ERASMUS UNIVERSITY ROTTERDAM

Erasmus School of Economics

Bachelor Thesis Urban Port and Transport Economics

A successful path to CCS development

Name student: Casper Taams

Student ID number: 621270

Supervisor: Martijn Streng

Second assessor: Maurice Jansen

Date final version: 07-07-2024

Abstract

The aim of this paper is to assess what the most important factors are that can determine the outcome of a carbon capture and storage (CCS) project. To do this, firstly a literature review will be performed to evaluate the current knowledge on CCS. This will be analysed to identify the key factors that can have an influence on CCS project. Secondly an analysis will be performed based on data of failed and successful CCS projects. With this, different hypotheses are examined and tested. The main results are that a detailed planning and stakeholder engagement are very important to make a project successful. Also, public funding of a project is found to have a negative effect on a project's outcome, but this likely has to do with the limited available data causing explanatory variables to not be in the analysis, also known as omitted variable bias. lastly, it appears that the region a project is located in is correlated with the reason why a project fails.

Table of contents

Chapter 1: Introduction

1.1 Background

As the deadlines of climate goals are getting closer it is important to take a look at the various methods that are used to realize these goals. One of these methods that has been gaining importance in the past couple of years is carbon capture and storage (CCS). It is important to first establish what the concept of CCS is precisely. CCS is a technology that keeps CO2 from being released into the air (Global CCS Institute, 2022). This is done in three steps. These are:

- Firstly, capturing the CO2, which is done by separating the CO2 from other gasses.
- Secondly, the CO2 gets compressed and transported to a site for storage. This transportation can be done in multiple ways such as via ships or pipelines. Pipelines are considered to be the most practical way of transporting as they can transport the highest quantities of CO2.
- In the third step, the CO2 gets injected into porous rocks in the ground, to be stored. To do this safely the CO2 has to be stored deep underground, with a depth of at least 800 meters (Gaurina-Međimurec et al., 2018).

There are three different ways of capturing the CO2. The first is pre-combustion, where fuel gets transformed into a mixture of hydrogen and CO2. The two then get separated, which allows for the capture of the CO2. The second way is post-combustion. This allows for the capture of CO2 by separating it using a liquid solvent. The third way is the oxy-fuel combustion process. With this method, fuel is burned with only oxygen, instead of with air (that also contains other gasses). This allows for an easy separation of the CO2 (Durmaz, 2018).

The development of CCS projects has seen rapid growth over the past decades. This is because CCS is seen as a crucial factor in achieving the climate goals (Parry et al., 2022). The first projects were launched in 1971 and since then there has been a massive increase in CCS projects around the world. With this also came an increase in technological advances. The first CCS project was only designed to capture CO2 from a natural gas processing plant. Nowadays, CO2 can be captured from a variety of industries, such as chemical production, cement, ethanol production and many more. The evolution of CCS projects can be divided into two periods. The first period is from 1970-2010. This was a period in which, especially in the United States, the capturing of CO2 was mainly used for getting oil out of the ground, or enhanced oil recovery (EOR). In other places, such as Europe, some countries were already developing CCS projects with the specific aim of using it as a solution for climate change problems. In the second period, from 2010 until the present, CCS became more recognized as earlier projects showed the potential it could have. Therefore, the development of CCS projects experienced a fast growth. This was especially the case since 2017 as it became clear that achieving the Paris Agreement would be difficult without the use of CCS. (Loria & Bright, 2021).

1.2 Research question

The main research question in this paper will be:

What are the most important factors that can determine the outcome of a CCS project?

To answer this research question, the following sub-question will be answered:

1. Why do CCS projects get launched?
2. Who are the driving forces behind CCS projects?
3. Who or what can have an influence on CCS projects?
4. What can be learned from practical examples?

To answer this, a general perspective on CSS projects will first be established. This is to find out why CCS projects happen and who the driving force behind them are.

1.3 relevance

To ensure a future world that is still liveable for everybody it is important to hold ourselves to the set climate goals. The main climate goal, that of the Paris Agreement, is to keep the increase in temperature below 2.0 degrees Celsius above the pre-industrial level, whilst also aiming to keep this below 1.5 degrees Celsius (Horowitz, 2016). As is shown in literature it is already proving difficult to achieve these goals. (Thompson, 2023) Therefore, it is important to not just look at methods that reduce greenhouse gas (GHG) emissions but to also look at methods that can store greenhouse gas emissions. As this can help achieve the climate goals these types of methods cannot be overlooked. The main method of this is carbon capture storage (CCS). CCS captures CO2, which is one of the gasses that belongs to the GHG, and therefore reduces GHG emissions which brings the climate goals a step closer.

When looking at all the scenarios for reaching the climate goals it is noticeable that most of these scenarios show a vital role for CCS. (Peters & Sognnæs, 2019) This underlies the importance of CCS and shows that there is almost no going around it. This is because the decrease in use of fossil energy is simply not going fast enough, which is why CCS is needed as an intermediate step.

CCS has also proven to be a robust and innovative method in reducing CO2 emissions and even in working towards a net-zero future (Majid, 2023). This is shown by the fact that many CCS projects worldwide have already been launched and are successfully working (Loria & Bright, 2021). Also, the Center for Climate and Energy Solutions found that an effective deployment of carbon capture could result in a 14% decrease in GHG by 2050, which is a significant reduction (Ahmad, 2019). Moreover, the Intergovernmental Panel on Climate Change (IPCC) stated in a report that in order to reduce emissions, to achieve the climate goals, carbon capture is unavoidable (Parry et al., 2022). Since all these organizations see CCS as one of the main options to solve climate problems the question arises why CCS is found to be such an attractive method. According to Bui et al. (2018), this is because of the specific advantages CCS has. This, first of all, comes from the fact that CCS is a method that can be integrated into already existing energy systems without having to make major adjustments to the system. This provides a big advantage as most renewable energy technologies cannot be easily integrated into an existing system, and therefore require a new system, which drastically drives up the costs. Also, CCS provides a relatively better option for industries with high emissions, compared to other CO2 solutions. This applies to for example the cement industry, which has high emission levels. CCS can provide a level of emission reduction for this that other solutions simply cannot provide. Lastly, CCS has the ability to be combined with low-carbon or carbon-neutral bioenergy, which can be used to create negative emissions. The difference here is that with carbon neutrality the emissions emitted are balanced out by reducing the same number of emissions. With negative emissions the reduction of emissions is greater than the outputted emissions (Budinis, 2020).

1.4 outline

The remainder of this thesis paper will be structured as follows. In chapter 2, a literature review will be done on the factors that have an influence on the process of CCS projects. In chapter 3 the data that is used, and the methodology that is applied will be discussed. In chapter 4 the results will be presented and interpreted. In chapter 5 there will be a discussion to provide a deeper analysis of the results. In chapter 6 the results will be summarized in a conclusion. Chapter 7 will show the references, and chapter 8 the appendix.

Chapter 2: Literature Review

To provide more information on which factors can have an influence on the outcome of CCS projects, this section will lay out a literature review on the subject CCS projects and their deciding factors. To do this, the current views and information on CCS projects will be summed up and analysed.

