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Carbon capture, utilization, and storage activities and sustainability reporting by oil and gas companies

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Summary

The thesis focuses on the oil and gas sector, which significantly contributes to releasing greenhouse gases that threaten the environment and fuel global warming. This research provides a critical overview of global and national carbon capture and storage, often seen as a tool to mitigate climate change. The study also assesses the engagement of oil and gas corporations in achieving Sustainable Development Goals and participating in the UNGC programme. Regression analysis is used to model the scale of (CCUS) projects and the active status of the United Nations Global Compact (UNGC) programme. The current study is organized into eight research questions that will be assessed through empirical inquiry utilizing various methodologies, such as a critical literature review, regression analysis, and content analysis. In addition, this study uses data from the Global CCS Institute, UNGC unpublished database, EIA, and World Energy Projection System (2021) to investigate the obstacles associated with CCUS.

Contents

Abbreviations

CATF-Clean Air Task Force

CCS-carbon capture and storage

CCU-carbon capture and utilization

CCUS-carbon capture utilization and storage

CO_2-carbon dioxide

COP-communication of progress

CSR- corporate social responsibility

EIA-U.S. Energy Information Administration

EOR-enhanced oil recovery

ETC-International Energy Transformation Commission

ETS-Emissions Trading System

EU-European Union

GHG-greenhouse gas

H2-hydrogen

IEA-International Energy Agency

IPCC-Intergovernmental Panel on Climate Change

MENA-(Middle East and North Africa)

MTCO2-million tonnes of CO2

Mtpa-one million tons per annum

NGO-Non-Governmental Organization

NORDICCS-The Nordic Competence Centre for CCS

NRE -Nouvelles Régulations Economiques

OLS-The Ordinary Least Squares

PSE-Public sector enterprise

SDG-Sustainable Development Goals

SME-Small and medium enterprises

UNGC-United nations global compact

WEPS-World Energy Projection System

1. Introduction

The preceding century has witnessed rapid industrialization, resulting in environmental degradation and climate change (Jiang et al., 2020). Carbon dioxide (CO_2) is the primary greenhouse gas that is responsible for the phenomenon of climate change (Wang et al., 2017). The combustion of natural gas and oil is a significant contributor to the emission of greenhouse gases (World in Data Ritchie et al., 2020). In 2021, oil and gas companies contributed to more than 50 percent of all CO_2 emissions, which poses a significant threat to the environment and causes global warming (World in data, Ritchie et al. 2020).

Carbon capture, utilization, and storage (CCUS) has been acknowledged as a crucial measure in mitigating climate change and advancing a sustainable and decarbonized future (Jiang et al., 2020). Chen et al. (2022) argues that CCUS is one of the logical methods to reduce greenhouse gas emissions and one of the most critical techniques to combat climate change, especially for companies that operate in the oil and gas industry (Chen et al., 2022). It is anticipated that Carbon capture and storage (CCS) will significantly reduce CO_2 emissions by up to 32 per cent by the year 2050, as per Jiang et al. (2020). There are two primary causes for CCUS's failure to meet expectations. First, the required investment has yet to be triggered on a significant scale (Wang et al., 2021). Second, CCUS investments are predominantly financed by public funds, including grants and state ownership, while private-sector investments are only partially leveraged (Wang et al., 2021). Several scholars suggest that business objectives and utilizing multiple financing methods are crucial for the success of CCUS initiatives (Herzog, 2011; Wang et al., 2021).

Regarding limiting global warming, the last few years have been marked by growing ambition from both countries and companies (Institute, 2021). However, commercial CCS ventures are still uncommon despite the potential significance of CCS technologies to climate change mitigation efforts (Institute, 2021). The technological barriers to these technologies are becoming more apparent, but the social barriers to their widespread adoption have yet to be thoroughly investigated (Pianta et al., 2021).

To attain the 2050 objectives of reducing global emissions by 32 per cent, as outlined by Jiang et al. (2020), it is crucial for corporations operating within the oil and gas industry to establish and execute sustainable development practices across their supply chain (Jiang et al., 2020). Sustainable development is founded on the basic requirements for human survival, and it seeks to extend human civilization via the interdependent and coordinated development of the economy, ecology, and human desires and requirements (Shang & Lv, 2023). Thus, Sustainable Development results in three components: economic prosperity, ecological security, and social stability (Shang & Lv, 2023). Additionally, Noreen et al. (2019) have stated that companies in the oil and gas industry highlight sustainability, which also includes adhering to health, safety, and environmental regulations and increasing their community obligations (NOREEN et al., 2019).

In response to addressing issues and implementing sustainable development practices, this research has focused on CCUS to determine if it is a viable method for mitigating climate change caused by greenhouse gas emissions. The present study has a twofold aim and makes a noteworthy contribution to the extant body of literature and empirical findings. The literature review examines the structure and advancement of CCS, particularly on the global and national levels. The secondary aim of the study is to evaluate the degree of commitment that oil and gas companies demonstrate in achieving Sustainable Development Goals (SDGs) through the United Nations Global Compact (UNGC) programme.

With this in mind, the present empirical investigation seeks to identify and examine the advancement of carbon storage in various countries, considering factors such as the status of the facility, the country in question, the capacity for storage, the industry of the facility, the date of operation, and the type of storage facility. Moreover, the objective of this study is also to examine the extent to which companies that have endorsed the United Nations Global Compact initiative incorporate CCUS as a means of mitigating the risks associated with carbon emissions, considering variables such as the geographical location, scale, and sub-sector of firms operating within the oil and gas industry.

The study has been structured around eight research inquiries, which will be evaluated through an empirical investigation utilizing various techniques, including literature review, quantitative research methods, and content analysis. The selection of the deductive method for this research was based on its systematic approach to examining research inquiries and validating or invalidating a hypothesis (Shinder & Cross, 2008). The research questions aid in comprehending the obstacles associated with CCUS and the peril of climate change.

Research Questions

RQ1: Does the cost of transportation and storage hinder the progress of CCUS?

RQ2: Are the general public's prevailing attitude and the government's policies towards Carbon Capture, Utilization, and Storage (CCUS) positive?

RQ3: How does the Paris Climate Summit of 2015 influence the development of CCS project capacity over time?

RQ4: In what ways does CCS project capacity vary based on industry type?

RQ5: Which countries are more invested in CCUS, Global South or Global North?

RQ6: To what extent have oil and gas corporations made progress in mitigating climate change and contributing to Sustainable Development Goals?

RQ7: What is the level of commitment to the COP status within the United Nations

Global Compact programme and how does it impact active participation in the

programme?

RQ8: How does participation in the UNGC programme vary based on the industry?

subsector and the scale of the company?

As mentioned earlier, the complete spectrum of the research questions has been divided into two categories, with questions 1 and 2 undergoing extensive qualitative research and the remaining questions undergoing quantitative research. The investigation of CCS projects through an empirical analysis will help evaluate a set of research questions, namely the 3, 4, and 5, thereby furnishing significant revelations regarding the present status of CCUS projects worldwide, along with their constraints and prospects for advancement in the future. The Ordinary Least Squares (OLS) regression method was employed to determine the size of actual and planned CCUS projects. While research questions 6, 7, and 8 examine the dedication of oil and gas corporations toward the UNGC initiative. This analysis aids in comprehending the significance of the active involvement of oil and gas companies as emitters and the measures they have implemented to alleviate climate change. The research questions under consideration incorporate the organizational size, sub-sector, and location and assess the level of commitment towards Sustainable Development Goals (SDGs) through applying probit and Poisson regression techniques.

The present research delves into the relationship between CCUS and the UNGC initiative. The study employs data analysis and regression modelling techniques to demonstrate a correlation between CCS and the UNGC programme initiative. Oil and gas companies, which are significant contributors to the emission of greenhouse gases, are adopting CCS technologies and generating sustainability reports to alleviate the effects of climate change. The research presents a tabular representation of seven corporations actively participating in the UNGC programme and investing in CCS. The study also scrutinizes their prioritized SDGs. In general, this research elucidates the correlation between CCS and UNGC, underscoring the significance of corporate accountability in tackling the issue of climate change.

Additionally, the present study has addressed the following topics: The paper begins by examining the fundamental aspects of CCUS to enhance comprehension of its significance, followed by a comprehensive review of literature encompassing the worldwide and domestic dimensions of CCUS. The section about the Global Scenario will encompass the following elements: Projects related to CCUS on a global scale, as well as the factors that motivate the implementation of CCS technology. The global implementation of CCUS faces various challenges, including government policy, markets, and uncertainties surrounding cross-sectoral and multi-stakeholder investments.

Subsequently, upon comprehending the worldwide patterns of CCUS, the investigation was delimited to the national-level scenario segment, focusing on Norway as an exemplary nation. The ensuing discourse will encompass the following facets. First, this paper discusses the current state of CCUS in Norway, including the existing infrastructure for CO2 transport and storage, the incorporation of CCUS into climate change mitigation strategies, and the public's perception of CCUS.

2. Research Methodology and Data

2.1 Data and Methods

The present investigation employed data obtained from various databases, including the Global Carbon Capture Storage Institute, a globally recognized research organization specializing in providing data on CCS. A total of 197 carbon storage initiatives were documented during the period spanning from 1970 to 2030, with each initiative being at varying stages of implementation. Moreover, the data on UNGC programme was sourced from the unpublished database of the UNGC, covering the period from 2000 to 2022. The dataset comprised 785 companies engaged in the production of oil, gas, and coal. The U.S. Energy Information Administration (EIA) and the International Energy Agency (IEA) databases were developed to evaluate carbon storage and capture endeavours from 2020 to 2030.

The study's empirical section will utilize quantitative methods and descriptive statistics to investigate the expansion of CCUS capacity growth on both a global and national scale. Furthermore, a summary of CCUS initiatives will be provided. OLS regression will be utilized to model the CCUS projects. The utilization of probit regression is intended to model the participation status of the UN Global Compact. The study will employ probit and poison models to examine the probability of oil and gas corporations adopting CCUS methods and committing to endorse any of the 17 Sustainable Development Goals. Several regression models were used with the statistical software Stata to investigate the research questions.

3. Conceptual background

Establishing long-term shared value in the carbon collection and utilization context is a multifaceted issue that may demand a comprehensive strategy (Ilinova et al., 2018). Stakeholder theory is a valuable framework for comprehending the requirements and expectations of numerous stakeholders involved in CCUS (Freeman, 1984; Ilinova et al., 2018). According to Freeman's (1984) theory, organizations should consider the concerns of all stakeholders, such as employees, customers, suppliers, and the environment, to attain sustainable and ethical practices (Freeman, 1984). This study utilized stakeholder theory to investigate CCUS, with the aim of comprehending the needs and expectations of various stakeholders engaged in both CCUS and the UNGC programme.

The recognition of the business case for sustainability has led to the implementation of sustainability management practices, as Hahn (2022) noted. The assertion posits that prioritizing sustainability initiatives is a financially beneficial strategy for companies, thereby rendering sustainable practices a prudent business conduct, irrespective of ethical implications (Hahn, 2022). Sustainability-related concerns have been recognized as significant risks in multiple sectors, such as business, academia, NGOs, and governments, as per Hahn's (2022) findings. According to Hahn (2022), sustainability-related risks are among the top five that can cause a significant impact. Specifically, climate action failure, biodiversity loss, and natural resource crises are three risks (Hahn, 2022).

3.1 CCUS and Sustainable Development

The exploration of CCS as a means of reducing greenhouse gas emissions has been undertaken within the framework of sustainable development, as discussed by Benson and Orr (2008) (Benson & Orr, 2008). The Intergovernmental Panel on Climate Change (IPCC) has employed CCS as a means of assessing prospective approaches to mitigating climate change (Change, 2014). Sustainable development is frequently defined by the third principle of the Rio Declaration (1992), which emphasizes the right to development to satisfy the needs of present and future generations (Karimi et al., 2016). Politicians, especially in countries wealthy in fossil fuels, consider CCS a bridge to a sustainable energy future and the most straightforward route to sustainable growth (Karimi et al., 2016).

One of the theories associated with deploying CCUS is the stakeholder theory. The "stakeholder theory" is an alternative firm theory developed by Freeman (1984). The phenomenon that Freeman attempts to explain is the connection between the firm and its external environment, as well as its behavior within this environment (Key, 1999). Business and Society scholars who have examined the relationship between a company and its external environment have produced a large body of literature on corporate social responsibility, responsiveness, and corporate social performance (Key, 1999).

Regarding business operations and corporate governance, the stakeholder theory is advocated as a replacement for this system (Jennings & Happel, 2002). Stakeholder theory is distinctive in that it spans the disciplines of business ethics, management, and corporate law. Although it is a single theory, it is applied in various ways in these fields. The cross-cutting character of stakeholder theory implies that it is a universal concept (Jennings & Happel, 2002). This makes Stakeholder theory highly applicable to both the CCUS and UNGC programs.

The expensive cost of carbon capture has impeded CCUS technology (Yao et al., 2018). There are no viable business models for the widespread deployment of CCUS technology due to a need for associated engineering practices and business activities (Yao et al., 2018). Yao et al. (2018) assert that it is imperative to assess external factors at the business model level, particularly for initiatives that entail a protracted supply chain and intricate stakeholder associations, such as carbon capture, utilization, and storage (CCUS) projects. Carbon capture, utilization, and storage (CCUS) may entail the participation of various stakeholders from diverse industries such as electricity generation, coal, chemical, oil and gas, transportation, and others (Yao et al., 2018).

Although CCUS relies primarily on existing technologies, and there are examples of large-scale demonstrations of these technologies in combination, it is best viewed as a 'new' technology for which no existing business model (Muslemani et al., 2020). The context of CCUS business models is models for sustainable practices. The combination of technologies remains an indispensable and crucial enabler for meeting urgent climate targets (Muslemani et al., 2020). It assures a sustainable and responsible use of fossil fuels in the coming decades and a safe transition to renewables in the longer term (Muslemani et al., 2020). However, the absence of viable business models has prevented governments and the private sector from accessing this market and advancing technology (Muslemani et al., 2020).

To quickly reach carbon neutrality on a worldwide scale and reduce greenhouse gas emissions, CCUS technology is essential (Zhang, 2021). Absorbing CO2 from fuel gas or the atmosphere, then transferring it for usage or long-term storage is the basis of CCUS technology (Chen et al., 2022). According to Zhang (2021), the high costs and long planning horizons that result from CCUS projects are more likely to be resolved by adopting adequate and stable incentives set by the CCUS legislation. Furthermore, stakeholders can make long-term and sustainable financial commitments if the legal framework has clearly defined objectives and indicators for risk management and commercialization support of CCUS (Zhang, 2021).

3.2 Analysing carbon capture utilization and carbon capture storage

The CCUS comprises Carbon capture storage (CCS) and Carbon capture utilization (CCU). Around 260 million tons of human-caused CO2 have been safely stored, demonstrating the efficacy of CCS in mitigating climate change (IEAGHG, 2023)d. The design of CCS infrastructures is characterized by an inherent combinatorial complexity containing a multi-echelon array of technological possibilities, ranging from the different capture plants to minimize CO2 emissions to the variety of transport methods leading to sequestration in deep geologic basins (d'Amore et al., 2021).

Additionally, both CCU and CCS have the potential to offer benefits in mitigating the impending issue of climate change through the reduction of carbon dioxide emissions (Philbin, 2020). In conjunction with implementing alternative sustainable technologies, such as solar, wind, tidal, and hydroelectric power generation, as well as the transition to electric vehicles for transportation purposes, this will facilitate the attainment of global objectives (Philbin, 2020). While CCU may have a lower potential for reducing carbon dioxide (CO2) levels than CCS, it still offers a viable approach for mitigating CO2 emissions and generating value-added materials that can be utilized in the circular economy framework (Philbin, 2020).

As opposed to the process of carbon capture and storage, the utilization of captured carbon (CCU) frequently results in the postponement of carbon dioxide released into the atmosphere for a designated duration (Ballal et al., 2023). The primary advantages of CCU are connected to decreased reliance on fossil carbon sources. Therefore, they are desirable options for CCUs because they can convert a waste product CO2 into fuels by reacting with H2 (hydrogen), which in turn reduces the risks and costs of deploying H2-based infrastructure (Ballal et al., 2023).

