Resistance against developing of Direct Air Capture:

The case of the Netherlands

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ABSRACT

In recent years, the concept of carbon capture technology has emerged as a promising and dependable strategy in our ongoing battle against climate change, which is arguably the most pressing issue of our time. One particularly noteworthy avenue is Direct Air Capture (DAC) technology, which offers a means to extract carbon dioxide directly from the atmosphere. In the context of the Netherlands, we have undertaken a comprehensive exploration of the resistance encountered in the adoption and diffusion of DAC technology, employing the insightful Multi-Level Perspective (MLP) framework.

Our investigation encompassed a meticulous gathering of data, involving an in-depth literature review, meticulously constructed surveys, and enlightening interviews with field experts. As a result, we effectively categorized the various barriers hindering the widespread acceptance of DAC technology into three distinct dimensions: environmental concerns, social resistance, and the energy consumption challenge. In tandem with this categorization, we strategically devised viable and pragmatic solutions aimed at surmounting each of these impediments.

To further our understanding and provide a visual representation of the complex interplay between these factors, we constructed a robust Fuzzy Cognitive Map (FCM). This dynamic model serves as a cognitive diagram that illustrates the intricate connections and relationships between the barriers, solutions, and influential drivers affecting the advancement of DAC technology in the Netherlands.

Taking inspiration from the MLP framework, we developed four distinct scenarios within the FCM to simulate potential trajectories for the DAC technology's evolution. These scenarios are intricately designed to reflect various possible shifts in the prevailing conditions and dynamics surrounding the technology's adoption. By carefully examining the outcomes within each scenario, we gained valuable insights into the dominant drivers that could catalyze the rapid progress and scaling up of DAC technology within the Dutch context.

Perhaps the most pivotal revelation stemming from the FCM analysis is the pivotal role that knowledge effect, through general and scientific knowledge, can play in steering the trajectory of DAC technology development in the Netherlands. This underscores the significance of policy and regulatory frameworks in fostering an environment conducive to innovation, investment, and widespread implementation of carbon capture solutions.

Keywords: Carbon capture, Direct Air Capture, Fuzzy cognitive map, Multi-level perspective, Climate change, Energy transition, Carbon dioxide

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS LIST

GHG	Green house Gas
UN	United Nations
SDGs	Sustainable Development Goals
COP	Conference of the Parties
DAC	Direct Air Capture
BECC	Bio Energy Carbon Capture
FCM	Fuzzy Cognitive Map
MLP	Multi Level Perspective
HT DAC	High Temperature aqueous solution-based direct air capture
LT DAC	Low Term solid sorbent direct air capture
CCS	Carbon Capture & Storage
CCU	Carbon Capture & Utilization
LNG	Liquid Natural Gas
EOR	Enhanced Oil Recovery
ESA	Electro-Swing Adsorption
M-DAC	Membrane-Based DAC
CDR	Carbon Dioxide Removal
ASHP	Air Source Heat Pump

INTRODUCTION

1.1. Background

Carbon dioxide (CO_2) is one of the most important greenhouse gases (GHG) in the atmosphere. Unlike the existence of other gases in the earth's atmosphere such as nitrogen and oxygen, suspended carbon dioxide molecules in the atmosphere absorb the reflected long-wavelength infrared energy from the Earth and trap atmospheric warmth. The gradual warming of the Earth leads to a phenomenon called climate change (Kumar, 2021). Climate change is defined as the long-term shift in weather conditions and temperatures. Severe droughts, intense floods, melting polar ice on a vast scale, and terrible storms are some examples of climate change's consequences (Bellard, 2012). According to the United Nations (UN) reports, increasing the global temperature must be limited to under 1.5 degree Celsius to maintain the Earth as human habitat (Meinshausen, 2022). There are several frameworks and agreements for decreasing the climate impacts such as Sustainable Development Goals (SDGs) and the Paris agreement (COP 21). Regarding these treaties, all solutions can be categorized into three dimensions: adaptation, mitigation, and financing for these changes (Biesbroek, 2013).

Mitigation or reducing climate change consequences includes methods that can reduce the amount of trapped greenhouse gases in the atmosphere by using decreasing sources of GHG or accumulate and store the GHG (Svendsen, 2011). Using renewable energy such as wind, ocean and solar is consider as a promising method to reduce source of GHG emission in the atmosphere. Replacing of these energy sources with fossil fuels results in decreasing of CO_2 emission and also climate change consequence. However, there are some fundamental challenges to replace fossil fuel with renewable energy.

There are some limitations to replace the renewable energy to fossil fuels such as construction of special infrastructure, technical limitations (storage of renewable energy) and huge amount of governmental investigation. Therefore, currently complete shifting to the renewable energy in the industrial and residential areas is not possible and the governments are forced to deploy fossil fuels as the main source of energy in their societies, hence the production of the CO_2 is inevitable.

Therefore, beside the first method, scientists and governments are interested in carbon capture as an alternative to reducing carbon emission (Svendsen, 2011). Carbon capture has been applied for many years in the refineries or petrochemical industries to absorb exhaust gases and is viewed as a practical method for fighting climate change to reach net zero by 2050 (Svendsen, 2011). Traditional methods of carbon capture focus mainly on removing the carbon from industrial processes but the new carbon capture technologies are based on absorbing CO_2 from the atmosphere, emission points and also storing and utilizing of carbon within the natural environments or within industrial processes.

In general, carbon capture methods are divided into three categories: fixed carbon capture, Direct Air Capture (DAC) and Bio Energy Carbon Capture (BMCC) (Caskie, 2020). Among these methods, DAC technology is different with the other methods, since this method is not directly linked to industrial exhaust gases, and it works without consideration of the location of CO_2 emission. DAC is a method to absorb carbon dioxide from ambient air (Zolfaghari, 2022). DAC is expected to play a significant role in climate change mitigation by 2030, even though this technology is in its infancy level (Sovacool, 2022). Scientists believe that this technology is one of the few technologies that could eliminate carbon dioxide from atmosphere at a large scale (Broecks, 2021).

However, scaling up of DAC method has some diverse challenges: energy consumption, environmental problems and social resistance. DAC plants for sucking the ambient air and also removing the carbon requires a lot of energy, and it is one of the challenges in developing of DAC plants. Also, noise and vibration problems and land usage are considered as social problems against this new technology. Carbon capture storage concern leaking problem is consider as some of environmental challenges of DAC plants. These issues are the most important challenges toward DAC method and each of them has some sub categories. This research investigates these problem areas for developing of this technology with focus on Netherlands and proposes recommendations to solve these problems.

1.2. Direct Air Capture Technology

Carbon capture methods are divided into two important categories: point source and direct air capture. The main aim of point source methods is preserving the current amount of carbon dioxide in the air by avoiding emissions from stationary sources such as power plants, petrochemical plants or other industrial factories. Therefore, carbon neutrality is viewed as the main goal of point source methods (Leonzio, 2022). Figure 1 depicts a schematic diagram of point source carbon capture from a power plant.

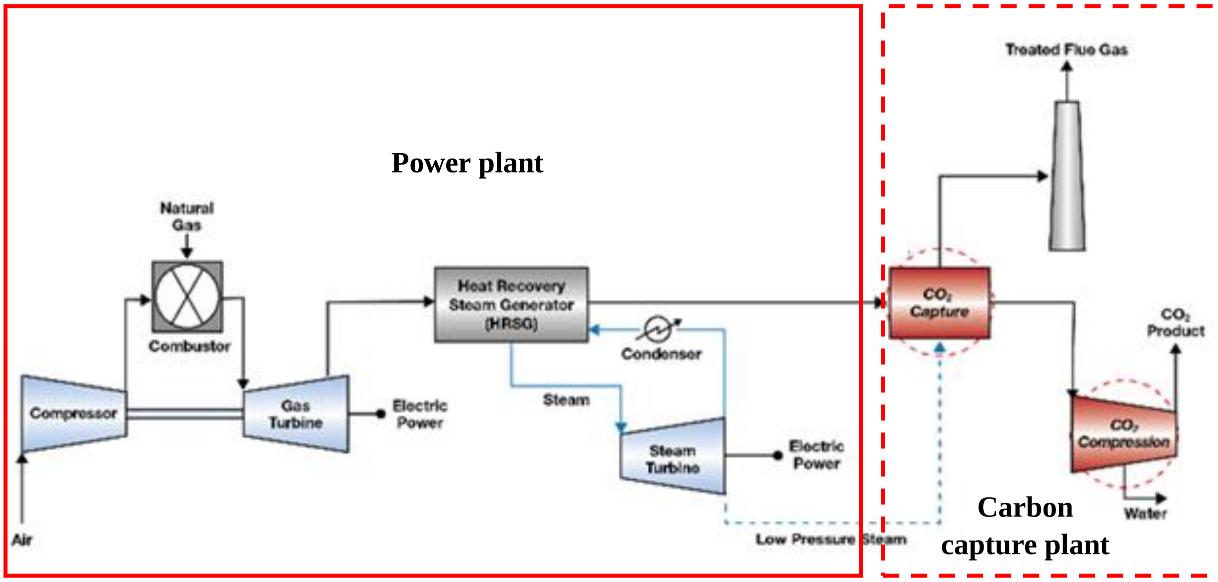

Figure 1: Power plant carbon capture (Leonzio, 2022)

However, DAC removes carbon dioxide directly from the atmosphere including CO2 emitted throughout emissions. Therefore, this method is known as negative carbon emission method due to reducing overall level of CO2 in the atmosphere (Leonzio, 2022). In addition to this characteristic, DAC plants can be moved from one site to other areas which decrease the need for pipe lines, fittings and the other expensive electrical and mechanical equipment from the capture plant to the sequestration areas (Leonzio, 2022).

Generally, DAC plants can absorb CO2 from the air by two different methods including: aqueous alkaline solvent process and solid sorbent process. In the aqueous alkaline solvent process, after sucking the air with huge fans, aqueous potassium hydroxide (KOH) is added to the air and the molecules of the solvent react with the CO2 from the air to compose potassium carbonate (K_2CO_3) and water. Afterwards, by implementation of several chemical and thermodynamic procedures on (K_2CO_3), a high-purity CO2 gas can be acquired and then it can be transported to the other industries (food/agricultural/oil&gas) or for long-term sequestration[1] (Beuttler, 2019). Similar to the aqueous alkaline solvent process, the solid sorbent process includes two significant procedures: adsorption and desorption. In this method, the vacuumed air

[1] Injection into the underground

enters to the air contactor to capture the CO2 by a solid adsorbent. After absorbing CO2, the solid adsorbent is subjected to heat and/or vacuum to release the CO2. The solid sorbent is then cooled down before it can be reused (Gutknecht, 2018).

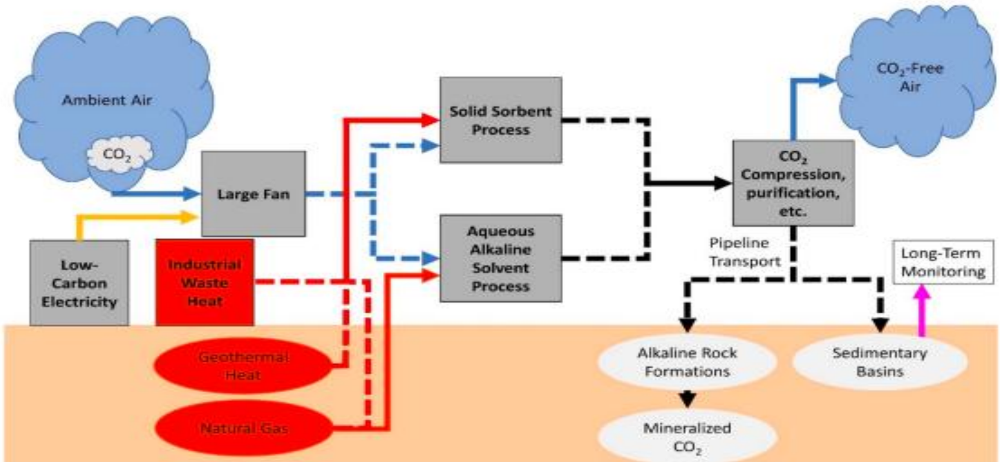

Figure 2: Schematic diagram of process diagram of Direct Air Capture (Beuttler, 2019)

The graphical depiction of DAC method is shown in Figure 2 and also a real DAC plan is displayed in Figure 3.

Figure 3: Direct air capture plant in Hinwil, Switzerland (Gutknecht, 2018)

Nowadays, there are 12 active DAC plants around the world (Ozkan, 2022) a number that it is expected to increase more than 19 plants by 2030. The specifications of these DAC plants are tabulated in Table 1.

Table 1: Specifications of current DAC plants (Ozkan, 2022)

Item	Company Name	Location	Method
1	Climeworks	Kanton Zurich (Switzerland)	Solid
2		Hellisheidi (Iceland)	Solid
3		Hinwil (Switzerland)	Solid
4	Carbon Engineering	Squamish, British Columbia (Canada)	Liquid
5		Squamish, British Columbia (Canada)	Liquid
6		Permian basin, Texas (USA)	Liquid
7	Global Thermostat	Menlo Park, California (USA)	Liquid
8		Huntsville, Alabama (USA)	Liquid
9		Magallanes (Chile)	Liquid
10		Sapulpa, Oklahoma (USA)	Liquid
11	Mechanical Tree	Arizona (USA)	Liquid
12	Infinitree	New York (USA)	Liquid

The largest DAC plant is Helliisheildi, Iceland and was commissioned in September 2021 with a capture capacity of around 4000 ton CO2 per year (Broecks, 2021).

1.3. Status-quo of the Netherlands in carbon capture technology

The Netherlands is recognized as a leading country in green industries and sustainability initiatives. The Dutch government has set ambitious climate targets and has been investing in renewable energy, energy efficiency, and carbon capture technologies. The country has made significant efforts transistioning to a low-carbon economy and promoting renewable energy sources. The Netherlands has been actively investing in renewable energy sources such as, solar, biomass and particularly wind. Additionally, The Netherlands has been actively working on CCS initiatives to reduce greenhouse gas emissions. There are several active carbon capture projects in this country such as Rotterdam CCUS Cluster, Porthos, ROAD CCS and Athos projects. Although there are some active companies in the field of the DAC, there is no large or pilot DAC plant in the Netherlands. However, the Netherlands is known for its expertise in engineering and sustainable solutions; hence it's plausible that DAC projects or research will be planned in coming years.

1.4. Scope of the Study

According to the current and future carbon capture and storage projects in the Netherlands and importance of this zero negative emission technology for the government of this country, Netherlands was selected for this research (Leonzio, 2022). However, although this country is known for its progressive environmental policies and innovative technologies (wind & solar farms/ biomass energy/ waste Incineration), there are some concerns about these green technologies such as noise pollution, deforestation and land usage. Moreover, as mentioned in the introduction, the barriers against development of carbon capture technology is in three different categories such as social, environmental and energy consumption which all of these challenges exist in the Netherlands. As a result, considering the unique characteristics of the Netherlands in the field of the sustainability, this country would be a practical case study for analyzing all of these challenges to diffusion of Direct Air Capture technology.

1.5. Research Objectives

Identification of the main challenges to scaling up of direct air capture as a method of carbon capture in The Netherlands is the first target of this research. Moreover, in the second step, Fuzzy Cognitive Map (FCM) was be applied to test practical pathways to implement this technology more effectively in the Netherlands.

1.6. Research Question

Main Question

What are the environmental, energy-related, and social challenges involved in the diffusion of Direct Air Capture (DAC) in the Netherlands, how are these dimensions interconnected systemically, and what are the recommendations for successful diffusion in the Netherlands?

Sub-questions

- What are the critical environmental concerns to scaling up DAC technology (Both supportive and discouraging)?
- What social factors contribute to public resistance to and acceptance of developing DAC plants?
- How does energy consumption and policy pose a challenge for or enable the development of DAC plants?
- How can environmental, energy, and social contexts relevant for DAC scaling up in the Dutch case be represented using Fuzzy Cognitive Method (FCM)?