The climate goals are there or a reason as the problems that come with climate change are serious. According to some, the world is now even in a state of climate emergency. To prevent the problems that come with climate change a massive reduction in GHG is needed. There are multiple methods and technologies already active or in the making to make this happen. One of the most promising and practical of these is CCS (Gills & Morgan, 2019).

In 2015 the United Nations held a meeting on, among other topics, the future of the energy transition and how to reduce greenhouse gasses. At this meeting, the need to use CCS as a tool to reduce GHG was recognized as many countries had already adopted CCS as a method of reducing CO2. Furthermore, CCS was adopted as one of ten exploration priorities in the so-called strategic energy technology (SET) plan of the European Union (Cozier, 2015). Also, the Intergovernmental Panel on Climate Change (IPCC) stated in a report that to reduce emissions, to achieve the climate goals, carbon capture is unavoidable (IPCC, 2022). This shows that big organizations deem it necessary for CCS to be involved in the plans for the future, as the climate goals can otherwise not be achieved.

2.1 CCS projects in general

For CCS projects to be deployed at the greater scale that is needed it is important to show that this is feasible. This means that it is of significant importance to show how CCS projects can be successful and truly be a solution. For this to happen CCS projects have to be analysed to find out which factors can have an influence on CCS, and which ultimately determine its success.

Before looking at specific factors it is important to create a more general view on the organization of CCS project. This begins with how CCS projects get launched. For this, there has to be a policy in place that allows for the development and deployment of CCS. Meaning that politics can play a crucial role in CCS development. This is for example in the financial part of CCS projects. Many CCS projects do not have enough commercial viability to receive commercial financing. Therefore, these projects rely on governmental funding to be developed. Also, CCS project need multiple permits to be allowed to operate, and political regulations could help smoothen this process. This shows that for CCS projects to be developed at a greater scale the support of politics is needed. (Lipponen et al., 2017).

Romasheva and Ilinova (2019) established a list of topics that need to be considered by countries before launching CCS projects. This starts with the planning of CCS projects. As the climate goals are clear it is important that countries clearly incorporate CCS projects in their climate plans on a national and international scale. Countries, such as Norway, have done this and show vast improvement with CCS implementation. Also, for a CCS project to be launched the financing behind it may be the most important. CCS projects can have remarkably high costs, and as stated it can often be difficult to get these projects commercially financed. It is therefore important to have a clear financing plan. Furthermore, regulations have to be clearly established. Projects having to wait for permits create risks for that project as it creates insecurity. It is therefore needed that countries set up clear legislation considering the deployment of CCS projects. This legislation also has to be flexible as every CCS project can have specific components that may vary. Lastly, creating public awareness and public acceptance can be crucial as many CCS projects have been cancelled because of a negative public view.

These two studies show a basic overview of factors that can have an influence on CCS projects and underline the importance of preparation work in the planning phase of CCS projects. For the remainder of this literature review some of these factors will be more broadly discussed and emphasized. Also new factors will be introduced.

2.2 CCS stakeholders

As CCS projects are large projects there is often a variety of stakeholders that all have different specific needs for the project. For CCS projects to run smoothly cooperation between stakeholders is needed. For this it is important to start with identifying the stakeholders. Chrysostomidis et al. (2013) studied who the specific stakeholders are, what they want and how they can be managed. An overview of who the stakeholders are and what their specific needs are is given below:

- **General public**: the general public wants a secure project development and beneficial development of the region. This stakeholder is very important as it can have a substantial influence on the project's result and can thus be decisive in failing or succeeding. Sometimes the distinction gets made between the general public and the local public. These are practically the same except for the fact that the local public lives close to the CCS site, and therefore has a higher expectation of safety.
- **Policymakers**: These can be at the state level and the regional level. At the state level, they want to develop the country and reduce emissions to achieve the Climate Accords. At the regional level it is more about regional development, the acceptance of the project by the public and that the projects are secure.
- **Investors:** Investors want the CCS project to be a sustainable and socially responsible investment.

- **Industry:** The industry focuses on having the CCS development be a successful and effective project that stays within budget.
- **Technology suppliers:** This stakeholder wants money for its technology and for it to become more known to the public. This stakeholder can therefore have a big impact on the costs.
- **Non-governmental organizations:** This stakeholder focuses on the project being safe for the environment, the ecosystems and the (local) communities.
- **Controlling organizations/ regulators:** Making sure the project is properly running. They want access to information and to make sure everything is in accordance with the law.
- **Media:** They want transparency of information about the project. This stakeholder can have a big influence on the public opinion.
- **Project teams:** these are the people specifically working on making the project happen. They want good working conditions and can have a substantial influence on the success of the project.
- **Contractors and suppliers:** manage the contracts that are needed for the project and can, for example, have an influence on time management costs.

it could be argued that a CCS project is more a local project and should therefore have a more limited set of stakeholders. However, even though the deployment of these projects is local, the organization of it is more often from a national or even international context. This is because the CCS projects are in the worldwide interest of achieving the climate goals. There is a wide list of stakeholders described, but for each specific CCS project the list will most likely vary a bit. This could be because smaller projects will probably have fewer stakeholders, and vice versa for bigger projects. Also, as can be noticed, there are many stakeholders involved in a CCS project. Some more or less have the same interests, but some also have interests that may conflict with each other. For a CCS project to be developed as effectively as possible it is important to address these conflicts between stakeholders. In this, the key will often be in clear and open communication and information. It is therefore important that before a CCS project gets developed, a proper strategy for stakeholder management gets formulated (Ilinova et al, 2018).

2.3 examples from CCS projects

One would think that CCS projects have a lot of benefits and should therefore be quickly scaled up. Yet many CCS projects fail before they can be developed. By looking at examples from already launched CCS projects the reasons for this can be found and analysed.

First of all, it is important to understand why the failing (and success) factors of CCS projects should be identified. This can be explained by the amount of money that goes to waste when a project fails. CCS projects often require cooperation of many parties, proper legislation and have high costs of technology, infrastructure etc. This all causes these projects to be very expensive. Another concept of lost money is in the form of stranded CO2. This is the CO2 that was expected to be captured in a projected, but ultimately did not capture because the project was not as effective as possible, or even did not work at all. To minimize these costs of CCS projects it is important to identify the reasons projects fail, to avoid making the same mistakes. Identifying the success factors is also important to understand what is going right and why (Middleton & Yaw, 2018).

2.3.1 Basics of CCS projects

To start with a more general example, Thronicker and Lange (2015) analysed data from successful and unsuccessful CCS projects across the globe. Some of the main results from this were that the quality of work in the planning period has a significant positive effect on the project's success. An example of this is that many (failed) projects did not identify a proper CO2 storage site during the planning phase. This meant that investments had already been made even though an actual place to store the CO2 was not there yet. Another interesting result was the fact that public funding of CCS projects had a negative effect on the chance of success. The reason for this mainly comes from the fact that private businesses found the CCS project too risky or not worth it to invest in. Therefore the only way to develop the project was by public funding. Yet these projects often proved to be too risky in the end and failed. Also, projects that used CCS technology methods that are more often applied in the industry had a higher chance of success.

