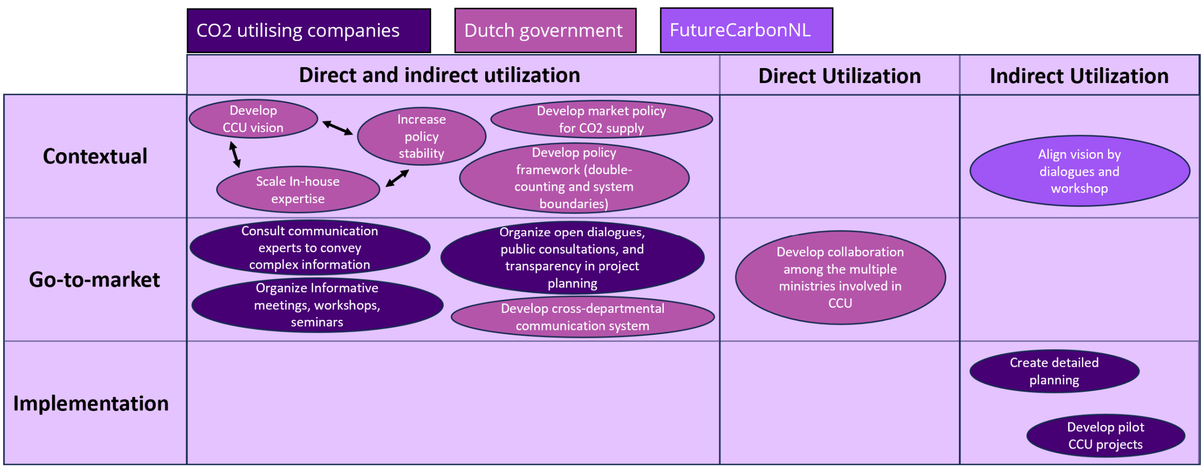

Figure 6.2: Niche stimulation

Contextual factors affecting both direct and indirect CO_2 utilization. Policy stability, CCU vision, and in-house expertise are crucial in shaping the CCU landscape. The lack of policy stability presents a significant challenge for CCU companies, hampering their ability to establish viable business models. This instability may lead to the persistence of less sustainable solutions in the long term. A long-term vision aligned with sustainability and environmental goals is essential to position CCU as a key contributor to climate and circular economy targets. To achieve policy stability and ensure a reliable CO_2 supply, the government must develop a clear, long-term strategy considering factors like fossil resource depletion, CO_2 utilization product diversity, and CO_2 source limitations. Hiring permanent employees with expertise related to circularity and energy transition can help ministries address expertise barriers and manage CCU policies effectively. Regulatory frameworks are needed to prevent double-counting of CO_2 emissions and address scope 3 emissions. Robust modeling methodologies are crucial for defining CCU system boundaries, allocating responsibilities and costs, and enhancing policy stability. For a stable CO_2 supply chain, addressing short-term and long-term challenges is necessary. Policymakers should focus on immediate challenges and complexities while working toward long-term objectives. Developing clear market policies aligned with the long-term vision will create a favorable environment for businesses and investors, ultimately enhancing supply stability in the CCU sector.

In the context of go-to-market factors, addressing stakeholder and end-user acceptance issues and improving governmental communication require the following actions. Initiatives should focus on comprehensive education and awareness programs for stakeholders and end-users, emphasizing CCU benefits and principles through informative meetings, workshops, seminars, and communication experts' involvement. Stakeholders have already taken steps in this direction. To enhance governmental communication, administrative systems should improve cross-departmental communication or establish a working group.

Regarding go-to-market factors in direct utilization, fostering greater coordination among ministries engaged in CCU is crucial. Establishing interagency working groups and a CCU advisory council, comprising experts, industry representatives, and government officials, can streamline decision-making, align strategies, and promote a unified approach to CCU development, fostering growth and success.

For contextual factors in indirect utilization, facilitating open dialogue and workshops among network stakeholders is essential. Comprehensive discussions should address diverse interests and priorities and encourage collaboration to identify shared objectives related to CCU and the circular economy, whether in promotion or optimization.

In the realm of implementation factors in indirect utilization, assessing the current industrial network, identifying integration opportunities, and developing detailed plans for modifications and specific technologies are vital. Selecting CCU technologies that align with industry goals and existing infrastructure is essential. Pilot CCU projects are crucial in demonstrating integration feasibility, collecting data, measuring performance, and promoting CCU adoption.

7 Discussion

This chapter explains the interpretation of results, evaluation of methodology, and significance of the findings. It provides insights into the limitations of this study, the implications, as well as the scientific relevance of this thesis. Furthermore, the practical and managerial relevance are examined.

7.1. Interpretation of results

As stated in the problem statement and backed by the literature review, the industrial clusters are the locations were the gathering of the stakeholders enables the development of CCU technologies. However, it was refuted in Section 5.3.1. Still, the industrial clusters are the locations where full value chain implementation can be developed cost-effectively, according to interviewees. Meaning that the niches are still in the early phases of development, and technologies need to be developed as later backed in the nurturing section.

As the research delves into both direct and indirect utilization niches, the recommendations for these niches revolve around nurturing the most pivotal alliances within each domain. In the case of direct utilization, the focal point centres on the CCU Alliance. In the domain of indirect utilization, the emphasis is placed on FutureCarbonNL. Meaning most stakeholders in each niche stem from a collaboration with either FutureCarbonNL or CCU Alliance.

As discussed in Section 5.3, we explored the direct and indirect utilization niches, each encompassing interlinked product categories. However, it remained a question of why these product categories were not recognized as distinct niches. In Section 6.1.1, an analysis of social network formation identified the preliminary networking stage. This indicates that the product categories do not yet exhibit sufficient clustering to qualify as distinct niches in their own right. Backed by the collaboration, they seek in more diverse collaborations, such as FutureCarbonNL and CCU Alliance, to learn from one another and to develop these alternative technologies. On the contrary, it is evident that hydrogen, alongside its derivatives such as methanol and ethanol, is a frequently explored product within the realm of (CCU. This is not merely a coincidence, as these three products share close ties, particularly regarding their potential for production synergy. Consequently, hydrogen can be regarded as a distinctive niche within the landscape of CCU development in the Netherlands. However, this assertion warrants more comprehensive research and investigation.

In light of the barriers identified (see Section 6.2), efforts have been proposed to address these challenges. It appears that certain barriers, namely policy instability, a lack of CCU vision, and the absence of in-house expertise, are interconnected. Developing a cohesive CCU vision and ensuring policy stability becomes a formidable task without in-house expertise. While outsourcing can facilitate the establishment of a CCU, it is imperative to formulate a sustainable long-term vision.

While the overall tone of this study may appear optimistic, primarily due to the positive aspects outlined in the ”stimulation” section of the research question, it is crucial to clarify that this positivity does not imply an unaddressed need for stimulation. Such a need does not exist. The results should be interpreted in the context of uncovering the true sustainability of CCU in the realm of decarbonization. Improvement in sustainability is contingent upon the genuine effectiveness on sustainability of CCU in achieving decarbonization goals. However, decarbonization primarily addresses the challenges faced by hard-to-abate emissions, encompassing existing facilities, high-temperature heat, and process emissions, for which viable sustainable alternatives have not yet emerged. Conversely, the discussion must also highlight the significance of circularity in this context. Neglecting the true sustainability of CCU may occur if the emphasis solely revolves around the necessity for circular carbon to maintain product quality. In such cases, when circularity is the primary objective, sustainability remains important but may be perceived as less critical and stimulation is more evident. Nevertheless, it should still be taken into consideration in the broader discourse.

7.2. Theoretical reflection

The innovation system theory by Markard and Truffer (2008) was used and allowed to develop an elaborate overview of the CCU innovation system from a multi-level perspective. The close relation of the CCS and CCU value chains gave an extra dimension to the analysis, as the first section of the value chains is the same. Still, the theory by Markard and Truffer (2008) provided a framework for this close relation. The multi-level perspective theory by F. W. Geels (2002) allowed for delineating the niches by the provided definition. The theory by Markard and Truffer (2008) provided an overview of the innovation system that can be visualised to place the niches in context. The definition of ”niches” made it difficult to discuss the concept with the interviewee in an understandable way, regularly falling back on CCU product groups during interviews. Nonetheless, the techniques of MLP and SNM allowed for a thorough analysis on every level, especially the niche level.

The applicability of the shielding and empowerment principles as proposed by Turnheim and Geels (2019) did not align with the context of this study. Typically, the shielding is to preserve innovation from regime constraints, while a niche as a protected space is essential. Empowerment is the process of evaluating whether a niche will drive regime change or niche innovation will adapt to the mainstream selection environment. Given the nascent stage of CCU development in the Netherlands, both principles were irrelevant to the research at this stage.

Kamp and Vanheule (2015) presented 15 nurturing indicators for the internal niche processes expectations, network formation, and learning processes. Based on stakeholder interviews, the industrial development nurturing indicator could not be extracted from the stakeholders in the analysed niches. Primarily, this is attributed to a scarcity of well-established facilities from which can be learned.

Turnheim and Geels (2019) addressed the concept of network formation in the SNM. Nevertheless, the model lacked a visual representation, unlike the one presented in Chapter 4. Integrating a visual representation is crucial, as it enhances the comprehensibility of the network and its stakeholders—a pivotal aspect in SNM analysis. Thus, this study incorporates a visual representation to provide a more holistic understanding of the network dynamics.

7.3. Limitations of research

Non-probability purposive sampling was employed to select individuals with expertise closely aligned with the research objectives. Nevertheless, this approach resulted in only one participant representing each stakeholder group. Moreover, the final interview count, totalling 14 interviews, fell short of the anticipated 15-20 due to the extensive array of stakeholder categories, which posed a challenge in encompassing all relevant groups.

As a result, the study may lack depth and richness in data due to unexplored perspectives and experiences. Notably, certain categories, such as food-related, process technology, engineering, infrastructure, clusters, NGOs, licensors, and various government divisions (excluding the Ministry of Economic Affairs and Climate), were omitted. This omission was related to direct and indirect utilization, where some stakeholder groups encompass both. This potential underrepresentation of perspectives from these groups may limit the study's generalizability to populations or groups not covered in the sample.

It is critical to recognise that this study is based on interviews, which record participants' thoughts at a specific time. These perspectives may change as CCU niches mature and more information about its availability and feasibility becomes available.

Due to the CCU's development immaturity, the decision was made to focus on the transition pathway for the entire Netherlands divided into direct and indirect niches rather than zooming in to perform an in-depth investigation of the dynamics inside a single niche or sector. Although these were analysed, they were done from a broader perspective. It may have been decided to concentrate on a single niche or sector. However, due to the absence of earlier research to form a basis for these in-depth investigations, specifically in this phase of the CCU development in the Netherlands, a broader perspective is taken for this research.

7.4. Scientific relevance and implications

The practical and theoretical implications of this research are examined in this sub-chapter. The practical implications explain why these discoveries are important. The theoretical implications reflect on how the three theories in this study were conceptualised and how this made an academic contribution.

7.4.1. Practical implications

The practical implications of this study are multifaceted and hold significance for regimes and niches. One of the key findings of this study is that CCU niches try to resolve two issues, namely contributing to the industry's decarbonization but mostly to circularity. This should be considered when making new CCU policy by the Dutch Government.

This study also found that CO_2 supplies will be uncertain in the short- and long-term. Multiple interviewees are sceptical about the sustainability and affordability of CO_2 utilization; therefore, the sector's emergence is expected to be small. Nonetheless, the technology can be sold to foreign countries. In addition, the government changes policy more than the companies like because of a lack of vision, in line with Naims and Eppinger (2022). Moreover, the government lacks expertise and communication between ministries. These factors make actors hesitant to invest their time and resources in developing CCU technologies. Stable policy, green energy, prevention of CO_2 emission double-counting, and Scope 3 emissions inclusion will make actors more confident in the technologies' perspective.

This study identified six barriers for direct and indirect utilization: uncertain CO_2 supply, true sustainability of CCU, Stakeholder and user acceptance, policy, and governmental expertise and communication. None of these have been identified as barriers in previous studies. The stakeholder acceptance barrier is linked with the vision misalignment of the indirect utilization barrier. This means the barrier originates from the regime as the regime actors resist change and pose obstacles to adopting new technology. Contrary to barriers originating from landscape factors, these barriers are beyond the control of the actors. These barriers contribute to earlier discussed barriers by Olfe-Kräutlein et al. (2021), but focusing on Europe.

The distinction between CCU and CCS strategies becomes obscured as the combined CCUS (CCU and CCS) strategy predominantly features in governmental approaches. This study recommends a clear delineation of these combined strategies. By advocating for this separation, the research predominantly focuses on the CCU aspect, addressing associated barriers and proposing strategies for overcoming them. Therefore, this study shows that CCU can not be seen as an alternative for CCS as stated by Bruhn et al. (2016). On the other hand, this study contributes to Ros et al. (2014) connecting CCU and CCS infrastructure, by providing insights from the CCU side. Moreover, this study shows that CCU contributes to the security of resources to develop products built from fossil-derived carbon chains (as we know today), in line with findings from Kaiser et al. (2022).

Additionally, this study enriches the discourse on the sustainability of the current oil and gas industry by presenting CCU as a viable alternative for transitioning away from fossil resources. Although CCU offers an alternative to renewable energies, its sustainability remains controversial. CCU does not significantly contribute to sustaining the oil and gas industry, as its mitigation mix is not comprehensive. Consequently, CCU does not serve as a substantial factor in maintaining the current oil and gas industry.

The direct generalizability of the barriers and proposed solution may be challenging, primarily due to different functioning governments and the fact that the Netherlands is a frontrunner in developing CCU technologies. Nonetheless, the niche identification could be of relevance to other countries. From the literature and problem statement, it became apparent that the niches evolved around the different industrial clusters as the decarbonisation of these clusters appeared to be important. Whereas the stakeholder identification unveiled, the stakeholders are scattered throughout the Netherlands and foreign countries.

Ultimately, this research provides a comprehensive understanding of the complex interplay between actors and policy in developing CCU in the Netherlands. It informs decision-makers in the Netherlands how they could influence the development and which development the niche and regime actors should keep an eye on because it could influence the potential adoption of the technology. This insight clarifies regime actors, allowing them to make informed decisions regarding investment, visions, acceptance, and integration. Furthermore, the study sheds light on how government commitment to CCU development can influence niche actors and, consequently, the overall development trajectory. It emphasises the significance of proactive policies and incentives to promote the development of sustainable energy alternatives and circular technologies.

7.4.2. Theoretical implications

This study holds significant theoretical implications that advance our comprehension of CCU development in the Netherlands, making novel contributions to academic research. Firstly, the research demonstrates how IS by Hekkert et al. (2007), MLP by F. W. Geels (2002), and SNM by Turnheim and Geels (2019) can be complementary and utilized in the field of CCU, which was previously unexplored. While previous studies have employed these frameworks in different settings, this research showcases their usefulness in a new context. Notably, leveraging SNM allows a deeper insight into the internal progression of niches, thereby facilitating the effective promotion of emerging niches. Furthermore, SNM uncovers the identity of missing actors and identifies key players within these niches.