The Climate Action Tracker estimates that the nations and areas that have adopted or are seriously considering adopting carbon-neutral objectives account for more than 70 percent of global emissions (Chen et al., 2022). In addition, the formation of a global agreement on the need for carbon neutrality has led to the search for technological choices that are both more cost-effective and more comprehensive while also presenting the lowest potential risk (Chen et al., 2022). For example, according to the Europe Carbon Capture Project and Activity Map created by the Clean Air Task Force (CATF), twelve nations have announced plans to implement carbon capture technology (see Table 1) (Chen et al., 2022).

Table 1: Countries that announce plans to implement Carbon capture technology.

Greece	Italy	United Kingdom	France
Belgium	Germany	Iceland	Sweden
Denmark	Poland	Netherlands	Norway

Source: own illustration based on Chen et al. (2022).

The subsequent section will delve into the global carbon capture and storage outlook. This will serve as an initial point for analysing literature about CCS on a global scale to examine scholarly perspectives on CCS technology and CCUS more broadly.

4. Global Scenario of carbon capture utilization and Storage

4.1 Background

Neutral carbon capture and storage formulation is a rational method of reducing greenhouse gas emissions (Institute, 2021). Carbon capture and storage are often mentioned as transitional techniques toward a sustainable energy system (Herzog & Drake, 1996). CCS technology is required to mitigate climate change, delivering significant emissions savings to energy-intensive businesses (Institute, 2021). Achieving the objective of constraining the increase in global temperature to 1.5°C above pre-industrial levels necessitates the expeditious reduction of greenhouse gas emissions (Tracker, 2023). Specifically, it entails halving these emissions by 2030 and achieving carbon neutrality around the mid-point of the century (Tracker, 2023). However, almost all analyses conclude that reducing emissions quickly enough to keep within a 1.5°C carbon budget is impossible (Institute, 2021). According to Kearns et al. (2021), to mitigate global warming, it is imperative to reduce greenhouse gas emissions to net zero at the earliest opportunity (Kearns et al., 2021). In recent years, there has been a noticeable escalation in the intricacy of climate change discourse. The current focus of the global climate change discussion is on achieving net-zero greenhouse gas emissions by the middle of the century by transforming the global economy (Institute, 2022). This goal necessitates the collaborative endeavours of all sectors responsible for the emission of greenhouse gases (Martin-Roberts et al., 2021). Furthermore, to achieve these goals, it has been projected that approximately 5.6 gigatonnes of carbon dioxide will need to be sequestered and stored annually by implementing CCS technologies by the year 2050 (Martin-Roberts et al., 2021).

To attain net neutrality and align with the objectives outlined in the Paris Agreement, the relevant stakeholders must take action to fulfil their climate change goals (Martin-Roberts et al., 2021; Institute 2021). According to the Institute (2021), there is a contention that the worldwide CCS sector must increase by over 100% by the year 2050 (Institute, 2022). An estimated 70 to 100 facilities will likely be required annually, generating up to 100,000 employment opportunities for construction workers and 30,000 to 40,000 positions for permanent operators and maintenance staff (Townsend & Gillespie, 2020). According to

Townsend and Gillespie's (2020) analysis of various scenario models, it has been determined that CCS plays a significant role in achieving long-term goals (Townsend & Gillespie, 2020). However, the current deployment rates of CCS still require enhancement (Townsend & Gillespie, 2020). According to the Institute (2021), the global market for CCS is projected to exceed that of natural gas within a few decades (Institute, 2022). This development is expected to contribute significantly to the growth of the low-emissions economy alongside renewable energy (Institute, 2022; Townsend & Gillespie, 2020).

Furthermore, CCS implementation beyond 2050 is extraordinarily unpredictable and impossible to estimate since policy and market conditions change, and the current CCS pipeline and CCS readiness assessments lose their validity (Townsend & Gillespie, 2020). In need of precise market data, it is feasible to base long-term assessments on the CCS deployment rate required to accomplish climate goals (Townsend & Gillespie, 2020; Martin-Roberts et al., 2021). Several plausible scenario models have been built that analyse the trade-offs between climate and socio-economic systems and provide insight into the spectrum of mitigation approaches necessary to meet long-term climate objectives (Townsend & Gillespie, 2020).

The level of ambition to achieve net-zero emissions by 2050 is necessary to avoid severe human involvement with the climate system, which necessitates an acceleration of investments in all forms of net-zero emissions solutions across all industries globally (Martin-Roberts et al., 2021). Simply put, the global response to climate change is shifting from aspiration to action, as seen by data on carbon capture and storage investment levels (Institute, 2022). Similarly, governments seeking the most cost-effective and efficient road to net zero identify CCS alongside all other mitigation alternatives as crucial to achieving climate goals and ensuring a just transition for society (Institute, 2022). Net-zero emissions may be assessed by the development of global CCUS projects (Townsend & Gillespie, 2020; Institute, 2022), which will be discussed in the following section.

4.2 Global CCUS Projects

The technology of CCS has undergone significant advancements since its initial deployment in Texas in 1971 (Loria & Bright, 2021). Approximately 90 comprehensive CCUS initiatives and over 150 projects exclusively focused on CO2 capture are being developed globally (IEA, 2023).

Many of these projects are intended to store the captured CO2 in one of the 40 CO2 storage hubs currently under development, as the Global CCS Institute reported in 2022 (Institute, 2022). According to the Global CCS Institute's research in 2022, the number of CCS projects under development had increased by 44 per cent, reaching a total of 196 as of September 2022 (Institute, 2022). The International Energy Agency (IEA) forecasts that CCUS can contribute to a 19 per cent decrease in GHG emissions by 2070 by reducing 6.9 Gt CO2e (CO2 equivalent) annually (IEA, 2023). Through CCS, CO2 is stored in deep underground reservoirs, whereas carbon capture and utilization produces CO2-derived products (Yoo et al., 2022).

The consistent and gradual rise in CCS initiatives observed from 2017 onwards underscores the growing worldwide inclination towards embracing this innovation to mitigate carbon emissions (Institute, 2022). The expeditious advancement of CCS initiatives portends a significant surge in the utilization of this technology in the foreseeable future (Institute, 2022; Bui et al., 2018). The expansion is imperative to alleviate the negative impacts of climate change resulting from the escalation of carbon emissions (Bui et al., 2018). Underground carbon dioxide sequestration presents a viable solution for mitigating carbon emissions without compromising our energy demands (Bui et al., 2018).

For decades, the private sector has helped establish the infrastructure and knowledge necessary to deliver millions of tons of CO2 to active and idle oilfields (Martin-Roberts et al., 2021). Among the world's twenty-one large-scale operational plants, nine are in the United States, each capturing more than 25 million tons annually (Martin-Roberts et al., 2021). However, it can be instructive to look at how other countries are performing with CCS projects to achieve climate targets (Martin-Roberts et al., 2021).

Twenty-four countries have made public policies for climate goals, and six have passed legislation mandating carbon-neutral development (Martin-Roberts et al., 2021). According to the Climate Action Tracker, these countries and regions are responsible for about 70 per cent of global emissions, highlighting the need for more cost-effective technological solutions and the broadest possible variety of risk-free technologies (Chen et al., 2022). The United States is leading the world in CCS expansion with its many large-scale projects. Since constructing the Terrell Natural Gas facility in the early 1970s (Martin-Roberts et al., 2021), the United States has been a global leader in using EOR-CCS technology (Martin-Roberts et al., 2021). In the United States, the importance of CO_2 to oil production and sales via EOR is a significant motive and driver for CCS capability (Martin-Roberts et al., 2021). Since the price of CO_2 is tied to the price of oil, CCS projects are more financially viable when oil prices are high, such as $70/barrel (Martin-Roberts et al., 2021).

The following table shows the Commercial CCS Facilities by Number and Total CO_2 Capture Capacity. Based on this, there are 30 operational CCS facilities of 197, which can capture 42.5 Mtpa of CO_2 (see Table 2).

Table 2: Commercial CCS Facilities by Number and Total Co2 Capture Capacity

	OPERATIONAL	IN CONSTRUCTION	ADVANCED DEVELOPMENT	EARLY DEVELOPMENT	OPERATION SUSPENDED	TOTAL
NUMBER OF FACILITIES	30	11	78	75	2	196
CAPTURE CAPACITY (MTPA)	42.5	9.6	97.6	91.8	2.3	243.9

Source: own illustration based on Institute (2022).

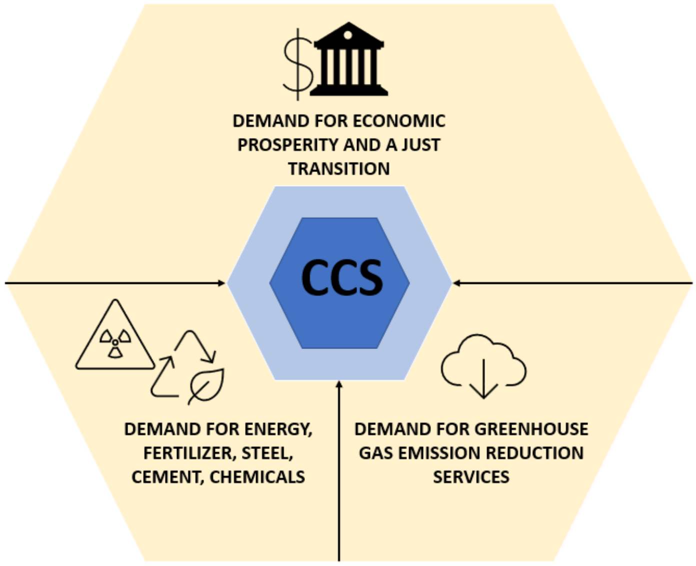
Implementing CCS is a crucial factor in attaining net-zero objectives and reducing the adverse effects of climate change that stem from carbon emissions, as noted by Martin-Roberts et al. (2021). According to Martin-Roberts et al. (2021), the present implementation rates of CCS initiatives can fulfil only about 10 per cent of the anticipated CO_2 storage capacity necessary by 2050 (Martin-Roberts et al. 2021). The current Scenario necessitates synchronized worldwide endeavours and substantial regulatory overhauls to attain the requisite storage capability. The cement, iron and steel, and chemical sectors, commonly referred to as "hard-to-abate" industries, present significant obstacles to decarbonization efforts, despite the potential of CCS technology (Institute, 2022).

Numerous corporations have implemented decarbonization tactics, particularly in sectors such as hydrogen production, natural gas processing, oil refining, power generation, chemical production, fertilizer production, bioenergy, waste incineration, synthetic natural gas, cement production, and methanol production (Institute, 2022). The endeavours of these corporations showcase the possibility of incorporating CCS technology to curtail carbon emissions and attain objectives of sustainable development (Institute, 2022).

The following section of the paper examines the factors that motivate the implementation of CCUS. Understanding the driving forces behind CCUS is critical as it enables us to identify the challenges associated with CCS and develop strategies to overcome them. This is essential for promoting the growth and development of CCUS projects worldwide.

4.3 Drivers for CCS

Figure 1: Demand Drivers for CCS



Source: own illustration based on Institute (2022).

Note: illustration (see figure 1) entails the concise representation of three fundamental components of demand that may be effectively employed during implementing Carbon Capture and Storage (CCS).

As the carbon budget associated with climate objectives decreases, the demand for emission reduction services will increase dramatically (Institute, 2022). This increased demand will require rapid sector expansion to provide essential businesses with emission-reduction services while supporting economic growth and job creation (Institute, 2022). Therefore, CCS is positioned at the intersection of critical demand generators and economic development, providing emission-reduction services to essential businesses while promoting economic growth and employment (Institute, 2022). The government recognizes the potential of CCS and continues strengthening its policies to encourage private-sector investment. North America, Europe, and the United Kingdom, leaders in CCS-related policy, have maintained or strengthened their positions over the past year (Institute, 2022).

If the price of CO2 emission allowances increases, CCS investment may become more economically viable than fossil fuel combustion without CCS (Pihkol et al., 2017). In addition, developing new business opportunities for CCU and CCS applications could generate enough revenue to cover CCS investment and operating costs (Pihkola et al., 2017). To realize this potential, however, it will be necessary to eliminate the present legislative barriers associated with CO2 transport by ship and to incorporate CCS into the European Union emission trading scheme (Pihkola et al., 2017). Pihkola et al. (2017) state that reducing greenhouse gas emissions substantially and swiftly is the primary social impetus for CCS.

According to Pihkola et al. (2017), post-combustion capture technologies are generally regarded as mature and frequently the only viable option for significantly reducing greenhouse gas emissions from existing fossil-fired power facilities. Critics, however, argue that implementing CCS in existing power plants would continue reliance on fossil fuels, which would be controversial given the need to reduce reliance on fossil fuels to combat global warming (Pihkola et al., 2017). The need for CCS is evident, as it can provide emission-reduction services while promoting economic growth and job creation. To attain net-zero goals through CCS objectives, regulatory reforms, and global coordination will be necessary (Martin-Roberts et al., 2021).

4.4 Challenges with the global implementation of CCUS

Implementing CCUS encounters numerous obstacles (Al-Mamoori et al., 2017). The transportation of carbon dioxide from land-based enterprises to the storage location poses a significant challenge in the carbon storage method due to the additional costs involved, including energy and expenses associated with carbon dioxide compression, as noted by Al-Mamoori et al. (2017). The indeterminate nature of these expenses poses a challenge in assessing the financial feasibility of carbon capture and storage initiatives (Al-Mamoori et al., 2017).

One of the challenges associated with CCS pertains to the unfavourable public perception linked to this technology, as Merk et al. (2022) noted. The unfavourable perception of the technology could stem from inadequate comprehension of its workings or apprehensions regarding its possible adverse impacts on nearby ecosystems (Braun, 2017). Swennenhuis et al. (2020) have observed that the implementation of CCS may need to be revised due to the resistance of labour unions towards environmentally sustainable measures in carbon-intensive industries (Swennenhuis et al., 2020). The authors Townsend and Gillespie (2020) suggest that it is essential to consider a typical gestation period of CCS projects, as well as the negative impact that short-term political cycles can have on investor confidence and pipeline stability for all CCS programmes (Townsend & Gillespie, 2020).

According to Mark et al. (2022), the utilization of CCU may be more advantageous than CCS due to its ability to capture CO2 as a renewable resource to produce fertilizers and inorganic carbonates (Merk et al., 2022). However, oil companies' complete integration of CO2 capture and enhanced oil recovery (EOR) technology within the coal, power, and other industries still needs to be completed. The complete industrial chain of CCUS-EOR has yet to be established noted by Kang et al. (2023). According to Kang et al. (2023), implementing CCUS-EOR may generate additional energy consumption, which could lead to the emission of pollutants and potentially impact the nearby ecological environment and personal safety (Kang et al., 2023).

The implementation of CCUS-EOR is faced with significant challenges, primarily stemming from its technical constraints (Kang et al., 2023). Kang et al. (2023) assert that effective implementation necessitates comprehensive demonstrations of reservoir type, physical properties, CO2 injection pressure, and mode (Kang et al., 2023). Furthermore, it is imperative to conduct efficient monitoring throughout the enhanced oil recovery (EOR) procedure to avert the occurrence of carbon dioxide (CO2) leakage and gas channelling within the geological formation, as posited by Kang et al. (2023).

To sum up, successfully deploying CCUS technologies entails overcoming various obstacles to attain the intended advantages. The development of effective strategies is of utmost importance in addressing the unfavourable public perception of CCS, as well as in integrating CO2 capture and Enhanced Oil Recovery (EOR) technologies utilized by oil companies in various industries such as coal and power (Merk et al., 2022; Kang et al., 2023; Townsend & Gillespie, 2020; Braun, 2017; Al-Mamoori et al., 2017). The formation of a complete industrial chain of CCUS and EOR is necessary to attain optimal benefits while mitigating any adverse impacts on the ecological environment and personal safety (Merk et al., 2022; Kang et al., 2023; Townsend & Gillespie, 2020; Braun, 2017; Al-Mamoori et al., 2017).