2.3.2 CCS project of the Netherlands

To look at more specific examples of failing CCS projects, the Netherlands can be analysed. In total, there have been plans for three CCS projects in the Netherlands, of which two were onshore and one offshore. The reason for these projects failing seems to lie in problems with social resistance, politics and funding. To look at it more specifically, the CCS project for Barendrecht was accepted by the government and had enough funding. Yet the project eventually failed because not enough effort was put into creating public acceptance. This was because the public had concerns about safety issues and negative impacts on the environment and people's health (Ashworth et al., 2012). Another CCS project in the Netherlands (the Northern Netherlands CCS initiative) was also cancelled. Social resistance played a role in this case as well, but at the same time, a lack of organization, a governance framework and a clear division of responsibilities and tasks also caused a big problem (Van Os et al., 2014). The third CCS project in the Netherlands was the ROAD project, which was a very promising project and at the time even one of the leading CCS projects in Europe. The project had some impressive success but was ultimately still cancelled. This time the reasons again had to do with a lack of both public and political acceptance, and a proper business case was missing (Read & Kombrink, 2018).

It seems that even though the failing reasons for the different projects somewhat vary they also have a lot in common, especially with regards to the lack of public acceptance. The public as a stakeholder therefore appears to be very decisive in the success of a CCS project. At the same time, the mentioned examples are only about the Netherlands which might influence the result. This is because the

Netherlands is a very densely populated country, and therefore the operating area of the CCS project is often close to people, which more easily leads to public resistance (Akerboom et al., 2021).

2.3.3 CCS project in the U.S.

Another study on determining factors of CCS projects was done by Abdulla et al. (2020). They analysed project attributes to figure out which were the most important in determining the outcome. This was done by analysing data from existing CCS projects in the US that have succeeded and failed via linear regression, a random forest model and by using input from experts. Combining this information led to three factors being the most important. The first is the capital cost of the project. This makes sense as more expensive projects rely on more financing which makes them riskier and more prone to failure. The second factor is the level of technological readiness. When projects make use of innovative CCS technologies there is a higher chance of failure. Instead, it is better to use CCS technologies that have already been used on a big scale, as this reduces risks and increases the chances of success. The third factor is the credibility of revenues from the project. This means that projects that have a higher credibility of revenues also have a higher chance of succeeding. There were also factors, such as the increase in local employment a CCS project would provide, that had mixed results. This factor would prove important in the random forest model, yet experts gave it the lowest ranking of importance. Moreover, the linear regression model found that this factor had a negative impact on the success of a project. This seems strange as this means that the increase in job availability gives the project a lower chance of succeeding. The reason for this is that CCS projects that aim to have a positive impact on local economies, through a big increase in job availability, are the same projects that have high capital costs. As earlier stated, this leads to a higher chance of failure. This example shows how the individual factors can also have an intertwining effect.

2.3.4 general lesson from the past

Loria and Bright (2021) looked at the past 50 years of CSS and discussed with businesses who have been in the field for a long time. With this information they analysed what was most important for CCS projects. Among the more important were for example efficiency and innovation of the whole project, which can greatly reduce costs (and thereby risks). Also, security and safety of the project was also of great significance. This can be about the storage of the CO_2, but also about risks to the public. Lastly, the importance of stakeholder engagement along with transparency was also emphasized.

2.4 The pubic as a stakeholder

In the literature the role of the public is often highlighted. This stakeholder seems to have a big influence on CCS projects and therefore needs to be further studied. For now research states that the public opinion on CCS is controversial, and often more negative than positive. Simultaneously the public awareness also appears to be very low (Vasilev, 2019).

Whitmarsh et al. (2019) studied the public views and awareness on CCS. They stated that if the public is against the CCS projects or just not supportive then the project can become inacceptable at a social dimension. Therefore serious effort should be put into achieving public acceptance. Yet this acceptance is difficult to achieve. The reason is because people are worried about the risks of CCS. For example, leakages could seriously harm the environment and the health of people. Also, framing seems to further create a negative view on the opinion of CCS. This is because the way information about CCS is displayed can more easily be interpreted negatively. Yet this is mostly the case with people that already viewed CCS negatively, who are then more inclined to interpret general information on CCS negatively as well. Especially when the CCS projects are very locally developed there is a big change of local public defiance. Because even though a lot of people might understand the global benefit of CCS, it does not outweigh the possible local downside of CCS risks for them. It is also found that people who live closer to potential sites for CCS have a lower acceptance rate of CCS, compared to those who live further away (Braun, 2017).

As public acceptance can play an important role in the success of CCS projects it is important to engage with the public to create this acceptance. Dunphy et al. (2022) studied how this can best be done. One of the things they underlined is that the goal in this should not just be to get CCS projects accepted by the public, but to create acceptability for the projects. This means that the public does not just accept the decision of a CCS project but has a say in the process of decisions regarding CCS deployment. To properly do this some guidelines were created that can help with this. These guidelines come down to clear communication, transparency, building trust and being honest. Examples of this are to engage with the public at an early stage. Which means to have communication with the (local) public before the major decisions of the CCS projects are made. This creates a more transparent communication with more trust. The way of communication is also important, as the study showed that having only a formal form of communication is not optimal. When having both a formal and informal way of communicating the public tends to have more trust. Furthermore, high quality information is important, and all the information should be put into the right broader context. This means to make it clear that CCS technologies do not undermine the development of renewable technologies, but are needed to bridge the gap.

Xenias and Whitmarsh (2018) also studied public acceptance in relation to CCS deployment. They found that public acceptance was again very important, ranking it third in importance after financial funding and policy. Important influences for creating public acceptance here were, among others, explaining the urgency and need of CCS deployment, providing clear information, political trust and early engagement. Experts also rated the 'fairness' for the public in decision making high, which relates to the earlier mentioned 'acceptability' of CCS projects for the public. Furthermore, Leiss and Larkin (2019) highlight the need for a public engagement strategy that starts at an early stage in the process. In this strategy the information to the public is of significance importance with the emphasis on credible, understandable, clear and on time information.

It appears that trust is a key element for the public, which makes sense. It seems that simply building trust is also more important in creating public acceptance than increasing public awareness. A study done by Terwel et al., (2011) showed that a more positive view of the public appears is also more likely to come from the trust in other stakeholders. Examples for this are that people tend to trust an NGO as a stakeholder more than the industry as a stakeholder. Public trust is also created when other stakeholders appear competent and 'stay in their own lane.' This means that the public trusts it more when the NGO discusses environmental topics, and the industry discusses economic topics than vice versa. Furthermore, there is more public trust when the people have confidence in the politicians who are making the plans.

2.5 Literature review conclusion

In this literature review all the components of CCS projects that can determine its outcome have been described and analysed. For this, it seems that many individual parts play a role in CCS projects to be successful. Also, since every CCS project has its own specific characteristics some methods that work for one project may not work for another project. Yet the basic guidelines for most projects are the same.

This starts with having a solid foundation for the project. Factors such as a detailed planning, a correct business case and practical matters, for example where the CO2 will be stored, have to be properly managed. Also, insights from experts and statistical models showed that capital costs, technical readiness and revenue incentives are some of the more important factors. Furthermore, stakeholders appear to be determining in a project's outcome. Of these, the general public seems to be especially important as it is a stakeholder that can have a strong view against the projects. In the US study, this stakeholder appeared less important, but it could be argued that this is due to the fact that the US is much less densely populated than for example Europe. The projects in the US could then more easily be planned further away from the public. And as earlier established, people who live further away from a project have a higher chance of acceptance towards the project. in order to gain public acceptance the key lies in gaining public trust rather than improving public awareness. Lastly, for CCS projects to succeed it is also important to have clear communication and transparency with stakeholders.