- What scenarios are derived from the FCM to improve DAC diffusion? Where are the key intervention points? Who are the key stakeholders that need to be involved?

1.7. Theoretical Frame work

There are several theories that explain the development of a new technology in a society such as diffusion of innovation, disruptive innovation, technological determinism, technological transition and socio-technical transition (Jørgensen, 2012). Among these theories, socio-technical transition theory, also known as the Multi Level Perspective, is a multidimensional theory that could consider different dimensions in developing of a new technology in a society includes: governmental support and incentives, cost competitiveness, barriers and challenges, social and environmental issues (Geels, 2019). This theory consists of three levels: niche innovations, socio-technical regimes, and an exogenous socio-technical landscape (Geels, 2018) . Figure 4 display these three levels and also their transition process.

Transitions take place when a niche innovation obtains sufficient momentum and challenges the dominant regime. This can occur when the innovation addresses a specific problem or need, has a clear advantage over existing technologies, and is supported by a diverse set of actors. As the niche innovation gains momentum, it may create new niches and begin to challenge the regime. Over time, the regime may adapt to incorporate the new innovation, or it may be replaced by a new regime.

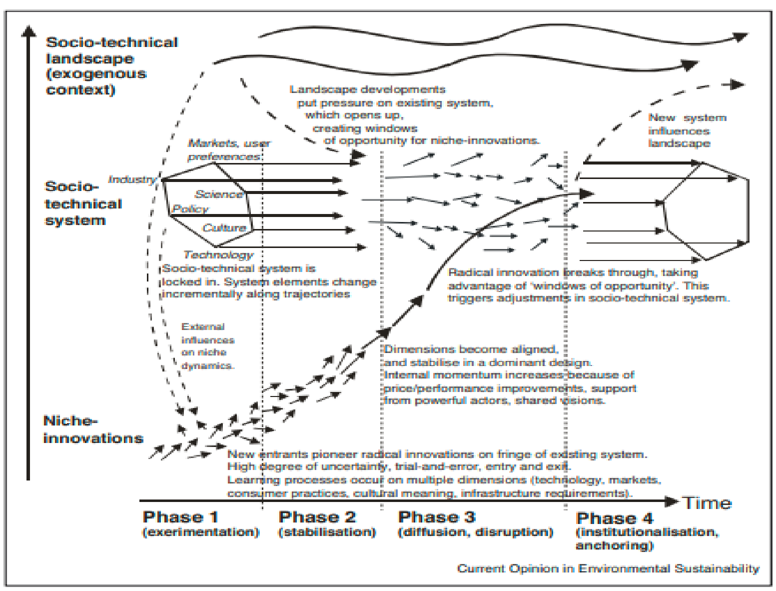

Figure 4: Multi-Level Perspective (Geels, 2019)

The regime level represents the dominant socio-technical system that is already established and institutionalized. It is typically characterized by stability, high levels of investment, and a dominant set of rules, norms, and practices. Also, the landscape level represents the broader socio-economic, cultural, and political context in which socio-technical systems exist. It includes factors such as global trends, cultural values, and political institutions.

This theory has been applied to a variety of fields, including energy systems, transportation, and agriculture (Geels, 2018). It provides a useful framework for understanding how socio-technical systems change over time and how policy interventions can support or hinder transitions to a more sustainable system. For instance, the concept of Marine Wind Energy and the North Sea Offshore Grid Initiative was examined through the lens of a Multi-Level Perspective (MLP) to understand why the transition to this technology has faced challenges (Flynn, 2016). The analysis reveals that the transition to this technology has stalled due to conflicts between the existing fossil fuel-dominated regime, policy uncertainties, technological challenges, and economic considerations (Flynn, 2016).

Carbon capture technology is known as a bridge between the industry and environment and currently it is the effective human tools against climate change. Despite these benefits, Direct Air Capture progress is slow and easy to stall, with several uncertainties and economic risk (Georgieva, 2017). Multi Level Perspective theory can explain the barriers to diffusion in socio-technical systems such as carbon capture and minimized the barriers by providing the policies regulations which can shape the technological transition.

LITERATURE REVIEW

To investigate the previous surveys in DAC technology, we categorize the literature for this technology in three categories including: environmental concerns, energy consumption and social contexts and then summarize these researches in order to state the challenges and opportunities of DAC technology.

2.1. Environmental concerns

The main role of DAC plants is capturing CO2 from the atmosphere and which combats climate change. However this modern technology creates some environmental problems especially in storage and transportation of absorbed carbon.

According to Leonizo et al. (Leonzio, 2022), although the DAC technology is a Net-Zero carbon emission method, in some cases it could generate other negative environmental impacts. In this survey, they evaluate the physiosorbents and chemisorbent methods using life cycle assessment (LCA). Their findings show that both of these methods could reduce carbon dioxide, however DAC plants working with chemisrbents have lower negative influences on the environment in comparison with the other plants. Additionally, they suggest that in order to improve CO2 capture capacity and lower environment problems, future research has to concentrate on Silica Amine sorbent as carbon absorber.

Ozkan et.al (Ozkan, 2022) explored the environmental problems of DAC plants. They categorized these problems in two aspects: the influence of the environment on the DAC plants and the effect of DAC technology on the environment. For the first aspects, they evaluated the energy needed capturing CO2 from the atmosphere. Although, nowadays the new DAC plants use renewable source of energy, the efficiency of DAC plants working with fossil fuels is more efficient. Thus, producing the CO2 in DAC plants working with fossil fuel (Natural Gas) is inevitable. Leaking of chemical material from utility process in DAC plants to the atmosphere or the environment was viewed as the negative effect of DAC on environment.

Storage of absorbed CO2 during the capture process is an important source of environmental problems of this technology (Salvi, 2019). In order to tackle this problem, transportation and sequestration were introduced. Nowadays, many industries such as beverage, food and oil & gas companies use captured CO2 in their work process. Large ships and pipe lines are utilized to transfer CO2 from DAC plants to factories, hence leakage in them (pipe lines/ ships) leads to the emission of CO_2 (preventing this problem needs regular inspection and maintenance). Buried CO_2 in the ground or sequestration is another way to store the CO_2 long-term, however this method not only has negative effect on environment such as ground water pollution but also changes the pressure between formation layers and increases the risk of earthquake (Salvi, 2019).

2.1.1. Environmental concerns in the Dutch context

The Dutch government strives to decrease the GHG emission to zero by 2050 (Gutknecht, 2018). In the first step, they are trying to produce 16% of all energy in the Netherlands by using sustainable sources by 2023. Solar energy, on-shore & off-shore wind farms, geothermal and hydropower are the practical ways to reach this goal. While these methods could reduce the carbon dioxide emission, they could not control all source of CO_2 and emission of CO_2 would be inevitable. Therefore, some carbon captured projects were initiated in the Netherlands that the most important of them is Porthos project in the Rotterdam (Cozier, 2019). Gathering and transportation of CO_2 through a pipeline to the North Sea and pumping to an empty gas field is the main aim of this huge project (Cozier, 2019). Although this mega project is expected to reduce the CO_2 emission by 2%, it has negative impacts on nature such as Nitrogen emission, leaking of captured CO_2 through pipeline and also causing pollution of the sea bed (Koornneef, 2008). There are many concerns for the continued operation of this project. These environmental problems should be solved in order to develop DAC plants, because the transportation or storage process in DAC plants are similar to other carbon capture methods and Dutch government may suspend the operation of DAC plants due to these problems based on two Conventions on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter and Protection of the Marine Environment of the North-East Atlantic (Haan-Kamminga, 2010).

2.2. Energy consumption

One of the main barriers in developing DAC plants is related to energy consumption. DAC is dependent on electricity and for providing this electricity, it needs energy.
Both types of DAC plants, solid sorbent and liquid solvent, approximately need 20% electricity and 80% thermal energy for their operations (McQueen, 2021). Huge fans, vacuum pump, reactors and filtration unit require energy for running, and also DAC plants need almost 300 MW for capturing 1 $MtCO_2\ yr^{-1}$ (McQueen, 2021). This amount of energy is significant and it is a big

challenge for utilizing of DAC at an industrial scale. Therefore, scientists should devise ways to reduce the energy consumption of DAC plants to capture larger amount of CO2 with less energy consumption (McQueen, 2021).

Fasihi et al. (Fasihi, 2019) analyzed the energy consumption of high temperature aqueous solution-based direct air capture (HT DAC) and low term solid sorbent direct air capture (LT DAC) as two commercial categories of DAC plants. Figure 5 shows the process of these two methods.

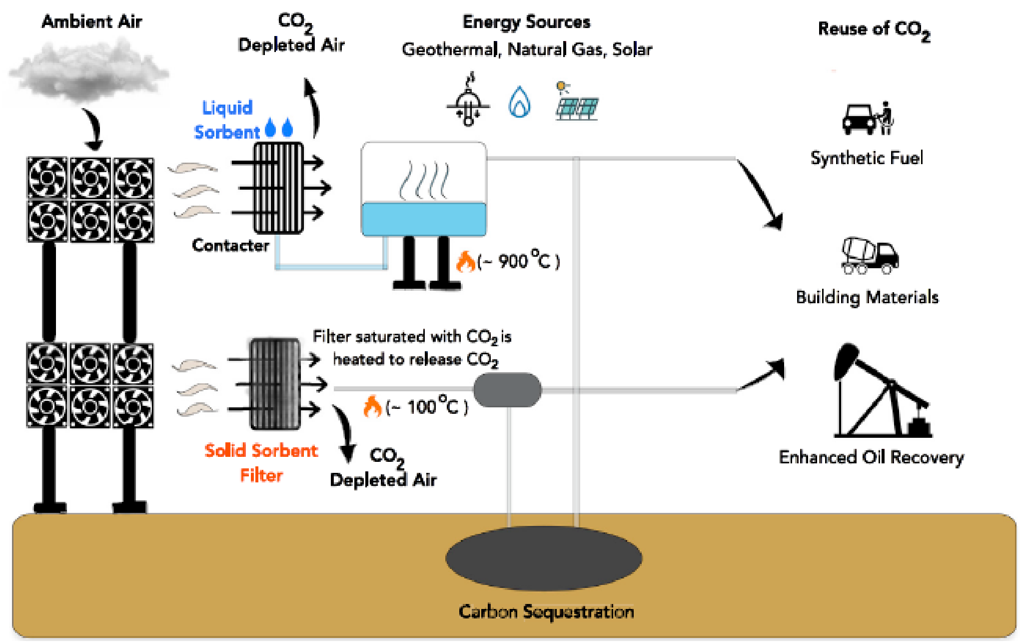

Figure 5: Process of aqueous solution and solid sorbent direct air capture (Ozkan, 2022)

In this research they revealed that although currently the energy consumption of these two methods is in the same level, the LT DAC technology will be a more advantageous option in the future in terms of energy consumption. This is because it has the potential for significant cost reduction by utilizing waste heat from other sources. Additionally, the LT DAC system is highly modular and does not require external water.

2.2.1. Energy consumption in the Dutch context

DAC technology requires large energy consumption compared with other carbon capture methods (Leonzio, 2022). Additionally, the Dutch government, in line with global treaties, has set goals to decrease CO2 emissions (Bellekom, 2012) especially by removing fossil fuels. For example, only in the electricity section, the Netherlands is going to reach 10 GW energy of wind power by 2020 (Bellekom, 2012) and it needs more infrastructure such as new grids and wind farms. Therefore, providing required and sufficient energy based on these limitations is one of the challenges in developing this technology particularly in the Netherlands. Providing energy from renewable sources such as wind and solar powers and also using heat pump technology Leonzio et al. (Leonzio, 2022) are suggested for solving this problem, but using of these methods have some challenges and limitations.

2.3. Social resistance

Although this technology is beneficial for human in all around the word, there are some opposition against developing of this technology particularly from people living in the vicinity of these plants. Sovacool et al. (Sovacool, 2022) performed 125 interviews with experts to evaluate DAC technology from different points of view. Social acceptance was one aspect that they discussed about comprehensively. They found that the opinion of people about carbon capture and storage vary based on their locations. For instance, people living in the Japan are not satisfied about developing of DAC plants due to land limitation and also cost of transferring of captured CO2. However, people in Saudi Arabia agree about expanding this technology in their country. Lack of enough information even among the experts would be viewed as another challenge against social acceptance.

To reach the zero greenhouse gas emission by 2050, using carbon capture technologies especially DAC method is indispensible. Therefore, in order to grow this technology, it is important to evaluate the public acceptance of DAC method in around the world. Wegner et al. (Wenger, 2021) conducted a survey on Swiss public about DAC plant. They found that while there is a huge DAC plant in the Swiss, the people in this country still do not have sufficient information about this new technology and assess them neutrally. Additionally, they estimated that in the future this subject will be intensified among the people when the government decides to develop large-scale of DAC plants.

Satterfield et al. (Satterfield, 2023) studied the public perception of US and Canadian people living near pilot DAC plants. They provided a questionnaire and received 2120 responses. The results showed that some people rejected this system as they believed that this technology not only is dangerous for climate (Leakage problem) but also is dependent to fossil fuels. However,

supporters of this technology declared that this technology is extremely beneficial in all aspects for current and future generations and this technology could guarantee human life in the future.
Willingness of end- consumers in the US to using the products made with carbon capture technology was investigated by (Lutzke, 2021). Results show that Carbonate beverages especially those contain carbon captured from point sources (power plants-factories) were less accepted by people. However, around 69% of participants in this research expressed that they are open to consume carbon capture and storage (CCS) products.

2.3.1. Social resistance in the Dutch context

There are several studies about social acceptance or barriers on carbon capture technology in the Netherlands (Van Alphen, 2007) (Shackley, 2009). According to Van Alphen et al. (Van Alphen, 2007), due to media coverage, the public perception of scaling-up carbon capture technology has become increasingly favorable, however there are several uncertainties about the safety of these plants. Construction of pilot carbon capture plants in order to show the performance, reliability and efficiency of them to the public is the best way to increase social acceptance (Van Alphen, 2007). Huijts et al. (Huijts, 2007) used the stakeholder analysis on acceptance of carbon capture plants in the Netherlands. Results show that the professional actors such as government, environmental NGOs and industry are keen on developing carbon capture plants. In addition, public opinion is positive for starting up these plants, while attitudes towards storage are negative due to lack of information about the consequence of the storage on their habitat.

Another issue that influences the attitude of the public in the Netherlands about diffusion of the new technology is available land (Klok, 2023). Nowadays, in spite of the facts that the wind farms have many advantages for Netherlands residences, there is some opposition against developing of them due to the land usage. Netherland is small country with a lot of farms and income of many people in this country depends on farming for their livelihoods (Koelman, 2018). Therefore, more wind farms means less farmland. This problem is also for the construction of DAC plants in this country. DAC plants need more land not only for developing but also for pipelines. Land may be viewed as a significant barrier against the diffusion of DAC.
Rotary part in the industry could produce noise and it leads to sleep disturbance and psychological distress among the people near this industrial plants (Bakker, 2012). According to Pedersen et al. (Pedersen, 2011) exposure to noise for a long time results in high blood pressure

and cardiovascular diseases particularly for people living near these areas. These problems are not limited only to humans and also include animals. Development of wind farms has negative impact on breeding geese, ducks and swans and it also affects their reproduction (Madsen, 2008). Therefore, due to these problems, people are not interested in living near companies with huge rotary machinery, and as a result, the price of the houses near these industries would decrease sharply (Dröes, 2021; Dröes, 2016).

Moreover, large industrial plants have a negative effect on tourism industry particularly in countries with land usage problems like Netherlands (Landry, 2012). For instance, according to a survey by Hartholt et al. (Hartholt, 2013) the wind farms in Netherlands not only decrease farm land, but also have an adverse impact on landscape aesthetics and hence it may result in decreasing the number of tourists in the country.

All of these problems were mentioned about huge industries in the Netherlands such as health problems, land usage and should be considered for developing DAC plants in the Netherlands. Consequently, all of these items have to be evaluated in order to find the best locations for construction of DAC plants in the Netherlands to minimize all of negative aspects on different stakeholders.