Furthermore, the study distinguishes itself by focusing solely on the development of CCU in the Netherlands while applying IS by Hekkert et al. (2007) with the MLP framework by F. W. Geels (2002) in the combined framework by Markard and Truffer (2008) in Figure 5.5 and the SNM by Turnheim and Geels (2019) concurrently. Prior research has not stepped into this precise domain, emphasising the uniqueness of this research. By taking this unique approach, the study goes beyond traditional evaluations of CO_2 mitigation and circularity, delving into the broader dynamics of a multi-level perspective. This method provides deep insights into the complex relationships between stakeholders, technologies, and policy environments in the context of decarbonization and mostly circularity.

After the literature review a shift in the conceptualization of niches is revealed, initially centered around industrial clusters, as highlighted in Section 2.2 and suggested by Devine-Wright (2022). Still, the industrial clusters are seen as locations where different CCU applications can emerge, however not the geographical delineation the define as niches. The combined IS and MLP literature by Markard and Truffer (2008) has played a pivotal role in steering away from the focus on industrial clusters, leading to the recognition of both direct and indirect niches.

However, while the MLP literature by F. W. Geels (2002) offers insights into identifying niches, it falls short of categorizing sub-niches. This study positions the different CO_2 use cases (see Figure 5.2) as sub-niches in the context of CCU in the Netherlands. This categorization is primarily driven by the observation that the practical implementation of the use case aligns closely with other sub-niches. It is essential to note that this characterization does not imply a definitive stance; rather, it reflects the current state of affairs. Therefore, it is important to acknowledge that future research endeavours may uncover nuances that elevate these sub-niches to full-fledged status. However, as of now, such a transformation has not been empirically established.

Moreover, this study refrains from treating direct and indirect utilization combined as a whole niche, recognizing substantial divergences in practices between the two. Indirect utilization is perceived as a distinct practice owing to the involved conversions, rendering CCU technology markedly different and technologically intensive compared to direct utilization. This difference points toward the deviant practice on which a niche is based. While one could argue that the conversion of CO_2 gas and CO_2 to minerals represents two disparate practices, they are presently considered similar enough to be grouped together, as evidenced by collaboration 1 (see Section 5.3.1). Notably, other collaborative efforts have chosen not to incorporate either of these two use cases. In addition, this study refrains to see Dutch industrial clusters as niches, because the different practices of stakeholders mainly happen outside the industrial clusters.

The study visually encapsulates the integrated use of IS by Hekkert et al. (2007) with the MLP framework by F. W. Geels (2002) in the combined framework by Markard and Truffer (2008) in Figure 5.5 and the SNM by Turnheim and Geels (2019). This visual representation offers a comprehensive and lucid overview of the current state of the CCU innovation system in the Netherlands, serving as a valuable starting point for future research in this field.

Furthermore, this study makes noteworthy contributions to discussions on both decarbonization (Thielges et al., 2022) and circularity (Wich et al., 2020). The emphasis, however, lies predominantly on circularity, given that decarbonization is primarily shaped by renewable energies, with only marginal influence from CCU. In the realm of circularity, this research plays a significant role in completing the circularity chain, as the utilization of CO_2 contributes to both R8 (Recycling) and R9 (Recovery) stages, representing the concluding steps in the circular economy framework proposed by Potting et al. (2017).

Finally, it is worth noting that sector-coupling, as introduced by Fridgen et al. (2020), remains outside the scope of this study. Nevertheless, this research serves as an initial exploration into the potential for sector coupling among the sectors illustrated in Figure 5.5. Despite not delving into sector-coupling specifics, Figure 5.5 highlights sectors with shared stakeholders (depicted as overlapping regimes), suggesting a feasible coupling in alignment with Fridgen et al. (2020). Moreover, given the early stage of CCU development in the Netherlands, there may be an opportune environment for planning shared infrastructure and facilitating coupling with sectors that do not share stakeholders but may exhibit synergistic potential.

7.5. Practical and managerial relevance

In this study, the niches under investigation were set by combining several CCU applications that can learn from each other. This means that the niches under analysis do not apply to the practical situation as the different stakeholders within the sector would recognize. However, due to the infancy of the sector, many barriers are relevant for the CCU sector in the broadest sense. Contributors to the development of CCU in the Netherlands are provided with an extensive collection of factors that hamper the development of both niches. These barriers ensure that CCU stakeholders can easily determine which barriers, with the corresponding stimulation measures, apply to their particular business. In addition, the internship company, Accenture, can use the findings in their advice to clients, amplifying the practical relevance of this research.

The results of this thesis provide insights for managers, governmental organizations, FutureCarbonNL, and CCU alliance to make more informed decisions about the development of their sector and how to stimulate the CCU sector. Recommendations are proposed for specific policymakers, such as the Ministry of Economic Affairs and Climate, the Ministry of Infrastructure and Water Management, and the Netherlands Enterprise Agency. These actors/organisations have high power compared to other stakeholders. In addition, the recommendations are relevant for businesses that want to improve nurturing of their niche. Also, relevant contextual barriers are presented to provide context for CCU businesses to consider.

8
Conclusion

This thesis investigated the development of CCU in the Netherlands and aimed to stimulate the development accordingly. This research was qualitatively conducted, which consisted of desk research and 14 semi-structured interviews. As a result of the problem statement and the research gap, the following research question was formulated:

"What are the carbon capture and utilisation niches in the Netherlands, and how to facilitate them?"

To answer the main research question, the following sub-questions were defined:

1. What are the CCU niches, its stakeholders and network in the Netherlands?
2. What are the enablers, opportunities, and barriers of different CCU niches in the Netherlands?
3. How can CCU niches successfully be stimulated in the Netherlands?

This thesis addressed these topics individually by utilising two interwoven frameworks: Strategic Niche Management within the integrated Multi-level Perspective (Macro-level of analysis) with the innovation system.

8.1. Answer to the Research questions

8.1.1. Sub-questions

SQ1	What are the CCU niches, its stakeholders and network in the Netherlands?

This sub-question was addressed by examining the stakeholders and their network via desk research in response to the unknown stakeholder landscape and the influence each has on the other. In response to the CES, the niches were expected to evolve around the industrial clusters but were refuted after further analysis conducted in Section 5.3.1. Instead, the stakeholder map under development provided the starting point for interviews with the identified stakeholders.

This resulted in an elaborated stakeholder network map, including the power and interests of the stakeholders. A simplified stakeholder map according to the stakeholder groups is presented in the following illustration, Figure 8.1, the elaborated stakeholder network map is presented in Figure 4.4 and Figure 4.5.

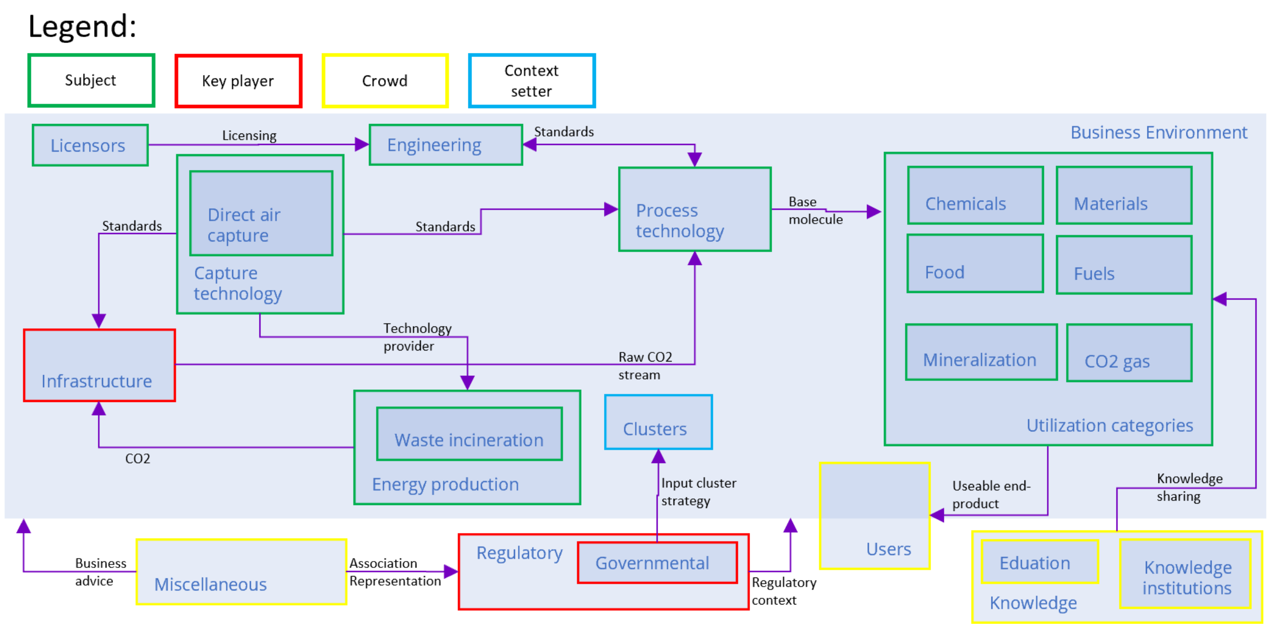

Figure 8.1: Stakeholder groups network diagram

From the network diagram, it can be concluded that the infrastructure and regulatory bodies are key players in the field. The clusters are stakeholders with high power due to the proximity of the full CCU value chain stakeholders, therefore, implementation is likely to occur first in the clusters.

The CCU niches were formed in accordance with the conducted interviews. It can be concluded that the technological foundation (conversion and non-conversion) of the CCU products formed the foundation for the niches under analysis and resulted in the direct and indirect utilization niches. Both conversion and niches are illustrated in Figure 8.2.

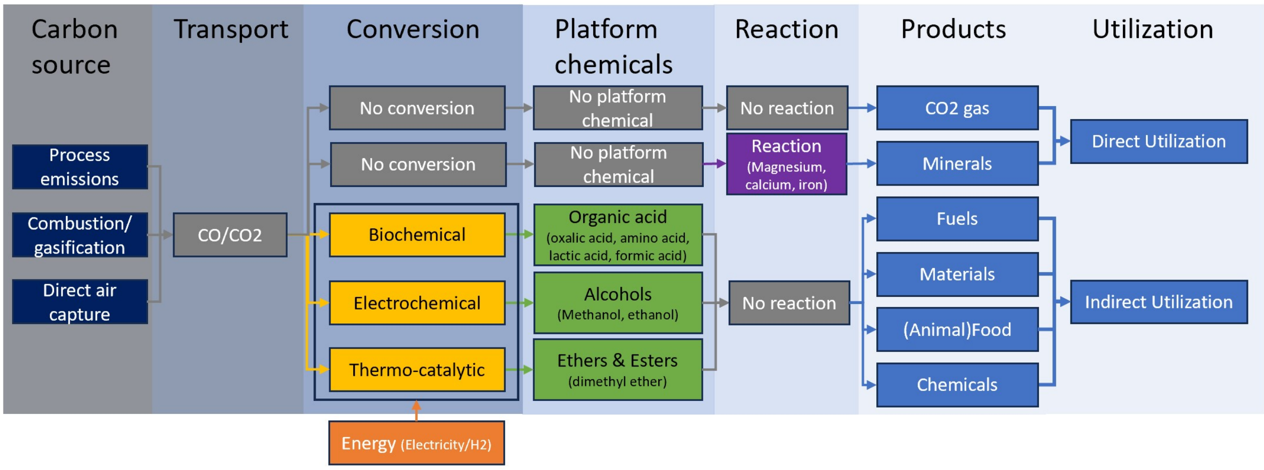

Figure 8.2: Carbon conversion chain (Adapted from factsheet FutureCarbonNL (FutureCarbonNL, 2023))

SQ2	What are the enablers, opportunities, and barriers of different CCU niches in the Netherlands?

From the innovation system interactions presented in Figure 5.5 and the niche development presented in Chapter 6, the enablers, opportunities, and barriers can be unveiled. It can be concluded that the enablers of the CCU niches have been presented in Section 5.1. It can be concluded that the enablers of the niches in the context of the CCU sector are the urgency of climate change, the willingness of the Dutch government to become internationally independent, and the notion of transitioning to a circular economy.

The opportunities unveiled are, on the one hand, becoming an international technology provider. On the other hand, the opportunity to transition away from fossil fuels arises while maintaining a carbon stream to accommodate the wealth as we know it today. Specifically to the direct utilization niche, the emergence of the CCU Alliance is a promising opportunity for negative emissions and policy development. Specifically in the indirect utilization niche, FutureCarbonNL plays a pivotal role in opportunities for catalyzing the growth and commercialization of CCU initiatives. When succeeding, it provides much-needed financial support to companies and organizations involved in CCU research and development. This funding not only facilitates the advancement of existing projects but also encourages new and innovative solutions in carbon capture and utilization.

For the SNM analysis, it can be concluded that the following barriers hamper the development of both CCU niches in the Netherlands. First, the uncertainty of CO_2 supply, caused by a lack of governmental vision, absence of market policy, in the short-term a lack of governmental planning, and in the long-term the depletion of fossil fuels, the diverse range of CO_2 utilization products, and limited availability of CO_2 sources. The second barrier is the true sustainability of CCU. This barrier is constructed by four aspects, namely, how the energy that is used is produced, the origin of the CO_2 source, no inclusion of Scope 3 emission in the LCA calculations, and the double counting of CO_2 by companies along the value chain. The third barrier is stakeholder and user acceptance, mainly consisting of financial considerations backed by limited understanding and knowledge of CCU among stakeholders and end-users. The fourth barrier is Policy, containing policy stability and the link to negative emissions and the ETS. The fifth barrier is governmental expertise and communication, making it difficult to execute projects by companies developing a vision and policy.

The barrier unique for the direct utilization niche is the governmental structure with the involvement of multiple ministries, rendering it difficult to achieve alignment among all relevant stakeholders.

Barriers unique to the indirect utilization niche include misalignment of vision, as it fails to prioritize either the promotion of a circular economy or the optimization of existing networks. Additionally, there are challenges related to integrating CCU initiatives into established industrial networks.

SQ3	How can CCU niches successfully be stimulated in the Netherlands?

From the MLP and SNM, it has become clear that CCU development is complex and needs active stimulation to become adopted more widely. The barriers that have been uncovered should be tackled is a specific order to stimulate the CCU niches effectively. Therefore, barriers related to the (1) context setting of the sector are essential and should be solved first. This gives the sector the stability they are asking for and will reduce their hesitance to invest as various barriers are present due to this lack of context. (2) Secondly, the go-to-market barriers hampering the business model development and discouraging businesses from entering the market should be tackled. (3) Thirdly, the co-development of CCU projects is important. Therefore, the implementation-oriented barriers should be solved by focusing on executing CCU projects.