4.5 Government Policy and Markets

Governments play a crucial role in defining the energy and policy landscape, directly affecting the development of large-scale CCS projects (Ku et al., 2020). They establish the regulatory framework, designate emission requirements, and provide incentives for reducing emissions through research, development, and innovation assistance (Ku et al., 2020). In addition, regulatory systems, and political will for CCUS influence CO2 emission regulation, pricing, and incentives. For example, governments can impose emission fees, taxes, and tax credits, which can affect the competitiveness of fossil fuels in comparison to lower-carbon fuel or feedstock alternatives or the priority of technologies (Lipponen et al., 2017).

It is important to note that developing CCS initiatives requires significant international political commitment and leadership (Ku et al., 2020). Finding and evaluating viable geological storage sites can take years or even decades, and these initiatives typically span multiple budget cycles and require substantial investment (Ku et al., 2020). During the past decade, the political will for CCS initiatives has been tested, resulting in policy and funding fluctuations that can impede the development of these projects (Ku et al., 2020). Additionally, distinct government structures and regional decisions can either facilitate or impede the growth of CCUS (Ku et al., 2020).

Due to the hierarchical administration structure, a country's provinces, states, and other administrative divisions can display great diversity (Ku et al., 2020). In addition, international agreements and covenants are significant because they can promote coordination or impose limitations on implementing CCUS in practice (Ku et al., 2020). Finally, political will and priorities can alter in response to economic cycles, significant events, and leadership shifts. Establishing a deliberate strategy to transition from reliance on fossil fuels to deeper decarbonization requires policy stability and consistency in laws and incentives that reduce the risk of developing CCS projects (Ku et al., 2020).

4.6 Cross-sectoral, multi-stakeholder investment uncertainty

Uncertainty regarding cross-sectoral and multi-stakeholder investments is a significant barrier to deploying CCUS technology (Institute, 2021). The order of investment decisions for an integrated CCS project determines the success or failure of CCUS deployment (Greig & Uden, 2021). Exploration of potential CO2 storage resources, evaluation of multiple target sites, scoping and pre-feasibility studies of potential CO2 capture projects, engineering and field development planning, and environmental studies to inform the feasibility and permitting decisions for an integrated CCS project comprise the decision sequence (Greig & Uden, 2021). This sequence typically takes between 3 and 8 years, depending on location, permitting regimes, and emitter facility characteristics. Nonetheless, this decision sequence is highly unpredictable. Many actors operating in different sectors and with limited visibility across the value chain must establish mutual trust, resulting in counterparty risk (Greig & Uden, 2021).

Assessing the geological or subterranean CO2 storage capacity at the supply chain level is difficult, which can increase investment uncertainty (Hasan et al., 2022). No documented cases of CO2 leaking out of existing industrial CO2 storage facilities into the atmosphere (Krevor et al., 2023). During source-sink matching and risk assessment, only a few works contemplate these uncertainties (Hasan et al., 2022). Due to the need for more sophisticated instruments and methodologies, estimating CO2 sequestration capacity often relies on empirical correlations and oversimplified extrapolation techniques (Hasan et al., 2022). Estimating the extent of CO2 retention, leakage, and distribution within the reservoir over time is considerably more difficult, resulting in increased uncertainty (Hasan et al., 2022). In the chemical industry, process parameter uncertainty is virtually always present. Therefore, numerous PSE (Public sector enterprise) strategies for coping with uncertainty have been developed (Hasan et al., 2022).

5. National Scenario of carbon capture utilization and Storage (Norway)

5.1 The current CCUS scenario in Norway

For decades, Norway has been actively involved in CCS. Successful projects such as Sleipner and Snøhvit have stored more than 22 million tons of CO2 (Ku et al., 2020; Mikhelkis & Govindarajan, 2020; Martin-Roberts et al., 2021). The Sleipner CCS project has been operational for more than 20 years, playing a crucial role in managing CO2 and providing valuable data for site characterization and monitoring (Ku et al., 2020). Norway also established Gassnova as a state-run enterprise in 2005 to support CCS research, development, and deployment, focusing on industrial sources (Ku et al., 2020; Dütschke & Duscha, 2022). Moreover, Norway has maintained its lead in emission intensity, with zero emissions from competitive onshore hydro and wind (Mier et al., 2022).

The International CCS action plan was developed as a constituent of the climate settlement of 2007 to aid Norway's progression towards a carbon-neutral state and promote other countries to set targets for mitigating climate change (Roettereng, 2016). According to Jiang et al. (2020), Norway has undertaken various feasibility studies and executed extensive CCS projects through both autonomous efforts and global partnerships (Jiang et al. 2020). CCS projects are strongly supported in Norway rather than in Germany, the German government's plans for CCS depend on the feasibility of exporting CO2 for storage, while Norway plans to import CO2 for storage (Merk et al., 2022). The impact of importing or exporting on public opinion of the technology is still being investigated (Merk et al., 2022). The interest in CCUS differs significantly throughout Europe, which has been a prominent leader in international efforts to mitigate climate change (Ku et al., 2020). Norway has set ambitious climate objectives for reducing greenhouse gas emissions and aims to establish a regulatory and legal regime on both the international and domestic levels for CCUS (Martin-Roberts et al., 2021; Zhang, 2021).

The success of well-structured CCUS initiatives depends on various institutional and project-related factors (Wang et al., 2021). Norway's efforts to meet its climate objectives have led to early CCS advancements, which have been facilitated by financial incentives provided by the Norwegian government (Martin-Roberts et al., 2021). Norway’s interest in CCS can be traced back to its abundant geological resources, mainly offshore (Buhr & Hansson, 2011). The country's extensive offshore geological capabilities, combined with a widespread political consensus on the importance of CCS in meeting climate aspirations, have contributed to its continued leadership in the field (Buhr & Hansson, 2011).

Comparative research suggests that geological preconditions are crucial when exploring a country's attitude toward CCUS and mitigation categorization (Buhr & Hansson, 2011). For instance, a comparison between Sweden and Norway highlights the differences in geological preconditions and their implications for CCS (Buhr & Hansson, 2011). Buhr and Hansson (2011) argued that Sweden's potential for CO2 storage could be higher due to its geological proximity to natural reservoirs. In contrast, Norway's geological capability is vast, especially offshore (Buhr & Hansson, 2011). Thus, Norway's approach to CCS and mitigation categorization is heavily influenced by its geological preconditions, making it a leader in the field (Buhr & Hansson, 2011).

The Nordic Competence Centre for CCS (NORDICCS) has identified potential locations for carbon storage in the Nordic area based on geological features, availability, and related hazards (Mikhelkis & Govindarajan, 2020). According to their findings, the Nordic region has enough underground space to absorb 86 Gt of CO2, comparable to emissions over 554 years (Mikhelkis & Govindarajan, 2020). Additionally, the Norwegian continental shelf alone has the potential to absorb 29 billion tons of CO2 over a long period (Mikhelkis & Govindarajan, 2020). The Norwegian state has the proprietary right to subsea reservoirs on the continental shelf for extraction and CO2 storage and the sole right to manage those reservoirs (Directorate, 2017).

On the Norwegian continental margin, the Norwegian government facilitates the socioeconomically advantageous storage of carbon dioxide (Regjeringen, 2023). Companies with the requisite expertise and specific industrial plans necessitating storage on a commercial basis can submit to the Ministry of Petroleum and Energy for a license tailored to their business requirements (Regjeringen, 2023). The government will conduct a predictable, efficient, and adaptable process to grant appropriate storage options to industrial actors. To ensure competition, relevant areas for accolades will be announced, among other things (Regjeringen, 2023). Following the regulations governing the transport and storage of CO2 in subsea reservoirs on the continental shelf, the ministry ordinarily awards an exploration license before an exploitation license in each area (Regjeringen, 2023). Exploration licenses may be granted to one or more qualified businesses (Regjeringen, 2023). If multiple companies are granted a license, the ministry typically appoints one of them as an operator (Regjeringen, 2023).

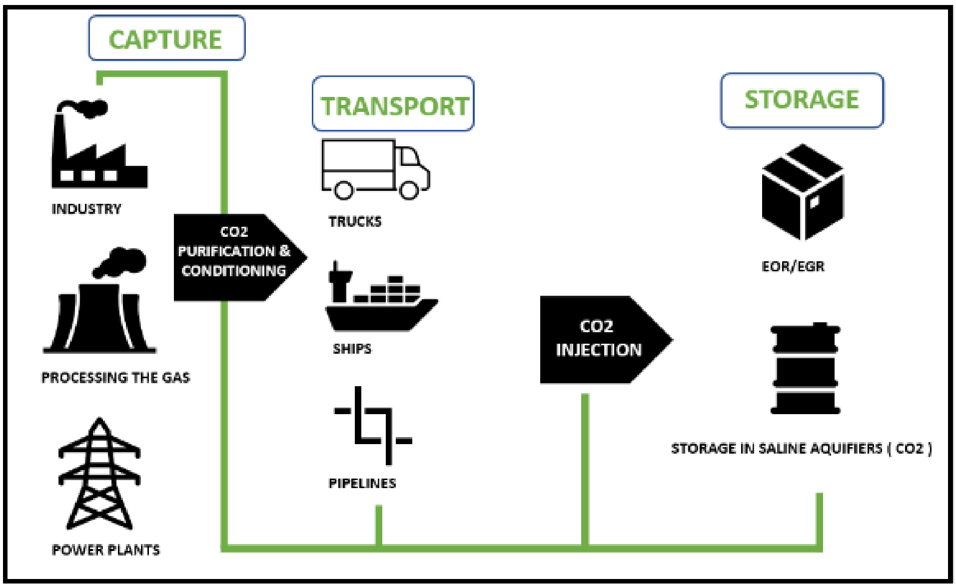
There is a recent shift toward developing multi-user transport networks and storage centers to facilitate the decarbonization of entire industrialized regions (Regjeringen, 2023). Roughly one-third of the CO2 transport and storage infrastructure currently under construction is multi-user. In addition, countries like Japan, Norway, and the United Kingdom are actively pursuing the commercialization of large-scale CO2 shipping as part of their decarbonization policies (Al Baroudi et al., 2021; IEA, 2023).

The following chapter examines the significance of CO2 transport and storage infrastructure and the methods for safely and cost-effectively transporting CO2 to the storage facility. Comprehending optimal methods for CO2 transportation that minimize environmental harm and seek to alleviate climate change is paramount.

5.2 CO2 transport and storage infrastructure

A carbon capture and storage infrastructure diagram is provided to better understand the process from capturing CO2 to transporting and storing it in a storage facility (see Figure 2).

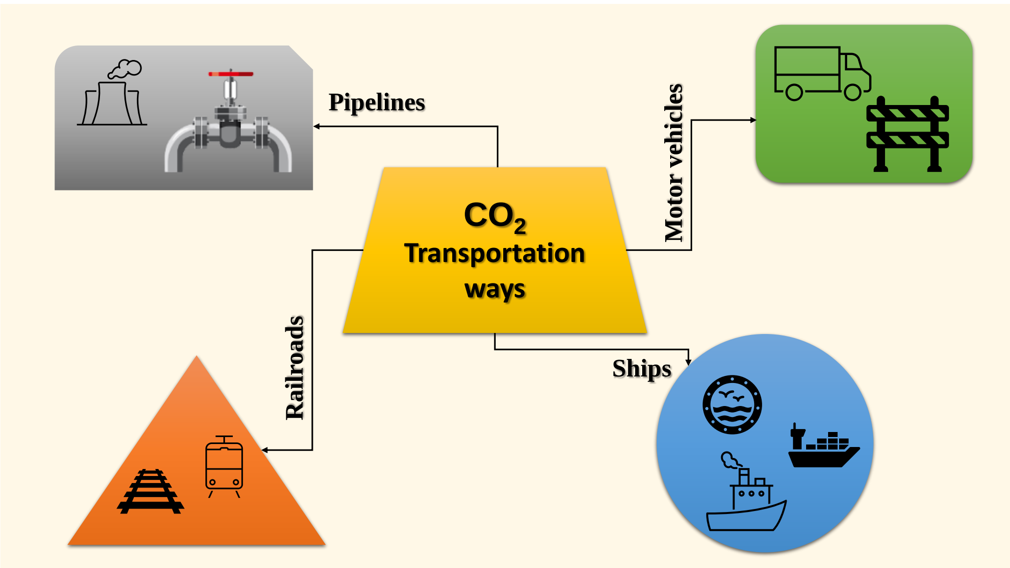
Figure 2: Carbon capture and storage – a conceptual diagram



Source: own illustration based on Kearns et al. (2021).

After CO2 is captured, it must be transferred to a storage facility (Mendelevitch, 2014; Kearns et al. 2021). While the cost of transporting CO2 is relatively low compared to other components of the CCS process, it may need the most significant attention to detail and direction from experts when the technology is scaled up (Neele et al., 2011). Transporting CO2 for sequestration involves establishing a coordinated and efficient transportation network (Al Baroudi et al., 2021). A CO2 transportation network and storage infrastructure would connect CO2 emitters in industrial clusters and power facilities to storage sites, facilitating the extensive decarbonization required to reach the net-zero objective (Moe et al., 2020). Pipelines and ships are both valuable forms of transportation of many different kinds (Mendelevitch, 2014). In addition, pipelines and ships are the most scalable methods with the lowest cost per ton of CO2 emissions (IEA, 2023). Therefore, it has been argued that pipelines are the most logical choice, especially when a consistent flow from CO2 collecting stations is necessary (Al Baroudi et al., 2021). However, when economies of scale do not support pipelines as the mode of CO2 transport for a CCUS project, alternative modes of CO2 transport, such as ships, railroads, and vehicles, are considered (see Figure 3) (Al Baroudi et al., 2021).

Figure 3: CO2 transportation ways – a conceptual diagram



Source: own illustration based on Al Baroudi et al. (2021) and Lee et al. (2017).

Regardless of the mode of transport used to transport CO2 from the point of collection to the final storage location (e.g., pipeline, vessel), regulatory frameworks will be necessary to limit environmental concerns (Weber & Tsimplis, 2017). Different modes of transportation present distinct environmental issues, necessitating separate liability plans (Gola & Noussia, 2022). Although both modes of transport (ships and pipelines) impose environmental and third-party liability on CO_2 carriers, there is a significant regulatory difference between the two (Weber & Tsimplis, 2017). When emitters need direct access to a suitable pipeline or when the quantity collected is insufficient to justify the construction of a pipeline, these methods are economically viable (Weber & Tsimplis, 2017). However, the justification of the pipelines is needed because the rapid expansion of liquid CO_2 through a pipeline breach results in a significant decrease in temperature, reaching approximately -80°C; the pipeline and surrounding structural steel may exhibit increased brittleness at this temperature, rendering them more susceptible to fracture upon impact (Brown et al., 2017). Furthermore, the impact of blast damages resulting from CO_2 pipelines in proximity may be exacerbated due to the comparatively high expansion coefficient of CO_2, as Brown et al., (2017) reported. Access to sufficient seaport facilities and sea or rail network connectivity influence decision-makers (Al Baroudi et al., 2021).

To enhance comprehension regarding the distinctions between two modes of transportation, namely ship, and pipeline, tables have been presented for each category outlining their respective benefits and drawbacks. This study aims to analyse the safety and cost efficiency of different modes of transportation and identify the situations in which they are most appropriate. This will prompt corporations to devise strategies for transporting CO_2 to a storage facility (see Table 3 & Table 4).

Table 3 Advantages and disadvantages of various modes of transportation with CCUS (Ships)

Pros	Cons
Shipping	
Comparatively low initial expenses (Weber & Tsimplis, 2017).	Less efficient for big pipeline capacity (Mendelevitch, 2014).
Possibility of linking onshore docks to offshore sequestration basins (d'Amore et al., 2021).	Liability strategies are required for many environmental concerns that come with using ships (Gola & Noussia, 2022).
Adaptable and flexible (Weber & Tsimplis, 2017).	More appropriate for lengthy international excursions but not for short trips between states (Kjärstad et al., 2013).
Decreases financial risk due to residual value (Mendelevitch, 2014)	Injection into the well or the placement of FSI units may need direct access to sufficient onshore infrastructure (IEAGHG, 2020; d'Amore et al., 2021).
More convenient and less costly for reaching places not served by pipelines (Weber & Tsimplis, 2017).	
More appropriate for extended international trips (Kjärstad et al., 2013).	
Specifically designed for transferring massive amounts of CO2 (Gola & Noussia, 2022)	
Potential to spread decarbonization to countries and industries where CCUS is physically or infrastructurally impractical (Al Baroudi et al., 2021).	