2.4. Multi-level perspective theory in green industries

The green industry, including the renewable energy, sustainable practices, and environmentally friendly technologies, has obtained significant attention in recent years. For instance, in recent years mitigation of the negative impacts of climate change is a hot topic among the scholars and it was proved using deep-structural changes in energy transition and carbon capture technology, human could reach to this substantial goal. The socio-technical approach to transitions views the carbon capture or energy transition as a combination of various components, such as technology, policies, markets, consumer behaviors, infrastructure, cultural significance, and knowledge (Smith, 2007). Due to their multidimensional nature, existing systems are often locked in and resistant to change, making them stable and difficult to modify. As a result, sustainability analyses have expanded their analytical focus from individual artifacts to encompass socio-technical systems (Geels, 2005). To understand the dynamics and complexities of the green industry's development (as an intricate socio-technical system), researchers' attention has shifted to the multi-level perspective (MLP) as an analytical framework (Geels, 2010). The multi level perspective (MLP) assumes that transitions follow a non-linear trajectory that form from the complex interaction of various factors at three distinct analytical levels: niches innovation level, socio-technical regimes and an exogenous socio-technical landscape. Also, the MLP provides a deep insight into the coexistence of dynamic change activities at niche level and relative stability of existing regimes (Geels, 2012). For example, Geels (Geels, 2012) assessed the drivers and obstacles for a shift toward low-carbon transportation systems using the MLP theory in the Netherlands and England. Results show that although there are several huge innovations in changing the automobile industry, the existing regime (internal combustion engines) is still dominant, but there are some cracks in the regime. There is momentum for transition to the low-carbon (climate change, governmental regulations), but they are not very strong yet and they are not able to change the stability and inertia of the current regime.

Nurdiawati and Urban (Nurdiawati, 2022) explored the adoption of the oil refineries in the Sweden to utilize decarburization technologies such as Hydrogen, bio fuels and carbon capture system using the MLP theory. This research reveals that among these three suggested methods, the bio fuel is the most compatible technology in terms of policy framework, knowledge and market function in comparison to other methods. Nowadays, even though landscape pressure is more powerful rather than previous years because of the decarburization goals by the EU and Paris agreement, there is still uncertainty regarding the feasibility of fully eliminating fossil fuels and achieving rapid decarburization by 2045, in alignment with Sweden's climate targets. Lefvert et al. (Lefvert, 2022) conducted a study to observe the development trend of the carbon capture storage/utilization industry in the Sweden and explore how incumbent actors' experience can assist the prediction of the future energy transition framework in this country. CCS/CCU has undergone a transformation, shifting its focus from primarily reducing CO2 emissions in heavy industry (fixed point) to becoming a crucial tool in achieving a climate-neutral energy system, although its technologies have not changes remarkably due to lack of the governmental supports and policy support scheme.

Currently, there is international interest in carbon capture technology as a practical way to mitigate climate change (Lefvert, 2022). However, DAC is currently positioned at "Technology Readiness Level"[2] 6 on the scale of 1 to 9, indicating that it remains in the phase of large-scale

[2] Technology Readiness Levels (TRLs) are utilized to gauge the advancement and maturity of technologies during the procurement phase of a program.

testing and prototyping and has not yet reached the stage of full commercial deployment [3]. Based on the MLP theory to Promoting this technology from the niche level to the regime level involves a strategic and systematic approach. It requires overcoming barriers and gaining widespread acceptance and adoption within the target market or industry. According to (Gandal, 2000) and (Morgan, 2013) there are some key steps that can help a technology achieve this transition (from Niche innovation level to socio-technical regimes) such as "Demonstrate value and performance", "Address barriers and challenges", Invest in research and development", "Educate and create awareness", "Cost competitiveness", "Positive network effects" and "Governmental support and incentives".

In this research, we try to identify the main barriers and concerns (as one of the transition step) of the DAC technology in The Netherlands context and evaluate the feasible and realistic solutions to solve these challenges to develop this technology in this country. Finally, we simulate these strategies using FCM to estimate the accuracy and reliability of these proposed methods. It should be mentioned that promoting a technology from niche to regime level is a gradual process that requires perseverance and adaptability. Listening to user feedback and continuously refining the technology based on market needs will be critical to its success (Shane, 2009).

[3] See this webpage: https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal#:~:text=DAC%20is%20currently%20categorized%20as,ready%20for%20full%20commercial%20deployment.

METHODOLOGY

3.1. Methodological approach

This research aims to analyze the environmental concerns, energy consumption and social resistance facing Direct Air Capture (DAC) development in the Netherlands. Figure 6 depicts the steps of the research design.

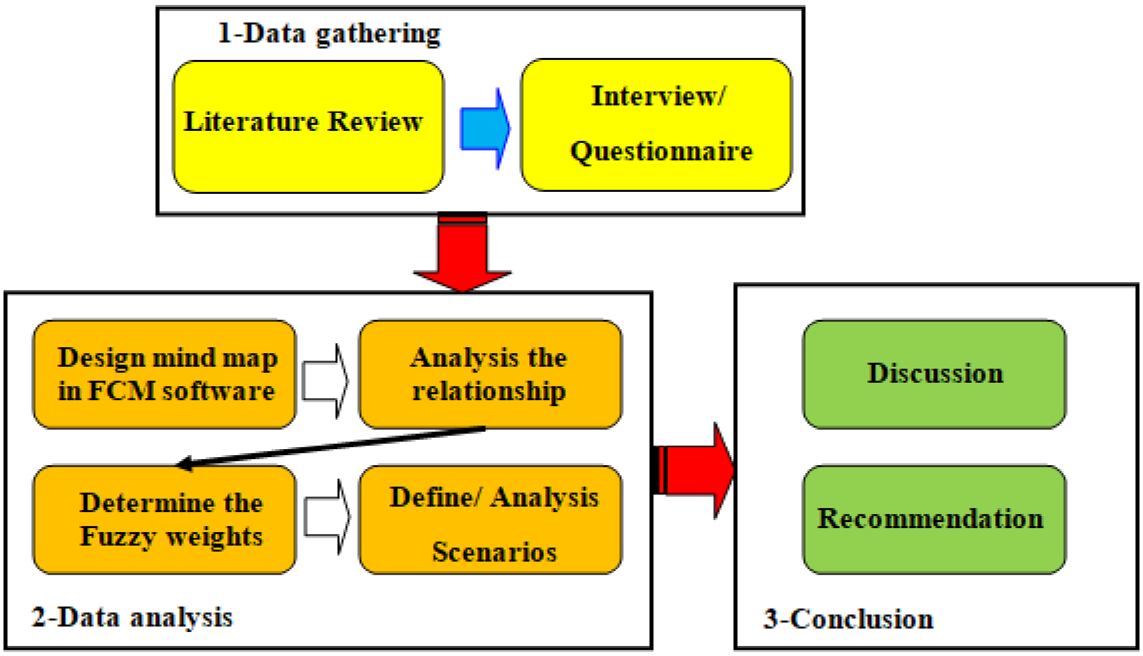

Figure 6: Steps of the methodological approach

According to Figure 6, the methodology of this survey has three main sections, data gathering, data analysis and conclusion. All of these items are defined below:

- **Literature review:** A comprehensive review has been conducted to recognize the important key points and finding related to this topic. Also, the literature review was continued until the end of research to analyze more research and investigate the topic from different points of view.
- **Questionnaire:** In order to understand public perception about this new technology, developing of DAC plants and also the main source of public resistance, a comprehensive questionnaire will be designed and ask people to express their ideas toward this new technology in The Netherlands.

- **Interviews:** By conducting interviews with specialists and companies actively engaged in this field, we can ascertain the expert's opinion on the challenges and opportunities presented by DAC (Direct Air Capture) technology**.**
- **Design Mind Map:** Based on the data which will be obtained in the data gathering section, the important components, positive and negative connection and fuzzy weights will be determined to create a mind map in order to test possible scenarios for developing of the DAC in the Netherlands.
- **Define Scenarios:** Some realistic and feasible scenarios will be carried out to investigate the different challenges on diffusion of DAC plants as a practical carbon capture technology in the Netherlands**.**
- **Conclusion:** After gathering the outcomes from predefined scenarios, these findings will be thoroughly examined and discussed. Subsequently, recommendations will be formulated to address obstacles hindering the progress of DAC (Direct Air Capture) technology. These recommendations will focus on devising practical and achievable policies for the successful implementation of this technology in the Netherlands.

3.2. Research strategy

Regarding to Figure 6, this research was based on desk research coupled with survey with people and interviews with experts to assess diffusion of the DAC technology in the Netherlands. To conduct this research, a case study was adopted to analysis the developing of DAC technology in the Netherlands by utilizing qualitative and semi-quantitative approaches to collect the necessary data. Using the obtained data and also the MLP theory the main components and linkages between variables will be identified and analyzed. Finally, the linkage between the main variables during the interviews, literature review and survey will be analyzed using fuzzy cognitive mapping (FCM). This analysis will form the foundation for developing policy recommendations.

3.3. Data collection

The literature review, questionnaires and interviews with experts are the main source of information in this research. Several scientific papers have been published on the topic of "environmental problem", "social resistance", "energy consumption" and "carbon capture methods". However, there are fewer studies on these topics regarding "Direct Air Capture", more specifically in the Netherlands. This issue may be attributable to the newness of the technology and the absence of a real or pilot power plant in the Netherlands. Thankfully, there are several companies are engaged in the carbon capture field, especially DAC method in the Netherlands. Trough conducting interviews we can gather valuable insights regarding the obstacles and prospects associated with CCS (See Table 2).

Table 2: List of active companies in carbon capture technology in the Netherlands for interview

item	**Name of company**	**location**	**Established year**	**Type of the projects**
1	Skytree	Amsterdam	2012	DAC
2	Shell	Amsterdam	1907	Fixed point cabon capture
3	Climeworks	Amsterdam/Zurich	2009	DAC
4	Bilfinger Tebodin	Rotterdam	2016	CO2 storage under sea
5	Carbyon	Eindhoven	2019	Research about CCS
6	World resources institute	Utrecht	1982	Fixed-point carbon capture

The selection of experts for this study will be based on different factors such as their availability, experience and willingness to provide pertinent information.

The selection criteria for the interview in this research are:

- Companies are active in the field of carbon capture
- Companies willing to be interviewed in English
- Companies with contact information and project Managers willing to have an interview

The list of potential carbon capture projects with brief description and status is given below (Table 3).

In order to receive public attitude about construction of the DAC plants in the Netherlands, a survey with 13 questions was provided and uploaded in the Qualtrics website (this website supports with Twente University). The link of the questionnaire was sent to Dutch people to state their ideas about developing of this technology in the Netherlands. The responses of the people could assist to figure out of the social barriers against developing of this technology in the Netherlands (See appendix A).

Table 3: List of experts and potential carbon capture projects in Netherlands

Project Name	Description
Porthos project	The first phase of the Porthos CCS project involves the capture and storage of CO2 from companies in Rotterdam. Scheduled to store an annual amount of 2.5 million tonnes of CO2 from the industry in empty gas fields beneath the North Sea from 2024.
Recabn pilot plan	Pilot plant is operational in Portugal since September 2022 and delivering CO2 feedstock to an algae reactor as part of EU Horizon 2020 with a capacity of 3.5 tons captured CO2 / year.
LNG-ZERO Project	Carbon capture and storage (CCS) solutions for LNG and HFO fuelled vessels. The companies working on this project have created a budget of €6,1 million, on which the Dutch government has granted a subsidy of €4,4 million.
Projects with positive response interviewed and examined	
-Recabn pilot plan (Recabn company) - LNG-ZERO Project (Carbotreat company)	

Expert	Date of the interview
Co-founder (Sophia Hummelman)- Recarbn	25.04.2023
Project manager (Frank Sanders)- Carbotreat	02.05.2023
Project manager (Behrouz Nouri)-World resource institute	08.06.2023

Proposed questions and consent forms are in appendices B and C.

3.4. Data analysis

In this research, Fuzzy Cognitive Map (FCM) is applied for data analyzing. FCM is a simple method to extract results from ambiguous data and modeling complex systems, also it is an appropriate and robust tool for cases with limited access to data (Özesmi, 2004), thus regarding to the aforementioned attributes and the limitations in data collection for DAC plants in the Netherlands, this method emerges as the most suitable choice for analyzing diverse scenarios within the scope of this research. The website that used to analyze the relationships among different components is "Mental Modeler". This website is useful for drawing components, relations, fuzzy weights and it can also be utilized for scenario analysis. In this research, different scenarios based on environmental, energy and social barriers were defined and then by using the "Mental modeler" the influence of them on diffusion of the DAC plants in the Netherlands was explored. In Table 4 the sub-questions and the methods we used to answer them are explained.

Table 4: Data sources and collection methods

Sub-question	Analyzing method
1- What are the critical environmental concerns to scaling up DAC technology? (Both supportive and discouraging)	Literature review- expert opinions-evaluating with MLP theory
2- What social factors contribute to public resistance to and acceptance of developing DAC plants?	Literature review- expert opinions-evaluating with MLP theory
3- How does energy consumption and policy pose a challenge for or enable the development of direct air capture plants?	Literature review- expert opinions- Public Attitude-evaluating with MLP theory
4- How we can we represent the Dutch environmental, energy, and social contexts relevant for DAC using Fuzzy Cognitive Method (FCM)?	Finding the main components/ relations and fuzzy weights from three previous sections
5- What scenarios are derived from the FCM to improve DAC diffusion? Where are the key intervention points? Who are the key stakeholders that need to be involved?	Define scenarios based on Dutch limitation and governmental laws and analyzing with the FCM method-

3.5. Design system representation of DAC situation

In this research, the Fuzzy Cognitive Method (FCM) described by (Özesmi, 2004) is applied to explore the complex relationships among different components with different nature to evaluate the feasibility of development of DAC technology. The mental modeler (software https://www.mentalmodeler.com) is applied for modeling the FCM map.

3.5.1. Structure of mind map:

Components, variables and factors are related to the developing of the DAC technology in the Netherlands and the casual linkages among them are recognized from the scientific literature, surveys and interview with experts. To find the main variables and also the linkages between them the following keywords are used: "Environmental advantages/disadvantages of carbon capture methods", "Influence of carbon capture on climate change", "Dutch policies toward climate change", "Public attitude toward large industrial plants/ DAC plants, "Energy consumption of DAC plants", "Diffusion of DAC plants and transition theory" and " DAC technology and climate policies".

3.5.2. Assigning fuzzy weights to casual relationship:

After determination of concepts and casual linkages, the relation must be assigned using fuzzy weights. The linkages are labeled with the fuzzy weights in the range of [-1 1] that shows the casual relationship among variables (nodes) with a degree of causality (Verbal expression is presented in Table 5). The FCM (Fuzzy Cognitive Map) model incorporates three key features that enable it to depict any system: Firstly, it utilizes signed causality to denote the positive or negative relationship between nodes. Secondly, the strengths of the causal relationships between nodes are represented as fuzzy values. Lastly, the FCM model captures dynamic causal links between nodes where a change in one node can affect other nodes in the system (Özesmi, 2004). Figure 7 illustrates a symbolic FCM with 5 components and 9 connections. The weight assigned to each edge connecting nodes C_i and C_j signifies the extent to which concept C_i influences concept C_j.