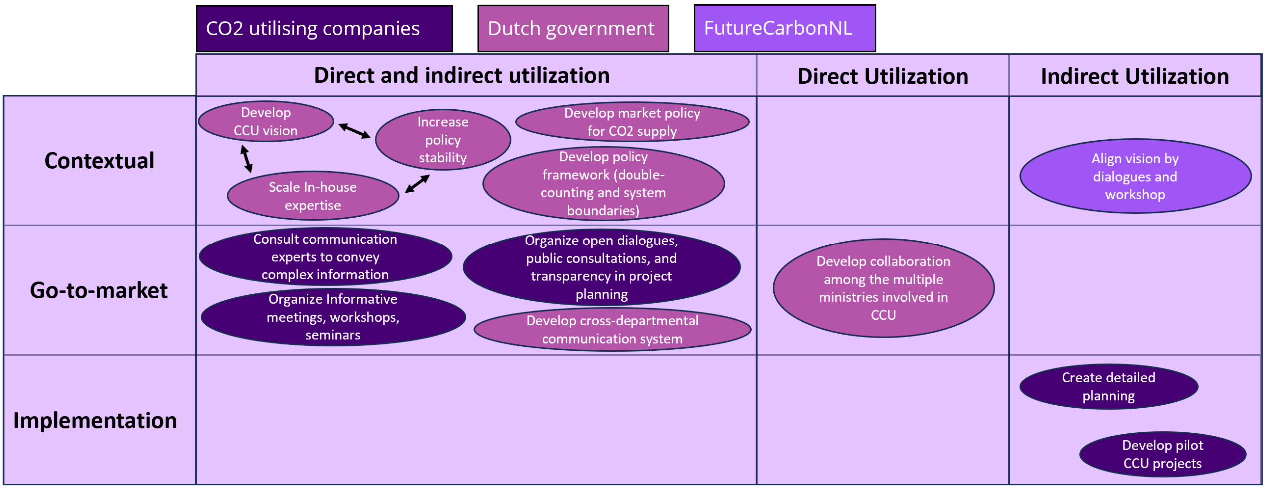

Figure 8.3: Niche stimulation

Contextual factors affecting both direct and indirect CO_2 utilization. Policy stability, CCU vision, and in-house expertise are crucial in shaping the CCU landscape. The lack of policy stability presents a significant challenge for CCU companies, hampering their ability to establish viable business models. This instability may lead to the persistence of less sustainable solutions in the long term. A long-term vision aligned with sustainability and environmental goals is essential to position CCU as a key contributor to climate and circular economy targets. To achieve policy stability and ensure a reliable CO_2 supply, the government must develop a clear, long-term strategy considering factors like fossil resource depletion, CO_2 utilization product diversity, and CO_2 source limitations. Hiring permanent employees with expertise related to circularity and energy transition can help ministries address expertise barriers and manage CCU policies effectively. Regulatory frameworks are needed to prevent double-counting of CO_2 emissions and address scope 3 emissions. Robust modeling methodologies are crucial for defining CCU system boundaries, allocating responsibilities and costs, and enhancing policy stability. For a stable CO_2 supply chain, addressing short-term and long-term challenges is necessary. Policymakers should focus on immediate challenges and complexities while working toward long-term objectives. Developing clear market policies aligned with the long-term vision will create a favorable environment for businesses and investors, ultimately enhancing supply stability in the CCU sector.

In the context of go-to-market factors, addressing stakeholder and end-user acceptance issues and improving governmental communication require the following actions. Initiatives should focus on comprehensive education and awareness programs for stakeholders and end-users, emphasizing CCU benefits and principles through informative meetings, workshops, seminars, and communication experts' involvement. Stakeholders have already taken steps in this direction. To enhance governmental communication, administrative systems should improve cross-departmental communication or establish a working group.

Regarding go-to-market factors in direct utilization, fostering greater coordination among ministries engaged in CCU is crucial. Establishing interagency working groups and a CCU advisory council, comprising experts, industry representatives, and government officials, can streamline decision-making, align strategies, and promote a unified approach to CCU development, fostering growth and success.

For contextual factors in indirect utilization, facilitating open dialogue and workshops among network stakeholders is essential. Comprehensive discussions should address diverse interests and priorities and encourage collaboration to identify shared objectives related to CCU and the circular economy, whether in promotion or optimization.

In the realm of implementation factors in indirect utilization, assessing the current industrial network, identifying integration opportunities, and developing detailed plans for modifications and specific technologies are vital. Selecting CCU technologies that align with industry goals and existing infrastructure is essential. Pilot CCU projects are crucial in demonstrating integration feasibility, collecting data, measuring performance, and promoting CCU adoption.

8.1.2. Research question

"What are the carbon capture and utilisation niches in the Netherlands, and how to facilitate them?"

The research question can be clearly answered with reference to the entire body of the thesis based on the research that was based on the sub-questions. Firstly, As became apparent from the problem statement and the literature review, CCU technologies were expected to emerge around the industrial clusters. Nonetheless, it can be concluded that there is no specific emphasis on the clusters since only 43 out of 73 of the stakeholders are affiliated with one of the clusters. Instead, this thesis showed that the niches defined are the direct and indirect utilization niches. Direct utilization covers the CO_2 gas as well as the CO_2 to minerals products. Indirect utilization comprises the CO_2 to fuels, CO_2 to materials, CO_2 to (animal)food, and CO_2 to chemicals. These different product categories can still learn from one another at this moment in time. Secondly, the facilitation of both niches can be done by dismantling the contextual barriers, followed by the go-to-market barriers, ending with the implementation barriers, as shown in Figure 8.3.

Contextual factors affecting both direct and indirect CO_2 utilization. Policy stability, CCU vision, and in-house expertise are crucial in shaping the CCU landscape. The lack of policy stability presents a significant challenge for CCU companies, hampering their ability to establish viable business models. This instability may lead to the persistence of less sustainable solutions in the long term. A long-term vision aligned with sustainability and environmental goals is essential to position CCU as a key contributor to climate and circular economy targets. To achieve policy stability and ensure a reliable CO_2 supply, the government must develop a clear, long-term strategy considering factors like fossil resource depletion, CO_2 utilization product diversity, and CO_2 source limitations. Hiring permanent employees with expertise related to circularity and energy transition can help ministries address expertise barriers and manage CCU policies effectively. Regulatory frameworks are needed to prevent double-counting of CO_2 emissions and address scope 3 emissions. Robust modeling methodologies are crucial for defining CCU system boundaries, allocating responsibilities and costs, and enhancing policy stability. For a stable CO_2 supply chain, addressing short-term and long-term challenges is necessary. Policymakers should focus on immediate challenges and complexities while working toward long-term objectives. Developing clear market policies aligned with the long-term vision will create a favorable environment for businesses and investors, ultimately enhancing supply stability in the CCU sector.

In the context of go-to-market factors, addressing stakeholder and end-user acceptance issues and improving governmental communication require the following actions. Initiatives should focus on comprehensive education and awareness programs for stakeholders and end-users, emphasizing CCU benefits and principles through informative meetings, workshops, seminars, and communication experts' involvement. Stakeholders have already taken steps in this direction. To enhance governmental communication, administrative systems should improve cross-departmental communication or establish a working group.

Regarding go-to-market factors in direct utilization, fostering greater coordination among ministries engaged in CCU is crucial. Establishing interagency working groups and a CCU advisory council, comprising experts, industry representatives, and government officials, can streamline decision-making, align strategies, and promote a unified approach to CCU development, fostering growth and success.

For contextual factors in indirect utilization, facilitating open dialogue and workshops among network stakeholders is essential. Comprehensive discussions should address diverse interests and priorities and encourage collaboration to identify shared objectives related to CCU and the circular economy, whether in promotion or optimization.

In the realm of implementation factors in indirect utilization, assessing the current industrial network, identifying integration opportunities, and developing detailed plans for modifications and specific technologies are vital. Selecting CCU technologies that align with industry goals and existing infrastructure is essential. Pilot CCU projects are crucial in demonstrating integration feasibility, collecting data, measuring performance, and promoting CCU adoption.

8.2. Future research

This study yielded useful results, particularly in identifying crucial barriers to creating the Dutch CCU and how they influenced and, more importantly, hampered the development.
Related to stimulating CCU development, how to widen the knowledge about the right decision for the right pathways, and how CO_2 utilization aligns with NL climate and economic goals, it is suggested that future research focuses on the following:

- LCA calculation models with scope 3 emissions, to take scope 1, 2, and 3 into account, for the whole CCU value chain to make CO_2 emission counting more realistic and for uncovering the true sustainability of the different CCU options along the value chain.
- Development of models which include ETS or carbon credits to prevent double counting of CO_2.
- Regulation development to enable ETS or carbon credit counting methods.
- Researching the true sustainability of different CCU options along the value chain.
- How CCU sector coupling could enable CCU development.

Related to the limitations presented, it is suggested that future research focuses on the following:

- As this study provided an valuable basis for further research, the research was not being able to get in touch with such as food-related, process technology, engineering, infrastructure, clusters, NGOs, licensors, and various government divisions. Therefore, future research should include these stakeholder groups.
- Because stakeholder perspectives may change as CCU niches mature and more information about its availability and feasibility becomes available.
- As this study prodived an context setting research by mapping the CCU developments in the Netherlands. Future research should zoom in to the different niches uncovered.

8.3. Recommendations

This thesis found that the Netherlands has a lot of internal niche (SNM) obstructions to overcome. It is recommended that stakeholders address the presented barrier in the sequence of contextual, go-to-market, and implementation barriers. The Dutch government should address all the identified barriers from the SNM analysis as the main stakeholder in the context setting. Practically, a lot of barriers are embedded in the different entities. Still, it remains important to solve the contextual barriers first. Thereafter, go-to-market barriers are more related to business and business model development. Lastly, solving the implementation barriers should enable CCU projects to emerge.

8.3.1. National government

To facilitate the advancement of CCU, the Dutch government must formulate a comprehensive CCU vision in alignment with the European perspective. This vision should be developed as a dedicated policy tailored to CCU, distinct from CCS. Nevertheless, it should encompass CCS considerations and acknowledge the pivotal role of CCU within the broader context of decarbonization and the circular economy.

This vision should be cultivated internally, leveraging in-house expertise to cater to CCU-developing companies' needs and ensure alignment with national objectives.

Furthermore, the government should craft a market policy to address the scarcity of CO_2 supply, which is expected to persist. Additionally, formulating a policy framework is essential to prevent any duplicative accounting of CO_2 emissions, encompassing capture, utilization, and end-product usage by companies.

Different ministries must foster cross-departmental collaboration to facilitate the efficient development of CCU initiatives. This collaboration will streamline processes, enabling businesses to expedite the implementation of CCU projects and achieve results in shorter timeframes.

8.3.2. Infrastructural companies

Infrastructure companies such as Gasunie and Linde Gas, which oversee the management of the OCAP network, play significant roles in the current CCU landscape. Linde Gas, in particular, holds a crucial position in CCU development due to their testing, pilot, and initiative-ready network availability in the Western part of the Netherlands. This network infrastructure is instrumental for companies seeking to test CCU technologies, making Linde Gas a pivotal partner. To further amplify their influence and bolster CCU technology advancement, they should consider expanding their collaborative efforts, particularly with regional stakeholders. Investing in research that addresses the integration of CCS and CCU networks while accounting for CO_2 concentration levels is another area of strategic focus that can enhance their impact.

Gasunie, on the other hand, should play a central role in connecting disparate clusters over the long term, given the anticipated scarcity of CO_2 supply. This inter-cluster connectivity is vital in ensuring supply flexibility, making Gasunie a linchpin in the CCU network ultimately contributing to the overall success of CCU initiatives.

8.3.3. Industrial clusters

Industrial clusters should be central in bridging the gap between supply and demand within the cluster. Presently, their involvement in collaborative efforts remains limited. This limitation primarily stems from regime actors within the industrial clusters. Therefore, integrating CCU technologies into their production processes is essential to facilitate and encourage these collaborative endeavours.

8.3.4. FutureCarbonNL

FutureCarbonNL should align the vision of the regime players with stakeholders challenging the regime. This has to be done through dialogues and workshops.

8.3.5. Co2 utilising companies

These companies are encouraged to engage the services of communication experts to effectively communicate their CCU initiatives to their customers. This will serve to improve the comprehension of those purchasing their products.

Furthermore, it is recommended that they actively foster open dialogues through public consultations and establish transparency in their project planning for residents living near their production plants.

To ensure a well-informed workforce, these companies should also arrange informative meetings, workshops, and seminars for their employees, aiming to educate them on the principles of CCU and the compelling reasons for its implementation within the company.

For those companies employing CCU technologies and preparing for expanded production, it is essential to develop comprehensive plans for the seamless integration of CCU technologies into their existing business operations. This strategic approach will pave the way for successful scaling and sustainable growth.

References

Akerboom, S., Waldmann, S., Mukherjee, A., Agaton, C., Sanders, M., & Kramer, G. J. (2021). Different this time? the prospects of ccs in the netherlands in the 2020s. *Frontiers in Energy Research*, *9*, 193. https://doi.org/10.3389/FENRG.2021.644796/BIBTEX

Bataille, C., Waisman, H., Colombier, M., Segafredo, L., Williams, J., & Jotzo, F. (2016). The need for national deep decarbonization pathways for effective climate policy. *Climate Policy*, *16*, S7–S26. https://doi.org/10.1080/14693062.2016.1173005

Bergman, E., & Feser, E. (2020). Industrial and Regional Clusters: Concepts and Comparative Applications, 2nd ed. *1999*. https://researchrepository.wvu.edu/rri-web-book/5

Bokka, H. K., & Lau, H. C. (2023). Decarbonising Vietnam's power and industry sectors by carbon capture and storage. *Energy*, *262*, 125361. https://doi.org/10.1016/J.ENERGY.2022.125361

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*, 77–101. https://doi.org/10.1191/1478088706QP063OA

Bruhn, T., Naims, H., & Olfe-Kräutlein, B. (2016). Separating the debate on CO2 utilisation from carbon capture and storage. *Environmental Science and Policy*, *60*, 38–43. https://doi.org/10.1016/j.envsci.2016.03.001

Bryson, J. M. (2004). What to do when stakeholders matter: Stakeholder identification and analysis techniques. *Public management review*, *6*(1), 21–53.

Carlsson, B., Jacobsson, S., Holmen, M., & Rickne, A. (2002). Innovation systems: Analytical and methodological issues. *Research Policy*, *31*, 233–245. https://doi.org/10.1016/S0048-7333(01)00138-X

Carlsson, B., & Stankiewicz, R. (1995). On the nature, function and composition of technological systems, 21–56. https://doi.org/10.1007/978-94-011-0145-5_2

Castillo, A. C., & Angelis-Dimakis, A. (n.d.). Enabling co2 reuse value geographical conditions [Last accessed on 7 April, 2023]. *Realising long-term transitions*, 86.

Chauvy, R., & Weireld, G. D. (2020). Co2 utilization technologies in europe: A short review. *Energy Technology*, *8*, 2000627. https://doi.org/10.1002/ENTE.202000627

Climate Change Committee. (2021). Independent Assessment: The UK's Net Zero Strategy. https://www.theccc.org.uk/publication/independent-assessment-the-uks-net-zero-strategy/

Co2 Value Europe. (n.d.). CCU Projects Database [Last accessed on 18 November, 2023]. https://database.co2value.eu/projects

Davis, S. J., Lewis, N. S., Shaner, M., Aggarwal, S., Arent, D., Azevedo, I. L., Benson, S. M., Bradley, T., Brouwer, J., Chiang, Y. M., Clack, C. T., Cohen, A., Doig, S., Edmonds, J., Fennell, P., Field, C. B., Hannegan, B., Hodge, B. M., Hoffert, M. I., … Caldeira, K. (2018). Net-zero emissions energy systems. *Science*, *360*(6396). https://doi.org/10.1126/SCIENCE.AAS9793/SUPPL{_}FILE/AAS9793-DAVIS-SM.PDF

De Nederlandse Bank. (2022). Consequences of the war in Ukraine for the economy of the Netherlands. https://www.dnb.nl/en/publications/research-publications/analysis/consequences-of-the-war-in-ukraine-for-the-economy-of-the-netherlands/

de Haan, A. B., Eral, H. B., & Schuur, B. (2020). *Industrial separation processes: Fundamentals*. Walter de Gruyter GmbH Co KG.