Chapter 3 Data and methodology

This paper aims to study what the most important factors are that can determine the outcome of a CCS project. To do this, an analysis will be done in Stata with data from CCS projects that have succeeded and failed. In his chapter the corresponding data and methodology will be outlined. This starts with information about the data sources and the data itself. After this all the steps to perform the analysis will be explained and robustness checks will be covered.

3.1 Data sources

In this thesis data from 3 sources is used:

1. The main source is data from the International Energy agency (IEA). This dataset contains data from all the CO2 capture, transport, storage and utilization projects that are already commissioned or in planning. It contains information on CCS projects from the 1970s until the present, such as the region the project is in, the sector it relates to and there is data on the capacity of million tonnes of CO2 that the specific project can process per year.
2. Another data source is from the MIT CCS program. This dataset has information on failed/cancelled CCS project worldwide including capturing capability, costs, reason of cancellation, region the project is located in and more. Even though this data source has been frozen since 2016, this dataset provided the best available data on cancelled CCS projects and was therefore best usable.
3. The third data source that was used is from the University of Edinburgh. This was a database that contained basic data from all CCS projects worldwide such as costs, type of separation, whether the project had public funding etc. this dataset was mainly used as an additional dataset to the IEA dataset to provide more information on for example project costs, which the IEA dataset did not have.

With all this data one combined dataset could be created that had information on variables for successful projects and failed projects. By comparing the two, the most important factors can be determined. The full datasets consists of the following variables:

- **Projects status**: This is whether the CCS projects is operational or cancelled.
- **Capacity**: This is information on the amount of CO2 that a project can capture. This variable is in million of tonnes CO2 per year.
- **Sector**: This about the sector the CCS project relates to. This can be Power & heat, natural gas processing/LNG, biofuels, hydrogen/ ammonia, other fuel transformations, cement, iron & steel, chemicals, other industry, direct air capture, transport, storage or transport & storage.

- **Region**: This is about the region where the CCS projects is located.
- **Costs**: This is about the costs of the CCS project. This variable is in millions of dollars.
- **Public funding**: This is about whether the project received public funding or not.
- **Reason**: This is about the reason for which a CCS project is cancelled. This variable is modified to be a categorical variable. This way a clearer picture can be created on the overlapping reason of why CCS project fail. The categories are Planning, Financing, legislation, uncertainty and public opposition.

An important remark to make is that the reason for failure was given as the main reason why a project failed. This means that sometimes projects were cancelled because of a combination of reasons. For example if a project had both financing and planning issues. In these instances the most important or dominant reason for cancellation was always used. Another example for this is that there are only three reported cancellations because of public opposition. All three of these originate from the Netherlands as public opposition there has particularly been a big problem. However, in those cases sometimes legislation and financing were also mentioned as failing reasons, but public opposition was the most dominant one. This also does not mean that public opposition is only a problem in the Netherlands. In Germany and Romania for example public opposition has also been mentioned as hurdles for the CCS project. Yet the main problem was ultimately financing issues or poor planning for example.

As stated, the final dataset is a combination of three datasets. This was done in two steps. First of all, the IEA dataset was trimmed down to only the relevant data on operational CCS projects. The reason is that the other projects are for example planned or under construction and can therefore not yet provide useful information on succeeding or failing factors. After this there was data for the successful projects, but data on failed projects was also needed. Therefore, the second step included gathering data on failed projects and adding them to the dataset. The MIT database provided the needed data for this. This data was not always complete and therefore the database of the University of Edinburgh was used to make the data complete. With all of this, data on the said variables could be acquired to do an analysis. In some cases specific data for variables such as costs, public funding or reason is missing because this information is not publicly disclosed, This was especially the case for some projects located in China. However, since those observations had relevant data for the other variables they were still included.

3.2 Descriptive statistics

Before the analysis it is useful to lay out some descriptive statistics of the data. These are given in table 3.2.1

Table 3.2.1: Descriptive statistics

Variable	Obs.	Mean	S.D.	min	max	Least frequent	Most frequent
Project status	81	N.A.	N.A.	N.A.	N.A.	Cancelled (44%)	Operational(56%)
Costs	54	2363.64	5209.34	8	38000	N.A.	N.A.
Capacity	80	1.79	2.26	0.00	14.6	N.A	N.A.
Region	81	N.A.	N.A.	N.A.	N.A.	Central and South America	North America
Public funding	75	N.A.	N.A.	N.A.	N.A.	No (37%)	Yes (63%)
Reason	34	N.A.	N.A.	N.A.	N.A.	Legislation (6%)	Financing (41%)
Sector	81	N.A.	N.A.	N.A.	N.A.	Transport (1%)	Power and heat (33%)

Note: costs is in millions of dollars. Numbers are rounded to two decimals.

From the table it shows that there is a total of 81 observations of which 45 are currently operational and 36 have been cancelled. This is the biggest dataset that could be acquired as there are not more CCS projects that have the data available that is needed. The table also shows some variations in number of observations per variable. As earlier stated, the reason is that for some observations specific information was not available. Notable is that the "reason" variable has low observations because this variable could only have values for the failed projects.

3.3 Imputed data

Since in the dataset there is a considerable amount of missing values this will have an impact on the results. An example of this is that every analysis including the costs will already be limited to 54 observations. This decrease in an already limited set of observations has a negative effect on the analysis as it reduces the power in the analysis, making it more difficult to achieve significant results. A solution to this is to impute results. This means that in STATA the missing values get filled in to get the best amount of observations possible. In this case multiple imputation (instead of single imputation) has been applied as it can better handle the uncertainty and variation in the model. This is done by creating multiple versions of the original dataset, analysing this and combining this into the best results. In the analysis, results with and without the imputations will be showed.

For the imputations the rule is to impute 10% of the missing values. Therefore, in this case 33 imputations have been performed. Also some assumptions have been checked. The first assumption was to make sure that the missing values were missing at random (MAR). For the second assumption convergence diagnostics have been checked. For the third assumption distributions between the imputed observations and original observations have been checked. All results showed that the imputations were performed correctly.

3.4 Hypotheses

To analyse the data a number of hypotheses will be tested. Since hypothesis 1 and 2 have a similar approach they will be discussed together here.

In the literature it was found that public funding was related to CCS projects being cancelled. Since in the dataset data on this is available, this can be tested. Therefore the first hypothesis is:

Hypothesis 1: *CCS projects that have received public funding are more likely to be cancelled.*

The literature also frequently stated that the (capital) costs of CCS projects play a big role in in whether the project gets cancelled or not. Therefore the second hypothesis is:

Hypothesis 2: *CCS projects that have higher costs are more likely to be cancelled.*

To test these hypotheses a logistical regression test will be performed. This is the most suiting test as the dependent variable is binary, for the project being 'Operational' or 'cancelled.' The test will be performed for both the public funding and the costs separately, as well as together with the capacity included as a control variable. There will be two output tables, for which one has the results of the original data, and one has the results with the imputed data.