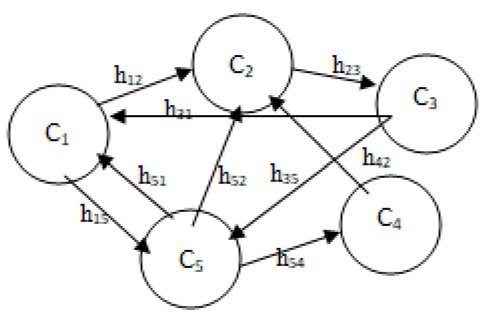

Figure 7: fuzzy cognitive map example

Additionally, the value of h_{ij} determines whether the connection between concepts C_i and C_j is direct or inverse. Consequently, there exist three conceivable forms of causal associations between nodes C_i and C_j that is shown in equation 1 (Furfaro, 2010).

$$\begin{cases} h_{ij} > 0 \rightarrow direct \quad relationship \\ h_{ij} = 0 \rightarrow indirect \quad relatioship \\ h_{ij} < 0 \rightarrow no \quad relationship \end{cases} \tag{1}$$

Fuzzy cognitive mapping is a tool used to determine the crucial variables that play a role in the acceptance of DAC technology in the Netherlands. It helps to identify the drivers (variables that are affecting others but they themselves are not affected), receivers (variables that are affected by others but they themselves are not affecting any variable), and ordinary variables (variables that are neither receivers nor drivers), as well as the indegree (number of ties entering a variable), outdegree (number of ties leaving a variable), and degree centrality of each variable (variable with the highest number of ties). The indegree, outdegree and degree of centrality are defined using equations of 2 to 4 respectively (Nasirzadeh, 2020).

$$InDegree\left(C_i\right) = \sum_{k=1}^{n} h_{ik} \tag{2}$$

$$OutDegree\left(C_i\right) = \sum_{k=1}^{n} h_{ki} \tag{3}$$

$$Cent\left(C_i\right) = InDegree\left(C_i\right) + OutDegree\left(C_i\right) \tag{4}$$

Where C_{ik} and C_{ki} are the casual connection weights.

Table 5: The ranges of strength of interactions

Expression	Quantitative Value
Very positive high connection	+1
High positive connection	+0.5
Neutral connection	0
High negative connection	-0.5
Very positive high connection	-1

3.5.3. Define scenarios:

Making scenarios is another prominent feature of mental modeler software. Scenarios in fuzzy cognitive maps can be used to simulate and explore different situations, potential outcomes, and the effects of various factors or inputs on the overall system behavior. This research utilized the hyperbolic tangent function to create four distinct scenarios, each representing different aspects of the study. The first scenario highlights the role of knowledge, while the second scenario focuses on the involvement of Dutch residents. The third scenario explores the potential impact of governmental aids, and the fourth scenario combines and examines all previous scenarios to facilitate the development of Direct Air Capture (DAC) technology in the Netherlands. The hyperbolic tangent function has a broader range of values spanning from -1 to +1, which ensure that even the most unfavorable cases are evenly represented by highly negative values (Kokkinos 2020). Assumption regarding the defined scenarios are made by adjusting (increase/decrease) certain components to attain the desired state scenario (as shown in Table 6). Additionally, the graphical results of these scenarios are examined in detail to understand the influence of the modification made to the system.

Table 6: Overview of Scenarios

Scenario	Preferred State	Percentage increase/decrease
A-1	Increase general knowledge	100%
	Increase technical knowledge	100%
A-2	Decrease public resistance	100%
A-3	Increase government role	100%
	Increase governmental subsidies	100%
A-4	Combined the A-1,A-2 and A-3 scenarios	100%

3.5.4. Conclusion from the outcomes:

According to analyzing the obtained data (literature review/survey/interviews) using the FCM, a set of recommendations for developing DAC plants as a net zero carbon method was proposed. These recommendations would promote the DAC plants from niche stage to the landscape regime. Practical instruments were defined in form of financial incentives (energy/knowledge) and technical aspects (new process/ new materials). These instruments were adjusted to demonstrate the trend and direction of the outcomes. Moreover, we identify and utilize the combination of these recommendations that show the highest probability of yielding desirable outcomes. This approach enables us to draw policy conclusions based on the most promising combinations of strategies.

3.6. Ethical Considerations

This study guarantees an unbiased and transplant perspective, without any commercial affiliations or associations that could potentially result in conflicts of interest. The data was collected from reputable academic sources, questionnaire, and interviews conducted with experts which consent with the ethical rules of the ethics committee of the Faculty of Behavioral, Management, and Social Sciences of the University of Twente. Additionally, the consent form which declares the interviewees rights during the interview is available in Appendix D.

RESULTS

This chapter describes the results of the questionnaires and interviews with experts, as well as the outcomes of the analysis using fuzzy cognitive map. Additionally, in this chapter the results of practical scenarios (mentioned in section 3.5.3) in developing of DAC technology were discussed.

4.1. Questionnaire specifications:

To better understand public attitude on DAC, an online questionnaire with 13 questions was designed and sent for Dutch residents with different gender, age and education levels (details were explained in section 3.3). In total, 150 people filled out the survey and sent it back to us for analysis. According to obtained information of Qualtrics website, 63 respondents were female and 87 were male. Most of the participants were in the range age between 35 and 45 years old and almost 87% of them had high education certification. Figure 8 displays the level of information about this carbon capture and especially the DAC technology among respondents.

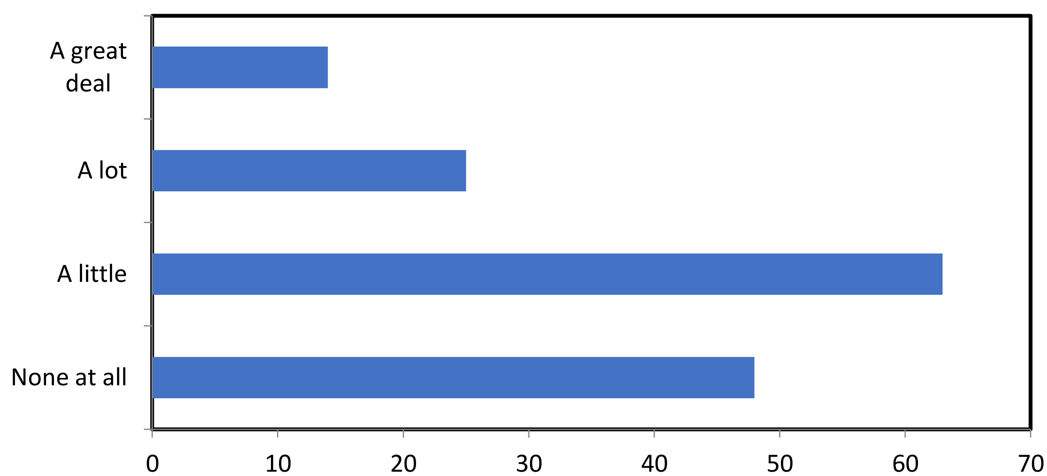

Figure 8: Knowledge level among respondents about DAC technology

Figure 8 reveals that around 75% of people participating to this survey did not sufficient knowledge about DAC and even carbon capture technology.

4.2. Sub-questions according to the data gathering

4.2.1. What are the critical environmental concerns to scaling up DAC technology? (Both supportive and discouraging)

- **Literature review outcomes:**

  some researchers believe that currently carbon capture especially direct air capture is the most effective and viable tool to reduce the climate change and only by this method human could reach to net zero target in 2050, although there are some environmental concerns about the developing of these industries in all around the words. Storage, transportation and also recycling of CO_2 for other purposes now are encountered as a hot topic among researchers and companies. Although these activities are beneficial for different industries and even the environment, in some cases they lead to the environment disasters. For instance, CO_2 leakage from the pipelines could lead to the asphyxiation of humans and animals and in the worst case results in contamination of ground water resources. Moreover**,** the sequestration of CO_2 in to the underground and also under ocean could change the formation of earth layers and also reduce the friction among the rocks; hence it may lead to the large seismic events. Additionally, noise pollution due to the big fans/rotary components (To suck ambient air) is another environmental problem of DAC plants. The noise pollution not only causes some health problems for human especially who live near these plants in long term but also has adverse effects on birds' migration and livestock. Furthermore, dumping of the toxic materials using in the air capture process is another concern of the environmentalists about this new technology.

- **Interview results:**

  Recarbn Company:

  Interviewee 1 believes that the DAC technology is an effective way to reduce CO_2 emissions in the atmosphere. Also, she declared that although the companies use the highest technology for transportation of the carbon dioxide, the CO_2 leakage is inevitable. Moreover, she explained the captured carbon is effective for the other industries such as oil and gas (enhanced oil recovery (EOR)), concrete and food industries. Additionally, Sophia believes that the new used sorbent/solvent for up taking of CO2 in the DAC plants are not toxic and will not pose a risk to the environment.

Carbotreat Company:

Similar to the Interviewee 1, the project manager of Carbotreat Company believed that carbon capture not only is beneficial for environment because of removing CO2 but also captured CO2 could be converted to alcohols and plastics as by-products. One of the substantial features of liquid carbon dioxide is the greenhouses horticulture. Research shows that using liquid CO2 has several advantages for improving the crop quality and growth. Additionally, injection of CO2 to empty gas fields (such as Porthos project in the North Sea) could prevent the probability of earthquake.

World resource Institute Company:

Unlike the Interviewee 1&2, the Interviewee 3 believes that the Carbon capture is not the most effective way for removing the CO2 content from atmosphere and reaching to net zero emission targets. He indicated that carbon capture along with the energy transition enables the governments to combat the climate change. Currently, some large oil and gas companies have invested several massive projects in the field of carbon capture and they are convinced the international community's that by execution of these project, the climate change problem will be solved (Green Washing)[4]. However, Interviewee 3 suspected to this assertion and he believes that the main of aim of these projects is for lobbying with governments to continue their activities in extraction of fossil fuels. Furthermore, while there several advance passive and active methods to control the noise in these days, the possibility of noise leakage and pollution is inevitable due to big fans in DAC plants.

4.2.2. What social factors contribute to public resistance to and acceptance of developing DAC plants?

- **Literature review outcomes:**

[4] Greenwashing is the process of conveying a false impression or misleading information about how a company's products are environmentally sound.

In general the renewable energy technologies or industries related to this always face opposition and scepticism by the people and also there are several uncertainties to accept these high-tech technologies by public (Wüstenhagen, 2007). Nowadays, climate change has resulted in serious challenges more or less for people in all around the world. Drought, flood and heat waves are some obvious consequence of the climate change. Therefore, finding a reliable and accurate method to solve climate change problem is a global request. However, the people live in the sensitive countries (drought areas) are more supportive of the carbon capture industries (Anderson, 2012). Additionally, public awareness has positive relation with the acceptance of the carbon capture industries. For instance, the results of a survey show that in the UK and Netherlands, people were positive about the construction of the industrial CCS in their countries although they had specific concerns (Broecks, 2021). Economic condition encounters the other key factor in public acceptance of the carbon capture industries. As an illustration, a public survey in the Brazil depicted that governmental investment in the carbon capture infrastructures were not the priority of people in this country. More than half of population declared that other services such as creating of job opportunities, health condition and safety ought to be prioritized by the government (Lima, 2021).

Even though CCS and CCU have several benefits for human, there is a public opposition against developing of this technology in the world. Risk of CO2 injection to the underground and possibility of the CO2 leakage, the efficiency of this technology by considering the high maintenance cost, dependency to the fossil fuels, CO2 transport and also lack of hygienic trust to the carbonate foods contain the captured CO2 are determined as the prominent factors against the carbon capture industries by social. (Broecks, 2021), (Itaoka, 2005), (Perdan, 2017), (Jacobson, 2019).

- **Survey results: Social factors:**

Thanks to the social media, nowadays most of the people especially in advanced countries like Netherlands are aware about the climate change and its negative impact in their life. Increasing of the ambient temperature and consequently raising the level of water could affect on Dutch residents life. Therefore, when we talk to the Dutch people, they have a proper knowledge about sustainability, environment and climate change, even though they did not enough knowledge about carbon capture industries and particularly DAC technology. In order to obtain the public attitude, a questionnaire with 13 questions were prepared and using Qualtrics website (https://utwentebs.eu.qualtrics.com/) the electronic version of this questionnaire was prepared and sent for Dutch residents. This survey contains 13 questions in two parts, 4 general questions and 9 specific questions (See Appendix A). The results of general questions were shown in the section 5-1. To prepare specific questions, we designed our questions based on the Dutch context. For example, unlike the large countries such as the USA and Canada, the land usage is viewed as a prominent challenge in the Netherlands (Koelman, 2022) and we considered this problem in our survey. In the following, the results of the surveys to specific questions are indicated.

Question 6 & 7:

Figure 9 displays the public attitude in accordance of living near to the DAC plants and also construction of several plants in the Netherlands.

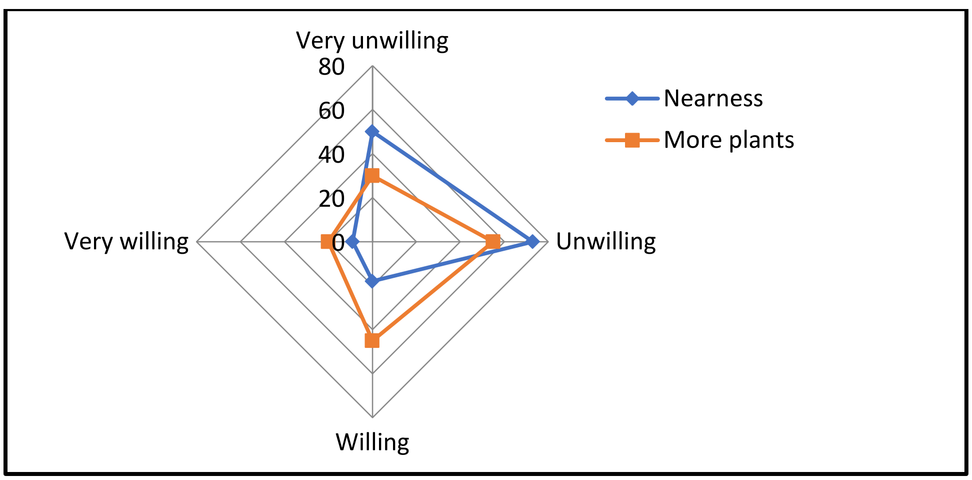

Figure 9: Public Willingness to live near to large plants and construction of more DAC plants

The results show that around 85% of the people contributed in this survey did not tend to live near the large industries like DAC plants. Also, based on the data presented in chart number 9, there is a general opposition among people towards the construction of multiple DAC plants in the Netherlands (around 68%), albeit with a slight variation.

Question 8:

Based on the information gathered from Figure 10, it can be concluded that Dutch residents perceive the DAC technology to have no detrimental impact on the tourism industry in their country.

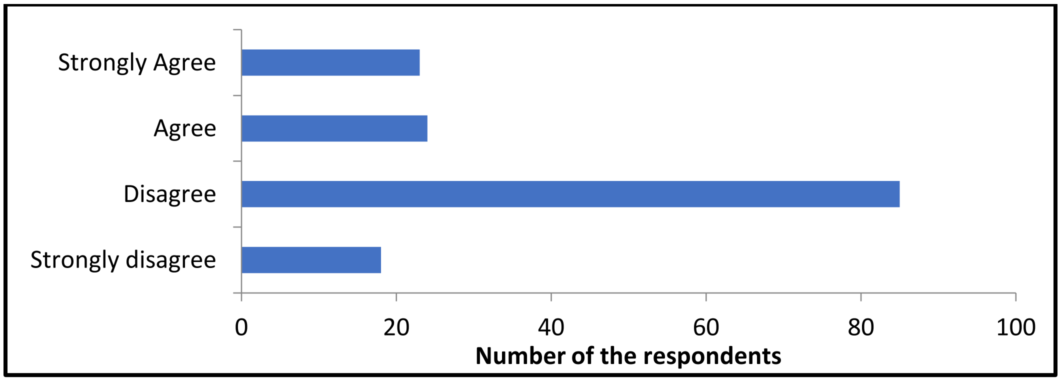

Figure 10: Allocation of the governmental subsidies and construction of new renewable energy for possible DAC plants

Question 9 & 10:

Figure 11 depicts the public perception on allocation of the governmental subsidies for DAC plants and also construction more infrastructures for renewable energy (wind and solar farms) to provide sufficient energy for the DAC plants. The data indicates that Dutch citizens are not in favour of providing government incentives for the development of the DAC industry in the Netherlands. However, there is a favourable opinion among the Dutch population regarding the use of renewable energy as a power source for DAC plants.