Source: own illustration based on Weber & Tsimplis (2017), d'Amore et al., (2021), Mendelevitch (2014), Gola & Noussia (2022), Kjärstad et al.,(2013),IEAGHG (2023).

Table 4 Advantages and disadvantages of various modes of transportation with CCUS (pipelines)

Pros	Cons
Pipelines	
Economies of scale result in significant decrease in unit costs for larger pipeline capacities (Mendelevitch, 2014)	Requires large infrastructure costs (Mendelevitch, 2014)
Effective for moving vast gas volumes over relatively short distances (Kjärstad et al., 2013)	Relatively low variable expenses (Mendelevitch, 2014)
Direct access to suitable pipeline when necessary (Al Baroudi et al., 2021)	Underutilized pipeline capacity reflects buried expenses (Mendelevitch, 2014)
	Limited accessibility to sea or rail network may be a consideration for decision-makers (Al Baroudi et al., 2021)
	Feasible when amounts collected are inadequate to warrant pipeline construction (Mendelevitch, 2014)

Source: own illustration based on Weber & Tsimplis (2017), d'Amore et al., (2021), Mendelevitch (2014), Gola & Noussia (2022), Kjärstad et al., (2013), IEAGHG (2023), Al Baroudi et al., (2021).

Carbon dioxide transportation is a crucial element in the operational process of CCS, as it encapsulates the practical storage of CO2 in geological formations (Weber & Tsimplis, 2017).

The transportation of carbon dioxide is an essential element of CCS procedures, as it facilitates the secure and efficient storage of CO2 in geological structures (Mendelevitch, 2014; Weber & Tsimplis, 2017; d'Amore et al., 2021; Gola & Noussia, 2022). The principal means of transportation are onshore and offshore pipelines and tankers. Every technique possesses unique advantages and disadvantages. The selection between the two alternatives is contingent upon the proximity and placement of the transportation pathway (Mendelevitch, 2014; Weber & Tsimplis, 2017; d'Amore et al., 2021; Gola & Noussia, 2022).

Onshore and offshore pipeline infrastructure costs are significant, with most funds going to compressor stations and monitoring (Mendelevitch, 2014). On the other hand, national legislation often controls pipeline transportation, which might simplify the legal framework for transit within a single country (Weber & Tsimplis, 2017). In addition, pipelines benefit from economies of scale, which may result in considerable cost savings for greater pipeline capacity (Mendelevitch, 2014). Increasing pipeline capacity, however, may need considerable extra expenditure since unused pipes represent hidden costs (Mendelevitch, 2014). In comparison, shipping has modest startup costs and may be more cost-effective for lengthy international voyages (d'Amore et al., 2021). Additionally, the residual value of ships in hydrocarbon transportation reduces financial risk (Mendelevitch, 2014).

Shipping is becoming a more realistic option for transferring carbon dioxide than offshore pipelines. Ship-based transport's inherent flexibility enables for connecting harbors or directly connecting onshore docks to offshore sequestration basins (IEAGHG, 2020; d'Amore et al., 2021). In addition, ships are a more feasible and cost-effective way to access geological regions not served by pipelines (Weber & Tsimplis, 2017). Transporting significant quantities of CO2 by ship might be accomplished similarly to transporting liquefied natural gas (LNG) (Scott et al., 2013). However, developing ships that carry enormous amounts of carbon dioxide present obstacles that need sophisticated technology and regulatory changes (Gola & Noussia, 2022). On the other hand, compressed CO2 via pipelines is more practicable over shorter domestic distances because pipelines are effective for transferring large gas quantities over relatively short distances (Kjärstad et al., 2013). Finally, the decision between pipelines and ships is influenced by various variables, including distance, location, and the unique needs of the transit route (Weber & Tsimplis (2017); d'Amore et al., (2021); Mendelevitch (2014); Gola & Noussia (2022); Kjärstad et al., (2013); IEAGHG (2023); Al Baroudi et al., (2021).

In Norway, a significant number of sources are located on or near the coast, and an established maritime tradition has created a suitable environment for CO2 transportation and shipping; in the United Kingdom, the Department of Business, Energy, and Industrial Strategy is actively exploring the implementation of this technology about the relation to sites isolated from CO2 transport and storage infrastructure in the British North Sea (Al Baroudi et al., 2021). Norway, the Netherlands, and the United Kingdom vigorously sought the resolution of using the North

Seas because of their shared desire to maximize the offshore storage potential in the North Sea, considered the epicenter of CCUS development in Europe (Zhang, 2021).

CO2 shipping has the potential to expand decarbonization to nations and sectors where CCUS is geographically or infrastructurally infeasible and to minimize the cost of early projects owing to its sink-source matching, minimal initial capital investment need, and a high degree of flexibility (Al Baroudi et al., 2021). Furthermore, as part of their decarbonization policies, nations such as Japan, Norway, and the United Kingdom are assertively pursuing the commercialization of large-scale CO2 shipping, which bodes well for developments shortly (Al Baroudi et al., 2021).

5.3 Integration of CCUS into the climate mitigation plan

Public policy support for CCUS in the mitigation plan and a more robust climate policy toward emissions reduction will aid in the deployment of CCUS (Zhou et al., 2022). Reaching Europe's goal of carbon neutrality by 2050 would require significant changes to the region's energy infrastructure (Zhou et al., 2022). The hope is that CCUS will help reduce carbon footprint while decreasing expenditures. However, enough policy signals have yet to be provided in Europe to acknowledge the significance of CCUS in the mitigation plan (Zhou et al., 2022). Nevertheless, it is a step in the right path to reform the EU ETS to reinforce the carbon price signal by creating a Market Stability Reserve (Zhang, 2021).

EU ETS is the primary legislation in the European Union's climate change programme. It is the first and most significant carbon market globally (Zhou et al., 2022; Zhang, 2021). The Emissions Trading System assures that in the event of a leak, the operator must relinquish emission permits (Zhang, 2021). The Directive on Environmental Liability governs environmental liability for localized damages. The liability for harm to health and property is left to the discretion of individual Member States (Mills, 2021). The cap under the EU ETS and allowances allocation should consider emission reductions arising from adopting CCUS to prevent the carbon price signal from being weakened by complementing regulatory measures (Zhang, 2021).

However, several difficulties must be addressed concerning critical policy factors and economic, technical, and environmental concerns (Philbin, 2020). Notably, for CCS, certain decision factors have been identified as having a high impact (capture technology, storage technology, and cost reduction), others as having a moderate impact (investment decision, environmental assessment, regulatory framework, and site selection), and others as having a low impact (namely transportation system, public awareness, government funding, monitoring technology, and international collaboration) (Philbin, 2020).

Further regulatory measures will also prompt the change, including applying emission performance criteria to carbon-intensive industries (Zhang, 2021). A more assertive climate policy to encourage low-carbon investment may pave the road for CCUS implementation (Zhang, 2021). Both regions should consider sector-specific regulations that apply CCUS-readiness requirements to the many industries that use a lot of carbon-intensive resources to increase the pace at which CCUS is being implemented (Zhang, 2021).

5.4 Public Perception in CCUS

CCS is a critical technology for mitigating climate change (Jiang et al., 2020). However, misinformation and a lack of understanding hinder its acceptance among the public and critical stakeholders (Parmiter and Bell, 2020). According to Parmiter and Bell (2020), false views such as "the technology does not work" continue to propagate, hindering its acceptance. Low levels of public knowledge are a general characteristic of social studies in CCS (Merk et al., 2022). While there is an abundance of studies on the technical components of CCS, several authors have called for more research on the socio-cultural dimensions (Karimi et al., 2016).

Public perception of CCS varies geographically, with attitudes becoming more unfavorable the closer a storage facility is and whether the CO2 source is native or imported (Merk et al., 2022). According to Braun et al. (2018), individuals residing near a potential CCS facility exhibit significantly lower levels of acceptance compared to those who live farther away (Braun et al., 2018). However, individuals consider CO2 emissions reduction as the primary advantage of CCS, and more worry about climate change leads to more favourable views of CCS (Merk et al., 2022).

Despite the widespread misunderstanding, a lack of public acceptability, particularly of onshore storage, has historically been a critical impediment to the development of CCS in Europe (Merk et al., 2022). In addition, inadequate community support has contributed to the failure of CCS implementation efforts, as is the case with other energy technologies (Alcalde et al., 2019).

To make CCS more acceptable to society, project-specific strategies include involving stakeholders early and openly, making information and sources available to help people get to know CCS, and ensuring people are aware of the community context and possible social effects using tools like community compensation (Krevor et al., 2023). Moreover, technology openness, information transparency, and public involvement are required to gain widespread adoption of CCS (Brunsting et al., 2011 & Glanz & Schönauer, 2021). The most accurate predictor of public acceptability of CO2 storage is the public's perception of the hazards and benefits of the CCS technology chain. The public perceives CCS's contribution to climate change mitigation as its primary advantage (Krevor et al., 2023). However, there is a belief that CCS does not address the core cause of CO2 emissions and maintains a non-sustainable industry (Krevor et al., 2023).

In conclusion, public perception of CCS is critical to its acceptance and implementation (Merk et al., 2022). Thus, evaluating social effects, community involvement, and participation must be addressed from the beginning of a project and adapted to the local environment (Merk et al., 2022). Moreover, project-specific strategies are necessary to make CCS more acceptable to society, involving stakeholders early and openly, making information and sources available, and ensuring people are aware of the community context and possible social effects. Finally, it is essential to understand the socio-cultural dimensions of CCS, as low levels of public knowledge and a lack of understanding of CCS as a climate mitigation technology among the public and critical stakeholders continue to pose challenges (Merk et al., 2022).

6. Results

6.1 Empirical Analysis of Carbon capture storage projects

6.1.1 Introduction

Based on the literature review, the previous sections have shown that the momentum of carbon capture and storage projects could be higher. As shown in the previous chapter, carbon capture and storage are essential for energy-intensive firms (Institute, 2021). Nevertheless, companies have struggled to capture and store carbon emissions due to several obstacles related to a bundle of factors, including management, technical and cost factors, and societal acceptance (Institute, 2021; Al-Mamoori et al., 2017; Merk et al. 2022). In addition, for several years, the offsetting impact of carbon capture and storage has been ignored or undervalued (Institute, 2021). However, as technology has improved, the general perspective on CCUS and related projects has shifted (Institute, 2021).

The question now arises about the future development of carbon capture and storage projects. Will the number of planned carbon capture and storage projects increase, and will capacity increase? A related question is what kind of project characteristics are most conducive to scaling up carbon capture and storage projects. Both more and larger projects will be needed to contribute to carbon offsets significantly. Empirical analyses have been chosen to interpret information empirically based on evidence. Rather than relying on theories and concepts, accurate results have been objected to and tested.

This section aims to analyse the determinants of CCS projects. Actual and planned carbon capture and storage projects are used. A particular focus is put on the operational date. Data from the Carbon Capture and Storage Associations are used and analysed using ordinary least squares (OLS) regressions. Carbon-intensive oil and gas companies are expected to accelerate their efforts to meet the Paris 2030 climate targets of Carbon neutrality and Decarbonization (Bricout et al., 2022). Thus, the main research questions are:

RQ3: How does the Paris Climate Summit of 2015 influence the development of CCS project capacity over time?

RQ4: In what ways does CCS project capacity vary based on industry type and size?

RQ5: Which countries have invested more in CCUS, Global South or Global North?

6.1.2 Conceptual background

Several theories can justify the spread of carbon capture and storage technology. The theory of diffusion developed by Rogers (2003) and the theory of the lead market (Beise & Rennings, 2005; Rogers 2010) are helpful in this context. As per the lead market theory, nations that are early adopters of a globally dominant innovation design play a crucial role in the international diffusion of innovation and establish the global benchmark (Beise & Rennings, 2005). Regarding carbon storage and usage, companies in the United States and Europe are leaders in this technology (Institute, 2021). There will be expected to be learning effects over time, and larger CCS projects will be observed in these countries (Institute, 2021; Rogers 2010).

Rogers (2010) assumes that progress appears in several stages, such as innovators, early adopters, early majority, late majority, and laggards (Beise & Rennings, 2005). The other factor is political, i.e., government intervention, which plays a role in developing and diffusing environmental innovations (Beise & Rennings, 2005). For example, the Glasgow Climate Pact 2021 explicitly mentions carbon storage as a solution (Depledge et al., 2021). However, the currently limited implementation of CCS technology implies that its incorporation is more likely to have a political rather than a rational impact (Depledge et al., 2021). One reason is that the spread of CCS in emerging markets is expected to increase (Depledge et al., 2021).

6.1.3 Empirical model

In the following, both the number of CCS projects and capacity are investigated. The empirical model relates carbon capture capacity measured in Mtpa (one million tons per annum) with the operational date and project characteristics. Given that the dependent variable is continuous, OLS (ordinary least square) can be applied, transforming the variable into a logarithm. Using the logarithm of capacity ensured an almost normal distribution of the variables (Wooldridge, 2015; StataCorp,2013). Research in this direction will give us an understanding of the importance associated with CCUS as a climate mitigation tool in the global south and global North and how to go way forward in achieving the climate goals by helping developing countries with CCUS technology suit and funding.

6.1.4 Data

The data was sourced from the Global CCS Institute, an international think tank specializing in CCS, for this research. The institute's mission is to accelerate the deployment of CCS globally and expedite its use to achieve carbon neutrality. The members committed to this cause are governments, corporations, research institutions, non-governmental organizations, and private businesses. The Global CCS institutes operate from Washington, D.C., Houston, London, Brussels, Abu Dhabi, Beijing, Tokyo, and Melbourne (Institute 2021).

CCS is a crucial emission reduction technology for achieving global climate goals (Jiang et al., 2020). The Global Status of CCS 2022 details significant CCS milestones from the previous 12 months, the status of technology worldwide, and the most significant opportunities and challenges it confronts. The data comprises 197 carbon storage initiatives in various operation phases from 1970 to 2030. The carbon storage and capture project evaluation from 2020 to 2030 was modeled based on the U.S. Energy Information Administration (EIA) data, the World Energy Projection System (2021), and the CCS database.

Thus, based on the theoretical and conceptual considerations outlined above, the determinants of the CO2 capacity equation are specified as follows:

$$\ln\,(Co2capacity)_i = \beta_0 + \beta_1 Operation\_year_i + \sum_{F=1}^{4} \beta_{2F} Facilityindustry_{iF} + \sum_{S=1}^{2} \beta_{3S} Storagecode_{iS} + \sum_{C=1}^{6} \beta_{4C} Country_{Cj} + \beta_5 Operational_i + u_i,$$

where i is the individual CCUS project with i*=1,…, 129,* and ln( ) represents the natural logarithm, β_0 is the constant and u_i is the error term assumed to be i.i.d. The dependent variable is the CO2 capacity of the CCUS project (Wooldridge, 2015). The primary explanatory variable is the operation year ($Operation\_year$) which is data in years when the CCUS facility is put into operation. The other key variable is the country dummy variables. We choose to include country dummy variables for countries with the most CCUS projects (Australia, Canada, Norway, United Kingdom, and the USA) and a joint dummy variable for developing countries (Brazil, China, Indonesia, Thailand, and Timor-Leste). The remaining countries build the reference category. The Co2 equation also contains some control variables. The facility storage code ($Storagecode_i$) is measured as two dummy variables ("Dedicated Geological" and "Enhanced Oil Recovery") with "Under Evaluation" as the reference category. Another essential feature is the facility industry of the CCUS project, which is measured as a set of dummy variables ($Facility\ industry$). We choose the four most significant groups ethanol production, hydrogen production, electricity production, and natural gas and petroleum as dummy variables, while the remaining groups are the reference category. These groups are bioenergy, cement, chemical, direct air capture, fertiliser, iron and steel, methanol, miscellaneous and waste incineration. The last variable measures the facility's status, measured as a dummy variable if the CCUS project is in operation and zero if it is in one of the other statuses (Advanced, Early Development, In Construction, Operation Suspended).