In the literature the location of a project also seemed to have an effect on the reason why it was cancelled. Such that for example public opposition did not seem to be a big problem in the U.S., but in more densely populated countries as the Netherlands it did seem to be a big reason for cancellation. Therefore the third hypothesis is as follows:

Hypothesis 3: *the reason why a project is cancelled is correlated with the region the project is located in.*

To test this there will first be an overview of how much every reason for cancellation occurs. After this a Cramer V statistical test will be performed to test whether an association can be found between why a project has failed and the region the project is located in. After this, a Fisher's exact test will be performed to further analyse the found association. This is here the most appropriate test as there is only a small sample size available. For theoretical purpose, a chi-square test will also be performed to test the association with the imputed values. Because of the imputation the sample size increased making the chi-square test more appropriate in this case. The results section will elaborate on this.

3.5 Robustness

The main model used in the analysis is a logistic regression model. This is the most appropriate method as in this case the dependent variable (project status) is binary. Meaning that the outcome is either 'Yes' or 'no,' or in this case 'operational' or 'cancelled'. To ensure the validity of this model a number of tests have been performed both for the original and the imputed data. Also, the robustness of the tests for the third hypothesis will be discussed.

3.5.1 Multicollinearity

Multicollinearity means that there is a correlation between at least two of the independent variables. This is a problem as it leads to unreliable and unstable results. To handle this a variance inflation factor (VIF) test will be performed. This test can only be performed on continuous and binary variables, and therefore the categorical variables will be excluded. This is shown in table 3.5.1

Table 3.5.1 VIF values.

variable	VIF (1)	VIF (2)
Capacity	1.32	1.09
Costs	1.34	1.08
Public funding	1.02	1.05

Note: VIF (1) is for the original data and VIF (2) is for the imputed data.

For a robust model VIF estimates need to be under 5, otherwise correlation is too high. As shown in the table all results for both models are well below 5, and therefore there is low correlation. This means that correlation will not cause a problem in the model.

3.5.2 Area Under the Curve (AUC)

To check the performance of the model it is useful to check the area under the curve (AUC). This establishes how well the model can separate between classes. In this case it can establish how well the model can separate the outcomes of successful and cancelled. A perfect model has an AUC value of 1 and a bad model has an AUC of 0. The AUC values are given in the table below:

Table 3.5.2: AUC values

Model	AUC
(1)	0.52
(2)	0.88

Note: model 1 is the original data and model 2 is the imputed data.

As shown in table 3.3 the AUC value in the original model is 0.52, which is considered poor. For reference, when the AUC is below 0.7 the model is considered to be limited and there is a bigger chance that the data is unreliable. This is because an AUC of 0.52 indicates that it is difficult for the model to establish whether something is true or whether it is due to random chance. The AUC value in the imputed model is 0.88 which is considered good-excellent. This indicates that the results of the model with imputed observations has a higher chance of being reliable.

3.5.3 Association tests

For the third hypothesis a Cramer V test, a Fisher's exact test and a chi-square test are performed. These tests do not have specific validity tests that can be checked for. However, there are some assumptions that have been checked. For example, the Fisher's exact test is best for a small sample size and the chi-square test is best for a bigger sample size. The tests have therefore been used accordingly. The only other assumption is that of independence, which means that all the observations should be independent of each other. This has also been checked for.

Chapter 4 Results

In this section the results of the analysed data will be presented. Hypotheses1 and 2 will first be analysed and discussed. After this the results for hypothesis 3 will be discussed. The results will be shortly interpreted here. A deeper analysis and interpretation will be provided in the discussion section in chapter 5.

4.1 Logistic regression

To test the first two hypotheses a logistic regression was performed. The first hypothesis was: *Public funding has a negative effect on the outcome of CCS projects*. The second hypothesis was: *CCS projects that have higher costs are more likely to be cancelled*. The regression results are shown in table 4.1.1

Table 4.1.1 : logistic regression on the effect of public funding on project outcome

Variable	**Project outcome (1)**	**Project outcome (2)**	**Project outcome (3)**	**Project outcome (4)**
Public funding	-1.04**			-0.89
	(0.51)			(0.63)
Capacity		-0.13		0.01
		(0.17)		(0.14)
Costs			0.35	0.24
			(0.40)	(0.53)
Constant	0.92**	0.49	-0.31	0.42
	(0.42)	(0.34)	(0.30)	(0.59)
Observations	75	80	54	51

Note: standard errors in parentheses. *p<0.1 **p<0.05 ***p<0.01. Rounded to two decimals.

As visible in the first logistic regression public funding has a significant negative effect on the outcome of the project. This means that when a project has public funding the chances of it being successful decreases. To get a better estimation of the public funding coefficient it is important to control for other variables. This is shown in the fourth logistic regression, where capacity and costs are used as control variables. The coefficient of public funding is still negative, but the negative effect has decreased a bit. Unfortunately in the fourth regression this effect is not significant. This likely has to do with the reduced observations in the fourth regressions compared to the first. Because capacity and costs, which had some missing values, where added as control variables the total observations reduced, lowering the statistical power of the regression.

When looking at the costs variable it is visible that the coefficient is not significant in the third and fourth logistic regression. The results of this can therefore not be interpreted. The most probable reason for this is the fact that the costs variable has substantial less observation than public funding for example. Because of this the observations for public funding had to be decreased to the same level as costs in the fourth regression. Resulting in public funding being significant in the first logistic regression, and not significant in the fourth regression.

To check for this an earlier mentioned method of multiple imputation (MI) has been applied. this fills out the missing values, maintaining the maximum possible observations. The results of this are shown in table 4.1.2

Table 4.1.2: logistic regression on the effect of public funding on project outcome with MI estimates.

Variable	**Project outcome (1)**	**Project outcome (2)**	**Project outcome (3)**	**Project outcome (4)**
Public funding	-1.00**			-1.04**
	(0.51)			(0.53)
Capacity		-0.13		-0.18
		(0.11)		(0.28)
Costs			0.12	0.34
			(0.61)	(0.82)
Constant	0.88**	0.46	0.19	1.15**
	(0.42)	(0.30)	(0.26)	(0.58)
Observations	81	81	81	81
Imputations	33	33	33	33

Note: standard errors in parentheses. *p<0.1 **p<0.05 ***p<0.01. Rounded to two decimals.

The results show that with the increase of observations, because of the multiple imputation, public funding now has significant results in both logistic regressions 1 and 4. This means that public funding does indeed cause a higher chance of project cancellation. Therefore, the first hypothesis that stated: *Public funding has a negative effect on the outcome of CCS projects* is supported by the data.

When looking at the costs variable it can be seen that even with multiple imputation the results remain not significant. Therefore, the second hypothesis that stated: *CCS projects that have higher costs are more likely to fail* cannot be supported with the data.

4.2 Association analysis

To analyse the third hypothesis some more steps have to be taken. Hypothesis 3 was: *The reason why a project is cancelled is correlated with the region the project is located in.* To start, it is first interesting to look better at the descriptive statistics of why projects get cancelled. This is shown in table 4.2.1

Table 4.2.1: Frequency table of reasons why CCS projects fail.

reason	**frequency**	**percentage**
Financing	14	41,18%
Planning	10	29,41%
Uncertainty	5	14,71%
Public opposition	3	8,82%
Legislation	2	5,88%
total	**34**	**100%**

As visible, financing appears to be the most common reason for CCS projects to fail with 14 cases. Closely after this is planning as a reason for failure with 10 cases. This is not unexpected as from the literature it was found that high costs and poor planning are in the top reasons for projects to fail.