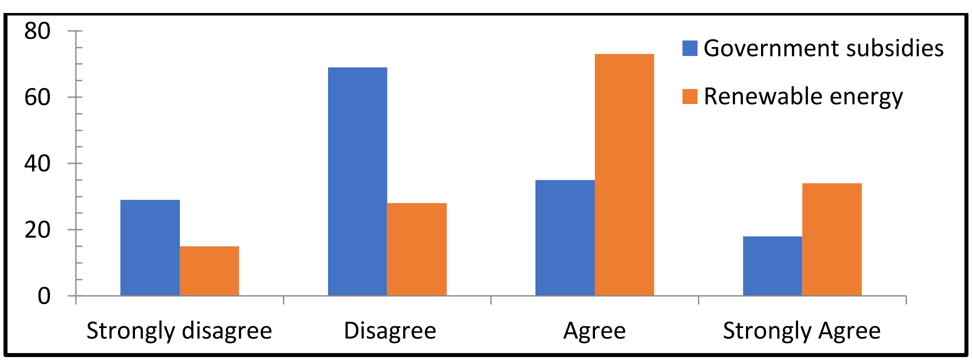

Figure 11:Allocation of the governmental subsidies and renewable energy to the DAC plants based on the Dutch context

Question 11 & 12:

According to the Figure 12, the respondents are not willing to consume the foods that the captured carbon from the DAC plants is one of their ingredients. Moreover, they believe that storage of captured CO2 underground or under the ocean near the Netherlands is a threat to their survival.

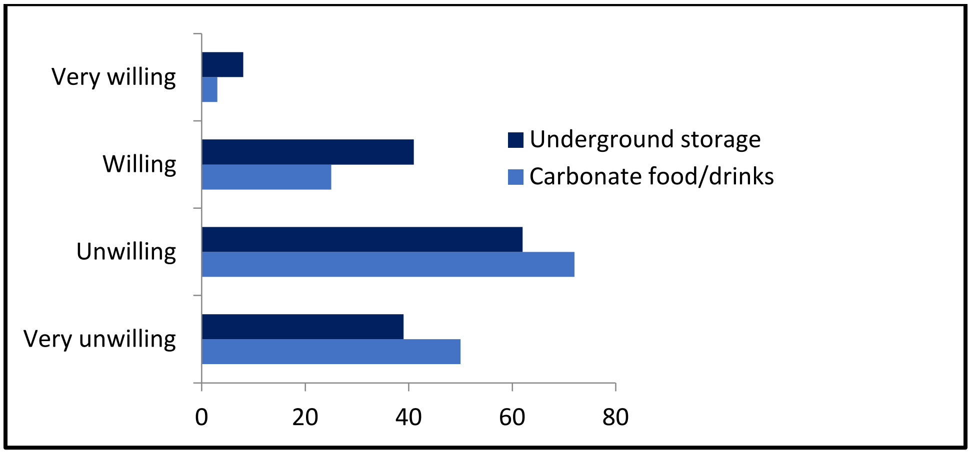

Figure 12: Public attitude toward using foods contained captured CO2 from the ambient air and underground storage of the CO2

Question 13:

Regarding to chart 13, most of the respondents mentioned the DAC technology would be a reasonable method in order to solve the climate change challenge or at least mitigate the negative effects of this global problem**.**

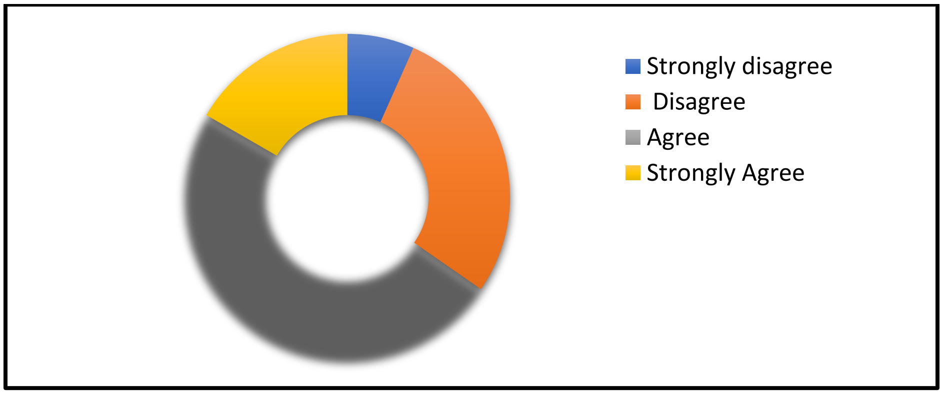

Figure 13: DAC approach to combat climate change

4.3. How does energy consumption and policy pose a challenge for or enable the development of direct air capture plants?

- **Literature review outcomes:**

One of the main barriers to widespread use of the DAC plants is energy consumption. The process of direct air release is more energy intensive rather than the point source methods (McQueen, 2021). This is because the CO2 gas in the atmosphere is much more dilute than flue gas of a flare in oil and gas industries; hence it needs more energy and cost to capture the CO2 (Brazzola) in comparison with the other carbon capture methods. Both DAC technologies, Solid DAC (S-DAC) and Liquid DAC (L-DAC) require heat to their process for carbon dioxide removal (CDR). Currently, natural gas is used to provide sufficient heat for these DAC technologies. However, in order to mitigate the dependency of DAC methods to fossil fuels, scientists proposed two new approaches, Electro-Swing adsorption (ESA) and Membrane-Based DAC (M-DAC). In these two methods, by changing the thermo-dynamic process, scientists could diminish the energy consumption in DAC plants (Lackner, 2013). These new DAC technologies are in their infancy and there are several challenges (Require expensive compressor) to replace them with the current DAC process (Fujikawa, 2021).

Utilizing low-carbon fuels such as hydrogen, wind and solar energies are the other recommended methods to provide enough energy for DAC plants (Lackner, 2013). Public resistance against building more wind or solar farms especially in the Netherlands could be viewed as a challenge in using the renewable energy for DAC plants (Reitsma, 2020), (De Leeuw, 2014). Furthermore, although using the hydrogen is an appropriate option for DAC plants, there are some uncertainties to use hydrogen as a reliable fuel (Need to infrastructures, high cost and high flammability).

Combination of Air Source Heat Pump (ASHP) and DAC technologies leads to mitigate energy consumption in the DAC plants. Diagram 14 shows the process of DAC plant along with the heat pump technology (Leonzio, 2022). Results show that not only the energy consumption will reduce remarkably but also the efficiency of DAC plant increase (Breyer, 2020). Complex installation, high cost of the maintenance and leakage risk in the heat pump are obvious scepticisms of this hybrid technology (Leonzio, 2022).

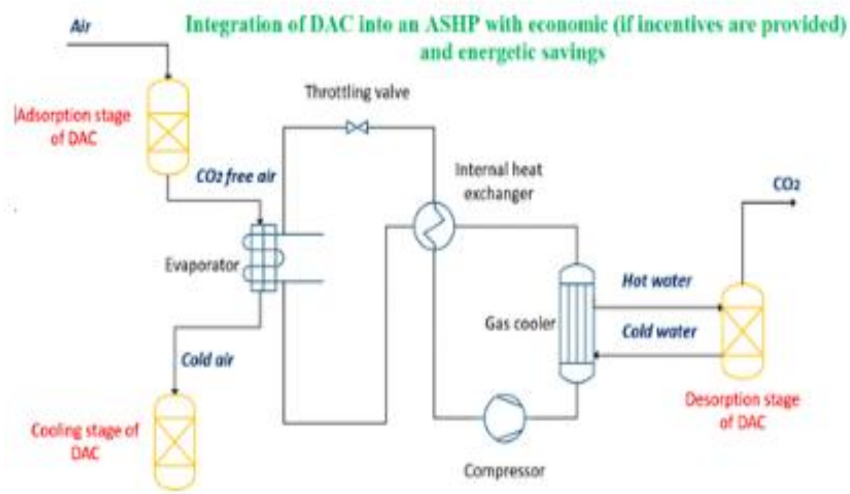

Figure 14: Integration of the Direct Air Capture and Air Source Heat Pump (Leonzio, 2022)

- **Interview results:**

All of the interviewees accepted the fact that currently the carbon capture industries particularly the DAC technology consume a lot of energy. Sophia and Frank believe that nowadays the DAC technology is a niche market and needs time to improve and increase its' efficiency. They indicated that currently, all companies active in this field are trying to find the reliable methods for reducing the rate of energy consumption in this technology. Using Renewable energy, modification in the chemical process and using efficient materials are potential strategies that could help to mitigate the energy consumption of this technology.

Interviewee A also indicated that identifying the "precise solutions need sufficient budget and unlike the USA, there is no governmental support for Direct Air Capture". Also, she declared that although "there are some active and expert companies in the Netherlands in this field, the received incentives from the government are insignificant, and it prevents the companies to invest in this technology". However, project manager company B believes that "the level of knowledge not only among the people but also the government is negligible". "Thus, the companies should increase the general information among the people to push the government to provide determined policies for promoting of this industry and donate sufficient budget for solving all of the problems in this technology such as energy consumption".

4.4. How we can represent the Dutch environmental, energy, and social contexts relevant for DAC using Fuzzy Cognitive Method (FCM)?

To explore the diffusion of DAC technology in the Netherlands and also providing the accurate policies in this regard, first a comprehensive FCM map based on the main pillars of the MLP frame work was created and then by defining scenarios the main variable to develop of the DAC in the Netherlands will be determined. It is worthy that the components, connections and also weighting factors in FCM were identified using literature review, interview with experts and survey.

4.4.1. Fuzzy Cognitive Model results

According to obtained data (literature review, surveys and interview with experts), we can categorize the components in FCM in four main categories: environmental, social, energy (cost) and government. The main components are shown in Table 7.

Table 7: Main components of the FCM map

Category	Component	Category	Component
A1: Environmental	CO2 Leakage	B6:Social	Visual impact
A2: Environmental	CO2 Storage	B7:Social	Scale of project
A3: Environmental	Biodiversity Destruction	C1:Energy	Companies
A4: Environmental	CO2 reduction	C2:Energy	Energy consumption
A5: Environmental	Climate change	C3:Energy	Availability of renewable energy
A6: Environmental	Toxic materials	C4:Energy	Fossil fuels use
A7: Environmental	Water consumption	C5:Energy	New Process
B1:Social	Vicinity to DAC plants	C6:Energy	New Technology
B2:Social	Land usage	D1:Governmental	Government
B3:Social	People (Dutch citizen)	D2: Governmental	Subsidies for DAC and energy
B4:Social	Noise pollution	D3: Governmental	Manufacturers
B5:Social	Knowledge of DAC	D4: Governmental	Economic cost

Additionally, Figure 15 displays the proposed FCM map for developing the DAC technology in the Netherlands according the main features of the MLP framework. Also, regarding to the obtained information from the literature review, survey and interviews, the linkages among the components are determined and tabulated in Table 8.

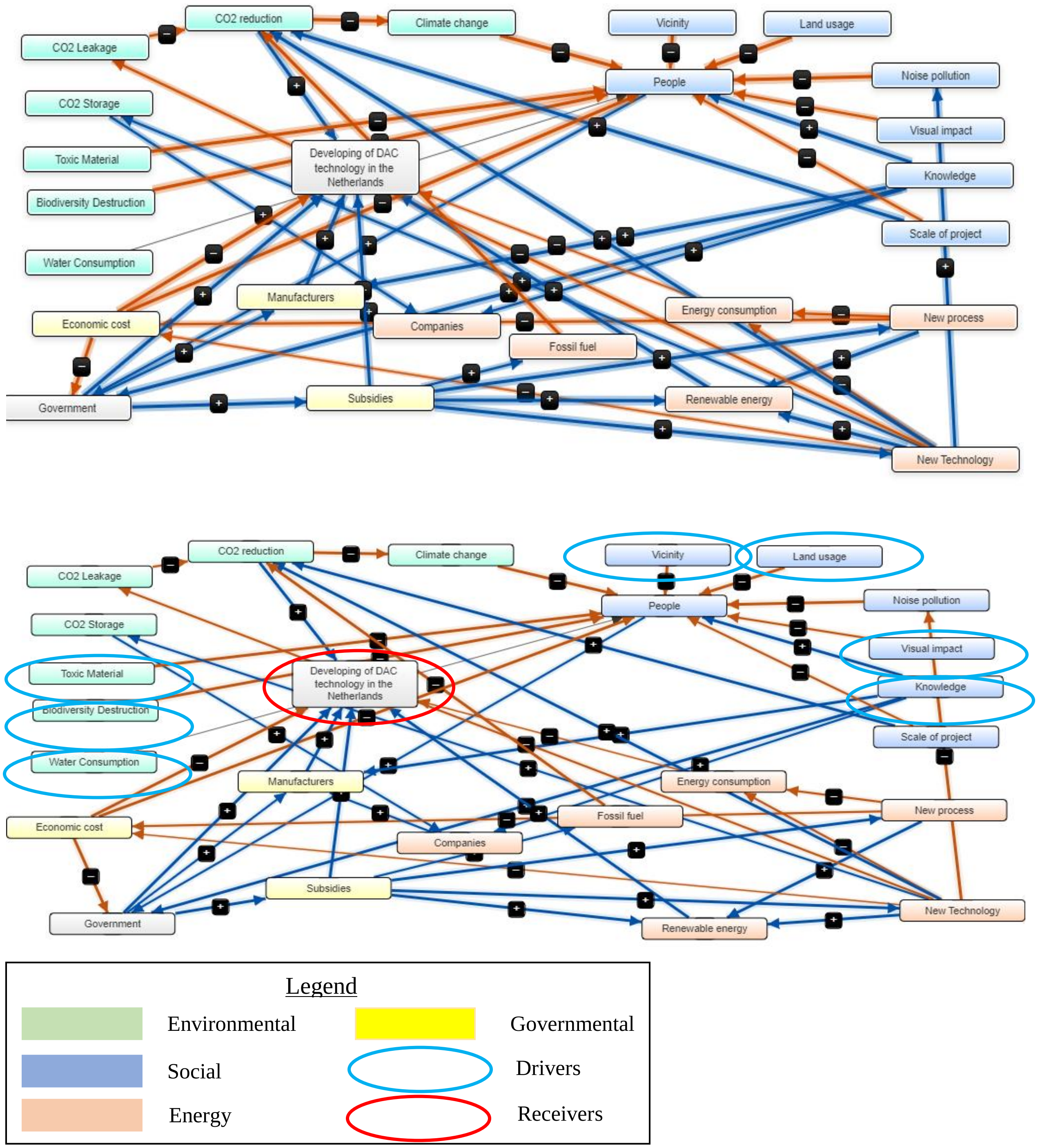

Figure 15: Fuzzy Cognitive map for developing of DAC technology in the Netherlands

4.4.2. Justification of the FCM

The justification of the relations suggested in the FCM is presented in Table 8. The number of degrees of interaction for each link between nodes is based on the data collection for the specific case of the DAC from a Dutch perspective. In this table the source of theses relations and also the fuzzy weights are displayed. To provide a more simplistic overview of the weight in the model, the only weights used are: -1 (extreme negative influence), -0.5 (moderate negative influence), 0.0 (neutral influence), 0.5 (moderate positive influence) and 1 (extreme positive influence). This simplification is used to align the value of the relation to the aggregation of the nodes.