Delgado, M., Porter, M. E., & Stern, S. (2016). Defining clusters of related industries. *Journal of Economic Geography*, *16*(1), 1–38. https://doi.org/10.1093/JEG/LBV017

Deloitte & VNCI. (2012). The chemical industry in the netherlands: World leading today and in 2030-2050. https://www.consultancy.nl/media/Deloitte%20-%20The%20Chemical%20Industry%20in%20the%20Netherlands-2751.pdf

Department for Business, Energy Industrial Strategy. (2018). Industrial strategy: Building a Britain fit for the future. *Industrial Strategy White Paper*, 121. https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

Department for Business, Energy Industrial Strategy. (2019). What is the Industrial Clusters mission? https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/803086/industrial-clusters-mission-infographic-2019.pdf

Department for Energy Security and Net Zero, Department for Business, Energy Industrial Strategy. (2020). The ten point plan for a green industrial revolution. https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

Devine-Wright, P. (2022). Decarbonisation of industrial clusters: A place-based research agenda. *Energy Research & Social Science*, *91*, 102725. https://doi.org/10.1016/J.ERSS.2022.102725

Digmayer, C., & Jakobs, E. M. (2017). Sustainability or eco fraud? Perception and communication of ’carbon capture and usage’. *IEEE International Professional Communication Conference*. https://doi.org/10.1109/IPCC.2017.8013939

Edquist, C. (2009). Systems of innovation: Perspectives and challenges. *The Oxford Handbook of Innovation*. https://doi.org/10.1093/OXFORDHB/9780199286805.003.0007

Erans, M., Sanz-Pérez, E. S., Hanak, D. P., Clulow, Z., Reiner, D. M., & Mutch, G. A. (2022). Direct air capture: Process technology, techno-economic and socio-political challenges. *Energy & Environmental Science*, *15*, 1360–1405. https://doi.org/10.1039/D1EE03523A

European Chemicals Agency. (n.d.). ECHA mission [Last accessed on 03 October, 2023]. https://echa.europa.eu/about-us/who-we-are/mission

European Circular Economy Stakeholder Platform. (2023). The Role of Materials in the Post COVID society. https://circulareconomy.europa.eu/platform/en/knowledge/role-materials-post-covid-society

European Commission. (n.d.). Biofuels [Last accessed on 22 June, 2023]. https://transport.ec.europa.eu/transport-modes/air/environment/biofuels_en

European Environment Agency. (2023). Country profile. https://www.eea.europa.eu/themes/waste/waste-prevention/countries

Eurpean Commission. (2021). European construction sector observatory country profile netherlands. https://single-market-economy.ec.europa.eu/sectors/construction/observatory_en

Food and Agriculture Organization of the United Nations. (n.d.). Knowledge for Investment [Last accessed on 15 June, 2023]. https://www.fao.org/support-to-investment/our-work/by-area-of-work/k4i/en/

Fraters, M. (2023). Nieuwe zitting Raad van State in stikstofzaak Porthos - Porthos. https://www.porthosco2.nl/nieuwe-zitting-raad-van-state-in-stikstofzaak-porthos/

Fridgen, G., Keller, R., Körner, M.-F., & Schöpf, M. (2020). A holistic view on sector coupling. *Energy Policy*, *147*, 111913.

FutureCarbonNL. (2023). Over Ons - FutureCarbonNL. *futurecarbon.nl*. https://futurecarbon.nl/over-ons/

Geels, F., & Kemp, R. (2000). Transities vanuit sociotechnisch perspectief.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8-9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). Understanding system innovations: A critical literature review and a conceptual synthesis. *System innovation and the transition to sustainability: Theory, evidence and policy*, 19–47.

Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological forecasting and social change*, *72*(6), 681–696.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*, 24–40. https://doi.org/10.1016/J.EIST.2011.02.002

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417. https://doi.org/10.1016/J.RESPOL.2007.01.003

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. *Science*, *357*(6357), 1242–1244.

Grewatsch, S., Kennedy, S., & Bansal, P. (2021). Tackling wicked problems in strategic management with systems thinking. *https://doi.org/10.1177/14761270211038635*. https://doi.org/10.1177/14761270211038635

Griffiths, S., Sovacool, B. K., Kim, J., Bazilian, M., & Uratani, J. M. (2021). Industrial decarbonization via hydrogen: A critical and systematic review of developments, socio-technical systems and policy options. *Energy Research & Social Science*, *80*, 102208. https://doi.org/10.1016/J.ERSS.2021.102208

Hekkert, M. P., Suurs, R. A., Negro, S. O., Kuhlmann, S., & Smits, R. E. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological forecasting and social change*, *74*, 413–432. https://doi.org/10.1016/J.TECHFORE.2006.03.002

Hong, W. Y. (2022). A techno-economic review on carbon capture, utilisation and storage systems for achieving a net-zero co2 emissions future. *Carbon Capture Science & Technology*, *3*, 100044. https://doi.org/10.1016/J.CCST.2022.100044

Hoogma, R., Kemp, R., Schot, J., & Truffer, B. (2002). *Experimenting for sustainable transport* (Vol. 10). Taylor & Francis.

Hughes, T. P., et al. (1987). The evolution of large technological systems. *The social construction of technological systems: New directions in the sociology and history of technology*, *82*, 51–82.

IEA. (2018). *World energy outlook 2018 – iea*. https://www.iea.org/reports/world-energy-outlook-2018
IEA. (2019). *Transforming industry through ccus - iea*. https://www.iea.org/reports/transforming-industry-through-ccus
IEA. (2022a). CO2 Capture and Utilisation – Analysis. https://www.iea.org/reports/co2-capture-and-utilisation
IEA. (2022b). *Net zero by 2050 – analysis - iea*. https://www.iea.org/reports/net-zero-by-2050
International Organization of Oil and Gas Producers. (2022). Ccus projects in europe.
IRENA. (2022). World Energy Transitions Outlook. https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022
Ishida, M., & Jin, H. (1997). Co2 recovery in a power plant with chemical looping combustion. *Energy Conversion and Management*, *38*, S187–S192. https://doi.org/10.1016/S0196-8904(96)00267-1
Jackson, R. B., Quéré, C. L., Andrew, R. M., Canadell, J. G., Korsbakken, J. I., Liu, Z., Peters, G. P., & Zheng, B. (2018). Global energy growth is outpacing decarbonization. *Environmental Research Letters*, *13*, 120401. https://doi.org/10.1088/1748-9326/AAF303
Jones, C., & Piebalgs, A. (2022). The role of ccus on the eu road to climate neutrality. https://doi.org/10.2870/30583
Kaiser, S., Gold, S., & Bringezu, S. (2022). Environmental and economic assessment of co2-based value chains for a circular carbon use in consumer products. *Resources, Conservation and Recycling*, *184*, 106422. https://doi.org/10.1016/J.RESCONREC.2022.106422
Kamp, L. M., & Vanheule, L. F. (2015). Review of the small wind turbine sector in kenya: Status and bottlenecks for growth. *Renewable and Sustainable Energy Reviews*, *49*, 470–480. https://doi.org/10.1016/J.RSER.2015.04.082
Kemp, R., & Rotmans, J. (2005). The management of the co-evolution of technical, environmental and social systems. *Towards environmental innovation systems*, 33–55.
Malerba, F. (2007). Sectoral systems of innovation: A framework for linking innovation to the knowledge base, structure and dynamics of sectors. *https://doi.org/10.1080/1043859042000228688*, *14*, p. 251. https://doi.org/10.1080/1043859042000228688
Markard, J., Stadelmann, M., & Truffer, B. (2009). Prospective analysis of technological innovation systems: Identifying technological and organizational development options for biogas in switzerland. *Research Policy*, *38*, 655–667. https://doi.org/10.1016/J.RESPOL.2009.01.013
Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy*, *37*, 596–615. https://doi.org/10.1016/J.RESPOL.2008.01.004
Meylan, F. D., Moreau, V., & Erkman, S. (2015). Co2 utilization in the perspective of industrial ecology, an overview. *Journal of CO2 Utilization*, *12*, 101–108. https://doi.org/10.1016/J.JCOU.2015.05.003
Ministerie van Algemene Zaken. (2023). Rijksoverheid stimuleert duurzame energie. https://www.rijksoverheid.nl/onderwerpen/duurzame-energie/meer-duurzame-energie-in-de-toekomst
Ministerie van Economische Zaken en Klimaat. (2019). Klimaatakkoord. https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/klimaatakkoord
Ministerie van Economische Zaken en Klimaat. (2020). Industriële clusters publiceren plannen 2030-2050. https://www.klimaatakkoord.nl/actueel/nieuws/2020/10/22/industriele-clusters-publiceren-plannen-2030-2050
Ministerie van Economische Zaken en Klimaat. (2021). Vision on industry in the Netherlands. https://www.government.nl/documents/letters/2021/04/09/vision-on-industry-in-the-netherlands
Ministerie van Economische Zaken en Klimaat. (2023). Netherlands no longer dependent on Russian energy. https://www.government.nl/latest/news/2023/02/10/netherlands-no-longer-dependent-on-russian-energy#:~:text=Almost%20a%20year%20after%20Russia,by%20pipeline%20but%20by%20ship.
Ministerie van Infrastructuur en Waterstaat. (2022). Circular Dutch economy by 2050. https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050
Ministerie van Infrastructuur en Waterstaat. (2023). Monitoring. https://www.rijkswaterstaat.nl/en/water/water-management/monitoring
Ministerie van Landbouw, Natuur en Voedselkwaliteit. (2022). Natura 2000. https://www.rijksoverheid.nl/onderwerpen/natuur-en-biodiversiteit/natura-2000#:~:text=Natura%5C%202000%5C%20is%5C%20een%5C%20Europees,om%5C%20de%5C%20biodiversiteit%5C%20te%5C%20behouden.
Mirella. (2022). CO2 Smart Use stopt - Flux. *Flux*. https://nflux.nl/project/co2-smart-use-stopt/
Naims, H., & Eppinger, E. (2022). Transformation strategies connected to carbon capture and utilization: A cross-sectoral configurational study. *Journal of cleaner production*, *351*, 131391.
Nederlandse Emissie authoriteit. (2022). Targets - Energy for transport. https://www.emissionsauthority.nl/topics/general---energy-for-transport/targets---energy-for-transport

Nederlandse Voedsel- en Warenauthoriteit. (2023). NVWA Consumentenmonitor Voedselveiligheid 2023. https://www.nvwa.nl/voedselveiligheid/documenten/consument/eten-drinken-roken/overige-voedselveiligheid/publicaties/nvwa-consumentenmonitor-voedselveiligheid-2023

Newell, P., & Ilgen, A. G. (2019). Overview of Geological Carbon Storage (GCS). *Science of Carbon Storage in Deep Saline Formations: Process Coupling across Time and Spatial Scales*, 1–13. https://doi.org/10.1016/B978-0-12-812752-0.00001-0

Newmark, R. L., Friedmann, S. J., & Carroll, S. A. (2010). Water challenges for geologic carbon capture and sequestration. *Environmental Management*, *45*, 651–661. https://doi.org/10.1007/S00267-010-9434-1/FIGURES/9

Nurdiawati, A., & Urban, F. (2022). Decarbonising the refinery sector: A socio-technical analysis of advanced biofuels, green hydrogen and carbon capture and storage developments in Sweden. *Energy Research & Social Science*, *84*, 102358. https://doi.org/10.1016/J.ERSS.2021.102358

Olfe-Kräutlein, B., Strunge, T., & Chanin, A. (2021). Push or pull? policy barriers and incentives to the development and deployment of co2 utilization, in particular co2 mineralization. *Frontiers in Energy Research*, *9*, 742709.

Oltra, C., Upham, P., Riesch, H., Boso, À., Brunsting, S., Dütschke, E., & Lis, A. (2012). Public responses to co 2 storage sites: Lessons from five european cases.

Organization of the Petroleum Exporting Countries. (2005). The role of OPEC: A Historical Perspective and Outlook to the future. https://www.opec.org/opec_web/en/894.htm

Palm, E., & Nikoleris, A. (2021). Conflicting expectations on carbon dioxide utilisation. *Technology Analysis and Strategic Management*, *33*(2), 217–228. https://doi.org/10.1080/09537325.2020.1810225

Paltsev, S., Morris, J., Kheshgi, H., & Herzog, H. (2021). Hard-to-Abate Sectors: The role of industrial carbon capture and storage (CCS) in emission mitigation. *Applied Energy*, *300*, 117322. https://doi.org/10.1016/J.APENERGY.2021.117322

Paris Agreement [Last accessed on 21 February, 2023]. (n.d.). https://climate.ec.europa.eu/eu-action/international-action-climate-change/climate-negotiations/paris-agreement_en

Petrova, M. A. (2016). From nimby to acceptance: Toward a novel framework—vespa—for organizing and interpreting community concerns. *Renewable energy*, *86*, 1280–1294.

Philbin, S. P. (2020). Critical analysis and evaluation of the technology pathways for carbon capture and utilization. *Clean Technologies 2020, Vol. 2, Pages 492-512*, *2*, 492–512. https://doi.org/10.3390/CLEANTECHNOL2040031

Pieri, T., Nikitas, A., & Angelis-Dimakis, A. (2023). Public acceptance and willingness to pay for carbon capture and utilisation products. *Clean Technologies*, *5*(1), 436–450.

Pieri, T., Nikitas, A., Castillo-Castillo, A., & Angelis-Dimakis, A. (2018). Holistic assessment of carbon capture and utilization value chains. *Environments 2018, Vol. 5, Page 108*, *5*, 108. https://doi.org/10.3390/ENVIRONMENTS5100108

Porthos. (n.d.). *Project - porthos* [Last accessed on 8 March, 2023]. https://www.porthosco2.nl/en/project/

Potting, J., Hekkert, M. P., Worrell, E., Hanemaaijer, A., et al. (2017). Circular economy: Measuring innovation in the product chain. *Planbureau voor de Leefomgeving*, (2544).