To further test hypothesis 3 it is important to find out whether there is an association between the reason why a project has failed and the region the project is located in. To do this the Cramer V statistic is calculated. A Cramer V of 1 means that there is perfect association between the variables, and Cramer V of 0 means that there is no association. In this case, the Cramer V statistic was equal to 0.93. this means that there is a strong association between the reason why a project is cancelled and the region the project is located in. In other words, specific reasons of project cancellation seem to occur more in certain regions, indicating a connection.

Now that the fact that there is a connection has been established, further tests can be performed. For this a Fisher's exact test is performed to examine whether there is a significant association between the reason why a project has failed and the region it is located in. The output is given in table 4.2.2

Table 4.2.2: output of Fisher's exact test

Reason	Region				
	Australia	Europe	Middle East	North America	**Total**
Financing	0	5	0	9	14
Legislation	0	2	0	0	2
Planning	1	3	1	5	10
Public opposition	0	3	0	0	3
Uncertainty	1	2	0	2	5
Total	2	15	1	16	34

Note P-value is 0.22. corresponding significance is *p<0.1 **p<0.05 ***p<0.01

What can be seen in table 4.2.2 is that the p-value of the test is 0.22, and therefore not significant. In relation to earlier findings this likely has to do with low observations, which results in low statistical power. In this case the problem does not lie in missing values, but more so in the fact that the available data on cancelled projects is limited to 34 observations. For this reason, the multiple imputation method has been applied again and is shown in table 8.1 in the appendix. The results are more or less the same apart from the fact that the p-value is now <0.01 and therefore significant. However, a downside from multiple imputation is that the method is designed to control for missing variables. In his case there are no missing variables so it is not the most appropriate method to use. It is however the only method that could be used considering that there was no other way of getting more observations. Therefore the results of the multiple imputation here are very limited and are purely shown to underline that a bigger sample size could likely make the original results significant. For this reason an interpretation of table 4.2.2 will still be given, even though the results are not significant.

The Fisher's exact test shows the proportions of the specific reason why a CCS project is cancelled in relation to the region where the project is located. Because of low observations it is not possible to draw conclusions for the regions of Australia and the Middle East. However, by looking at the table, differences between regions of Europe and North America can be seen. This difference is mainly that the reasons why projects in Europe fail seems to be a variation of all reasons. At the same time, the reasons why projects in Nort America fail seems to consistently not have to do with legislation or public opposition. This would indicate that in North America the legislations, such as getting permits might be easier than in Europe. Also Public opposition seems to be less of a problem in North America, compared to Europe.

Hypothesis 3 was: *The reason why a project is cancelled is correlated with the region the project is located in.* Although the results of the tests seem to support this hypothesis, the current data cannot provide significant results and the imputed data is very limited and can, because of this, not be used as valid significant result. Therefore the third hypothesis is not supported by the data.

Chapter 5: Discussion

The results have been laid out in the previous section and although some make sense, some also, on an intuitive basis, do not make sense. Therefore, in this section the results that require further interpretation will be discussed.

5.1 Public funding

For the first result it was found that public funding has a negative effect on the outcome of a CCS project. This is interesting as this does not directly make sense. To analyse this a broader perspective is needed. To begin with the fact that funding for CCS projects is difficult to achieve mainly because of the fact that CCS projects do not create revenue. This is because these projects do not produce a specific product to sell. Therefore, the costs of CCS projects have to be outweighed by the value put on the climate mitigation effect of the project. Since there is no revenue in CCS it become more difficult to get private funding Moreover, the CCS projects often also come with risks which further reduces the chances of private funding. Because of this public funding is often needed instead of or as an addition to private funding. But this does not yet explain why public funding would then have a negative effect on the project outcome.

One reason for this may lie in the research of Thronicker and Lange (2015) which has been discussed earlier in chapter 2.3.1 in the literature section. They also found a negative effect of public funding. They argued that this might be because public funding frequently goes to projects that the private sector deemed to risky to invest in. This would mean that public funding would consistently go to projects that are riskier. Logically, since these projects are already riskier, there is a higher chance that they will fail, which would support the negative effect of public funding. Although the argument from Thronicker and Lange makes sense it could be argued that it is not the complete explanation. This is as public parties carefully select which projects to give funding to. This means that it is not logical that projects with high risks consistently get selected for public funding. Because of this I would argue that the effect of public funding should be interpreted differently. From reasoning it follows that the projects that needed and received public funding are most likely bigger projects with great potential, but which also have higher costs, more stakeholders and more complexity etc. therefore it is likely that all those projects that received public funding did not fail because of the public funding, but because of one (or more) of the other risk factors associated with the project. This means that it is not that the public funding had a negative effect on public outcome, the public funding simply could not compensate enough for the negative effect of the already riskier projects.

In other words, public funding comes out in the regression as if it has a negative effect because of omitted variable bias. This means that one or more variables that are correlated with both the dependent variable and one or more of the independent variables are not included in the model. In this case this could mean that variables such as the level of uncertainty or the effect of having many stakeholders would have a negative effect if included in the model. In reality this is also likely the case. However since data of these variables is very difficult to measure and unavailable they are left out, causing the model to shift their effect to available variables, which is in this case to public funding.

5.2 costs

The results of the costs variable could not be interpreted because they were not significant. Some remarks regarding the analysis for costs in future research can still be made. From literature it was found that costs can be a major reason for CCS projects not to succeed. This is also clearly visible form the data of failed CCS projects in table 4.2.1 where financing is the main reason why projects fail.

To run a proper analysis of the influence of costs on a CCS projects outcome there is a need for additional and better data. This would mean that more observations are needed. But acquiring additional data on other influencing factors is also a must to avoid omitted variable bias. With an increase in the sample size and the proper control variables an appropriate analysis on the effect of costs can be performed. Another step could be to have a better specification of the costs of CCS projects. Which means to have precise data on costs for different components of a CCS projects. With that data the most expensive parts of a CCS project can be analysed, which can be used to better determine what the failing factors for costs are.

5.3 region

As the association analysis was not significant it could not be established that there is a valid correlation between the region a CCS project is located in and the reason why the projects was cancelled. However, logical reasoning and multiple imputation showed that with a bigger sample size it is likely to get significant results. These result can be very useful as quality data on the correlation between reason of failure and region location can be helpful in the planning stages of a CS project.

From the results of table 4.2.2 it was found that the biggest difference between Europe and North America was that the reason why projects in Europe fail seems to be a variation of all reasons. At the same time, the reasons why projects in Nort America fail seems to consistently not have to do with legislation or public opposition. Such a finding can be very valuable for the future planning of CCS projects. The difference of public opposition was already noted in the literature section and now it appears to also be true in practice. The main reason for the difference is most likely the fact that Europe is much more densely populated than North America, and therefore there is a higher chance of public opposition. This should be considered for future projects to avoid the repeating of mistakes with public opposition. One example for this is the Netherlands were there was a lot of public resistance. For this reason they decided to build a CCS project offshore, reducing the chances of public resistance.