Table 8: The justification of the FCM

Item	From	To	Relation Value	Justification
1	CO2 Leakage	CO2 reduction	-0.5	CO2 leakage caused environmental problems especially under seas (Changing the PH of water)- (Blackford, 2009)- (Mirzavand, 2022)- (Damen, 2006)
2	CO2 Storage	Companies	+1	Using of captured carbon in drilling and food industries. (Hunt, 2010)-
3	Toxic materials	People	-1	People disagree with industries with toxic waste. (Based on survey) –(Lindell, 1983)- (Based on survey)
4	Biodiversity Destruction	People	-1	Biodiversity is important for Dutch Residents (Based on)
5	Water Consumption	Biodiversity Destruction	-0.5	Lack of water causes a lot of challenges for plants and animals. (Scherer, 2016)
6	Water Consumption	People	-1	Companies that consume large volume of water bring problems for people especially who live near them. (Lambooy, 2011)
7	CO2 Storage	People	-0.5	People disagree to store CO2 near their living areas. (Based on survey)
8	CO2 reduction	Climate change	-1	CO2 reduction equals to solve the climate change problem. (Mikhaylov, 2020)
9	CO2 reduction	Development of DAC	+1	The main aim of the DAC technology is CO2 reduction
10	Climate change	People	-1	Nowadays, thanks to media, Dutch people have a good knowledge about climate change consequence. (Biesbroek,

				2011)
16	Vicinity	People	-1	People do not agree to live near DAC plants. (Based on the survey)
17	Land usage	People	-0.5	Farmers do not agree to construct several DAC plants in their fields. (Based on the survey)
18	Noise pollution	People	-0.5	Individuals are unwilling to reside in locations characterized by high levels of noise pollution.
19	Visual impact	People	-0.5	People believe that DAC plants do not have any effect on scenic view. (Based on the survey)
20	Scale of project	People	-0.5	People are not interested in living large industries in the Netherlands. (Based on the survey)
21	Scale of project	CO2 reduction	+1	The larger the scale of the project the higher the amount of CO2 capturing.
22	knowledge	manufacturers	+0.5	General awareness has strongly positive impact on manufacturers and companies viewpoint.
23	knowledge	government	+1	The governmental duties are based on knowledge driver factors, therefore a positive relation between the nodes. (Van der Duin, 2009)
24	knowledge	companies	+0.5	General awareness has strongly positive impact on manufacturers and companies viewpoint.
25	New technology	Energy Consumption	-1	New technology could reduce the energy consumption of DAC technology. (Based on the expert interview)- (Leonzio, 2022)
26	New technology	CO2 reduction	+0.5	New technology is able to increase the performance and CO2 reduction. (Based on the expert interview)
27	New technology	CO2 Leakage	-0.5	New technologies could reduce the leakage in the pipelines and also detect the leakage very fast. (Zuo, 2020)
28	New technology	CO2 storage	+0.5	New technologies could help the companies to storage carbon and also utilizing of it in their industries. (Jiang, 2013)
29	New technology	Noise pollution	+1	Using muffler as a new technology could mitigate the noise pollution remarkably. (Jang, 2019)
30	New process	Energy Consumption	-0.5	Using the heat pump in the DAC process results in reducing the energy consumption. (Leonzio, 2022)
31	New process	Renewable energy	+1	Utilizing of Hydrogen as renewable energy in the decarbonisation process could reduce the amount of the energy consumption. (Based on the interview with expert)

32	New process	Economic cost	-0.5	Study and providing facilities for new process is costly. (Breyer, 2020)
33	New technology	Economic cost	-0.5	
34	Renewable Energy	Development of DAC	+0.5	More renewable energy, development of the DAC technology. (Based on expert interview, survey and (Reitsma, 2020))
35	Fossil fuels	CO2 reduction	-1	Burning of fossil fuels leads to increase the carbon content in the atmosphere. (Bauer, 2016)
36	Energy consumption	Development of DAC	-1	Consumption of high rate of energy is one of the main barriers to diffuse of the DAC technology. (Based on the interview with expert and (Leonzio, 2022))
37	Companies	Manufacturers	+0.5	Energy companies and also companies which need to recycle the ambient CO2 is a good motivation for manufacturers to invest in the field of carbon capture.
38	Subsidies	New process	+1	Based on the obtained information from the interviews with expert and literature review, providing sufficient budget is viewed as the main requirement for improving the new technology, new process and renewable energy for promoting of the DAC technology in the Netherlands.
39	Subsidies	New technology	+1	
40	Subsidies	Renewable energy	+1	
41	Subsidies	Development of DAC	+1	
42	Subsidies	Manufacturers	0.5	Receiving the governmental subsidies motivate manufacturers to concentrate on construction of DAC method. (Based on the Interview with experts)
43	Manufacturers	Development of DAC	+0.5	Intention of the manufactures to construct the new DAC plants helps to diffuse of this technology in the Netherlands.
44	Economic cost	People	-0.5	The overall population has a negative relation with increasing costs.
45	Economic cost	Government	-1	Government are not willing to expand its annual budget in large scale.
46	Government	Subsidies	+1	Government plays important role in allocation of the subsidies.
47	Government	Development of DAC	+1	Government decision making has direct impact on developing of DAC technology and also increasing of general knowledge among people.
48	Government	Manufacturers	+0.5	Government orientation could motivate manufacturers to develop DAC technology.

4.4.3. Structural analysis of Fuzzy Cognitive Map

The structural analysis shows that the FCM includes 25 components (7 drivers, 1 receivers and 16 ordinary) with 48 connections. The variable type, outdegree, indegree, centrality, complexity score, density and connection per component are given in the Table 9. Indegree, outdegree and Centrality were calculated with equations 1-3. Developing of the DAC technology, people and CO2 reduction are considered as the elements with significant indegree values. Moreover, the three components with the highest outdegree values are new technology, knowledge and economic cost. Also, developing of the DAC technology, people and new technology has the most considerable centrality values among all of the defined variables. Receivers are components that be influenced by other variables. Drivers could influence the other components and they cannot be controlled with other concepts. In this mind map the value of connection per component is 1.8. The complexity score, calculated as the ratio of the number of receivers to the number of drivers, is 0.14. Additionally, the density of the system is 0.075, which represents the clustering coefficient and indicates the level of connectivity within the entire system.

Table 9: Structural Analysis of FCM

Item	Component	Indegree	Outdegree	Centrality	Type
1	Developing of DAC technology in the Netherlands	6.49	0	6.49	Reciever
2	CO2 Leakage	1	1	2	ordinary
3	CO2 reduction	5	2	7	ordinary
4	Climate change	1	2	3	ordinary
5	CO2 Storage	1.5	3	4.5	ordinary
6	Toxic Material	0	0.5	0.5	driver
7	Biodiversity Destruction	1	1	2	ordinary
8	Water Consumption	0	1	1	driver
9	Vicinity	0	0.5	0.5	driver
10	Land usage	0.5	0.5	1	ordinary
11	Noise pollution	0	0.5	0.5	driver
12	Visual impact	0.5	0.5	1	ordinary
13	People	6.79	1.41	8.2	ordinary
14	Knowledge	0	3.5	3.5	ordinary
15	Scale of project	0	4	4	driver

16	Energy consumption	2	2	4	ordinary
17	New process	1	1	2	ordinary
18	New Technology	1	5	6	ordinary
19	Renewable energy	1	2	3	ordinary
20	Fossil fuel	0	3	3	driver
21	Companies	1.5	2.44	3.94	ordinary
22	Economic cost	0	1	1	driver
23	Government	2.5	2.5	5	ordinary
24	Subsidies	1	1	2	ordinary
25	Manufacturers	1.5	1	2.5	ordinary

Total Components	25	Density	0.075
Total Connections	48	Number of receiver components	1
Connections per component	1.8	Number of driver components	7
Complexity Score	0.14	Number of ordinary components	16

4.5. What scenarios are derived from the FCM to improve DAC diffusion? Where are the key intervention points? Who are the key stakeholders that need to be involved?

Defining scenarios is considered the best method for analyzing the FCM results (Nápoles, 2018). In other words, by considering the FCM as a transfer function, the scenarios could be viewed as the input signals to this transfer function, and these inputs (scenarios) can affect the final goal. Therefore, with the lowest consequences and cost, it is possible to obtain a deep understanding of the impacts of inputs on the outcomes.

According to the obtained information, it is obvious that currently the DAC technology not only in the Netherlands but also in all around the world is in the Niche innovation stage; hence this technology requires extra momentums to promote to the Socio-technical and Socio-technical landscape (Exogenous context) regimes. Based on the interview with experts, survey and also the literature review, lack of general knowledge among people, governmental subsidies, technical knowledge are the substantial pillars to develop the carbon capture industry in the Netherlands. Therefore, regarding to these main columns, four different scenarios were defined to discuss the most influential drivers to influence barriers against diffusion of the DAC technology.

4.5.1. “Knowledge strategy” scenario

According to interview with companies, survey and also literature review, the "Knowledge strategy" scenario was formulated. Around 70% of respondents to survey were not familiar to the carbon capture technology (see Figure 8) and also the positive points and disadvantages of it, although most of them were educated people or were studying in high education level. Additionally, even though the DAC plants lead to reduction of carbon content in the atmosphere, there are some negative side effects such as energy consumption and environmental pollution. However, Researchers and companies demonstrated that by creation of new process and utilizing the new technology, most of the barriers against developing of the DAC technology could be eliminated. Increasing the level knowledge among the people leads their willingness to push the government and also companies to construct more DAC plants in The Netherlands and also motivate the researchers and engineers to find feasible and practical solutions to increase the performance and also reduce the negative consequences of DAC technology. Assessment of the role of knowledge (Technical and General) in diffusion of the DAC technology in the Netherlands is the main goal of this scenario. Figure 16 displays the impact of increasing of knowledge on other components in the defined FCM. 30 percent increase in developing of DAC, 65% and 56% decrease in climate change and energy consumption respectively and 85% increase in people acceptance are the key outcome of this scenario.

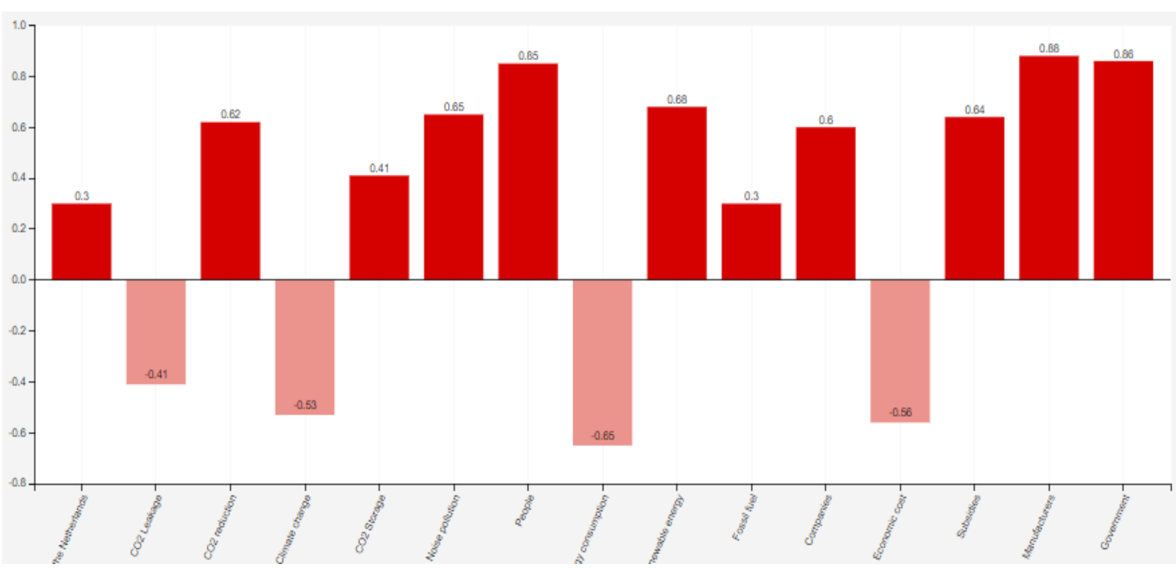

Figure 16:“Knowledge strategy” scenario - Increase the level of general and technical knowledge

4.5.2. "Public attitude" scenario

Public attitude is one of the main factors to develop of DAC technology particularly in a democratic country like The Netherlands in comparison with the other countries. The negative public attitude could push the government to confine alloction of budget or susidies to companies to construct the carbon capture industries in the Netherlands. There is no comperhensive study in the field of public acceptance of DAC technology in the Netherlands, and also the companies working in this field do not enough information about public oreinetion toward developing of DAC plants in the Netherlands. Positive attitudes towards innovation and creativity foster an environment where individuals and companies are more likely to take risks and experiment with new ideas. Attitonally, People's attitudes and perceptions of technology can influence the overall adoption rate. If people are skeptical or perceive technology negatively, it might hinder widespread adoption and slow down progress. Therfore, in order to analyze the role of Dutch residents in promotion of the DAC industry in the Netherlands the second scenario was designed as public attitude effect. The influence of positive public attitude on other variables and also DAC development was shown in the Figure 17. 13% percent increase in developing of the DAC, 6% decrease in the energy consumption and 14 percent increase in using the renewable enrgy for providing the energy for DAC technology are the main results of this scenario.

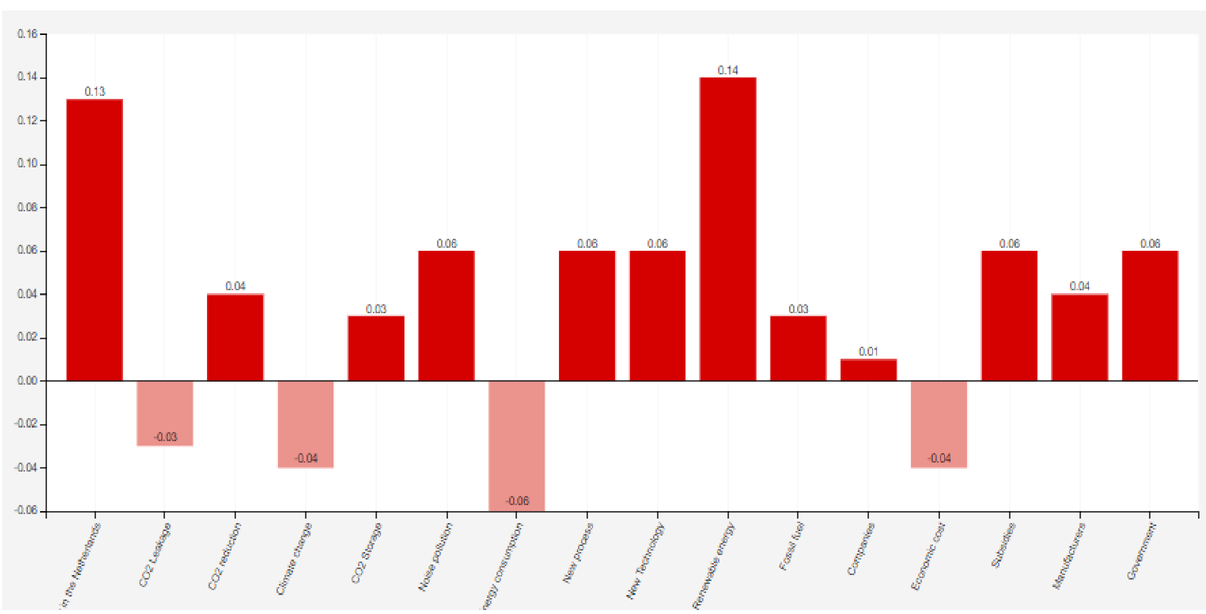

Figure 17: "Public attitude"- Public acceptance increase

4.5.3. "Governmental support" scenario

Interview with companies shows that lack of sufficient and determined subsidies accounts as one of main barriers that hampers the diffusion of the DAC technology in the Netherlands. Although there are some international agreements and projects for carbon capture in the Netherlands, currently there is no governmental tendency to expand the DAC technology in the Netherlands. The third scenario is determined based on the increasing the effect of government on the diffusion of the DAC technology in the Netherlands.