Quéré, C., Andrew, R., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P., Korsbakken, J. I., Peters, G., Canadell, J., Arneth, A., Arora, V., Barbero, L., Bastos, A., Bopp, L., Ciais, P., Chini, L., Ciais, P., Doney, S., … Zheng, B. (2018). Global carbon budget 2018. *Earth System Science Data*, *10*, 2141–2194. https://doi.org/10.5194/ESSD-10-2141-2018

Raven, R. (2005). Strategic niche management for biomass: a comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark. *Technische Universiteit Eindhoven.* https://doi.org/10.6100/ir590593

Rijksoverheid. (n.d.). Nationaal groeifonds [Last accessed on 5 November, 2023]. https://www.nationaalgroeifonds.nl/doel-nationaal-groeifonds

Rijksoverheid. (2023). Jaarplan. https://www.rijksoverheid.nl/documenten/jaarplannen/2023/10/10/bijlage-1-tabel-uitgaven-aan-externe-inhuur-en-personeel-per-ministerie-in-2022

Rissman, J., Bataille, C., Masanet, E., Aden, N., Morrow, W. R., Zhou, N., Elliott, N., Dell, R., Heeren, N., Huckestein, B., Cresko, J., Miller, S. A., Roy, J., Fennell, P., Cremmins, B., Koch Blank, T., Hone, D., Williams, E. D., de la Rue du Can, S., … Helseth, J. (2020). Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070. *Applied Energy*, *266*, 114848. https://doi.org/10.1016/J.APENERGY.2020.114848

RIVM. (n.d.-a). Organisation [Last accessed on 05 July, 2023]. https://www.rivm.nl/en/about-rivm/organisation#rm-milieu-en-veiligheid-283761-more

RIVM. (n.d.-b). Stikstof [Last accessed on 03 July, 2023]. https://www.rivm.nl/stikstof

Ros, M., Read, A., Uilenreef, J., & Limbeek, J. (2014). Connecting CCS and CCU. *Energy Procedia*, *63*, 2691–2701.

Rotmans, J., Kemp, R., & Asselt, M. V. (2001). More evolution than revolution: Transition management in public policy. *Foresight*, *3*, p. 18. https://doi.org/10.1108/14636680110803003/FULL/PDF

Rotmans, J., Kemp, R., van Asselt, M., Geels, F., Verbong, G., & Molendijk, K. (2000). Transities & transitiemanagement. de casus van een emissiearme energievoorziening. *Maastricht, ICIS, MERIT*, *83*.

Roy, B., & Schaffartzik, A. (2021). Talk renewables, walk coal: The paradox of india's energy transition. *Ecological Economics*, *180*, 106871. https://doi.org/10.1016/J.ECOLECON.2020.106871

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technology analysis & strategic management*, *20*(5), 537–554.

Sekaran, U., & Bougie, R. (2010). *Research methods for business : A skill-building approach*. Wiley.

Sick, V., Stokes, G., & Mason, F. (2022). *Implementing co2 capture and utilization at scale and speed: The path to achieving its potential* (tech. rep.).

Skoczkowski, T., Verdolini, E., Bielecki, S., Kochański, M., Korczak, K., & W□glarz, A. (2020). Technology innovation system analysis of decarbonisation options in the EU steel industry. *Energy*, *212*, 118688. https://doi.org/10.1016/J.ENERGY.2020.118688

Smith, A., & Raven, R. (2012). What is protective space? reconsidering niches in transitions to sustainability. *Research policy*, *41*(6), 1025–1036.

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N. H., Rice, C. W., Abad, C. R., Romanovskaya, A., Sperling, F., & Tubiello, F. N. (2014). Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 811–922. https://opus4.kobv.de/opus4-hsog/frontdoor/index/index/docId/1865

Sondeijker, S., Geurts, J., Rotmans, J., & Tukker, A. (2006). Imagining sustainability: The added value of transition scenarios in transition management. https://doi.org/10.1108/14636680610703063

S&P Global. (2023). Dutch electricity and gas transmission and distribution framework: Supportive key takeaways. www.spglobal.com/ratingsdirect

Sun, J. W. (2005). The decrease of CO2 emission intensity is decarbonization at national and global levels. *Energy Policy*, *33*(8), 975–978. https://doi.org/10.1016/J.ENPOL.2003.10.023

Tata Steel. (2021). Tata Steel commissions India's first plant for CO2 capture from blast furnace gas at Jamshedpur. https://www.tatasteel.com/media/newsroom/press-releases/india/2021/tata-steel-commissions-india-s-first-plant-for-co2-capture-from-blast-furnace-gas-at-jamshedpur/#:~:text=Tata%20Steel%20will%20reuse%20the,network%20with%20increased%20calorific%20value.

Tata Steel. (2022). Tata steel hydrogen route. https://www.tatasteeleurope.com/corporate/news/Tata-Steel-invests-65-million-euroin-next-phase-hydrogen-route

Thielges, S., Olfe-Kräutlein, B., Rees, A., Jahn, J., Sick, V., & Quitzow, R. (2022). Committed to implementing ccu? a comparison of the policy mix in the us and the eu. *Frontiers in climate*, *4*, 943387.

Turnheim, B., & Geels, F. W. (2019). Incumbent actors, guided search paths, and landmark projects in infra-system transitions: Re-thinking strategic niche management with a case study of french tramway diffusion (1971–2016). *Research Policy*, *48*, 1412–1428. https://doi.org/10.1016/J.RESPOL.2019.02.002

United Nations. (2015). Adoption of the Paris Agreement.

Upham, D. P., Sovacool, P. B., & Ghosh, D. B. (2022). Just transitions for industrial decarbonisation: A framework for innovation, participation, and justice. *Renewable and Sustainable Energy Reviews*, *167*, 112699. https://doi.org/10.1016/J.RSER.2022.112699

Van der Laak, W., Raven, R., & Verbong, G. (2007). Strategic niche management for biofuels: Analysing past experiments for developing new biofuel policies. *Energy policy*, *35*(6), 3213–3225.

van der Linden, N. (2019). *Inventarisatie van de behoefte van de industriecluster aan grootschalige infrastructuur vor transport van elektriciteit, waterstof, warmte en co2 nodig voor het realiseren van klimaatdoelstellingen*. https://repository.tno.nl/islandora/object/uuid%3A033cd1dc-1e5e-46a2-992f-1a53db71548b

Van Eijck, J., & Romijn, H. (2009). Prospects for jatropha biofuels in tanzania: An analysis with strategic niche management. In *Sectoral systems of innovation and production in developing countries*. Edward Elgar Publishing.

van Egmond, S., & Hekkert, M. P. (2012). Argument map for carbon capture and storage. *International Journal of Greenhouse Gas Control*, *11*(SUPPL), 148–159. https://doi.org/10.1016/j.ijggc.2012.08.010

Vila-Henninger, L., Dupuy, C., Ingelgom, V. V., Caprioli, M., Teuber, F., Pennetreau, D., Bussi, M., & Gall, C. L. (2022). Abductive coding: Theory building and qualitative (re)analysis. *Sociological Methods Research (SMR)*. https://doi.org/10.1177/00491241211067508

VNCI. (n.d.-a). FutureCarbonNL: “De wereld draait straks op CCU-technologie uit Nederland” [Last accessed on 03 July, 2023]. https://www.vnci.nl/chemie-magazine/actueel/artikel/futurecarbonnl-de-wereld-draait-straks-op-ccu-technologie-uit-nederland

VNCI. (n.d.-b). VNCI Koninklijke Vereniging van de Nederlandse Chemische Industrie [Last accessed on 03 July, 2023]. https://www.vnci.nl/over-vnci

Wich, T., Lueke, W., Deerberg, G., & Oles, M. (2020). Carbon2chem®-ccu as a step toward a circular economy. *Frontiers in Energy Research*, *7*, 162.

World Economic Form. (2023). 8 ways the circular economy outperforms linear businesses. https://www.weforum.org/agenda/2023/03/8-ways-the-circular-economy-outperforms-traditional-business-models/

Xia, Z. (2017). *Design principle on carbon nanomaterials electrocatalysts for energy storage and conversion* (Doctoral dissertation). University of North Texas.

Xu, S. (2021). The paradox of the energy revolution in China: A socio-technical transition perspective. *Renewable and Sustainable Energy Reviews*, *137*, 110469. https://doi.org/10.1016/J.RSER.2020.110469

Yan, Y., Borhani, T. N., Subraveti, S. G., Pai, K. N., Prasad, V., Rajendran, A., Nkulikiyinka, P., Asibor, J. O., Zhang, Z., Shao, D., Wang, L., Zhang, W., Yan, Y., Ampomah, W., You, J., Wang, M., Anthony, E. J., Manovic, V., & Clough, P. T. (2021). Harnessing the power of machine learning for carbon capture, utilisation, and storage (CCUS) – a state-of-the-art review. *Energy & Environmental Science*, *14*(12), 6122–6157. https://doi.org/10.1039/D1EE02395K

Yin, R. K. (2018). *Case Study Research and Applications* (6th ed.). Sage.

Zapantis, A., Amer, N. A., Ian Havercroft, R. I.-M., Steyn, M., Yang, X., Gebremedhin, R., Zahra, M. A., Pinto, E., Rassool, D., Williams, E., Consoli, C., & Minervini, J. (2022). *Global status of ccs*. https://status22.globalccsinstitute.com/2022-status-report/global-status-of-ccs/

Zoi, K., & Edesio, M. B. (2019). Carbon Capture Utilisation and Storage: Technology Development Report. *Joint Research Centre*. https://doi.org/10.2760/185420

Appendix A - Interview protocol

The interview technique is generally described as follows:

1. Prior to the interview, the lead investigator explains the informed consent forms and requests permission to record the talk and quote their statements anonymously in this thesis, as described in the interview opening in Table 8.4.
2. The principal investigator describes the study's history and goals.
3. The principal investigator prepared a set of questions for respondents to use to drive the conversation.
4. The first five interviews will be devoted to exploring the different niche(s). The remaining interviews will be devoted to uncovering information related to the niche(s).
5. Interviews span 55-60 minutes on average, depending on respondent availability.
6. The recording is transcribed within five days after the interview to avoid information loss or missed interpretation.
7. After transcription the recording will be deleted immediately.

Interview consent form

Informed consent form – Interview master thesis "Development of carbon capture and utilisation in the Netherlands"

You are being invited to participate in a research study titled "**Development of carbon capture and utilisation in the Netherlands**". This study is being done by Thorsten Kuipers from the TU Delft, in collaboration with Accenture NL.

The purpose of this research is to determine the current landscape of the Carbon capture and utilisation (CCU) options in the Netherlands and to provide stimulation measures for the different CCU options and will take you approximately 60 minutes to complete. You will be asked to provide information regarding the (political, environmental, technical, institutional, and process/ social) that could enable, stimulate, or hamper the development of the CCU sector in the Netherlands, as well as the expectations, formation of networks and learning process centred of CCU niches in the Netherlands. Analysing this data, the status quo of the CCU sector and (potential) stimulation measures of different CCU niches in the Netherlands will be obtained.

The interview will be either audio-recorded or video-recorded, based on your preference and whether the interview takes place online or face-to-face. As with any online activity, the risk of a breach is always possible. But of our ability, your answers in this study will remain confidential. We will minimize any risks by gathering and storing as little personal data as necessary and storing the data on a TU Delft approved high-security storage solution and private TU Delft OneDrive location, only accessible by the research team. The data from the interviews will be anonymised before publication in the thesis report. The research team has access to the following data: name, email address, audio/video recordings, anonymised transcripts, and anonymous summary. People of Accenture outside this research team do not have access to any of the above data except for the anonymous summary that will be shared in the final thesis. The final thesis report will be published in the TU Delft thesis repository including the summary and will be publicly accessible.

Participation in this study is voluntary and you can withdraw at any time. You are free to omit any questions. A summary of the interview will be provided to you after the interview. You are free to request the removal of parts of the summary before publication in the thesis report. This summary will be anonymous. All other personal data collected (audio/video recording, notes, participant list) will be deleted at the latest 3 years after the completion of the project. When an extension is required, the participant is always asked for consent if extended use of the data is allowed.

For any questions or complaints regarding the research, feel free to contact us:

- Researcher: Thorsten Kuipers
- Supervisor Accenture: Marc Boerema
- Supervisor TU Delft: Jaco Quist

PLEASE TICK THE APPROPRIATE BOXES	**Yes**
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION	
1. I have read and understood the study information above, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐

Figure 8.4: Informed consent form part 1

PLEASE TICK THE APPROPRIATE BOXES	Yes
2. I understand that taking part in the study involves an audio-recorded or video-recorded interview.	☐
3. I understand that the study will end in Fall 2023.	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)	
4. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [name, email address] and associated personally identifiable research data (PIRD) [audio or video].	☐
5. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: anonymisation of the summary of the interviews before publication, secure data storage on the TU Delft OneDrive, and access to the recordings are limited to the research team.	☐
6. I understand that personal information collected about me that can identify me, such as my name and email address, will not be shared beyond the study team. I understand that the anonymised transcript data I provide will be destroyed when the project is completed and that anonymised transcriptions can be stored till 3 years after the finish of the project. When an extension is required, the participant will be asked consent if extended use of the data is allowed.	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION	
7. I understand that after the research study aggregated and anonymised information I provide will be used for a master's thesis report, which will be published in the TU Delft thesis repository. Only anonymised summaries will be published in the report.	☐
8. I agree that my responses, views, or other input can be quoted anonymously in research outputs.	☐
D: (LONG-TERM) DATA STORAGE, ACCESS AND REUSE	
9. I give permission for the summary of the interviews I provide to be archived in TU Delft repository to be used for future research and learning. I understand that access to the TU Delft repository is public.	☐

Signature

____________________ ____________________ __________
Name of participant Signature Date

Study contact details for further information:

Thorsten Kuipers

or the thesis supervisor Dr.ir. Jaco Quist

Figure 8.5: Informed consent form part 2

Interview questions

Table 8.4: Interview opening

English	Dutch
Appreciation for the cooperation	Bedankt voor uw medewerking
First, I will tell you something about myself.	Ik zal eerst even wat over mijzelf vertellen.
The purpose of this research is to determine the current landscape of the Carbon capture and utilisation (CCU) options in the Netherlands and to provide stimulation measures for the different CCU options and will take you approximately 60 minutes to complete.	Het doel van het onderzoek is het in kaart brengen van het landschap van verschillende CO_2-gebruik toepassingen en hoe dit gestimuleerd kan worden voor de verschillende opties, en zal u ongeveer 60 minuten kosten om te voltooien.
The data will be used for my Master Thesis and maybe eventually be used for publication.	De gegevens zulen worden gebruikt voor mijn Master scriptie en wellicht bij een publicatie van de scriptie.
You will be participating anonymously	Deelnemen is anoniem
As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential.	Zoals bij elke online activiteit is het risico van een inbreuk altijd mogelijk. Uw antwoorden in dit onderzoek zullen naar ons beste vermogen vertrouwelijk blijven.
We will minimize any risks by encrypting sensitive data, use strong passwords, store it offline, only share the data with individuals who have been authorized to access it by your consultation.	We minimaliseren alle risico's door gevoelige gegevens te versleutelen, sterke wachtwoorden te gebruiken, deze offline op te slaan en de gegevens alleen te delen met personen die door uw raadpleging gemachtigd zijn om er toegang toe te krijgen.
No personal data will be collected other than provided in the interview.	Er worden geen persoonsgegevens verzameld anders dan door uzelf verstrekt
Ask permission for an video/audio-recording of the interview	Toestemming vragen om een audio recording te maken van het interview
The interview will be summarized for approval, and send by e-mail within 5 working days to your mailbox.	Een samenvatting van het interview zal worden gemaakt. U ontvangt deze per e-mail binnen 5-werkdagen ter goedkeuring
You have the right to request access to and rectification or erase of personal date.	U heeft het recht op toegang tot en correcties of verwijdering van persoonlijke data.
Non-response on the sent summary after 10 working days or 2 weeks is assumed as permission to use the data.	Als u niet reageert op de e-mail binnen 10 werkdagen of 2 weken wordt aangenomen dat er toestemming is om de samenvatting te gebruiken.