The finding that Nort American projects seem to not have problems with legislation is also interesting. This would indicate that the laws and regulation around CCS projects is different for the various regions, and that permits, permissions etc. are easier to get in North America than in other regions. This is especially interesting when looking at the need for global policy of CCS projects. As CCS is a potential solution for achieving the climate goals it is in global interest to have an optimal planning policy for this to have CCS projects located as much as possible in regions where chances of failure are lower.

5.4 Limitations and future research

It is noticeable that for most of the analyses additional data is needed to get significant and valid results. One part of this is due to the sample size. Because the number of CCS projects that are successfully operating or that have failed is limited, the sample size will also be limited. Another part is because of the lack of available data. A lot of data that could be interesting is not available to the public, or not available at all. An example of this is that from literature public opposition and uncertainty were found to be major reasons as to why CCS projects fail. Yet the data to analyse this is not available to test to which extent this applies in practice. It will also be difficult to establish how this data should be measured. In theory it is possible to estimate values for public opposition and uncertainty, but in reality the outcome of this will be very subjective. Because of this now, and in the future, it will be difficult to perform an analysis on the deciding factors of CCS projects that truly shows valid results.

For future research I would recommend establishing a working framework before doing an analysis. This framework would outline all the factors that can be of influence and show how they are measured. For this an extensive data collection would also have to take place to get the needed data to support a theoretical framework. After this an analysis can be performed to show the most important factors that can decide a CCS projects outcome.

Chapter 6: conclusion:

The research in this paper was done to assess the following research question: *What are the most important factors that can determine the outcome of a CCS project?* To do this a literature review was done, and an analysis based on data of failed and succeeded CCS projects was performed.

The literature review mainly showed that there are many factors that can influence the success of a CCS project. However, the most important one is about the general planning of the project. Having a detailed planning which includes a proper business case and takes care of all practical matters is a must for CCS projects to be successful. With this risk factors such as the costs or the technical readiness should be taken care of. Furthermore, stakeholders seem to be very important. A project involves many different stakeholders and it is thus important to have a quality stakeholder engagement with clear communication and transparency to ensure that the project runs smoothly. Especially the general public appears to be an important stakeholder. To avoid problems with this stakeholder it is more important to create public trust in the project than public awareness.

In the analysis a logistic regression and an association analysis was performed on available data of observations of failed and succeeded CCS projects. The influences of public funding, costs and the region the projects are located in were tested. And the capacity value was used as a control variable. It was found that public funding has a negative effect on a project's outcome. However, as stated in the discussion section, This should most likely be a positive effect, but comes out as negative because of omitted variable bias. the results of the costs variable were not significant, likely due to a limited sample size, and therefore not interpretable. The outcome of the association analysis showed the potential relation between the failing reason and the region a CCS project is located in. The results of the association analysis were that the reason why projects in Europe fail seems to be a variation of all reasons. While the reasons why projects in Nort America fail seems to consistently not have to do with legislation or public opposition. This brings to light how CCS planning differs between continents, and maybe even countries. It is also a basis for a debate on whether the planning of CCS projects should be done more worldwide considering the climate change being a global problem.

Chapter 7: References

Abdulla, A., Hanna, R., Schell, K. R., Babacan, O., & Victor, D. G. (2020). Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments. Environmental Research Letters, 16(1), 014036. https://doi.org/10.1088/1748-9326/abd19e

Ahmad, F. (2019) Strengthening international collaboration on carbon capture use and storage. Center for climate and energy solutions. https://www.c2es.org/wp-content/uploads/2019/03/strengthening-international-action-ccus.pdf

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. https://doi.org/10.3389/fenrg.2021.644796

Ashworth, P., Bradbury, J., Wade, S., Feenstra, C. Y., Greenberg, S., Hund, G., & Mikunda, T. (2012). What's in store: Lessons from implementing CCS. International Journal Of Greenhouse Gas Control, 9, 402–409. https://doi.org/10.1016/j.ijggc.2012.04.012

Braun, C. (2017). Not in My Backyard: CCS Sites and Public Perception of CCS. Risk Analysis, 37(12), 2264–2275. https://doi.org/10.1111/risa.12793

Budinis, S. (2020). Going carbon negative: What are the technology options? International energy agency. https://www.iea.org/commentaries/going-carbon-negative-what-are-the-technology-options

Bui, M., Adjiman, C. S., Bardow, A., Anthony, E. J., Boston, A., Brown, S., Fennell, P. S., Fuss, S., Galindo, A., Hackett, L. A., Hallett, J. P., Herzog, H. J., Jackson, G., Kemper, J., Krevor, S., Maitland, G. C., Matuszewski, M., Metcalfe, I. S., Petit, C., . . . Mac Dowell, N. (2018). Carbon capture and storage (CCS): the way forward. https://doi.org/10.1039/c7ee02342a

Čavčić, M. (2023). What's happening with Netherlands' first large-scale carbon transport and storage project in North Sea? Offshore Energy. https://www.offshore-energy.biz/whats-happening-with-netherlands-first-large-scale-carbon-transport-and-storage-project-in-north-sea/

Chrysostomidis, L., Perumalpillai, S., Bohm, M., Crombie, M., Beynon, E., Lee, A. (2013) CO2 capture project's CCS stakeholder Issues Review and Analysis. *Energy Procedia* 37 (2013) 7832 – 7839. doi: 10.1016/j.egypro.2013.06.676

Cozier, M. (2015). The UN COP21 Climate Change Conference and the role of CCS. Greenhouse Gases, 5(6), 697–700. https://doi.org/10.1002/ghg.1577

Duetschke, E., Schumann, D., Pietzner, K., Wohlfarth, K., & Höller, S. (2014). Does it Make a Difference to the Public Where CO2 Comes from and Where it is Stored? Energy Procedia, 63, 6999–7010. https://doi.org/10.1016/j.egypro.2014.11.733

Dunphy, N., Velasco-Herrejón, P., Lennon, B., & Smith, A. L. (2022). Engaging effectively with public(s) in the realization of CCS projects. Social Science Research Network. https://doi.org/10.2139/ssrn.4286313

Durmaz, T. (2018). The economics of CCS: Why have CCS technologies not had an international breakthrough? Renewable & Sustainable Energy Reviews, 95, 328–340. https://doi.org/10.1016/j.rser.2018.07.007

Energy transitions commission. (2018). Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors. https://www.energy-transitions.org/publications/mission-possible/

Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., Garcia, W. D. O., Hartmann, J., Khanna, T., Luderer, G., Nemet, G. F., Rogelj, J., Smith, P., Vicente, J. L. V., Wilcox, J., Dominguez, M. D. M. Z., & Minx, J. C. (2018). Negative emissions-Part 2: Costs, potentials and side effects. Environmental Research Letters, 13(6), Article 063002. https://doi.org/10.1088/1748-9326/aabf9f

Gaurina-Međimurec, N., Mavar, K. N., & Majić, M. (2018). Carbon Capture and Storage (CCS): Technology, Projects and Monitoring Review. The Mining-Geology-Petroleum Engineering Bulletin, 33(2), 1–14. https://www.bib.irb.hr/999407