OLS can estimate the CO2 equation with heteroscedasticity robust standard errors (Wooldridge, 2015). The coefficients of the dummy variables can be interpreted as percentage effects using the following formula (exp(coeff-1) X100). Table 5 reports descriptive statistics based on the estimation sample.

Table 5: Summary statistics

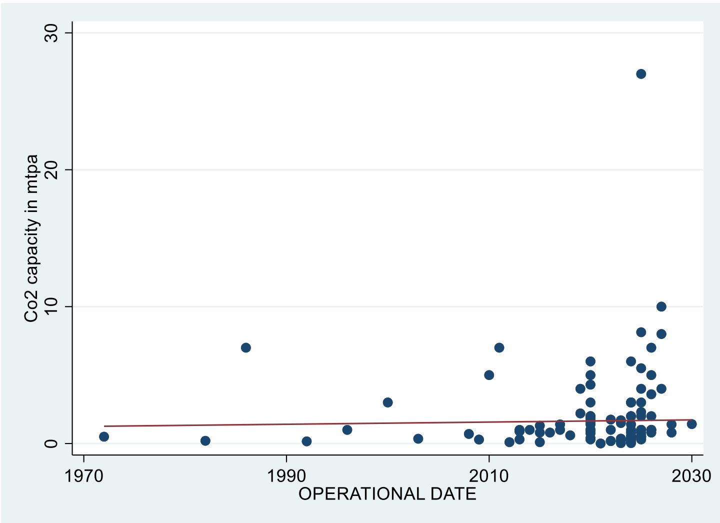
Variables	Number of observations	Mean	Standard deviation	Min	Max
lncapturecapacitymtpaco2	129	-0.33	1.35	-5.52	3.3
Capturecapacitymtpaco2	129	1.69	2.98	0	27
Operational date in years	129	2020	9	1972	2030
Dummy variables		Mean			
Ethanol Production	129	0.32			
Hydrogen Production	129	0.05			
Power generation	129	0.15			
Natural gas and oil	129	0.22			
Australia	129	0.04			
Canada	129	0.09			
Norway	129	0.02			
UK	129	0.05			
USA	129	0.56			
Developing countries	129	0.1			
Dedicated Geological	129	0.64			
Enhanced Oil Recovery	129	0.26			
Operational	129	0.23			

Source: Global CCS Institute 2022, own calculations.

6.1.5 Results

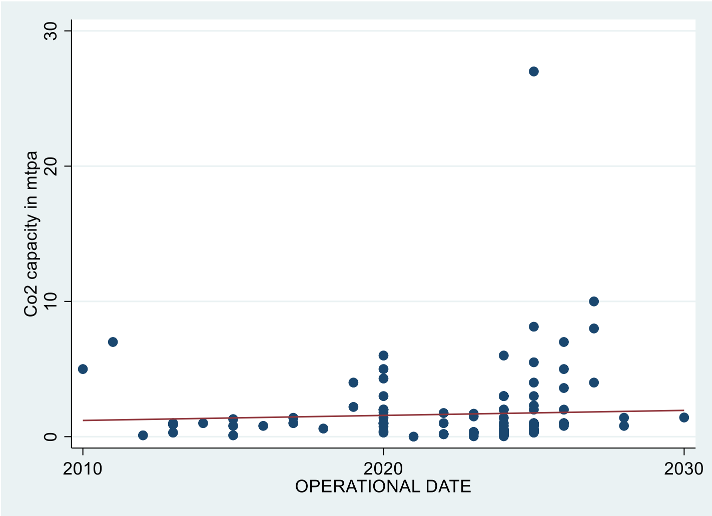
The scatterplot shows the relationship between CO2 and operational date at the project level (see Figure 4). The scatterplot shows the relationship between CO2 and the operational date at the project level for a shorter period (see Figure 5). Bivariate relationships between capacity and actual and planned operating dates are examined using correlations and scatter plots to get a feel for the data. In the first scatterplot, the X-axis represents the operational year from 1970 to 2030, and the Y-axis, the independent variable, represents the annual CO2 capacity in Metric tons (see Figure 4). The period range for the second scatterplot is 2010 to 2030 (see Figure 5). The two scatterplots indicate no observable increase in the capacity of CO2 at the project level as time progresses. The observed trend of increasing CCS projects from 2020 is incongruent with the initial research inquiry on capacity augmentation.

Figure 4 CO2 Capacity year 1970-2030



Source: Global CCS Institute 2022; Own calculation.

Figure 5 CO2 Capacity scatterplot year 2010-2030



Source: Global CCS Institute 2022; Own calculation.

Table 6 OLS regression of the relationship between CO2 capacity and operational date

	Coefficient	t-stat	p-value
Operational date	0.00	0.05	0.96
Constant	-1.69	-0.06	0.95

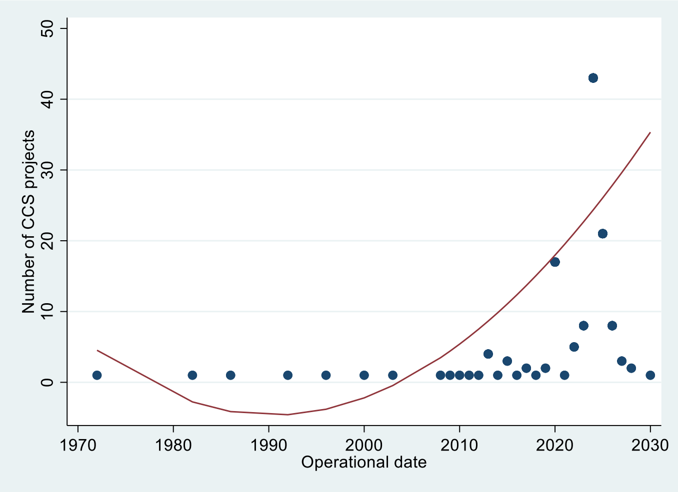
*Source: Global CCS Institute 2022; Own calculations; ***p<0.01; **p<0.05, *p<0.1*

Note: The dependent variable is log CO_2 *capacity. The number of observations is 135.*

The next step is to report the result of the OLS regression. The logarithm of CO2 capacity is the dependent variable. The results demonstrate that the operational date is not statistically different from zero (p-value of 0.96), showing that the project capacity is stable over time. This can also be observed in the subsample of realized projects for 1970 and 2010. The global storage capacity and, thus, the offsetting potential have stayed the same.

Consequently, the offsetting potential has decreased compared to total global CO2 emissions, which increased over time. If we instead examine the capacity of the number of CCS projects, a different pattern emerges over time (see Figure 6). The number of projects increased between 2010 and 2030.

Figure 6 Number of CCS projects



Source: Global CCS Institute 2022; own calculation.

Cumulatively by year, only between 1 and 10 new CCS projects are planned per year. Instead, there are 20, and another year about 40 projects (see Figure 6). Although several CCS attempts have occurred since the first CCS experiment began in 1970, their growth has been steady and low. This is due to CCUS technology advancements, which have developed devices for capturing and storing feasible and effective carbon (Institute, 2021).

The reason for plotting the operational date and number of CCS projects on the graph was to Analyse the growth of such projects over the time frame of 60 years, of which the data of 7 years help to get a bird's eye view of future projects. The resulting graph illustrates a moderate rise in the number of projects planned between 2020 and 2030. However, it still needs to be determined whether the underway and completed projects are sufficient to meet the objectives of the Paris Agreement.

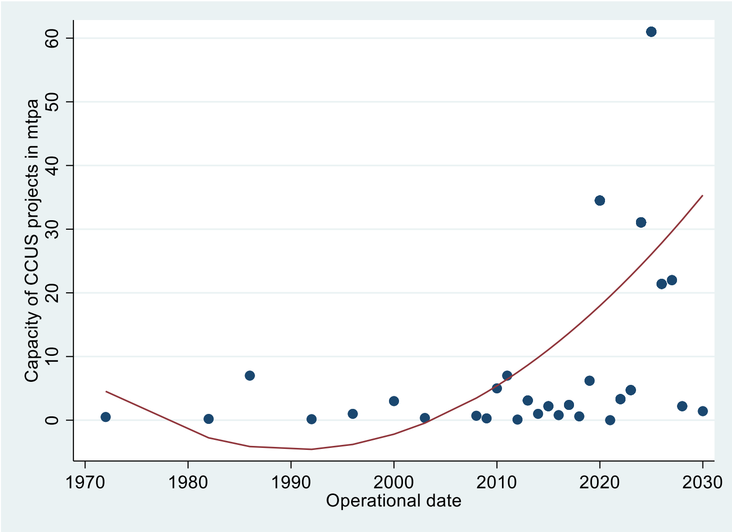
Table 7 Variation of the CCS projects: based on the operational date.

	Coefficient	t-stat	p-value
Operational date	0.84	5.71	0.00
Constant	-1668.27	-5.64	0.00

Source: Global CCS Institute 2022; Own calculations.

Note: The dependent variable is the number of CCS projects. The number of observations is 135. The R squared is 0.18, indicating that the timing of the CCS projects explains 18 per cent of the variation of the CCS projects.

Figure 7 The capacity of CCUS projects in Mtpa



Source: Global CCS Institute 2022; own calculations.

According to the IEA's Sustainable Development Scenario (SDS), roughly 2,000 CCS facilities will need to be operational by 2050 if we meet the goals set out in the Paris Agreement, which translates to the construction of 70–100 sites per year required (Martin-Roberts et al., 2021).

As shown in the previous graph, however, the capacity of CCUS initiatives must be increased even further to meet the requirements of the Paris Agreement. Therefore, commencing in 1970 and continuing through 2023, the total capacity will increase gradually. In contrast, there may be an increase in the storage capacity of CCUS projects for future initiatives between 2023 and 2030.

6.1.6 Multivariate analysis of the determinants of CO2 capacity

The subsequent phase involves analysing the project attributes most conducive to expanding the capacity. In addition to the commencement date, various factors may be pertinent to the efficacy of extant and proposed CCS initiatives. An aspect to consider pertains to the nature of the facilitating industry and the cooperation partner. The companies operating in the CCS sector have established numerous partnerships and collaborations that result in carbon emissions (Martin-Roberts et al., 2021).

The second aspect pertains to the developmental phase of CCS initiatives and the project's geographical origin. More companies from emerging and developing nations are expected to undertake more extensive CCS initiatives following the objectives outlined in the Paris

Agreement (Martin-Roberts et al., 2021). The inquiry regarding relationships is empirical, as the theoretical framework does not provide distinct guidelines.

The database contains information on the status of CCUS facilities to analyse the current projects based on four phases: advanced, early development, In construction, operational suspended, and operational (Institute, 2022). This categorization helps understand the importance of oil and gas companies and companies in other industries towards implementing CCUS within their operations in complaints with SDGs and the reporting parameters concerning scope one emission.

Table 8 descriptive statistics of facility status

FACILITY STATUS	Freq.	Percent
Advanced	79	40.1
Early Development	75	38.07
In Construction	11	5.58
Operation Suspended	2	1.02
Operational	30	15.23
Total	197	100

Source: Global CCS Institute 2022, own calculations.

Table 8 shows the distribution of the CCS project's completion levels. Thirty CCS facilities are operational, and there are now seventy-nine CCS facilities at the advanced complition stage. Seventy-five more projects are now in the preliminary planning phases, while eleven CCS facilities are being constructed and two facilities have suspended their operations.

Table 9 descriptive statistics of facility storage

FACILITY STORAGE	Freq.	Percent
Dedicated Geological	66.86	66.86
Enhanced Oil Recovery	34	20.12
Under Evaluation	21	12.43
Various	1	0.59
Total	169	100

Source: Global CCS Institute 2022, own calculations.

Table 9 shows the CCS technology storage options currently in use or under evaluation. According to Penuela et al. (2022), the predominant approach for carbon dioxide storage is geological storage, which entails the injection of carbon dioxide into subterranean geological formations (Penuela et al., 2022). The study has identified four categories of facility storage methods: Dedicated Geological, Enhanced Oil Recovery, Under Evaluation, and Various. Of the 169 facilities, 113 (equivalent to 66.86%) indicated that they employed Dedicated Geological storage. Enhanced Oil Recovery was implemented in 34 facilities, accounting for 20.12% of the total, whereas employment Under Evaluation was noted in 21 facilities, representing 12.43% of the total. A singular facility reported the utilization of the Various storage method. In summary, the findings indicate that Dedicated Geological storage is the predominant method employed for facility storage, trailed by Enhanced Oil Recovery and Under Evaluation. The findings of this research could hold significant ramifications for policymakers and industry experts who aim to encourage the adoption of sustainable and efficient storage practices within facilities.

Another relevant project feature is the upstream industry working with the company carrying out the carbon storage. Ethanol production has the most significant total number of CCUS projects, 40. Despite this, the oil and gas sector, including natural gas processing, electricity production, and oil refining, has 68 projects in different phases of development (see Table 10).

Table 10 descriptive statistics of the facility industry

FACILITY INDUSTRY		Freq.	Percent
Bioenergy		5	2.54
Cement Production		5	2.54
Chemical Production		8	4.06
Direct Air Capture		5	2.54
Ethanol Production		40	20.3
Ethanol Production and		1	0.51
Fertiliser Production		8	4.06
Hydrogen Production		21	10.66
Iron and Steel Production		1	0.51
Methanol Production		2	1.02
Natural Gas Processing		29	14.72
Oil Refining		4	2.03
Power Generation		35	17.77
Power Generation and		3	1.52
Synthetic Natural Gas		1	0.51
Under Evaluation		2	1.02
Various		22	11.17
Waste Incineration		5	2.54
Total		197	100

Source: Global CCS Institute 2022; own calculations.

Table 10 depicts the frequency and proportional distribution of facility industries that employ carbon capture technology. Each bioenergy, cement production, chemical production, direct air capture, and refuse incineration use carbon capture technology with a frequency of less than 5% of all facilities. Ethanol production accounts for 20.3% of total facility capacity, followed by natural gas refining (14.7%) and power generating (17.8%). Hydrogen, fertilizer accounted for 11 and 4 per cent of total facility capacity. Additionally, information is available on facilities undergoing evaluation, which account for 1.0% of all facilities. This result demonstrates that specific industries, such as ethanol production and power generation, have a higher adoption rate of carbon capture technology than others. In contrast, waste incineration and direct air capture have a relatively lower adoption rate.

The study was prompted by the need to determine which sector contributes most to SDG 13: Climate Action, as seen in the table above. According to a study by the International Energy Transformation Commission (ETC), heavy industry accounts for 53% of all CO2 emissions (Xu & Lin, 2020). Decades-long emissions of harmful carbon dioxide by the oil and gas industry necessitate additional efforts to mitigate their adverse effects. These companies should work harder to develop sustainable practices and cutting-edge technologies to reduce climate risk and contribute to achieving multiple worldwide climate goals (Jiang et al., 2020; Wang et al., 2017).

The following (see Table 11) shows the OLS regression of the determinants of CO2 capacity, which is the final step in the analysis and is a multivariate regression that includes project characteristics and date of operation. The dependent variable is the logarithm of carbon capture capacity. Three significant independent variables concerning the facility industry are Ethanol production, Hydrogen production, power generation, and natural gas and oil. The motive behind choosing these industries was due to the number of CCUS projects they have which are in varying phases. In addition, location and operational status are included.

Table 11 OLS regression of the determinants of CO2 capacity

Variable Name	Coefficient		t-stat	p-value
Operational date	0.01		0.69	0.490
Ethanolproduction	-1.13	***	-3.06	0.003
Hydrogen production	0.65	*	1.66	0.099
Power generation	0.73	**	2.52	0.013
Natural gas&oil	0.75	*	1.85	0.067
Australia (ref all other countries)	0.97		1.49	0.139
Canada	0.55		1.18	0.241
Norway	0.95		1.53	0.130
UK	1.99	***	2.98	0.003
USA	0.79	*	1.88	0.063
Developing country	0.47		1.02	0.310
Dedicated geological	-0.55	*	-1.75	0.083
Enhanced oil recovery(EOR)	-0.44		-1.34	0.182
Operational	-0.33		-0.71	0.480
Constant	-23.82		-0.7	0.483
R-squared	0.40			
Number of observations	129			

Source: Global CCS Institute 2022; Own calculations.