Exploratory interview questions

Table 8.5: Exploratory interviews

	English	Dutch
Introduction		
	Could you please tell me about yourself or your organisation and your organisation's experience with CCU?	Kunt u iets vertellen over uzelf of uw organisatie en de ervaringen binnen uw organisatie?
	Why did you or your organization decide to get involved in the development of CCU?	Waarom heeft u of uw organisatie besloten om betrokken te raken bij de ontwikkeling van CCU?
Landscape		
	What are the main developments influencing the development of CCU in the Netherlands? (e.g. national, international level or other sector level) Would you expect changes in these developments and factors?	Wat zijn de belangrijkste ontwikkelingen die van invloed zijn op de ontwikkeling van CCU in Nederland? (bijvoorbeeld nationaal, internationaal niveau of ander sectoraal niveau) Verwacht u veranderingen in deze ontwikkelingen en factoren?

	Related to the previous question, what do you think about factors such as climate change, economics, and political circumstances in influencing the use of CO_2? Could it be a barrier or an opportunity to develop CCU? Do you consider other factors as well?	Gerelateerd aan de vorige vraag, wat vindt u van factoren als klimaatverandering, economie en politieke omstandigheden die het gebruik van CO_2 beïnvloeden? Zou het een barrière of een kans kunnen zijn om CCU te ontwikkelen? Houdt u ook rekening met andere factoren?
Regime		
	What are the main barriers –to CCU development in the Netherlands? (e.g. industry, culture, policy, technology, markets, and infrastructure)	Wat zijn de belangrijkste belemmeringen voor CCU-ontwikkeling in Nederland? (bijv. industry, culture, policy, technology, markets, and infrastructure)
	What are the main opportunities and drivers that can drive the adoption of CCU in the Netherlands?	Welke factoren zijn volgens u de kansen die de acceptatie van CCU in Nederland kunnen stimuleren?
Articulation and shaping of Expectations		
	Which CCU options do you think are the most important in the Netherlands?	Welke CCU-opties zijn volgens jou de belangrijkste in Nederland?
	Could you rank them?	Kan je een volgorde van belangrijkheid geven?
External expectations	What is your expectation related to these CCU options?	Wat is uw verwachting met betrekking tot deze CCU opties?
External expectations	And what is happening with regards to these options?	En wat gebeurt er met betrekking tot deze opties?
Exogenous expectations	Have your expectation changed overtime? Why did they change?	Is uw verwachting in de loop van de tijd veranderd? Waarom zijn ze veranderd?
Social network formation		
Network composition	Are you aware of other alliances? And there actors missing?	Kent u andere allianties? Missen er belangrijke spelers?
Network composition	What are the most important CCU actors?	Wat zijn de belangrijkste CCU-actoren?
Learning process		
Development	What has been learned about the CCU options/categories you have mentioned?	Wat is er geleerd over de door u genoemde CCU-opties/categorieën?
Social and environmental impact	How does the technology impact safety and the environment?	Wat is de impact van de technologie op veiligheid en milieu?
Development of the user context	What activities are currently being conducted to increase knowledge and awareness about CCU?	Welke activiteiten worden momenteel uitgevoerd om kennis en bewustwording over CCU te vergroten?
Government policy and regulatory framework	Is the institutional structure and legislation relevant for dissemination? How? Can these two encourage the implementation of CO_2 utilization? How?	Is de institutionele structuur en wetgeving relevant voor de verspreiding? Hoe? Kunnen deze twee de implementatie van CO_2-benutting stimuleren? Hoe?
Business models		

	What measures and actions would be needed to accelerate the implementation of CCU (conducted by (i) government, (ii) companies, (iii) citizens and civil society, and (iv) researcher or university)	Welke maatregelen en acties zijn nodig om de implementatie van CCU te versnellen (uitgevoerd door (i) overheid, (ii) bedrijven, (iii) burgers en het maatschappelijk middenveld, en (iv) onderzoeker of universiteit)
The concluding questions		
	Is there additional information you might want to share regarding the CCU development that has not been covered?	Is er aanvullende informatie die u misschien wilt delen met betrekking tot de focus van dit onderzoek die niet aan bod is gekomen?
	Do you have any recommended interviewees for further interviews?	Zijn er mensen die u zou aanbevelen om nog volgende interviews mee te doen en waarom?

Niche-related interview questions

Table 8.6: Niche-related interview questions

	English	Dutch
Introduction		
	Could you please tell me about yourself or your organisation and your organisation's experience with CCU?	Kunt u iets vertellen over uzelf of uw organisatie en de ervaringen binnen uw organisatie?
	Why did you or your organization decide to get involved in the development of CCU?	Waarom heeft u of uw organisatie besloten om betrokken te raken bij de ontwikkeling van CCU?
Landscape		
	What are the main developments influencing the development of CCU in the Netherlands? (e.g. national, international level or other sector level) Would you expect changes in these developments and factors?	Wat zijn de belangrijkste ontwikkelingen die van invloed zijn op de ontwikkeling van CCU in Nederland? (bijvoorbeeld nationaal, internationaal niveau of ander sectoraal niveau) Verwacht u veranderingen in deze ontwikkelingen en factoren?
	Related to the previous question, what do you think about factors such as climate change, economics, and political circumstances in influencing the use of co2? Could it be a barrier or an opportunity to develop CCU? Do you consider other factors as well?	Gerelateerd aan de vorige vraag, wat vindt u van factoren als klimaatverandering, economie en politieke omstandigheden die het gebruik van co2 beïnvloeden? Zou het een barrière of een kans kunnen zijn om CCU te ontwikkelen? Houdt u ook rekening met andere factoren?
Regime		
	What are the main barriers to CCU development in the Netherlands? (e.g. industry, culture, policy, technology, markets, and infrastructure)	Wat zijn de belangrijkste belemmeringen voor CCU-ontwikkeling in Nederland? (bijv. industry, culture, policy, technology, markets, and infrastructure)
	What are the main opportunities and drivers that can drive the adoption of CCU in the Netherlands?	Welke factoren zijn volgens u de kansen die de acceptatie van CCU in Nederland kunnen stimuleren?
Articulation and shaping of Expectations		
Internal expectations	What is your expectation related to this CCU niche?	Wat is uw verwachting met betrekking tot deze CCU-niche?
External expectations	And what is happening with regards to these options?	En wat gebeurt er met betrekking tot deze opties?
Exogenous expectations	Did your expectations change because of developments that were not in your control? Or because of other CCU-related development, but not directly related to your niche?	Zijn uw verwachtingen veranderd door ontwikkelingen die u niet in de hand had? Of vanwege andere CCU-gerelateerde ontwikkelingen, maar niet direct gerelateerd aan uw niche?

Endogenous expectations	Have your expectation changed overtime? Why did they change?	Is uw verwachting in de loop van de tijd veranderd? Waarom zijn ze veranderd?
Social network formation		
Network composition	1. What kind of organizations do you collaborate with? 2. Are there any actors missing? if so, who are they?	1. Met wat voor soort organisaties werkt u samen? 2. Ontbreken er belangrijke spelers? zo ja, wie zijn dat?
Quality of the sub-network	Could actors do more? How good is the collaboration?	Kunnen betrokken partijen meer doen? Hoe goed is de samenwerking?
Network interactions	1. Do actors in the network interact? and when Yes? to what extend? 2. Is there sufficient collaboration between actors? Why?	1. Interageren actoren in het netwerk? en wanneer ja? in hoeverre? 2. Zie je uitdagingen in samenwerking en afstemming tussen actoren? Hoe deze te overwinnen?
Network alignment	Do agree with the current CCU niche development? and when yes? to what extent? based on vision, expectations, and strategies?	Bent u het eens met de huidige CCU-niche-ontwikkeling? en wanneer ja? in welke mate? gebaseerd op visie, verwachtingen en strategieën?
Learning process		
Technical development and infrastructure and industrial development	What has been learned about the CCU options/categories you have mentioned?	Wat is er geleerd over de door u genoemde CCU-opties/categorieën?
Social and environmental impact	How does the technology impact safety and the environment?	Wat is de impact van de technologie op veiligheid en milieu?
Development of the user context	What activities are currently being conducted to increase knowledge and awareness about CCU?	Welke activiteiten worden momenteel uitgevoerd om kennis en bewustwording over CCU te vergroten?
Government policy and regulatory framework	Is the institutional structure and legislation relevant for dissemination? How? Can these two encourage the implementation of co2 utilization? How?	Is de institutionele structuur en wetgeving relevant voor de verspreiding? Hoe? Kunnen deze twee de implementatie van co2-benutting stimuleren? Hoe?
Niche potential and analysis	What have you learnt about the available Co2 resources	Wat heb je geleerd over de beschikbare bronnen
Second order learning	Why are the options you mentioned important? When did you realize? These are important.	Waarom zijn de door u genoemde opties belangrijk? Wanneer besefte je dat deze belangrijk zijn?
Business models		
	What measures and actions would be needed to accelerate the implementation of CCU (conducted by (i) government, (ii) companies, (iii) citizens and civil society, and (iv) researcher or university)	Welke maatregelen en acties zijn nodig om de implementatie van CCU te versnellen (uitgevoerd door (i) overheid, (ii) bedrijven, (iii) burgers en het maatschappelijk middenveld, en (iv) onderzoeker of universiteit)
The concluding questions		
	Is there additional information you might want to share regarding the CCU development that has not been covered?	Is er aanvullende informatie die u misschien wilt delen met betrekking tot de focus van dit onderzoek die niet aan bod is gekomen?
	Do you have any recommended interviewees for further interviews?	Zijn er mensen die u zou aanbevelen om nog volgende interviews mee te doen en waarom?

Table 8.7: Interview closing

English	Dutch
Again gratitude for time/cooperation	Nogmaals bedankt voor uw tijd en medewerking
Is there anything you would like to add to your answers?	Wilt u nog iets toevoegen aan uw antwoorden
Do you have any questions or remarks regarding this interview and my research?	Heeft u vragen of opmerkingen over dit interview en mijn onderzoek?
I there any information that you have shared confidential, if so, can it be used anonymously?	Is er enige informatie confidentieel, indien het geval, kan het anoniem worden opgenomen?
State that the summary will be sent for approval	De samenvatting wordt verzonden voor goedkeuring
Approval is within 2 weeks, otherwise, it is assumed that permission is given to use the data in for the research.	S.v.p. goedkeuring verlenen binnen 2 weken. Indien geen reactie zal na 2 weken de goedkeuring worden aangenomen.
You have the right to request access to the provided information or to withdraw from the study.	U heeft het recht om toegang te vragen tot verstrekte informatie of om u terug te trekken van het onderzoek
Do you know other people relevant to my research?	Kent u andere mensen relevant voor dit onderzoek en wie mogelijk een interview zou willen afleggen?
Are you interested to receive the final research report?	Bent u geïnteresseerd om het eindresultaat in het onderzoek te ontvangen?
Is it possible to ask follow-up questions?	Is het mogelijk om follow-up vragen te stellen?

Appendix B - Code book

List of pre-defined codes for thematic analysis in Atlas Ti

Table 8.8: Predefined code categories list

Landscape	**Barriers**
Factors influencing the development	Industry
Barrier influencing the development	Culture
Opportunity influencing the development	Infrastructure
Regime	Techno-scientific
Barrier influencing the development	Policy
Drivers to the development	Markets
Articulation and shaping of expectations and visions	Technology
Internal expectations	**Drivers**
External expectations	Industry
Exogenous expectations	Culture
Internal expectations	Infrastructure
Endogenous expectations	Techno-scientific
Social network formation	Policy
Network composition	Markets
Quality of the sub-network	Technology
Network interactions	**Stimulation**
Network alignment	Industry
Learning process	Culture
Technical development and infrastructure	Infrastructure
Industrial development	Techno-scientific
Social and environmental impact	Policy
Development of the user context	Markets
Government policy and regulatory framework	Technology
Second-order learning	
Business models implementation actions needed	

Final list of codes for thematic analysis in Atlas Ti

Table 8.9: Final codes with code categories list

Interview	Code categories	Codes
#1	regime	Ongoing discussion, primary carbon source
#1	regime	Local maintenance
#1	drivers	Long-term applications
#1	network composition	Initiatives
#1	network composition	Missing Actors
#1	network composition	Future collaborations
#1	Regime	Policy environment, Investment in CO2 utilization, Demonstration projects, Practical experience
#1	drivers	System analysis, feedback loops, industry, policymakers
#1	exogenous expectations	No change in opinion
#2	culture	Progress in understanding
#2	driver	Possibilities, permissibilities, economic attractiveness
#2	regime, external expectations	Atmospheric CO2, biogenic CO2, availability of biogenic CO2
#2	external expectations	Route of permanent CO2 storage, waste incineration plants
#2	endogenous expectations	Synthetic fuels
#2	regime, internal expectations	Aviation industry, European legislation, alternatives
#2	regime	Alternatives, biogenic CO2
#2	regime, social and environmental impact	Biogenic CO2, atmospheric CO2, multiple factors, origin of CO2, green energy production, impact of CCU on safety and environment
#2	regime,	Alternatives, renewable electricity, environmental impact, decarbonization, energy challenge
#2	development of the user context	Lectures, education, government, future collaborations
#2	barrier	Double counting prevention, responsibility allocation, models and regulations, system boundaries, CO2 emissions attribution
#2	business models	Economic attractiveness, responsibility allocation, ETS, scope 3 emissions
#2	Business models	ETS, defining Responsibilities, Lifecycle emissions measurement methods, Clear rules and standards
#2	government policy and regulatory framework	European legislation, government
#2	Network composition	CCU alliance, bof2urea consortium, initiate
#2	network composition	Missing Actors
#2	Development of the user context	Perceptions of technology, willingness to pay, future collaborations
#2	regime	Alternatives, feasibility, role of CCU, energy demand, efficiency, system efficiency
#3	Landscape	Energy transition, raw material transition, policy vision
#3	landscape	Long-term applications, policymakers
#3	landscape	Climate change, sustainable economy
#3	Regime	Financial incentive, market model, route of permanent CO2 storage, subsidy, carbon sink
#3	Regime	Ambition, market model, subsidy projects, added value per ton CO2
#3	Regime	Market model
#3	regime	Awareness, public debate
#3	expectations	Carbon program, industry collaboration
#3	Regime	European legislation, market model
#3	Regime	Systemic questions, system analysis