Gills, B., & Morgan, J. (2019). Global Climate Emergency: after COP24, climate science, urgency, and the threat to humanity. Globalizations, 17(6), 885–902. https://doi.org/10.1080/14747731.2019.1669915

Global CCS institute. (2022). CCS is a climate change technology. https://www.globalccsinstitute.com/about/what-is-ccs/

Heuberger, C. F., Staffell, I., Shah, N., & Mac Dowell, N. (2016). Quantifying the value of CCS for the future electricity system. Energy & Environmental Science, 9(8), 2497–2510. https://doi.org/10.1039/c6ee01120a

Ilinova, A., Cherepovitsyn, A., Evseev, O. (2018). Stakeholder Management: An Approach in CCS Projects. Resources, 7(4), 83. https://doi.org/10.3390/resources7040083

IPCC. (2022): Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

IRENA (2024), Decarbonising hard-to-abate sectors with renewables: Perspectives for the G7, International Renewable Energy Agency, Abu Dhabi. https://mc-cd8320d4-36a1-40ac-83cc-3389-cdn-endpoint.azureedge.net/-/media/Files/IRENA/Agency/Publication/2024/Apr/IRENA_G7_Decarbonising_hard_to_abate_sectors_2024.pdf?rev=d6776c5c224b4289af597070ec7d956c

Leiss, W., & Larkin, P. (2019). Risk communication and public engagement in CCS projects: the foundations of public acceptability. International Journal Of Risk Assessment And Management, 22(3/4), 384. https://doi.org/10.1504/ijram.2019.103339

Lima, P. R., Pereira, A. A. M., De Lorena Diniz Chaves, G., & Meneguelo, A. P. (2021). Environmental awareness and public perception on carbon capture and storage (CCS) in Brazil. International Journal Of Greenhouse Gas Control, 111, 103467. https://doi.org/10.1016/j.ijggc.2021.103467

Lipponen, J., McCulloch, S., Keeling, S., Stanley, T., Berghout, N., & Berly, T. (2017). The Politics of Large-scale CCS Deployment. Energy Procedia, 114, 7581–7595. https://doi.org/10.1016/j.egypro.2017.03.1890

Loria, P., & Bright, M. B. (2021). Lessons captured from 50 years of CCS projects. The Electricity Journal, 34(7), 106998. https://doi.org/10.1016/j.tej.2021.106998

Majid, A. (2023). Why carbon capture is key to reaching climate goals. World Economic Forum. https://www.weforum.org/agenda/2023/10/why-carbon-capture-is-key-to-reaching-climate-goals/

Middleton, R. S., & Yaw, S. (2018). The cost of getting CCS wrong: Uncertainty, infrastructure design, and stranded CO2. International Journal Of Greenhouse Gas Control, 70, 1–11. https://doi.org/10.1016/j.ijggc.2017.12.011

Moutenet, J., Bédard, K., & Malo, M. (2012). Public awareness and opinion on CCS in the province of Québec, Canada. Greenhouse Gases, 2(2), 126–135. https://doi.org/10.1002/ghg.1278

Parry, E., Mannion, P., Siccardo, G., Patel, M. (2022) Now the IPCC has recognized that carbon removals are critical to addressing climate change, it's time to act. Mckinsey sustainability. https://www.mckinsey.com/capabilities/sustainability/our-insights/sustainability-blog/now-the-ipcc-has-recognized-that-carbon-removals-are-critical-to-addressing-climate-change-its-time-to-act

Pianta, S., Rinscheid, A., & Weber, E. U. (2021). Carbon Capture and Storage in the United States: Perceptions, preferences, and lessons for policy. Energy Policy, 151, 112149. https://doi.org/10.1016/j.enpol.2021.112149

Pietzner, K., Schumann, D., Tvedt, S. D., Torvatn, H. Y., Næss, R., Reiner, D. M., Anghel, S., Cismaru, D., Constantin, C., Daamen, D. D., Dudu, A., Esken, A., Gemeni, V., Ivan, L., Koukouzas, N., Kristiansen, G., Markos, A., Ter Mors, E., Nihfidov, O. C., . . . Ziogou, F. (2011). Public awareness and perceptions of carbon dioxide capture and storage (CCS): Insights from surveys administered to representative samples in six European countries. Energy Procedia, 4, 6300–6306. https://doi.org/10.1016/j.egypro.2011.02.645

Read, A., Kombrink, M. 2018) Public close-out report overview- Rotterdam opslag en Afvang demonstratieproject. Global CCS institute. https://www.globalccsinstitute.com/wp-content/uploads/2019/09/ROAD-Close-Out-Report-Overview-final.pdf

Romasheva, N., & Ilinova, A. (2019). CCS Projects: How regulatory framework influences their deployment. Resources, 8(4), 181. https://doi.org/10.3390/resources8040181

Swennenhuis, F., Mabon, L., Flach, T. A., & De Coninck, H. (2020). What role for CCS in delivering just transitions? An evaluation in the North Sea region. International Journal Of Greenhouse Gas Control, 94, 102903. https://doi.org/10.1016/j.ijggc.2019.102903

Terwel, B. W., Harinck, F., Ellemers, N., & Daamen, D. D. (2011). Going beyond the properties of CO2 capture and storage (CCS) technology: How trust in stakeholders affects public acceptance of CCS. International Journal Of Greenhouse Gas Control, 5(2), 181–188. https://doi.org/10.1016/j.ijggc.2010.10.001

Thronicker, D., & Lange, I. (2015). Determining the Success of Carbon Capture and Storage Projects. Social Science Research Network. https://doi.org/10.2139/ssrn.2559732

Townsend, A., Raji, N., Zapantis, A. (2020). The value of carbon capture and storage (CCS). Global CCS Institute. https://www.globalccsinstitute.com/wp-content/uploads/2020/05/Thought-Leadership-The-Value-of-CCS-2.pdf

Van Os, H. W., Herber, R., & Scholtens, B. (2014). Not Under Our Back Yards? A case study of social acceptance of the Northern Netherlands CCS initiative. Renewable & Sustainable Energy Reviews, 30, 923–942. https://doi.org/10.1016/j.rser.2013.11.037

Vasilev, Y. (2019b). INTERNATIONAL REVIEW OF PUBLIC PERCEPTION OF CCS TECHNOLOGIES. International Multidisciplinary Scientific GeoConference SGEM. https://doi.org/10.5593/sgem2019/5.1/s20.052

Whitmarsh, L., Xenias, D., & Jones, C. R. (2019). Framing effects on public support for carbon capture and storage. Palgrave Communications, 5(1). https://doi.org/10.1057/s41599-019-0217-x

Chapter 8: Appendix

Table 8.1: output of chi-square test with multiple imputation

	Region				
Reason	Australia	Europe	Middle East	North America	**Total**
Financing	0	65	0	39	104
Legislation	0	32	0	0	32
Planning	1	33	1	35	70
Public opposition	0	33	0	0	33
Uncertainty	1	32	0	2	35
Total	2	195	1	76	274

Note P-value is 0.00. corresponding significance is *p<0.1 **p<0.05 ***p<0.01. Chi2 statistic is 63.40

In table 8.1 instead of a Fisher's exact test a chi-square test is performed as this is here the more appropriate method considering the bigger sample size.