Note: significance level, 1,2,5 levels

Stata command: reg y x, r

The operational date is not significant at the conventional level. The "Ethanol Production" predictor variable has a negative coefficient of -1.13, a t-statistic of -3.06, and a significance level of 0.003. The relationship is statistically significant at 0.05, suggesting that specialization in CCS projects combined with ethanol production is less favorable to achieving a high capacity. The "power generation" predictor variable has a positive coefficient of 0.73, a t-statistic of 2.52, and a p-value of 0.013. The relationship is statistically significant at the 0.05 level. The study incorporates country dummy variables for the nations with the highest number of CCUS projects: Australia, Canada, Norway, the United Kingdom, and the United States. A collective dummy variable has also been included for developing countries, including Brazil, China, Indonesia, Thailand, and Timor-Leste. The reference category is constructed by the countries that are left.

The coefficient for the United States dummy variable is 0.79; this means that projects in the United States have an 80 per cent higher capture capacity than Australia, the reference country. Nevertheless, the coefficient for the variable "developing country" is 0.47. This means that being from a developing country is tied to an average increase of 0.47 units in carbon capture capacity compared to Australia, the reference country. On the other hand, the p-value of 0.31 shows that this finding is not statistically significant at the standard 0.05 level of significance.

Furthermore, four predictor variables, including ethanol output, power generation, the United Kingdom, and the constant term, have statistically significant coefficients at the 0.05 level. The negative coefficient for ethanol production shows that when ethanol production goes up, the dependent measure goes down. The positive coefficients for power production, the United Kingdom, and the constant term show that the dependent variable increases when these factors increase.

Some additional interpretations

Several variables were analysed statistically to determine their relationship with the carbon capture capacity. A positive coefficient of 1.99, a t-statistic of 2.98, and a p-value of 0.003 indicate that the United Kingdom had a stronger positive association with the dependent variable than the reference group (Australia). Furthermore, this relationship is statistically significant at the 0.05 level, indicating that it is highly improbable to be the result of random coincidence. The predictor variable operational date, which assesses the date a carbon capture facility became operational, did not demonstrate a significant correlation with the dependent variable. A coefficient of 0.01, a t-statistic of 0.69, and a p-value of 0.49 indicated this. Therefore, the operation date has no significant effect on carbon capture capacity.

The R-squared value of 0.40 signifies that the independent variables used in the analysis account for 40% of the variance in carbon capture capacity. This indicates that the remaining sixty per cent of the variance may be attributable to factors not included in the analysis. These findings contribute to a better understanding of the factors that influence carbon capture capacity and can aid in improving carbon capture policies and practices.

The findings do not demonstrate statistical significance despite indicating a clear correlation between the United States variable and carbon capture capacity. Likewise, the variable about developing countries implies a clear correlation with carbon capture capacity. Again, however, the outcomes do not exhibit statistical significance. Hence, the integrity of these associations across all developing nations remains to be determined, necessitating further investigation to establish the actual impact of national origin, i.e., the United States or developing country, on carbon sequestration potential.

Table 12 Evolution of carbon storage and capture projects

Year	Carbon Capture in MTCO2	Total CO2 emissions	Carbon capture in per cent of total CO2 emissions
2020	36	35961	0.1
2021	36	37858	0.1
2022	39	38384	0.1
2023	44	38917	0.1
2024	75	39458	0.2
2025	172	40007	0.4
2030	216	41420	0.5

Source: U.S. Energy Information Administration (EIA), World Energy Projection System (2021), and CCS database and Carbon Capture in MTCO2 originates from Zhang et al. (2022).; Own calculations.

Table 12 illustrates the projected evolution of carbon capture and storage projects from 2020 to 2030. It outlines the estimated carbon capture in a million tonnes of CO2 (MTCO2) for each year, the total CO2 emissions in a million tonnes, and the percentage of CO2 emissions captured through carbon capture and storage initiatives.

An important question is whether the scale of CCS projects planned until 2030 is sufficient to significantly reduce global CO2 emissions, which are expected to increase according to the standard scenarios of the World Energy Projection System. To this end, the scale of CCS projects is compared with total CO2 emissions for different periods (2020-2030). In addition, information on the size and operational date of CCS projects is drawn from the CCS database. The results show that the percentage of CCS offset potential increases from 0.1 percent to 0.5 per cent in 2030. This indicates that more than carbon capture and storage projects may be required to reduce greenhouse gas emissions and limit global warming. The main conclusion is that the CCS technology needs to be revised to make a significant impact, and it is seen as more problematic and elicits higher resistance (Ferguson & Ashworth, 2021). Instead, the focus should be on further investment in various technical solutions in response to the urgent need to combat climate change. Renewable energy (e.g., solar photovoltaics (P.V.), wind, and geothermal) are considered more favorable (Ferguson & Ashworth, 2021).

The relatively high energy consumption and cost are widely recognized as the primary gap deterring the development and deployment of CCUS. According to Zheng et al. (2022), the reduction in costs of CCUS has been comparatively lower than what was initially projected, in contrast to the progress made in the field of renewable energy. Using fossil fuel with carbon capture, utilization, and storage (CCUS) and renewable energy sources has shown potential as viable technologies in developing low-carbon pathways. According to Zheng et al. (2022), failure to achieve a significant breakthrough in CCUS technology within the given timeframe may result in substantial energy, environmental, and economic costs associated with mitigating the effects of climate change (Zheng et al., 2022).

6.1.7 Carbon capture utilization and storage initiatives of active participants in the United Nations global compact programme

Oil and gas companies are investing in CCUS technology while concurrently contributing to greenhouse gas emissions (Tewari et al., 2021). This poses a challenge in terms of sustainability, as increased GHG emissions are expected to have catastrophic environmental consequences (Tewari et al., 2021). Therefore, according to Tewari et al. (2021), experts contended that CCUS management and control is a primary area of investment and research and development for oil and gas companies (Tewari et al., 2021).

Companies are participating in UNGC programme, which promotes sustainable business practices and requires companies to report on their progress toward the SDGs to address this challenge (Compact, 2023 & U.N. Global Compact Programme, 2022). It is recommended that companies participating in the UNGC program prioritize facilitating ongoing learning and promoting corporate sustainability performance (U.N. Global Compact Programme, 2022). Additionally, it is suggested that these companies improve stakeholder access to information about implementing the Ten Principles and their contributions towards attaining the SDGs (Compact, 2022). CCUS is one of the themes that companies must report on as part of the UNGC programme's transparency and reporting requirements (Compact, 2023 & Tewari et al., 2021). Participation in the UNGC programme would raise the company's profile in the eyes of the public and ensure that the entire world is aware of the green initiatives being taken to reduce carbon emissions (U.N. Global Compact Programme, 2022).

Integrating the CCUS and UNGC program principles allows companies to explore prospective solutions. A notable illustration of this approach is evident in the efforts of Dril-Quip. This company endeavors to mitigate the carbon footprint of industrial operations while ensuring that the quality of life is not adversely affected (OE Digital, 2022). Dril-Quip is taking a proactive approach to tackle this issue by utilizing innovative problem-solving techniques to develop solutions that can effectively minimize greenhouse gas emissions (OE Digital, 2022). These solutions will facilitate secure and dependable carbon capture, transportation, utilization, and storage (OE Digital, 2022). In early 2021, the organization formally committed to contributing to the wider resolution by enrolling as a member of the UNGC, recognized as the largest sustainability initiative globally (OE Digital, 2022 & U.N. Global Compact Programme, 2022). The UNGC programme endeavors to conform companies to its universal principles about human rights, labour, environment, and anti-corruption (OE Digital, 2022).

Consequently, the scholarly inquiry is directed towards investigating the correlation between CCUS (CCS project facets) and UNGC programme involvement, as well as assessing the degree to which corporations engage in the UNGC programme and allocate resources towards CCS projects. Table 13 lists several companies involved in the oil, gas, and coal industries, their country of origin, CCS technology investment, and the SDGs they prioritize (Compact, 2023). Furthermore, it should be underlined that The UNGC Global Compact Programme Strategy Assignment for the years 2021-2023 provides information on the count of companies that have pledged their commitment towards the objectives of the Paris Agreement (UNGC, 2021). This includes the number of enterprises that have committed to achieving net zero emissions of carbon neutrality (UNGC, 2021). Additionally, the report highlights the number of companies that have formulated science-based plans for transitioning to net zero emissions by the year 2050 (UNGC, 2021). Furthermore, the document also sheds light on the number of companies making progress toward decarbonizing their portfolios (UNGC, 2021).

Table 13 was extracted from the UNGC's website and each company's sustainability report (Compact, 2023). The reports demonstrated that businesses discuss CCS and have developed various CCS-related initiatives. All listed companies have invested in CCS technology and are active members of the UNGC, which promotes sustainable business practices. In addition, the businesses have identified several SDGs as priorities, including SDG 13 - Climate Action, SDG 5 - Gender Equality, SDG 8 - Decent Work and Economic Growth, and others. This table illustrates the importance of sustainability and climate change mitigation initiatives in the energy sector (Compact, 2023).

Table 13 CCUS initiatives and active participation of oil and gas companies in the UNGC programme

Name of the company	Type of the Business	Country	Sector	Investment in CCS	Prioritized SDGs	Participation status in UNGC
Equinor	Company	Norway	Oil, gas, & coal	**Yes**	SDG- 4, 7,8,13,14,17	Active
Aker Solutions ASA	Company	Norway	Oil, gas, & coal	**Yes**	SDG - 3,5,8,12,13,14,16	Active
Vår Energi ASA	Company	Norway	Oil, gas, & coal	**Yes**	SDG-5,8,9,10,13,14,16,17	Active
TechnipFMC	Company	United states of America	Oil, gas, & coal	**Yes**	SDG-5,9,10,13	Active
BP Plc	Company	United kingdom	Oil, gas, & coal	**Yes**	SDG-1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	Active
Neptune Energy	Company	United kingdom	Oil, gas, & coal	**Yes**	SDG-3,4,5,7,8,10,13, 14,15,16,17	Active
Hindustan Petroleum Corp. Ltd.	Company	India	Oil, gas, & coal	**Yes**	SDG-1,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17	Active

Source: (Compact, 2023); Own calculations.

The purpose behind selecting these corporations was to examine whether those that engage in the United Nations Global Compact initiative also devote resources to carbon capture and storage endeavors. In addition, the research opted to analyse enterprises from diverse geographical locations worldwide to assess the degree of engagement of both developed and developing countries in the UNGC initiative, as well as to ascertain the level of cognizance and involvement of developing nations in the CCS project undertakings.

The rationale behind emphasizing this facet of the study was to scrutinize the way oil and gas corporations originating from diverse geographical locations accord precedence to SDGs contingent upon their nation of origin. Notable is the fact that all these corporations are active participants in the United Nations Global Compact. This voluntary initiative encourages businesses to adopt sustainable and socially responsible policies and disclose their progress toward Sustainable Development Goals. However, participation in the UNGC does not imply that a company is wholly committed to sustainable practices or reducing its carbon footprint effectively. It is, therefore, essential to look beyond a company's participation in voluntary initiatives and evaluate its performance in reducing emissions and attaining the SDGs through the various projects it undertakes, as well as its impact on society and Scope 1, 2, and 3 emissions (Compact, 2023).

6.1.8 Discussion & Conclusion

In conclusion, even though the United States variable suggests a positive correlation with carbon capture capacity, the results are not statistically significant. Likewise, the variable for developing nations indicates a positive correlation with carbon capture capacity, but the results are not statistically relevant. Therefore, whether these relationships hold for all developing nations is still being determined. Additional research may be necessary to determine the effects of being from the United States or a developing nation on carbon capture capacity.

The main finding of the research is that project characteristics are most important, followed by location, while the period is not significant, suggesting that project capacity does not increase until 2030. The prospect of achieving carbon neutrality presents a potentially pivotal moment for CCUS to establish a presence within the forthcoming emissions-reduction portfolio (Zheng et al., 2022). Significantly reducing the costs of CCUS technology by accelerating the innovation of new generation capture technology may be the breakthrough point for CCUS (Zheng et al., 2022).

The commitment of oil and gas companies to sustainable growth can be analysed further by examining the communication of their progress within the UNGC programme. To determine the importance of SDGs, sustainable reporting, and investment in CCUS as a current mitigation mechanism, ten energy-sector companies from Norway, the United States, the United Kingdom, and India were analysed for this study. This will be explained in detail in the following section of the report, which is modeled after an empirical study of UNGC's active participants.

6.2 Empirical analysis of participation in the United Nations Global Compact programme

6.2.1 Introduction

Corporate sustainability encompasses many environmental, social, and economic aspects (Ashrafi et al., 2019). Many companies support the United Nations Sustainable Development Goals (SDGs) and participate in its sustainability programme (Compact, 2023). The latter programme entails carrying out essential obligations and reporting on human rights, labour, the environment, and anti-corruption (Noreen et al., 2019; Sethi & Schepers, 2014).

Responsible corporations apply the same values and principles everywhere they operate, and they understand that excellent practices in one area do not compensate for damage in another (U.N. Global Compact Programme, 2022). Companies that incorporate the ten principles of the United Nations Global Compact into their strategies, policies, and processes and develop a culture of integrity are fulfilling their fundamental duties to people and the world and laying the groundwork for long-term success (U.N. Global Compact Programme, 2022).

This section investigates the determinants of participation of oil, gas, and coal companies in the UNGC programme. The emphasis is on firm characteristics such as sub-sector, size, and location. The data is derived from the U.N. Global Compact programme for the period 2000-2022, covering approximately 785 oil, gas, and coal-producing companies (United Nations Global Compact Participants Database, unpublished data).

The analysis of the status of the UNGC programme in the oil and gas industry is essential as they belong to the most significant emitters worldwide. Evidence based on the UNGC shows that only half of the oil companies stay in the programme, and significant differences exist across countries (UNGC database). The reporting criteria guide businesses toward carbon neutrality (U.N. Global Compact Programme, 2022). The UNGC programme assists large companies and SMEs achieve their sustainable development objectives (SDGs). It thus goes beyond national sustainability reporting, which only must be carried out by large companies (European Commission, 2023; Corporate sustainability reporting). The collective global climate goals and targets can only be attained through collaboration, contribution, and concise reporting (U.N. Global Compact Programme, 2022).

The following are some of the reasons why one would be interested in knowing more about UNGC participation: First, it is essential to ascertain whether oil and gas businesses know the dangers of climate change and other environmental issues and whether they are taking steps to disclose their progress toward being carbon neutral and improving the environment. The second step is to research the level of commitment that different companies have made to the UNGC programme, their current COP status, and the possible results of this research.

This work builds on Knudsen (2011) and Rasche et al. (2021). The latter demonstrates that firm size, ownership, and the presence of a local network are significant determinants of the decision to remain in the United Nations global compact programme (Knudsen, 2011; Rasche et al., 2021). According to Knudsen (2011), delisting from the U.N. Global Compact programme began in 2008. Many companies were removed for neglecting to report progress (630 companies, representing almost 15 per cent of U.N. Global Compact corporate members) (Knudsen, 2011).

6.2.2 Conceptual background – UNGC programme

According to Noreen et al. (2019), the primary drivers of global climate change are the emissions of greenhouse gases and carbon dioxide, which are predominantly attributed to the activities of the oil and gas sector (Noreen et al., 2019). Businesses in the oil and gas sector have long promoted sustainability, meeting sustainability requirements related to health, safety, and the environment while also increasing their contribution to their communities (Noreen et al., 2019). One of the sustainability guidelines and principles promoters is the UNGC programme, established in 2000 and is a voluntary programme that depends on public accountability, openness, and disclosure to supplement regulation (Noreen et al., 2019). It invites businesses to "adopt, promote, and implement a set of fundamental principles in the areas of human rights, labour standards, the environment, and anti-corruption within their sphere of influence." (Noreen et al., 2019 ;Knudsen, 2011; Berliner & Prakash, 2012; Berliner & Prakash, 2015).