#3	development	Role of CCU, biogenic CO2, green fuel, FutureCarbonNL
#3	network composition	CCU alliance, Nvde, taskforce negative emissions
#3	regime	Availability of biogenic CO2, availability of hydrogen
#3	Network composition	Bio-based circular
#3	rest	Methanol, scale
#3	network allignment	Perceptions of technology, role of CCU
#3	rest	Missing opportunities, soft tech, data technology developments, monitoring and reporting, progress measurement, blockchain
#3	business models	Market model, stimulation, inspiration
#3	business models	Policy vision
#3	business models	Uniform measurement
#3	business models	Value chain
#3	network composition	Value chain, start-ups, SMEs
#3	government policy and regulatory framework	Carbon sink, CO2 removal, policy support
#3	Developement of the user context	Communication experts, behavioral psychologists
#3	external expectations	CCU fuels, mineralization, CO2 storage
#4	Landscape	Raw material transition, climate change, climate change, energy transition
#4	Regime	Forced investment, Investment in CO2 utilization, aggressive investment
#4	regime	Innovation acceleration, knowledge sharing, fundamental research, piloting, Demonstration projects
#4	regime	Financial requirements, infrastructure, prerequisites
#4	landscape	Geopolitical conflicts, alternatives, independence, general trends
#4	regime barriers	Expensive
#4	regime	Regime breakdown, stimulus, sustainable products
#4	regime	Scope 3 emissions, ETS
#4	regime	Industry, expensive
#4	landscape	Geopolitical conflicts, industry
#4	rest	Technology development
#4	drivers	Scope 3 emissions, ETS, models and regulations
#4	landscape	Decarbonization, geopolitical dependency
#4	landscape	Geopolitical independence, Russia-Ukraine war, Suez canal
#4	regime social	Environmental impact, industry
#4	Learning process: development of the user context	Education, position papers, role of CCU
#4	development of user context	Awareness, podcast
#4	network composition	Missing Actors
#4	direct and indirect use	Indirect use of CO2, direct use of CO2
#4	government policy and regulatory framework	Commitment, government commitment, chicken and egg, adaptation of governments and conditions
#4	government policy and regulatory framework	Policymakers, capacity problem, communication problem, technological developments, new complex problems
#4	niche definition	CO2 sources
#4	business models	Government measures, financial risk mitigation, sustainable product requirements, support for startups, funding, derisking
#4	business models	Sustainable packaging materials, market demand, industry reluctance
#5	landscape	Raw material transition
#5	landscape regime	European legislation, Green Deal in Europe, emission trading system, ETS
#5	landscape and regime	Green Deal in Europe, fit for 55, emissions reduction, repower EU
#5	drivers	Subsidy, European subsidies, innovation acceleration

#5	business models	Piloting, scaling up, knowledge and patents, business case, global technology
#5	regime barriers	Industry, financial barriers, cost constraints
#5	business models	Initiatives, global technology, business model, technology provider, market outside Netherlands, Bvnl
#5	internal expectations	War economy, expectations
#5	endogenous expectations	Overtime learning
#5	rest	Performance materials, fundamental differences
#5	rest	Oxygen-holding polymers
#5	internal expectations	Business opportunities, international expansion, technology supplier, strategic planning
#5	government policy and regulatory	CO2 emissions attribution, biogenic CO2, environmental impact, policy
#5	business models	Forced investment
#5	business models	Business opportunities, business case
#5	landscape rest?	Raw material transition, circular
#5	rest	Circularity, route of permanent CO2 storage
#5	internal expectations	Knowledge infrastructure, demonstration country
#6	regime	Policy vision, European legislation, international collaboration
#6	government policy and regulatory framework	SDE++, direct use of CO2
#6	government policy and regulatory framework	Policy support, subsidy, research funding
#6	regime	European legislation, fossil fuel reduction
#6	drivers barriers	CO2 emissions prevention, raw material transition, energy transition
#6	drivers barriers	European legislation, policy vision
#6	regime and rest	Policy environment, ETS, short-term applications, role of CCU, biogenic CO2, atmospheric CO2
#6	internal expectations	Feasibility, long-term planning
#6	endogenous expectations	Role of CCU, CCS
#6	development of the user context	Knowledge sharing
#6	network alignment	CCUS, confusion
#6	network composition	Initiatives, universities
#6	network composition	Renewable carbon initiative, nova-instituut
#6	external expectations	Negative emissions, commercialization
#6	barriers	Financial efficiency, Investment in CO2 utilization, effectiveness of tax spending
#6	network alignment	Mineralization, negative emissions
#6	social and environmental impact	Initiatives, CO2 removal, impact on the environment
#6	industrial development	Overtime learning
#6	development of user context	Maintain the chemical industry
#6	barrier	Scope 1 CO2 emissions, recycling, energy net, emissions reduction
#6	external expectation	Chemical industry, innovation
#6	government policy and regulatory framework	Scope 3 emissions, scope 1 CO2 emissions
#6	external expectations	Direct use of CO2, emissions reduction
#6	drivers + business models	Reduce fossil resources
#6	external expectations	Carbon shortage, negative emissions, supply and demand
#7	landscape	Energy transition, raw material transition
#7	regime drivers	Industry collaboration
#7	regime drivers	Industry collaboration
#7	barriers regime	Barriers, more expensive than fossil
#7	regime	Policy

#7	regime	Stimulus, admixture obligation
#7	regime	Blending obligations, synthetic fuels, CCU fuels, biofuels
#7	regime	Subsidy, pilot projects, testing
#7	barriers	Expensive, cost constraints, growth fund
#7	internal expectations	Missing opportunities
#7	network composition	Missing Actors
#7	network expectations	Suppliers
#7	quality of the sub-network	Many meetings
#7	network alignment	Network alignment
#7	external expectations	Waste incineration plants, waste gasification plants
#7	development of user context	Circularity, perception
#7	development of user context	Sustainable industry lab, government support, policy influence
#7	social and environmental impact	Safety
#7	development of user context	Acceptance, societal acceptance, willingness to pay
#7	governmental policy and regulatory framework	Blending obligations, admixture obligation
#7	business models	Subsidy, pilot projects, funding
#7	regime drivers	Green energy production, role of CCU, industry
#8	regime	Knowledge about CCU, petrochemical processes
#8	drivers	ETS, promote CO2 removal, negative emissions
#8	drivers	Negative emissions
#8	barriers	Policy support, existing business, disruptive business
#8	regime policy	International influence, IRA act, changing dynamics, policy impact, international developments
#8	business models	Policy support
#8	quality of the sub-network	Network alignment, chemical industry
#8	barriers	Barriers, novel product, convincing companies
#8	barriers	Delivery time, equipment, barriers
#8	drivers	Negative emissions, CO2 extraction, biogenic CO2, fossil CO2
#8	Network interaction + barrier	Hydrogen-focused, existing players, facilitating
#8	regime + barriers	Business case, economic affairs, policy people, scaling up phase
#8	regime	LVO, economic affairs, subsidy, system separation
#8	barriers	Lobbying groups
#8	industrial development	Project administration, big projects
#8	regime barriers	Existing regulations, novel product, change regulations
#8	external expectations	Solutions
#8	business models	Parallel routes, more money
#8	regime + barrier	Different view, CCU community
#9	regime barriers	Negative LCA outcome
#9	landscape	Fossil CO2 application
#9	regime barrier	Value chain, biogenic CO2, fossil CO2
#9	regime barrier	CO2 quality, link CCS and CCU infrastructure
#9	regime barrier	Origin of CO2, CO2 network
#9	internal expectations	Transition speed
#9	regime barriers	Alternative methods
#9	internal expectations	No change in opinion
#9	Network alignment	Complicated topic
#9	development of the user context	Workshops, reading, limited resources
#9	business models	Subsidy, more money, project site, permit granting
#10	external expectations	Early development

#10	regime	Infrastructure, CO2 reuse
#10	landscape	Feedstock, European perspective
#10	internal expectations	Policy vision, waste incineration plants
#10	network composition + quality of the sub network	Agreements with buyers, industry collaboration
#10	network alignment	Synergy of developments
#10	business models	Policy vision, technological developments, long-term planning, Investment in CO2 utilization, ETS, route of permanent CO2 storage
#10	development of user context	Environmental organizations, maintain existing industry
#10	business models	Policy support, ETS, negative emissions
#11	Network composition	Initiatives, value chain, Missing Actors
#11	regime barriers	Aversion to production, NIMBY effect
#11	Internal expectations	Expectations, investment decisions
#11	Government policy and regulatory framework	Lobbying groups
#11	regime	Outgoing industry, maintain existing industry
#11	business models	Reliable government
#11	Government and regulatory framework	Institutional structure, stability, volatile government
#11	rest	FutureCarbonNL, RD focus
#11	Regime policy	Aversion to production, chemical industry, Policy environment
#11	regime	Industry, industry policy
#11	regime policy	Vision development
#11	barriers	Pilot plant, market outside Netherlands
#12	drivers	Stimulating measures, Paris climate goals
#12	barrier	Policy environment, industry, CO2 credits
#12	business models and government policy	Industry policy
#12	Network composition	Scaling support, engineering company, stakeholders, lead investors
#12	external expectations	Reduce consumption, Direct air capture
#12	quality of the sub network	Excellent collaboration
#12	network alignment	CO2 reduction, Enhanced Oil Recovery, climate change, policy vision
#12	network interactions	Ways of working, start-ups
#12	network interactions	Ways of working, synthetic fuels
#12	network alignment	Synthetic fuels, biomass
#12	Social and environmental impact	Awareness, societal acceptance
#12	development of the user context	CCU alliance, Policy environment
#12	internal and external expectations	Biogenic CO2, atmospheric CO2
#12	internal expectations	Policy vision, strategic volume, demonstration country, biomass
#12	internal and external expectations	Business case, Direct air capture
#12	Internal expectations	Letter of intents, trust
#12	network composition	Scale technology
#12	government and regulatory framework	SDE++, IRA act, Direct air capture
#12	second order learning	Direct air capture, contests
#12	Development of the user context	Industry collaboration
#13	internal expectations	CO2 reuse, route of permanent CO2 storage, stimulus
#13	external expectations	SAF, fossil source, market functioning
#13	external expectations	Intent of interest

#13	network composition	Policy environment, industry, initiatives, industry collaboration, subsidy
#13	quality of the sub-network	Link CCS and CCU infrastructure, policy influence, ongoing discussion
#13	network alignment	Energy transition, carbon shortage
#13	network alignment	Government alignment
#13	government polciy and regulatory framework	Stimulus, connection with other markets, political choices
#13	industrial development	OCAP-network, Investment in CO2 utilization, development synergy
#14	Development of the user context	Technology barrier, economic competitiveness
#14	Social and environmental impact	Energy source
#14	rest	Origin of CO2
#14	network composition	FutureCarbonNL
#14	Industrial development	Technology sharing
#14	industrial development	Process execution
#14	Quality of the sub-network	Industry collaboration
#14	regime	Insecure market situation, inflation, fluctuating prices, market uncertainty
#14	government policy and regulatory framework	Energy demand, nuclear energy
#14	External expectations	Mineralization, irreversible process

Appendix C - Stakeholder allocation

Table 8.10: Stakeholders CO_2 Smart Grid

Sources
AEB Amsterdam
AVR Rotterdam
Tata Steel
Infrastructure
OCAP
Port of Amsterdam
Port of Rotterdam
Gasunie
EBN
Application
LTO Glaskracht
Chemical industry
Locations
Port of Amsterdam
Port of Rotterdam
R&D
TKI indsutry
Market
Support
Greenports
Province of Noord-Holland
Province of Zuid-Holland
Amsterdam Economic Board
Deltalinqs
Nature and Environment Federation

Appendix D - Reasoning Power Interest Grid

Table 8.11: Power and interest of different stakeholder groups

Group of stakeholders	Explanation	Power	Interest
Licensors	Solely facilitating licenses.	Low	High
Engineering	Providing engineering solutions.	Low	High
Direct Air Capture	Development of off-grid carbon capture solutions.	Low	High
Capture Technology	Development of carbon capture solutions.	Low	High
Infrastructure	They are crucial for short-term and long-term development as the value chain depends on infrastructure development. Companies are currently employing CO_2 infrastructures.	High	High
Waste incineration	Play a role in the first implementation of inter-company use cases but are dependent on governmental vision development.	Low	High
Energy production	Play a role in the first implementation of inter-company use cases but are dependent on governmental vision development.	Low	High
Clusters	Are involved in first implementation of CCU value chain in cluster were different forms of energy come together and emitters and users are present. However their cluster strategies minimally mention CCU in mitigation strategies. Also, past events showed that developments for the CCU value chain were too early.	High	Low
Utilization categories	They are very dependent on governmental vision development.	Low	High
CO2 gas	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Chemicals	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Materials	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Fuels	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Food	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Mineralization	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Process technology	Are marginally involved in the development of CCU and are partly subject to the governmental plans.	Low	High
Knowledge	Different aspects of CCU are explored by this group.	Low	Low
Education	Universities are researching different aspects of CCU.	Low	Low
Knowledge institutions	Organizations are researching different aspects of CCU.	Low	Low
Regulatory	Providing regulatory context to the development of CCU.	High	Low
Governmental	Various aspects of the government influence the business environment. This has to be performed by facilitating and regulating measures.	High	High
Users	Users of CO2 derived products.	Low	Low
Miscellaneous	Various entities whom different contribute but are not all essential drivers.	Low	Low

Appendix E - Nurturing

Network formation

Table 8.12: Network formation results

Network formation	Sub-category	Fre-quency	Stakeholder
Direct and Indirect			
Carbon capture start-up arranged a network outside FutureCarbonNL and CCU Alliance with TNO, three TUs in the Netherlands, universities in Belgium, ASML, VDL, and Philips.	Composition	1	Start-up
The government is not seen as a reliable business partner.	Quality of the sub-network	1	Chemical production company
EU vision towards the CCUS (combined CCU and CCS) strategy should be separated as the focus on hard-to-abate industries hampers CCU while the focus is on circular economy.	Alignment	1	Ministry of climate
Direct			
Start-ups need help attracting lead investors.	Composition	1	Start-up
One direct utilization start-up is worried about being unable to tap into the indirect utilization network because of a different focus.	Interaction	1	Start-up
Horticulture is flexible in collaboration.	Interaction	1	Start-up
Indirect			
All relevant stakeholders are present in the network for this development moment.	Composition	4	University, ministry of climate, oil and gas company and biochemical company
Infrastructure and demand is underrepresented in the CCU value chain.	Composition	1	Chemical production company
Sebik is mentioned as a missing actor.	Composition	1	Branch organization
Thereafter, the first actors to include are the NGOs, provinces and municipalities.	Composition	1	University
Network misses people who do the actual work, there are to many coordinators.	Composition	1	Chemical production company
Involve medium-sized businesses and start-ups more because they have a lot to offer in terms of innovation, as the network is not seen as innovative enough.	Composition	1	Institute for open innovation
Sub-networks would involve smaller enterprises which empowers innovation.	Composition	1	Institute for open innovation
Fuel producers are stiff in collaboration due to their standard procedures they have in place.	Interaction	1	Start-up
The network interactions are seen as difficult but beneficial because of the broad range of businesses which reduces competition.	Interaction	1	Branch organization, oil and gas company
Network was able to meet several time a week to write the FutureCarbonNL proposal.	Interaction	1	Oil and gas company
Some think the network has a very strategic nature.	Alignment	1	Branch organization
The complexity of CCU initiatives involving various stakeholders with diverse interests.	Alignment	1	Start-up
The network is seen as a strong RD focus because of the representatives involved.	Alignment	1	Chemical production company
The vision to stimulate a circular economy or optimise the current one differs within the network.	Alignment	1	Institute for open innovation