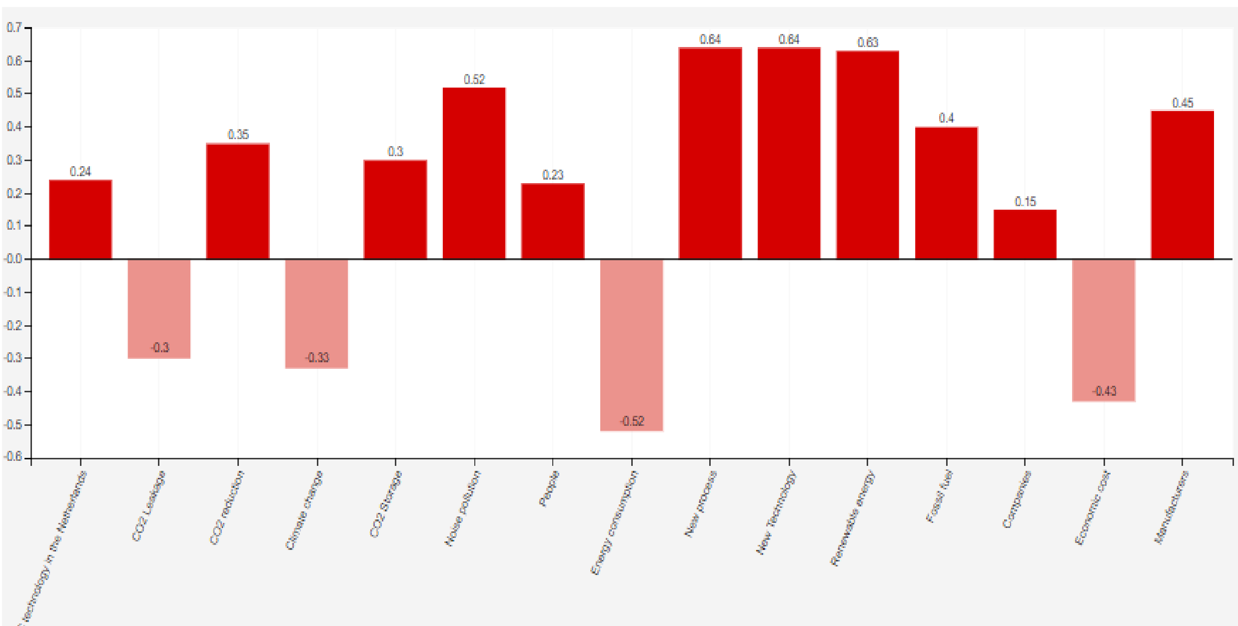

Figure 18: "Governmental support"- Effect of the Dutch government

The outcomes of this scenario in percentage increase and decrease are displayed in Figure 18. The key results are 24 percent increase in DAC development, 52 percent decrease in energy consumption and 64 percent increase in new technologies.

4.5.4. "Mixed" scenario

Scenario number 4 is defined in order to examine the parameters of government, social acceptance and knowledge on diffusion of the DAC technology simultaneously. Figure 19 displays the effect of these parameters on other components.

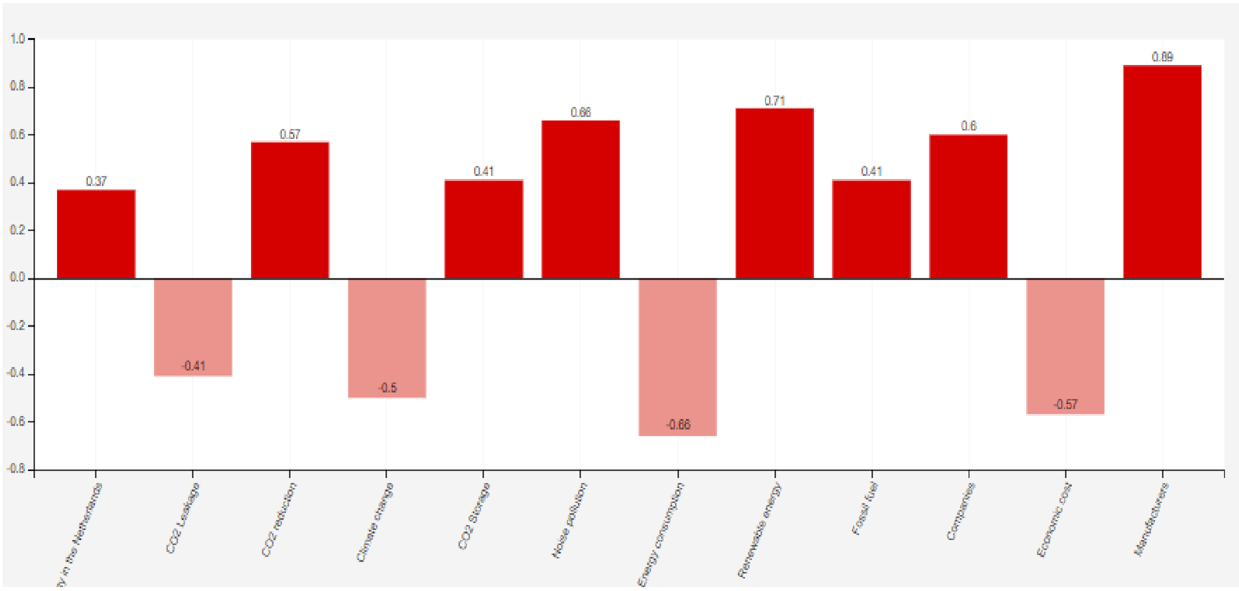

Figure 19: Combining the three previous scenarios

37% increase in development of the DAC technology, 89% increase in manufactures, 66% and 57% reduction in energy consumption and economic cost respectively are considered as the main outcomes of this scenario.

DISCUSSION

5.1. What are the critical environmental concerns to scaling up DAC technology? (Both supportive and discouraging)

The Intergovernmental Panel on Climate Change (IPCC) highlighted that, in order to achieve the main targets of Paris agreement and save our planet, human must accelerate reduction of the GHG emission significantly, and hence scientists introduced carbon captured methods particularly DAC method as a practical and quick ways to reach these goals. Independency of this method to carbon emission source and location is one of the main features of this method in comparison with the other carbon capture methods. Unlike the other carbon capture methods, DAC method is able to mitigate the carbon content of the atmosphere and it could help to obtain the net-zero goals. Currently, there are 19 DAC plants in the world, capturing around 10000 tco2/year, and this capacity should scale up to 60 Mt CO2/year by 2030. This level of deployment will require several large-scale plants in all around the world.

Even though this technology has numerous advantages for the climate change, it may cause some environmental concerns. According to the literature review, there are some environmental concerns about developing the DAC technology in the Netherlands. CO2 storage was one of the most important environmental concern barriers that scientists were encountered in different research. The risk of CO2 leakage to the ambient atmosphere is an important challenge that no one can deny it- even the most ardent supporters of this technology. Additionally, the CO2 leakage not only pollutes the air but also could be dangerous for living creature and biodiversity. Despite the third interviewee's confidence in the effectiveness of advanced monitoring technology, the possibility of CO2 leakage and its potential adverse consequences cannot be completely dismissed. There remains a concern that malfunctions in detecting such leaks could lead to an environmental disaster.

Water consumption of DAC is another environmental problem of this new technology. The liquid-DAC needs 1-7 tons of water to capture one ton CO2, but the solid sorbent-DAC plants do not require large amount of water in their process. Therefore, change the process of DAC plants from the liquid type to the solid plant could reduce the amount of water consumption remarkably.

Using the toxic materials in the DAC process was mentioned as another environmental concern of DAC technology. However, interview with experts indicated that using new and advanced polymer materials not only reduce the energy consumption but also decrease the poisonous property of absorbent materials. Therefore, using these environmentally friendly materials could potentially address the issue. However, their current high cost and early development stage necessitate further study before implementing them on a large scale.

5.2. What social factors contribute to public resistance to and acceptance of developing DAC plants?

The results of survey show that Dutch residents are familiar with climate change and its consequences. However, the general knowledge of people about carbon capture and especially the DAC method even among educated ones is not sufficient. In democratic countries like Netherlands, the role of people to grow a new technology is significant, thus the active companies in the carbon capture field should increase the level of information and reduce the concerns about this new technology among Dutch residents. The survey results shows that livings near large industries like DAC plants and storage of carbon underground or near the coastal areas were the most important concern of the respondents as a small population in the Netherlands. Also, the respondents agreed with using the renewable source of energy to provide the sufficient electricity for DAC plants in the Netherlands, but they disagree with paying the governmental subsidies to develop the DAC technology and also use food/beverages that contain the captured ambient CO2.

Moreover, interview with experts showed that they do not aware about public attitude toward DAC technology in The Netherlands, since they more focus on the technical aspects to decrease the other challenges such as the environmental and energy consumption. Even though the active companies in The Netherlands require governmental support, public pressure could be considered as important stimuli on government, there is not any comprehensive study on public attitude about this technology in this country and also they have no plans to raise awareness about this technology among people. Based on the survey results, it appears that Dutch residents are inclined to seek practical solutions for addressing climate change. This aspect could prove beneficial for companies aiming to raise public awareness about the new technology and, in turn, persuade the government to grant them governmental subsidies.

5.3. How does energy consumption and policy pose a challenge for or enable the development of direct air capture plants?

High energy consumption of the DAC plants is a critical aspect that could hamper development of this technology in the Netherlands. Currently, this technology requires natural gas (as a fossil fuel) for energy supply in its process. Burning of fossil fuel leads to increase the content of CO2 and this is in conflict with the main purpose of this technology. Additionally, Dutch government is going to mitigate the GHG emission to zero and acquire a safe, affordable and reliable low-carbon energy supply by 2050[5]. Therefore, in order to solve this exigent challenge scientists proposed several ways. Using low-carbon energy (renewable energy) sources such as solar, wind, biomass, geothermal and hydropower is one of the best solutions that could provide sufficient energy for DAC plants. Also, based on the obtained information of the survey, approximately 80% of respondents agreed with using renewable energy for DAC technology. High cost of infrastructures, availability of source of energy and skepticism in their performance are the important barriers to replace renewable energy to fossil fuels. Additionally, Dutch residents (Based on the survey) do not agree with allocation of governmental subsidies to the energy companies to expand the renewable energy infrastructures in the Netherlands.

Changing in the process is another practical way to reduce energy consumption of in the DAC technology. In ESA and M-DAC approaches by changing the heating process, the scientists reduced the rate of energy consumption in the DAC technology. However, currently these emerging methods are still in their early stage of development, and there are various hurdles, such as the need for costly compressors, that must be overcome before they can fully replace the existing DAC process.

Using Heat pump and also Heat exchanger (as new technologies) to compensate sufficient heat could reduce the amount of the energy for heating process in the DAC technology. The computerized simulations outcomes show that utilizing the heat pump in the DAC process not only diminish energy usage but also increase the efficiency of the DAC plant. However, this hybrid technology faces evident uncertainties due to challenges like intricate installation and expensive maintenance costs.

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[5] All details were outlined in the Energy Agreement for Sustainable Growth. (for more details: https://www.government.nl/documents/publications/2013/09/06/energy-agreement-for-sustainable-growth)

5.4. How we can represent the Dutch environmental, energy, and social contexts relevant for DAC using Fuzzy Cognitive Method (FCM)?

A fuzzy cognitive map (FCM) is a mathematical modeling tool used to represent and analyze complex systems or relationships between concepts. It is a type of cognitive map that incorporates fuzzy logic, allowing for degrees of uncertainty or vagueness in the relationships between concepts. To explore of the development of the DAC technology in the Netherlands, a FCM map was designed in this research.

MLP theory was applied to design the FCM for developing of this technology in The Netherlands from niche level to regime level. Therefore, the challenges and barriers classified in three dimensions (environmental concerns, energy consumption and social resistance) and the possible and realistic solutions according the MLP theory such as knowledge, governmental supports, positive network effect and research & development were defined as the components in this map. Whole of defined components in the FCM were displayed in the Table 7. Regarding to the data gathering (literature review, surveys and interview with companies) all of the relations, connections and fuzzy weights were determined (see Tables 8 &9).

According to Table 9, there are 25 components and 48 linkages between the variables. Also, out of these variables, 7 are drivers, 1 receiver and rest of the components are ordinary.

5.5. What scenarios are derived from the FCM to improve DAC diffusion? Where are the key intervention points? Who are the key stakeholders that need to be involved?

According to obtained data, four practical scenarios were designed to recognize how the defined variables in the FCM result in developing of the DAC technology in the Netherlands. Regarding to the literature review and interview with companies, it is clear that DAC technology requires more technical progress to overcome its weakness points. Also, the questionnaire outcomes displayed that the Dutch residents do not possess sufficient information about this new technology. Therefore, the first scenario was introduced based on the increase of knowledge among the society and companies. Table 10 exhibits the effect of raising the knowledge on the DAC development and also other important related components.

Table 10: Results of "Knowledge strategy" scenario

Concepts	Percentage change	Concepts	Percentage change
DAC development	30% ↑*	People	85% ↑
CO_2 Leakage	41% ↓	Energy consumption	65% ↓
CO_2 Storage	41% ↑	Government	85% ↑
Climate change	53% ↓	Economic costs	56% ↓

**Note: ↑ denotes Increase and ↓ means decrease*

According to Table 10, DAC development component, considered as the main target of FCM, increased by 30%. Also, the climate change and energy consumption as negative points decreased 53% and 65% respectively. Therefore, technology promotion and also increase the level of general knowledge among the people in the society lead to develop of the DAC technology in this country and mitigate its main barriers such as high economic cost, energy consumption and also the environmental concerns. Fasihi et al. (Fasihi, 2019), Leonzio et al. (Leonzio, 2022) and were point out the importance of new science and technology to reduce the energy consumption and solve other barriers against this promotion of DAC technology. Also, Sovacool et al. (Sovacool, 2022) stated that the increasing level of knowledge among people about the advantages of carbon capture industries acts as the catalyst to accept this new technology and it would be helpful for development of the DAC technology in the society that verify the outcome of the FCM.

These outcomes exhibit that implementation of this scenario is essential for promotion of DAC technology from niche innovation stage to regime level. However, there are several challenges involved in attaining these new processes and technologies. These challenges necessitate numerous scientific studies and the expertise of specialists from various disciplines (Based on interview with Recarbn Company).

Public acceptance plays a substantial role in Dutch government's decision-making process and policy implementation. By actively involving the public, fostering transparency, and addressing concerns, the government aims to ensure that policies and initiatives reflect societal needs and values, leading to greater public support and successful implementation. Therefore, the "Public attitude" scenario was designed according to increase the public acceptance among Dutch population. Table 11 portrayed the main positive and negative outcomes of second scenario on FCM components.

Table 11: Results of "Public attitude" scenario

Concepts	Percentage change	Concepts	Percentage change
DAC development	13% ↑*	Renewable energy	14% ↑
CO2 Leakage	3% ↓	Energy consumption	6% ↓
CO2 Storage	4% ↑	Government	6% ↑
Climate change	4% ↓	Economic costs	4% ↓

**Note: ↑ denotes Increase and ↓ means decrease*

Table 11 demonstrates that the expansion of DAC technology in the Netherlands is correlated with a rising rate of public acceptance, albeit at a slower pace compared to the first scenario. Based on the designed FCM, the public acceptance could push the government to pay more attention to DAC technology to ameliorate the negative consequences of the climate change (Sovacool, 2022) (Van Alphen, 2007). Even though the Dutch residents are not familiar to the carbon capture technologies, they have sufficient information about the climate change consequences[6,7], and it could be a positive driver for the government to invest in this technology in the Netherlands (Van Alphen, 2007).

"Governmental support" scenario was proposed to evaluate the role of the Dutch government in diffusion of the direct air capture. Table 12 exhibits the positive and negative impact of governments on other components.

Table 12: Results of "Governmental support" scenario

Concepts	Percentage change	Concepts	Percentage change
DAC development	24% ↑*	Renewable energy	62% ↑
CO2 Leakage	35% ↓	Energy consumption	52% ↓
CO2 Storage	30% ↑	New process/technology	64% ↑
Climate change	33% ↓	Economic costs	43% ↓

**Note: ↑ denotes Increase and ↓ means decrease*

Regarding to Table 12, governmental support not only has a beneficial impact of the development of DAC, new technology/process and renewable energy but also it could reduce the energy consumption and economic cost, and these results also could be verified with the obtained outcomes of Leonzio et al. (Leonzio, 2022) and Fujikawa (Fujikawa, 2021) researches.

[6] Based on my personal interactions, I found that the Dutch residents possessed accurate information regarding this pressing concern.