In 2010, the Global Compact was a network comprised of over 10,000 participants, including over 6,930 enterprises in over 135 countries (Gilbert & Behnam, 2013). In 2023 the number of participants is 22,400 from 160 countries (Compact, 2023). It allows firms to voluntarily align their business activities with ten principles in four subject areas (i.e., human rights, labour rights, environmental protection, and anti-corruption) (Compact, 2023b; Kell, 2013). The ten principles are not exclusive to any industry, area, or kind of organization; they are intended to be globally applicable (Kell, 2013). Three of the ten principles pertain to the environment, which is challenging to implement in polluting industries such as oil and gas (U.N. Global Compact Programme, 2022).

Consequently, it is not surprising that several energy and gas companies have withdrawn from the programme and been delisted (Knudsen, 2011). On the other hand, incorporating the SDGs as a core corporate value can positively impact the communities and countries where businesses operate. This initiative aims to create more eco-friendly enterprises and facilitate the transition to a more sustainable future (U.N. Global Compact Programme, 2022).

UNGC programme seeks to minimize emissions from all sectors by offering a template for businesses to provide examples of how they currently contribute to the SDGs and how they may lead in the future via the U.N. Global Compact programme (Noreen et al., 2019). In addition, the U.N. Global Compact's emphasis on learning and debate influences compliance by "socializing" players progressively into new regulations; without a certain degree of rule internalization, voluntary rule compliance cannot be attained (Rasche et al., 2013). Furthermore, UNGC provides a forum for agreeing on interpreting and implementing laws governing social and environmental conduct in a particular setting (Rieth et al., 2007). Moreover, such decentralized debates increase the desire and ability of actors to comply with regulations freely (Rieth et al., 2007). These considerations demonstrate that while the Global Compact is not a regulatory instrument in the strictest sense, it may nonetheless significantly influence the corporate responsibility practices of firms (Rasche et al., 2013).

Furthermore, as the UNGC covers more than 135 countries worldwide, it allows companies to network with each other (Gilbert & Behnam, 2013). As local networks have been established all over the globe, the UNGC might be considered a genuinely global network (Gilbert & Behnam, 2013). According to empirical research, participation in local networks is primarily motivated by the opportunity to network with other local businesses to aid in the decentralized implementation of the principles (Whelan, 2010). Therefore, the Global Compact is sometimes referred to as a "network of (local) networks" due to the increasing significance of local networks in establishing its foundation within diverse national and cultural contexts (Gilbert & Behnam, 2013).

Nevertheless, UNGC must refrain from intending to enforce or evaluate initiative participants' conduct because the organization needs more authority and resources to implement such a regulatory structure (Gilbert & Behnam, 2013). This indicates that the initiative needs to offer a legally binding code of conduct with explicit performance criteria and independent monitoring and enforcement of compliance with the ten principles (Ruggie, 2021). Although the UNGC does not monitor whether participants honour their commitments, to remain "active," all business participants must submit an annual COP report, a mild form of self-regulation (Rasche et al., 2022). The COP is a public document (accessible via the UNGC's website) to inform all stakeholders of a company's efforts to support the ten principles. However, UNGC does not validate the content of COP reports, and it is not standardized and must only adhere to minimal requirements (Rasche et al., 2022).

It has been observed by Knudsen (2011) and Rasche et al. (2021) that a common characteristic of the UNGC initiative is the tendency for numerous companies and organizations to discontinue their participation in the program after a specific duration, across all sectors. The determination of whether to remain enrolled in or withdraw from the program is contingent upon both external and internal factors, with the latter encompassing the size of the company and its subsector. This matter shall be subject to further investigation in the subsequent section. In addition, there is a specific emphasis placed on the COP (Communication of progress) status of the companies. The data obtained from the UNGC programme has been analysed using probit and poisson regression techniques. Oil and gas companies with high carbon footprints are anticipated to intensify their endeavours to comply with the climate objectives outlined in the Paris Agreement by 2030 (Martin-Roberts et al., 2021; institute 2021). Henceforth, the primary inquiries for investigation are:

RQ6: To what extent have oil and gas corporations made progress in mitigating climate change and contributing to Sustainable Development Goals?

RQ7: What is the level of commitment to the COP status within the United Nations Global Compact programme, and how does it impact active participation in the programme?

RQ8: How does participation in the UNGC programme vary based on the industry subsector and the company's scale?

6.2.3 Empirical model

The following examines the UNGC programme status based on specific characteristics. Some oil and gas companies that subscribed to the international sustainability programme dropped out after some time (United Nations Global Compact Participants Database, unpublished data). The question of which type of oil and gas firms are leaving the programme is empirical. Oil and gas companies from certain countries likely show a better commitment to the sustainability goals of the UNGC programme. In addition, the characteristics of the firm also matter. The strength of the database is that not only large corporations, but also small and medium-sized enterprises are included.

Equation 1- Probit model

Probit regression is a type of regression analysis that models the relationship between a binary dependent variable and one or more independent variables. In the context of the probit model, the dependent variable is binary, taking on only two possible values, often 0 or 1, indicating the absence or presence of a particular characteristic or event, respectively (StataCorp, 2013). the relationship between a response variable and its predictors can be assessed using probit regression, which helps understand the results quickly and provides a high-accuracy prediction (Ghasemzadeh & Ahmed, 2019). In regression analysis, independent predictor variables are investigated for their influence on outcomes; depending on whether there are one or more predictors, the effect of each is determined by the dependent variable (1,0) (Opić, 2020).

For example, in the context of the UNGC program, the probit model can be used to analyse the likelihood of companies being actively involved in the program, given their size, region, and sector. A probit model is specified to determine whether companies are actively involved in the UNGC programme. The dependent variable is the likelihood of the active status of companies in the UNGC programme, $\mathrm{Prob}(Y=1)_i$ it is modelled as a function of three variables (United Nations Global Compact Participants Database, unpublished data):

$$\mathrm{Prob}(Y=1)_i = f\left(\alpha_0 + \alpha_1 Size\_class_i + \sum_{r=1}^{5} \alpha_2 Region_{ir} + \alpha_3 Subsector_i\right)$$

where i=i,…785 is the firm index and f is the link function.

Size - class is a dummy variable for size category (SME versus large). The region is a set of dummy variables with North America as the reference category for *(Africa, Asia, Europe, Latin America, | Mena (the Middle East and North Africa), Northern America, and Oceania),* and subsector *(industries that companies belonging to).* The subsector is equal to 1 if oil and gas companies belong to the oil and gas producing segment and 0 if it belongs to the oil equipment and services. The terms α 's are regression coefficients obtained by maximizing the likelihood estimations, and ε is the error term that is a random variable following the standard normal distribution (Wooldridge, 2015).

Another research question to be investigated is the determinants of COP. This allows access to which types of oil and gas companies are more active in sustainability reporting. As the number of COPs is a count data variable, the poisson model can be used (Cameron & Trivedi, 2013).

Equation 2- Poisson model

SMEs are expected to have a lower probability of staying in the UNGC programme than large firms. The reason is that they have less experience in preparing sustainability reports as compared to the larger firms who are often required to do so according to the law (Commission, 2022). An escalation in sustainability reporting may ensue because of government regulations or the implementation of novel legislation. In certain countries, such as France and Sweden, companies that exceed a certain threshold are mandated by law to undertake this action (Chelli et al., 2014). As per Section 116 of the Nouvelles Régulations Economiques (NRE) Act, passed in 2001, publicly traded companies in France, must disclose information regarding the social and environmental consequences of their operational undertakings (Chelli et al., 2014).

The purpose of this analysis was to identify the categories of oil and gas corporations that exhibit the highest degree of engagement in disclosing their sustainability initiatives. To achieve the objective, a poisson regression model was employed as the optimal statistical methodology, owing to the count variable characteristic of the variable under investigation, specifically the count of COPs reported by each organization.

Furthermore, the study was conducted to examine the involvement of firms based on their geographical location, thereby offering significant perspectives on how the region may influence a company's dedication to the UNGC initiative. This study offers valuable insights into the sustainability reporting practices of various types of companies and the impact of location on their engagement. As a result, it can guide legislative and regulatory actions related to sustainability practices in the industry.

The dependent variable(Y) is the number of COPs, and the independent variables are the size of the company (X1), Location (X2), and Sub-sector (X3). This is how the regression function is expressed:

Number of COPs(Y)= F (size of the company, location, sub-sector).

The specification for the Poisson regression model for the study is as follows:

$$COP_i = Exp\ (\alpha_0 + \alpha_1 Size\_class_i + \sum_{r=1}^{5} \alpha_2 Region_{ir} + \alpha_3 Subsector_i)$$

where i=i,…785 is the firm index and Exp is the exponent function. COP is the expected number of COPs reported by oil and gas companies participating in the UNGC programme. The independent variables are the same as in probit regression. The equation is estimated by the poisson estimator.

This model is suitable for the number of occurrences of an event in a specified period or area. Overall, this poisson regression model aims to determine the relationship between the number of COPs reported by oil and gas companies and their size, location, and sub-sector. In addition, it allows for the estimation of the effect of these factors on the expected number of COPs, which can provide insights into the sustainability reporting practices of companies in the industry. Both probit and Poisson regression results will be provided in the following section "descriptive statistics". Which will analyse research questions 6,7 and 8.

6.2.4 Descriptive statistics

The database of the UNGC with 785 companies is analysed, and the focus is on three determinants: country, size, and sub-industry. These independent variables aided the investigation in delving deeper into the empirical models developed using the probit and poison regression. Independent impetus for selecting independent variables is often the requirement imposed by stakeholders on large or publicly traded companies to divulge details regarding their endeavors toward sustainability.

Oil and gas companies of greater size, particularly those engaged in production, are subject to heightened institutional pressure concerning their handling of environmental challenges (Commission, 2022). This pressure emanates from a variety of stakeholders, including media outlets, government agencies, and environmental authorities. In contrast, smaller companies, or those with a minor environmental impact, such as oil and gas equipment and service providers, may experience less pressure (Commission, 2022). Consequently, the probability of their retention in the programme is higher.

When businesses become signatories, they commit to submitting an annual COP to the UNGC (Sethi & Schepers, 2014; Compact, 2023). This document represents the corporation's communication with its stakeholders (Sethi & Schepers, 2014). The COP is comprised of three essential constituents, namely, an endorsement statement from the Chief Executive Officer (CEO), a record of measures taken subsequent to joining or since the previous report that either enforces UNGC principles or bolsters wider U.N. initiatives, and outcome assessments that demonstrate the metrics employed (Sethi & Schepers, 2014). The corporation designs, administers, and composes the COP (Sethi & Schepers, 2014).

In the following, the COP status of oil and gas companies is investigated. It provides adequate information on four areas of broad public concern, including the environment, human rights, labor rights, and anti-corruption, according to the UNGC (Compact, 2023). As shown in Table 14, the proportion of active firms is 55.3 per cent. However, it is essential to note that forty per cent of the corporations have been removed from the list, and five per cent have ceased communicating with UNGC. Non-active firms are either delisted or non-communicating (U.N. Global Compact Programme, 2022).

Table 14 COP status (Active, Delisted, Non- communicating, non-active)

COP Status	Number of Firms	Per cent
Active	434	55.29
Delisted	316	40.25
Noncommunicating	35	4.46
Non- active	351	44.71

Source: (United Nations Global Compact Participants Database, unpublished data), own calculations.

Calculating COP status was to identify how many companies have been active or inactive to determine how many are still active in the programme and continue reporting various projects and accomplishments for greater transparency. This aided the research in determining the effectiveness of the programme and the level of oil and gas industry companies' commitment to sustainable reporting.

Table 14 shows statistics of 434 active UNGC programme participants and 351 non-active participants from various industries. Interestingly, "active" and "not active" participation has almost the same value. The difference between active and inactive participants is negligible, and the underlying causes are unknown. This is one of the limitations of this empirical model, which makes it challenging to determine which energy-sector enterprises have become inactive and from which region and location they originate. To surmount this limitation, the scope of this study was restricted to analysing and identifying the status of companies by region and nation.

The next step is to analyse the share of companies active in the UNGC programme in the oil and gas sector by region and country to see the results more clearly. Table 15 shows the proportion of active UNGC participants by region, while Table 16 shows the corresponding proportion by country. Table 15 summarizes the active UNGC status of corporations in various regions. The table displays the proportion of firms active in the UNGC programme and the total number of oil and gas companies (see Table 15). The proportion of active UNGC participants in Europe is 64.2 per cent. The proportion of active UNGC participants is relatively low in Africa is 39.2 per cent and 28.9 per cent in the MENA region. For the total sample, the proportion of active UNGC participants is 55 per cent. Europe and North America are in leading positions from the perspective of the region.

Finding statistics by region and country was done to emphasize that location is one of the most critical factors and reasons for companies to remain in the UNGC programme. In addition, location can determine which nations are more committed to the green transition, which adhere to social and economic sustainability principles, and which have public policies that guide businesses toward a sustainable future.

Table 15 Active Participation by Region

Region	Mean	Per cent	Number of nonmissing values
Africa	0.392	39.2	51
Asia	0.481	48.1	129
Europe	0.642	64.2	313
Latin America and the Caribbean	0.527	52.7	207
MENA	0.289	28.9	45
Northern America	0.743	74.3	35
Oceania	0.600	60.0	5
Total	0.553	55.3	785

Source: (United Nations Global Compact Participants Database, unpublished data), Own calculations.

Table 16 Proportion of Active UNGC participants in per cent

Country	Number of oil and gas producers	Proportion of active UNGC participants in per cent
Spain	53	64
France	37	84
Colombia	36	64
United Kingdom	29	72
China	28	57
Argentina	20	65
Brazil	19	63
Mexico	19	47
Japan	15	73
India	14	57
Germany	13	69
Nigeria	12	42
Canada	9	44
Pakistan	9	33
United States of America	9	89
Russian Federation	9	56
Poland	8	13
Ukraine	7	29
Bolivia	6	33
Korea	6	67
Ecuador	6	67
Norway	6	67
Sweden	6	100
Thailand	6	83
Total	519	60

Source: (United Nations Global Compact Participants Database, unpublished data), Own calculations.

Note: The number of observations is 785. The period is 2001-2022. Therefore, the table only shows the proportion of active firms in countries with six and more firms.

The results of Table 16 show that the UNGC programme status varies significantly between countries. The highest result has been identified in the Scandinavian nation - Sweden, with

(100 per cent) active participation status, Sweden followed by the United States of America with (89 per cent), France (84 per cent), Japan (73 per cent), and the United Kingdom (72 per cent). The lowest proportion of active oil and gas companies can be observed in Poland (13 per cent). The empirical research has progressed to a point where the companies' participation has been whittled down to determine their country or region of origin. Based on this, we have determined that all active participant countries are from developed nations. Oil companies in Northern and Western Europe and OECD nations are more committed to the UNGC than their counterparts in other regions.

6.2.5 COP Status

Sector – Oil and gas industry

The following phase examines the proportion of UNGC programme status by subsector. We attempted to limit our research by focusing on the oil and gas industry sector and determining whether the oil and gas industry sectors are a part of the UNGC programme and have a high COP status.

Respectively, table 17 summarizes the active UNGC status of companies in the oil and gas sectors with a focus on Oil & Gas Producers, Oil Equipment, and Services & Distribution sectors. The table depicts the average proportion of active UNGC participants for each subsector. The mean column displays the average proportion of companies in each industry that are active UNGC participants. For instance, the average proportion of active UNGC participants in the Oil & Gas Producers industry is 59.4 per cent, while the corresponding proportion for the whole sector is 55.3 per cent. This suggests that companies in the Oil & Gas Producers sector are more likely to participate actively in the UNGC than those in the Oil Equipment, Services & Distribution sector.

Table 17 Active participation by sector (Oil & Gas producers; Oil Equipment and services)

Sector	Proportion in percent	Number of firms
Oil & Gas Producers	59.4	519
Oil Equipment, Services & Distribution	47.2	265
Total	55.3	785

Source: (United Nations Global Compact Participants Database, unpublished data), Own calculations.

As of this point in research, we have narrowed down the active participation of the companies concerning the parameters and have concluded the participation percentage of companies in the sectors (see Table 17). Now the research allocated the next step to analyse whether the differences between the characteristics are significant. In conclusion, the descriptive statistics show that the proportion of oil and gas companies participating in the UNGC programme varies by country, region, and sub-sector. The following section will discuss the empirical analysis using probit regression of the active UNGC programme status determinants.