Articulation of vision and expectations

Table 8.13: Articulation of vision and expectations results

Expectations	Sub-category	Frequency	
Direct and Indirect			
The availability of cheap raw materials and energy is needed so Europe and the Netherlands can compete with the U.S. And China on CCU production prices.	Internal	2	Branch organization and knowledge institute
The government aims to include various CO_2 mitigation options, including CCU. Still, it lacks an overarching vision of how this fits the CO_2 supply chain and decarbonisation strategy.	External	2	University, knowledge institute
Long-term CO_2 supply constraint due to fossil resource depletion.	External	1	Ministry of climate
Long-term CO_2 competition due to a broad spectrum of products and limited CO_2 sources.	External	1	Branch organization
The IRA act by the Biden administration stimulates CCU production in the USA.	Internal and external	2	Knowledge institute, start-up
Direct air capture units are expected to enable small to medium CO_2 supply needs.	Internal	1	Branch organization
Long-term CO_2 storage is expected to be enabled by mineralization technology.	External	1	Institute for open innovation
Short-term CO_2 supply constraint due to CCS developments in the Netherlands	External	1	Ministry of climate
Short-term CO_2 supply constraint due to the lack of planning by the government on market development policies.	External	1	Branch organization
Direct			
The failure of CO_2 smart grid development did not change expectations.	Endogeneous	1	Circular and sustainability consultant
Indirect			
Technologies will likely be developed in the Netherlands due to existing knowledge available and production culture.	Internal	4	Oil and gas company, branch organization, chemical production company, start-up
CO_2 to materials are likely to become cost-effective due to product oxygen bindings.	External	2	Ministry of climate, knowledge institute
No large-scale implementation in the future due to limited green CO_2 source availability.	Internal and external	3	Branch organization, knowledge institute, and circular and sustainability consultant
Strategic volumes of CCU to secure geopolitical independence are expected.	Internal and external	2	Branch organization, start-up

Learning processes

Table 8.14: Learning processes results

Learning processes	Sub-category	Frequency	Stakeholder
Direct and Indirect			
Scope 3 emissions have to be included in the LCA.	Technical development	1	Ministry of climate
CO_2 for CCU has to be of higher quality than the CO_2 used for CCS.	Infrastructural development	1	Circular and sustainability consultant
The availability of the OCAP network makes it an opportunity for other CCU applications that are in development.	Infrastructural development	1	Branch organization

The origin of the CO_2 source is relevant.	Social and environmental impact	1	University, biochemical company
How the energy used is produced.	Social and environmental impact	1	University, biochemical company
The duration of the CO_2 storage is important. The storage duration on both direct and indirect utilization is generally low, except for the mineralization route, which is mainly permanent storage and, in exceptional cases.	Social and environmental impact	1	University
Complex environmental considerations surrounding CCU in terms of carbon streams and LCA models questioning the true sustainability of CCU.	Social and environmental impact	1	Circular and sustainability consultant
Stakeholder awareness is hampering the technology adoption.	Development of the user context	3	University, branch organization, oil and gas company, waste incinerator
For end-user as well as stakeholder awareness, different initiatives were already undertaken to enable stakeholder awareness (e.g. informative meetings, lectures, using communication experts to bring these difficult messages, writing position papers, and internal master classes).	Development of the user context	4	University, institute for open innovation, branch organization, knowledge institute
The willingness to pay extra is a technology adoption barrier to the current regime.	Development of the user context	3	University, branch organization, oil and gas company
The technological development is seen as a requirement for adoption.	Development of the user context	1	Oil and gas company
Inform stakeholders what CCU is.	Development of the user context	1	Ministry of Climate
End-users don't know what CCU is.	Development of the user context	1	Start-up
Community doesn't want the production in their backyard because they don't know what CCU is.	Development of the user context	1	Chemical production company
The technology is a barrier because it needs to be developed.	Development of the user context	1	biochemical company
The origin of CO_2 feedstock, whether fossil, biogenic or a mix, when designing CCU networks.	Development of the user context	1	Circular and sustainability consultant
Industry reluctance to adopt costly technologies.	Development of the user context	2	Branch organization, knowledge institute
The high costs associated with CCU projects.	Development of the user context	1	Branch organization
Introducing a novel CCU product to the market and the need to gain industry acceptance and social acceptance	Development of the user context	1	start-up
The logistics of CCU projects, specifically the timely delivery of equipment and the process of building and scaling up operations.	Development of the user context	1	start-up
Industry uncertainty and operating within an uncertain market environment.	Development of the user context	2	Circular and sustainability consultant, biochemical company
The need for high-quality CO_2 feedstock in CCU applications, particularly in greenhouses and product manufacturing.	Development of the user context	1	Circular and sustainability consultant
The integration of CCU technology into industrial processes.	Development of the user context	1	university
Stimulating policies, like subsidies, blending requirements for indirect utilization, and taxes on fossil products, are seen as ways for technology dissemination.	Government policy and regulatory framework	3	institute for open innovation, oil and gas company, start-up
The inclusion of scope 3 emissions in the ETS is seen as a way to enable market models.	Government policy and regulatory framework	2	branch organization, start-up, institute for open innovation

A commitment of all involved parties is essential to de-risk companies.	Government policy and regulatory framework	1	branch organization
The lack of in-house experts at the government is seen as a barrier to making system-level decisions.	Government policy and regulatory framework	1	Chemical production company
The government is not a reliable business partner.	Government policy and regulatory framework	1	Chemical production company
Lack of regulation and system boundaries to prevent double CO_2 counting.	Government policy and regulatory framework	1	university
Existing policies do not adequately accommodate innovative CCU approaches.	Government policy and regulatory framework	1	Start-up
Existing regulations may not align with or adequately address the unique aspects of CCU technologies and products.	Government policy and regulatory framework	1	Start-up
The political landscape does not fully support CCU initiatives, leading to alternative market-driven approaches.	Government policy and regulatory framework	1	Start-up
Not efficiently allocating taxpayer money for CCU projects.	Government policy and regulatory framework	1	Ministry of climate
The differences in the administrative systems within different governmental departments of the Netherlands and their impact on funding flexibility.	Government policy and regulatory framework	1	Start-up
Scaling up CCU projects and the need for policymakers and economic affairs officials to grasp the complexities and timeframes involved.	Government policy and regulatory framework	1	Start-up
ETS and SDE++ availability to allocate financing.	Government policy and regulatory framework	1	Branch organization
Securing a stable supply of CO_2 for CCU.	Niche potential and analysis	1	circular and sustainability consultant
International demand for negative emissions, driving the atmospheric and biogenic CO_2 use	Niche potential and analysis	1	start-up
Transitioning away from fossil resources catalyzes CCU initiatives.	Business models	1	Ministry of climate
The capital at companies related to the fossil industry could be used as a catalyst for CCU initiatives.	Business models	1	Start-ups
Financial challenges are related to CCU projects in mid-TRL levels.	Business models	1	oil and gas company
Clear documentation, rules, and standards in the CCU domain enable successful implementation.	Business models	1	University
Assign value to CO_2 sequestration in products and materials (mineralization) and the link between negative emissions and ETS.	Business models	1	Waste incinerator
End-market involvement benefits the awareness and public perception as well as the end-market becomes knowledgeable and uses their bargaining power.	Business models	1	branch organization
Policy stability enables business models.	Business models	1	Knowledge institute, start-up
The need for seamless collaboration between policy, regulation, and industry to overcome these hurdles and technical and commercial challenges.	Business models	1	Start-up
Pilot level and demo level development for technology scalability and international market positioning.	Business models	1	Knowledge institute

Market availability and hinterland, including knowledge availability in the Netherlands as well as industry.	Business models	1	Oil and gas company
Timing of CCU innovation development, as the Netherlands is ahead in the international perspective. Making the Netherlands the technology provider to other nations.	Business models	1	Knowledge institute
Direct			
The niche (start-ups) learnt how to manage large projects by handling project administration.	Industrial development	1	start-up
The governmental structure hampers the development of CCU because the sector has to deal with a lot of different ministries, which makes it difficult to align all the stakeholders.	Government policy and regulatory framework	2	Branch organization, start-up
CCU alliance as a driver for project development and negative emissions.	Business models	2	Branch organization, waste incinerator
Indirect			
The conversions used in the indirect utilization are energy intensive. Therefore, these applications can only emerge when the energy supply in the Netherlands is all green and is excessive.	Social and environmental impact	2	University, biochemical company
Important is how much energy is required to convert CO_2 and that the energy used is green.	Social and environmental impact	2	University, biochemical company
The perception of the industry of CCU as a complicated endeavour.	Development of the user context	1	Circular and sustainability consultant
Integrating CCU initiatives into existing industrial networks and the influence of established players.	Development of the user context	2	start-up, circular and sustainability consultant
FutureCarbonNL as a growth fund driver to develop CCU technologies.	Business models	2	Oil and gas company, branch organization

Appendix F - International CCU projects

Table 8.15: International CCU projects (Co2 Value Europe, n.d.; International Organization of Oil and Gas Producers, 2022)

Project	Country	Application	Status	Operation date	TRL
Bell Bay Powerfuels	Australia	Methanol	Early development	No data	9
SolarMethanol	Australia	Methanol	Early development	No data	9
Carbon2Product	Austria	Hydrocarbons, olefins	Early development	2030	9
Vienna green Co2	Austria	Hydrogen	In planning	No data	9
Power-to-Methanol Antwerp BV	Belgium	Methanol	Advanced development	2023	9
North-CCU-hub	Belgium	Fuels, plastics, and materials	Early development	2024	8
THREADING-CO2	Belgium	Monoethylen glycol, polyester	Early development	2026	9
CO2ncrEAT	Belgium	Construction products	Early development	No data	9
Columbus	Belgium	Methane	Early development	2025	6
Flite	Belgium	Ethanol	In planning	2027	9
Leilac 1	Belgium	Cement	In planning	No data	9
H2BE	Belgium	Hydrogen	In planning	2030	9
Steelanol	Belgium	Ethanol	Producing		9
VALCO2 II	Belgium	Hydrogen carbonates, formic acid and fuels	Producing		8
OCEAN	Belgium	Oxalic acid	Producing		9
CARMAT	Belgium	Building materials	Producing		9
CATCO2RE	Belgium	Methanol, methane	Producing		9
ANRAV	Bulgaria	Cement	In planning	2028	9
CO2MENT	Canada	Cement	Advanced development	2024	7
Next-Generation Bioreactor Technology	Canada	Ethanol	In planning	No data	9
CO2 To Graphene Reactors	Canada	Graphene	Producing		9
CarbonCure technologies	Canada	Cement	Producing		9
Hari Oni	Chile	Methanol, gasoline, liquified gas	Producing		9
Petrokemija	Croatia	Ammonia	In planning	No data	9
Bio-CCS/U	Czech	Liquid fuel	Producing		9
ConsenCUS (site 1)	Denmark	Formic acid, Formate	Advanced development	2025	7
Green fuels for Denmark	Denmark	Hydrogen, methanol, kerosene	Early development	No data	9
Vordingborg	Denmark	Kerosene, naptha, diesel	Early development	No data	9
Greensand	Denmark	Cement	Producing		9

Forest CUMP	Finland	Polyolefins, polyurethane	Advanced development	2024	6
SHARC	Finland	Hydrogen	Early development	2026	6
FLEXCHX	Finland	Liquid fuel	Producing		8
eM-Rhone	France	Methanol	Early development	No data	5
C2B	France	Sodium hydrogencarbonate	Finished		7
VASCO 2	France	Algae, fuels	Finished		6
C2FUEL	France	DME, formic acid	Finished		5
Cryocap	France	Hydrogen, methanol	Producing		8
Vabhyogaz 3	France	Bicarbonate	Producing		9
Carbon2chem	Germany	Fertilizer, methanol, alcohols	Advanced development	No data	9
TAKE-OFF	Germany	SAF	Advanced development	2024	5
Catch4climate	Germany	Fuels	Advanced development	No data	8
Corbon2business	Germany	Methanol	Early development	No data	7
MariSynFuel	Germany	Methanol	Early development	2026	5
Concretechemicals	Germany	Kerosene, naptha, jet-fuel	Early development	No data	8
Capture2Use	Germany	Materials	Early development	No data	6
FlexDME	Germany	Dimethylether	Finished		7
Align-CCUS	Germany	Methanol	Finished		6
NECOC	Germany	Methane	Finished		5
Westküste100	Germany	Methanol, hydrogen, kerosene	In planning	No data	4
Leilac 2	Germany	Cement	In planning	No data	7
CEMEX	Germany	Cement	Producing		8
RECODE	Greece	NanoCaCO3, formic acid, oxalic acid, glycine	Early development	No data	8
ConsenCUS	Greece	Formic acid, formate	Early development	2025	8
Tata steel	India	Steel	Finished		7
Tuticorin Alkali	India	Chemicals and fertilizers	Producing		8
Cleankerk	Italy	Clinker	Early development	No data	9
ECO2CO2	Italy	Methanol for fine chemicals	Finished		7
Herccules (site 1)	Italy	Binder (materials	In planning	2027	8
SPIRALG	Italy	Phycocyacin	Producing		8
Taiheiyo Cement Corporation	Japan	Cement	Producing		8
CO2carbon	Latvia	carbon nanomaterials and graphite	Advanced development	2024	7
Norks e-fuel	Norway	Fuels	Advanced development	2024	8
E-fuel pilot	Norway	SAF, Waxes	Early development	No data	9
PyroCO2	Norway	Acetone	Early development	2026	7

Mo Industrial E-fuel	Norway	Methanol	Finished		7
MoReCCU	Portugal	Nanomaterials, graphite	Advanced development	2024	6
LIPOR	Portugal	kerosene, diesel, jet-fuel, specialty chemicals	Advanced development	No data	5
Photofuel	Portugal	Alcohols and Alkanes	Finished		6
Triskelion	Spain	Methanol	Early development	No data	3
Green MEIGA	Spain	Methanol	Early development	No data	9
AggrecaCO2	Spain	Aggregates	Early development	No data	7
SoLDac	Spain	Ethylene	Early development	2025	6
Holcim	Spain	Cement	Finished		6
ECCo2	Spain	Cement	Finished		7
LifeCO2ToFUEL	Spain	Methane	Finished		7
CCU lighthouse Carboneras	Spain	Cement	Producing		8
CO2ALGEAFIX	Spain	Algae	Producing		8
BIOSEA	Spain	Algae	Producing		8
ECO-CEMENT	Spain	Cement	Producing		8
HySkies	Sweden	Ethanol, SAF, kerosene	Early development	No data	6
Flagship ONE	Sweden	Methanol	Finished		5
Stepwise	Sweden	Hydrogen	Finished		7
Project AIR	Sweden	Methanol	In planning	2025	7
Flagship THREE	Sweden	Methanol	no data		5
Flagship TWO	Sweden	Methanol	no data		4
Accsess	Switzerland	Calcium carbonate	Early development	2025	7
COZMOS	Turkey	Methanol, C-3 hydrocarbons	Finished		6
CO2Fokus	Turkey	Dimethylether	Producing		8
Net-zero Teesside (CCUS)	United Kingdom	Energy from Waste, fuels	Early development	2026	9
Veolia	United Kingdom	Energy from Waste	Finished		6
Infinium/Amazon	USA	Fuels	Finished		4