[7] Refer to website (https://www.eib.org/en/press/all/2021-357-majority-of-dutch-people-think-their-country-will-fail-to-drastically-reduce-carbon-emissions-by-2050)

Providing governmental political and economic supports has important positive influences on companies and manufacturers to invest and expand this technology in the Netherlands.

To assess the impacts of previous scenarios on development of DAC simultaneously, the "Mixed" scenario was defined. In this approach, the rate of the government, knowledge (public/ cutting edge technologies) and public acceptance were increased in the designed FCM in the same time. Table 13 depicts some of outcomes of this scenario.

Table 13: Results of "Mixed" scenario

Concepts	Percentage change	Concepts	Percentage change
DAC development	37% ↑*	Renewable energy	71% ↑
CO2 Leakage	41% ↓	Energy consumption	66% ↓
CO2 Storage	41% ↑	Economic costs	52% ↓
Climate change	50% ↓		

**Note: ↑ denotes Increase and ↓ means decrease*

The obtained results demonstrate that combination of all of the proposed drivers leads to increase the development of the DAC component in the FCM by 37%, which is more than the other scenarios.

The results of these scenarios show that all of the defined scenarios could be helpful to promote the DAC technology in the Netherlands. Technical knowledge is essential to diminish the negative side effects and raising the efficiency of this technology. Universities, scientific community and research & development department of companies could play important role to increase the science and new technologies/processes to develop the DAC industry in The Netherlands. Define common projects between universities and companies active in the field of the carbon capture could provide an important collaboration that not only solve the challenges of the DAC industry but also lead to wealth creation for companies and universities, and it could be considered as a win-win deal.

Moreover, in contemporary times, enhancing awareness regarding climate change and its potential solutions is effectively achieved through various channels, including social media, NGOs, E-learning platforms, and peer learning. To extend knowledge among the public, key stakeholders such as the government, educational institutions, communities, and civil society play crucial roles.

Although the increasing of general - scientific knowledge and public acceptance are important in the development of the DAC in the Netherlands, governmental support plays the most substantial role in promoting DAC technology within a society in my point of view. By providing strategic assistance, the government fosters this technology in this country. Measures can include financial incentives, tax breaks, subsidies, grants, and favorable regulations tailored to the specific needs of this industry. Additionally, the government can collaborate with industry stakeholders to develop long-term strategies and roadmaps, fostering a conducive environment for DAC technology.

CONCLUSION AND RECOMMENDATIONS

Today GHG emission and also climate change is one of the most dangerous global thread that endangered the life in our planet. Drought, increasing the average temperature, flood and lack of sufficient food are some examples of climate change. According to Paris agreement, in order to combat the climate change and mitigate the hazardous effects of it, the rise in mean global temperature must limit to 1.5 °C. To reach to these targets and reach net-zero, the GHG emission especially the CO2 should be reduced approximately to 50% by 2030. Carbon capture methods are considered as the one of the practical ways to diminish the CO2 in the atmosphere end-of-pipe" solution and they could pave the way to reach net-zero emission by 2050. Storage of the carbon and also utilizing of the captured carbon in different industries are viewed as other benefits of carbon captured technology.

There are several carbon captured methods, but the direct air captured method due to the novelty and substantial features (no dependency to the emission source /mobility) was explored in the Netherlands as one of the lead countries in green technologies in the world. The main aim of this research was to investigate the effect of barriers in development of the DAC in the country based on the MLP framework. According to this frame work, in order to diffuse of a new technology, different aspects of innovation such as social, cultural, economic and environmental should be explored, and also several aspects in order to promote of a new technology from niche level to regime or landscape levels were provided . Even though the DAC technology is beneficial for reducing the impacts of climate change, there are several challenges in scaling up of this technology particularly in the Netherlands including: energy, environmental and social barriers. Literature review, a survey with 150 Dutch residents and three interviews with active companies in the field of the carbon capture method were the primary sources of data gathering in this study. Regarding to this information the most significant environmental, social and energy concerns in diffusion of DAC based on the Dutch context were identified and tabulated in the Table 7.

Moreover, a Fuzzy Cognitive Map was designed to explore the influence of these barriers on development of DAC. All variables, linkages and the fuzzy weights were identified based on the obtained information. The technology readiness level of DAC is currently at level 6 on a scale of 1 to 9. This indicates that DAC is still in the stage of large-scale testing and prototyping (Niche innovation stage), and it has not yet reached a stage where it is ready for full commercial deployment. Consequently, this technology requires effective supports (momentum) to develop in commercial stage (Transfer from niche innovation stage to the regime or landscape level).

To investigate these dynamics, four different scenarios were established. The initial scenario focused on enhancing the general and technical knowledge. The findings from the FCM analysis showed a significant 30% increase in the DAC development. Additionally, the results of the second scenario, which addressed the public acceptance, exhibited a notable 14% progress in DAC development element. The third scenario highlighted the significance of governmental support. By increasing the government's role, DAC development in the Netherlands experienced a notable 24% improvement. Furthermore, the fourth scenario integrated all these factors together to assess their combined effect on DAC technology. The results demonstrated a substantial 37% increase in the DAC development variable, indicating the positive impact of synergistic momentum from multiple factors. Based on these scenarios, it can be inferred that increasing governmental support and technical knowledge would be more beneficial in developing Direct Air Capture (DAC) technology in the Netherlands compared to other factors. Currently, the Netherlands lacks subsidies and a policy framework for the development of DAC technology, unlike the USA (45Q tax credit, California’s Low-Carbon Fuel Standard), which hinders the scaling up of this technology and addressing the negative effects of the DAC industry. Therefore, a strong suggestion is for the Dutch government to extend support to companies operating within this domain, through means such as subsidies, grants, and tax exemptions. Such support would not only contribute to mitigating the challenges of climate change but also foster increased employment opportunities and economic prosperity within the nation.

Furthermore, the level of knowledge about carbon capture among Dutch residents is not satisfactory, and there is no significant public pressure on the government to prioritize this technology as a key solution for combating climate change. Consequently, it is recommended that NGOs and start-ups make greater efforts to enhance the general knowledge level among the Dutch population. Using online platforms, celebrities and influencers can help reach a wider audience and generate interest among Dutch residents especially Z generation about this cutting edge technology.

In the course of this study, certain limitations were encountered. These included the absence of a pilot or actual DAC (Direct Air Capture) facility in the Netherlands. Therefore, establishing collaborations with technology providers, particularly in Europe, is highly advisable. Additionally, due to time constraints, our research was based on a sample of 150 surveys and three interviews. To enhance the accuracy of outcomes, particularly concerning public perception, a recommendation is to expand the use of surveys in future research efforts.

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APPENDIX A:

Survey questions

Resistance against developing of Direct Air Capture: the case of the Netherlands

My name is Pouyan Ali Mouri and I am currently a master's student of energy and environmental management at University of Twente. I am writing my final thesis about exploring the feasibility of scaling up Direct Air Capture (DAC) technology in the Netherlands. Direct air capture (DAC) is a technology that involves capturing carbon dioxide (CO2) directly from the air and storing it or utilizing it for various purposes, such as creating renewable fuels or as a feedstock for chemical processes (Figure 1). However, there are several social, energy, and environmental barriers against the development of this technology particularly in the Netherlands.

Aim of the study: This survey aims to investigate the different challenges in relation to the development of the DAC plants and also propose practical solutions to improve the diffusion of this technology in the Netherlands.

Ethical consideration: All of the collected data from the survey is stored securely and they will be deleted after the 60 days.

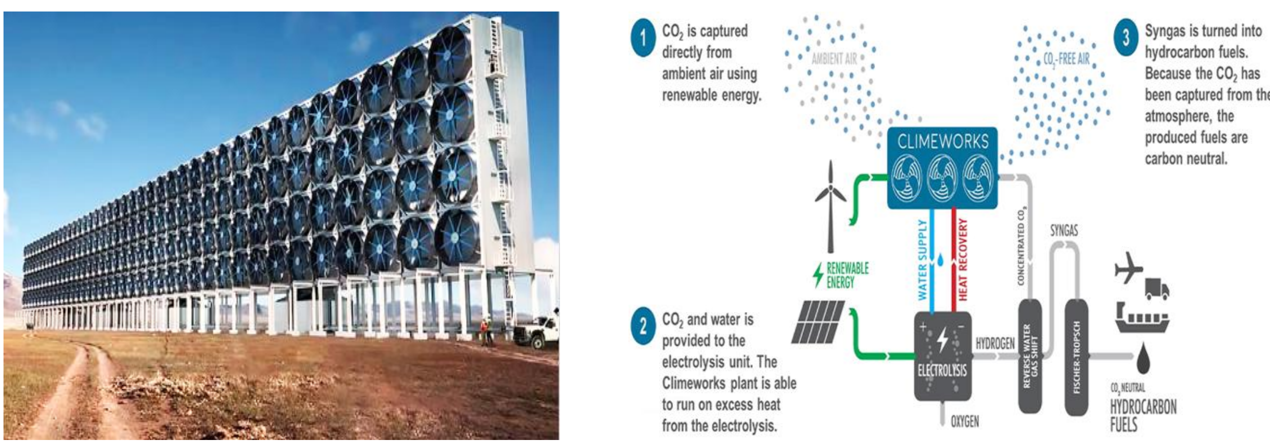

Figure 1: Direct Air Capture technology

Your willingness to participate in the survey

1. Are you willing to participate in this research? ☐Yes ☐ No

General questions

2. What is your gender?

a. Female   b. Male   c. non-binary / third gender   d. Prefer not to say

3. What is your age range?

a. 18 - 30 years old   b. 31 - 45 years old   c. 45-65 years old   d. more than 65

4. What is your level of education?

a. Diploma   b. Bachelor's degree   c. Master's degree   d. PhD degree and more

Specialized questions

5. On a scale of 1 to 4, how much do you know about carbon capture technology, especially Direct Air Capture? (1 being "not knowledgeable" and 4 being "very knowledgeable")

a.1 b.2 c.3 d.4

6. On a scale of 1 to 4, how willing are you to live near large plants such as DAC plants? ("1-Very unwilling; 2- Unwilling; 3- Willing; 4- Very willing")

a.1 b.2 c.3 d.4

7. On a scale of 1 to 4, considering of limited land availability in the Netherlands, what is your opinion about the construction of several large DAC plants in this country? ("1-Very unwilling; 2- Unwilling; 3- Willing; 4- Very willing")

a.1 b.2 c.3 d.4

8. On a scale of 1 to 4, how much do you agree or disagree that building large plants or industrial installations, such as a DAC plant, has adverse effects on tourism? ("1-Strongly disagree, 2- Disagree, 3-Agree, 4- Strongly agree")

a.1 b.2 c.3 d.4

9. On a scale of 1 to 4, to what extent do you agree with the government allocating subsidies to private companies for the construction of DAC plants in the Netherlands? ("1-Strongly disagree, 2-Disagree, 3-Agree, 4- Strongly agree")

a.1 b.2 c.3 d.4

10. On a scale of 1 to 4, how much do you agree or disagree with the strategy the constructing more offshore/onshore solar and wind farms in order to provide sufficient energy for DAC plants in the Netherlands? ("1-Strongly disagree, 2-Disagree, 3-Agree, 4- Strongly agree")

a.1 b.2 c.3 d.4

11. On a scale of 1 to 4, how interested are you in using foods that the captured carbon from the DAC is one of their ingredients (such as soft drinks or carbonated water)? ("1-Very unwilling; 2- Unwilling; 3- Willing; 4- Very willing")

a.1 b.2 c.3 d.4

12. On a scale of 1 to 4, what is your stance on storing captured carbon dioxide underground or under ocean near the Netherlands coast? ("1-Very unwilling; 2- Unwilling; 3- Willing; 4- Very willing")

a.1 b.2 c.3 d.4

13. On a scale of 1 to 4, how much do you agree or disagree that Direct Air Capture is the most reasonable way to solve the climate change problem? ("1-Strongly disagree, 2-Disagree, 3-Agree, 4- Strongly agree")

a.1 b.2 c.3 d.4

APPENDIX B:

Interview question

QUESTION 1: What specific Direct Air Capture technology (DAC) your company is performing or developing? How many DAC plants are being scheduled in Europe and particularly in the Netherlands?

QUESTION 2: What is the last status of the DAC technology in the Netherlands? What is the approach of the Dutch government toward this technology? Has a governmental grant been allocated for the construction of the DAC plant (practical/pilot) in the Netherlands?

QUESTION 3: Which requirements should be provided and by who, to motivate companies to investigate scaling up DAC technology in the Netherlands?

QUESTION 4: What are the main environmental barriers to DAC technology and carbon storage? (For instance, How can the leakage of stored carbon dioxide be prevented?)

QUESTION 5: What social factors contribute to public resistance to developing DAC plants in the Netherlands? (For instance, what are the health problems for people living near DAC plants?)-

QUESTION 6: How do energy consumption and policy pose a challenge to the development of direct air capture plants in the Netherlands? What can be done technically to reduce the energy consumption of this technology?

QUESTION 7: Is it currently economical to use this technology for reducing the amount of CO2? If not, what measures should be taken to make this technology economically viable? How feasible are these measures?

QUESTION 8: Among the social, environmental, energy consumption, economic, and policy concerns/barriers for DAC, which are the most significant in your opinion and why?

QUESTION 9: How do you predict the future of this technology globally and also in the Netherlands?

APPENDIX C:

Consent form

CONSENT FORM

CONSENT FORM TO TAKE PART IN A RESEARCH INTERVIEW

Research Topic: Resistance against developing of Direct Air Capture: The case of the Netherlands

Taking part in the study

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.

I understand that taking part in the study involves answering questions from a semi-structured questionnaire, note-taking by the researcher, audio recording of interview session which will be transcribed as text for effective data analysis (this will be destroyed once the research is completed)

I understand that in any report on the results of the research, my identity will remain anonymous if preferred to be so.

I understand that I am entitled to access the information I have provided after the interview and I have the right to request for modification, clarification, or changes where applicable.

I understand that I am free to contact the researcher for further clarification and information.

Use of the information in the study

I understand that the information I provide will be treated confidentially and used strictly for research purpose/master thesis report writing.

Consent to be Audio Recorded

I agree to be audio recorded.

Signatures

Frank Sanders		02-05-2023
The participant	**Signature**	**Date**
Pouyan Ali Mouri		
Researcher	**Signature**	**Date**

p.alimouri@student.utwente.nl

Dr. Steven Mcgreevy

Study Supervisor

CONSENT FORM

CONSENT FORM TO TAKE PART IN A RESEARCH INTERVIEW

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I agree to be audio recorded.

Signatures

Sophia Hummelman	S. Hummelman	10 May 2023
The participant	**Signature**	**Date**
Pouyan Ali Mouri		
Researcher	**Signature**	**Date**

p.alimouri@student.utwente.nl

Dr. Steven Mcgreevy

Study Supervisor

CONSENT FORM

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Consent to be Audio Recorded

I agree to be audio recorded.

Signatures

Behrouz Nouri	B.N	14/06/2023
The participant	**Signature**	**Date**
Pouyan Ali Mouri		
Researcher	**Signature**	**Date**

p.alimouri@student.utwente.nl

Dr. Steven Mcgreevy

Study Supervisor

APPENDIX D:

Ethical approval

Status: Approved by commission

The BMS ethical committee / Domain Humanities & Social Sciences has assessed the ethical aspects of your research project. On the basis of the information you provided, the committee does not have any ethical concerns regarding this research project. It is your responsibility to ensure that the research is carried out in line with the information provided in the application you submitted for ethical review. If you make changes to the proposal that affect the approach to research on humans, you must resubmit the changed project or grant agreement to the ethical committee with these changes highlighted.

Moreover, novel ethical issues may emerge while carrying out your research. It is important that you re-consider and discuss the ethical aspects and implications of your research regularly, and that you proceed as a responsible scientist.

Finally, your research is subject to regulations such as the EU General Data Protection Regulation (GDPR), the Code of Conduct for the use of personal data in Scientific Research by VSNU (the Association of Universities in the Netherlands), further codes of conduct that are applicable in your field, and the obligation to report a security incident (data breach or otherwise) at the UT.