6.2.6 Empirical results of probit estimations of the determinants of the Active UNGC status

The descriptive statistics show that characteristics like size, region, and sub-sector play a role in determining the UNGC programme status. Therefore, the next step is constructing an empirical model using probit regression, which provides a comprehensive picture of all the parameters discussed in the descriptive statistics. As a result, the following Stata-generated model enhances the research's comprehension of UNGC participation (see Table 18).

Table 18 Probit estimates of the determinants of the active UNGC programme status

Variable name	Coefficient		z-stat	dy/dx		z-stat
SME (reference category large)	-0.66	***	-6.84	-0.24	***	-7.55
Oil & GasProducers (ref. Oil equipment and	0.22	**	2.27	0.08	**	2.29
Africa (North America)	-0.81	***	-2.82	-0.29	***	-2.85
Asia	-0.81	***	-3.18	-0.29	***	-3.24
Latin America	-0.47	**	-1.95	-0.17	**	-1.96
MENA	-1.08	***	-3.63	-0.39	***	-3.70
Europe	-0.25		-1.02	-0.09		-1.03
Oceania	-0.30		-0.46	-0.11		-0.46
Constant	0.81	***	3.52			
Number of observations	785					
Pseudo R2	0.0867					

*Note: ***, ** and * denote significance at the 1, 5 and 10 per cent.*

Source: (United Nations Global Compact Participants Database, unpublished data), Own calculations.

Table 18 presents the outcomes of a probit regression analysis conducted to ascertain the factors that influence the Active UNGC programme status of the firms. This status denotes a company's dedication to adopting the principles of corporate sustainability and responsible business practices as advocated by the UNGC programme. The dependent variable is a binary variable with the value *one* if the organization is an active UNGC participant and *zero* otherwise.

In addition, the analytical process considers multiple independent variables, such as the magnitude of the enterprise, the field of operation, and its geographical placement.

The estimated coefficients for each independent variable are displayed in the coefficient column. Keeping all other variables constant, these coefficients represent the change in the log odds of being an active UNGC participant associated with a one-unit change in the independent variable. The z-stat column displays the associated z-statistic for each coefficient, which indicates the number of standard errors removed from the zero in the coefficient. For example, a z-statistic greater or lower than 1.96 indicates statistical significance at the 5 per cent level, respectively. Finally, the dy/dx column depicts the marginal effect of each independent variable, which is the change in the predicted probability of being an active UNGC participant associated with a one-unit change in the independent variable, all other variables being held constant.

The findings indicate that the active UNGC status of a company is significantly influenced by its size. Diminutive enterprises are less likely to possess an active UNGC status than their larger counterparts. The coefficient of small and medium-sized enterprises (SMEs) exhibits a statistically significant negative association at a confidence level of 1 per cent. The discovery implies that relatively minor firms may encounter more significant obstacles in executing sustainable and ethical business strategies than their larger counterparts.

The analysis findings suggest that the industrial sector is crucial in determining the active UNGC status. Companies operating in the oil and gas production industry are likely to possess more active UNGC programme status than their counterparts in the oil equipment and services sector. At a significant level of 5%, the coefficient between oil and gas producers exhibits a positive and statistically significant relationship. This discovery implies that corporations operating in specific industry domains may be more dedicated to sustainability and ethical business conduct.

Furthermore, the location of the organization is a crucial factor in determining its active status. Organizations in specific geographical areas such as Africa, Asia, Latin America, and MENA exhibit a lower probability of possessing an active status than their North American counterparts. The coefficients of these regions exhibit statistical significance at or below the 5% level and are characterized by negative values. The discovery implies that enterprises in specific geographical areas may need help executing sustainable and ethical commercial strategies due to divergent economic, political, and social circumstances.

The regression model's constant term exhibits statistical significance at the 1 per cent level and is positive. This suggests that, despite accounting for the other variables in the model, a positive intercept impacts the probability of possessing an active status. The presented table displays a pseudo-R-squared value of 0.0867, indicating that the model accounts for approximately 8.67% of the variability in the dependent variable, which is comparatively modest.

The study's results emphasize the significance of considering a company's size, industry sector, and geographical location when evaluating its dedication to sustainability and ethical business conduct. The findings indicate that enterprises of smaller scale, those operating in specific industry domains such as oil equipment and services, and those in geographical regions such as Africa and Asia may encounter more significant obstacles in adopting sustainable and ethical business strategies. According to the findings, SME (small and medium-sized enterprise) status is negatively associated with active UNGC membership. In contrast, employment in the oil and gas production industry is positively associated with engagement. MENA (Middle East and North Africa) negatively correlates with active participation, whereas Europe is not statistically significant.

For further research, the empirical analysis of poisson regression of the number of COPs must be investigated to determine the level of communication in progress from oil and gas companies (see Table 19).

6.2.7 Empirical results of Poisson estimates of the number of COPs

Table 19 Poisson estimates of the number of COPs

Variable name	Coefficient		z-stat
SME (reference category large)	-0.51	***	-6.58
Oil&GasProducers (ref. Oil equipment and services)	0.40	***	5.10
Africa (North America)	-0.26		-0.97
Asia	0.03		0.13
Latin America	0.01		0.04
MENA	-0.83	***	-2.71
Europe	-0.07		-0.33
Oceania	0.23		0.82
Constant	1.82	***	9.04
Number of observations	785		
Pseudo R2	0.0867		

Source: (United Nations Global Compact Participants Database, unpublished data), Own calculations.

*Note: ***, **, and * denote significance at the 1, 2, and 5 per cent levels.*

The research was highly motivated to determine the degree of commitment to COP status in the UNGC programme. This is the only way to ensure that the UNGC programme is more than a façade, and it can work as a countercheck and self-check for the companies on their progress toward green transition. Therefore, the study employed identical categories as the probit regression to gain further insight into the issue by scrutinizing the discrepancies among the results. In addition, the study employed the poisson regression model to examine the frequency of COP submitted by firms, utilizing region, industry, and company size as the predictor variables. The selection of these variables was made to obtain a comprehensive understanding of the degree of commitment exhibited by companies towards sustainability, considering their respective industries and geographical locations.

The regression model's findings suggest that the submission of COPs is subject to significant variation depending on the companies' industry, size, and location. Oil and gas producers exhibit a higher propensity to furnish COP reports in comparison to their counterparts in the equipment and services segment of the oil industry. It is observed that small and medium-sized enterprises (SMEs) are less likely to submit COP reports compared to larger companies. Furthermore, the MENA region exhibits the lowest number of COPs.

Table 19 presents the regression analysis findings, including the regression coefficients and z-statistics for each independent variable. Each independent variable's coefficient estimates its impact on the dependent variable, which is the quantity of COP reports that have been submitted. A coefficient with a positive sign signifies that an escalation in the corresponding variable is positively correlated with an increase in the number of COP reports submitted.

Conversely, a coefficient with a negative sign indicates a negative correlation between the two variables. For example, the Oil & Gas Producers sector exhibits a coefficient of 0.40, which is statistically significant, implying a higher probability of submitting COP reports. In contrast, small and medium-sized enterprises (SMEs) exhibit a negative coefficient of -0.51, which suggests a lower propensity to submit corporate social responsibility (CSR) reports. The MENA region exhibits a statistically significant negative coefficient (-0.83) at a 5% level, indicating that companies located in this region are comparatively less inclined to furnish COP reports than their counterparts in other regions.

Despite the limited explanatory power of the model's pseudo-R2, which stands at 0.0867, the findings offer significant contributions to understanding the determinants that potentially impact corporate reporting behavior regarding the number of COP reports submitted. The results of this study have the potential to provide valuable insights into strategies for promoting sustainability reporting among companies on a global scale.

6.2.8 Discussion & Conclusion

The results show that only 47 per cent of oil and gas companies that have joined the United Nations Global Compact since it began have stayed on the programme. This is a low proportion, given the substantial adverse environmental impacts of the oil and gas sector. The proportion of active companies in the UNGC programme is also slightly higher for the subset of oil and gas-producing companies that generate the most significant emissions than companies that provide services and supply equipment.

The probit model results for UNCG status show that oil and gas companies in Europe and North America have the highest probability of participating in the programme. In contrast, companies based in Africa, Asia, Latin America, or MENA (Middle East and North Africa) have the lowest probability. This suggests that in countries with a clear and early commitment to the green transition (such as in West and Northern Europe), oil and gas sector companies are less likely to opt out of the UNGC programme. Leaders in these regions need to weigh the advantages of participating in the UNGC and the disadvantages of not participating. Oil and gas companies may see their participation in the UNGC as an opportunity to improve their reputation.

7. Discussion

CCUS, including CCS, is a crucial component of climate change mitigation as per Jiang (2020). Over the past two decades, successful CCS initiatives in Norway, such as Sleipner and Snøhvit, have stored over 22 million tons of CO2 (Ku et al., 2020; Martin-Roberts et al., 2020). However, increased costs and a negative public perception impede the implementation of CCS technology (Al-Mamoori et al., 2017; Merk et al., 2022; Al-Mamoori et al., 2018). In addition, the choice of transportation infrastructure, such as pipelines and ships, is influenced by the route's duration and the storage facility's location (Mendelevitch, 2014; Weber & Tsimplis, 2017; d'Amore et al., 2021; Gola & Noussia, 2022).

According to Al Baroudi et al. (2021), Norway's lengthy history of maritime activity and coastal location make it an ideal place for the shipping industry and CCUS projects (Al Baroudi et al., 2021). The deployment of CCS technology and Europe's aim of carbon neutrality by 2050 necessitate the support of policymakers and the implementation of robust climate policies (Al Baroudi et al., 2021). Oil and gas companies from Norway, the United States, the United Kingdom, and India are crucial to the success of CCS projects due to their commitment to sustainability and initiatives to mitigate the effects of climate change through the United Nations Global Compact programme (d'Amore et al., 2021). However, project characteristics and location impact the adoption and spread of CCS technology. Due to resource constraints, smaller businesses may require assistance in global sustainability projects (Mikhelkis & Govindarajan, 2020; Weber & Tsimplis, 2017). By 2050, it is anticipated that the demand for CCS technologies to capture and store approximately 5.6 gigatonnes of CO2 annually will increase (Martin-Roberts et al., 2021).

The global energy system is enduring transformations, fuelled by technological advances and the increasing penetration of wind and solar power generation (Ku et al., 2020). Numerous nations have a high social acceptance of renewable energy, and their governments have enacted policies to encourage its development (Ku et al., 2020). Large-scale deployment of renewable energy systems is widely regarded as an effective climate-change mitigation strategy but reaching 100 per cent renewables still need to be determined (Ku et al., 2020). However, renewable sources such as hydro, solar, and wind produce environmental impacts and require vast quantities of mineral resources that must be managed (Tylor-Jones & Azevedo, 2023). Although removing carbon from the atmosphere is an urgent matter, policymakers should adopt international frameworks for deploying green technologies to ensure a smooth energy transition (Nepal et al., 2021).

In line with the Paris Agreement, all signatory nations are required to attempt to limit the global temperature increase to less than 2°C above pre-industrial levels (Bajpai et al., 2022). Although steps have been taken to promote renewable energy and increase energy efficiency, it is anticipated that humanity's reliance on fossil fuels, particularly petroleum oil and natural gas, will persist for the next three to four decades, with demand coming primarily from developing nations (Bajpai et al., 2022).

Carbon capture and storage is an essential responsibility for energy firms (Chen et al., 2022). nevertheless, organizations have struggled to collect and store carbon emissions due to several obstacles (Jiang et al., 2020). For several years, the environmental impact of carbon capture and storage has been ignored or undervalued (Institute, 2021). However, as technology has improved, the general perspective on CCUS and related projects has shifted (Institute, 2021). We have conducted an empirical investigation of carbon capture and storage variants to compile the research. The regression model will assist us in pinpointing the beginning of CCUS implementation operations. First, the CO2 Capacity scatterplots are the outcome of Stata modelling, and the logarithm of the CO2 capacity on the operational date demonstrates that the project's capacity only increases with time.

CCS can decrease climate change dramatically by keeping CO2 from entering the atmosphere (Braun, 2017). Nevertheless, this global advantage is accompanied by local dangers; specifically, the release of CO2 from subsurface deposits might impair the surrounding ecosystem and wildlife (Braun, 2017). To avoid these threats to the world's ecosystem and biodiversity and to limit the increase in global temperature to 2 °C, the E.U. has proposed that industrialized nations reduce their greenhouse gas emissions and releasing CO2 by 80–95 per cent by 2050, relative to 1990 levels (Kjärstad et al., 2016).

Scholars argue that intensive industries should have valid frameworks to minimize their emissions and satisfy the stakeholder. To achieve this increased participation rate in the UNGC programme would be an ideal start. Based on the study's results, valuable perspectives on the factors that influence the participation of oil and gas companies in the UNGC program were analysed. Research suggests that only 47% of oil and gas enterprises have sustained their participation in the UNGC initiative. Firms located in Europe and North America are more likely to engage in the program, while those located in Africa, Asia, Latin America, and MENA are less likely. The UNGC status of a company is significantly impacted by its size, location, and industry sector, with smaller companies less inclined to have an active status than larger counterparts. This suggests that smaller companies may face greater challenges in implementing sustainable and ethical business practices.

Subsequent research endeavours ought to examine the effectiveness of various incentive strategies to encourage engagement across a wide range of regions and industries. Moreover, there is a need for additional research to examine the cultural, political, and economic factors that influence corporations' decisions to participate in the UNGC. Ultimately, additional research could be undertaken to examine the potential association between corporations' ecological and societal achievements and their involvement in the United Nations Global Compact.

8. Conclusion

In conclusion, the following observations can be made regarding the research inquiry on the pros and cons of CCUS based on the literature review. First, the findings of research question 1 indicate that insufficient funding and limited participation of private enterprises are the primary impediments hindering the advancement of CCUS. From the existing body of literature and analysis, it appears that the expenses associated with transport and storage pose a notable obstacle to the advancement of CCUS.

Despite the progress made in technology and infrastructure, the expenses associated with transportation and storage remain very high, impeding the widespread implementation of CCUS. To tackle this challenge, research and development endeavours may focus on enhancing transportation and storage technologies' efficacy and economic viability by implementing transportation networks, selecting appropriate transportation modes, and managing risk assessments. Furthermore, policymakers and industry leaders may collaborate to formulate policies and regulations that promote allocating resources toward CCUS infrastructure and offer incentives for implementing low-carbon technologies. Mitigating the cost impediments linked with the transportation and storage of CCUS could facilitate the expeditious implementation of this pivotal technology and curtail the discharge of greenhouse gases in the future. However, given the high cost of CCUS projects, all projects financed with public funds need to be assessed based on a cost-benefit analysis in comparison with other projects, e.g., investments in renewable energy sources.

Concerning research question 2, the public's attitude towards CCUS is diverse and significantly impacted by their comprehension of the technology and its prospective advantages. Despite recognizing CCUS as an indispensable instrument in addressing climate change, there persists a considerable amount of misinformation and misunderstanding regarding its execution. The prevailing trend among governments is to adopt a favorable stance towards CCUS, as evidenced by enacting laws and providing financial resources to facilitate its advancement. However, even with the potential efficacy of said policies, their implementation may be impeded by various factors, including but not limited to the expenses associated with transportation and storage and a dearth of public approval. The effective execution of CCUS necessitates the resolution of these obstacles and the involvement of the community and interested parties in a clear and comprehensive approach.

Regarding research inquiries number 3, 4, 5, 6, 7, and 8 the findings were derived from an empirical analysis of projects related to CCS and participation in the UNGC programme. The findings of research question 3 indicate that the Paris Climate Summit in 2015 could have led to an acceleration in the spread of CCS projects. However, the observed increase must catch up to the projected capacity necessary to achieve the global climate objectives. Moreover, the fourth research question's findings suggest that the type of industry significantly influences the capacity of CCS projects. The analysis findings suggest that specific sectors, such as Ethanol manufacturing and power generation, exhibit a greater propensity to embrace carbon capture technology than other industries, as evidenced by the most significant number of CCUS initiatives. Thus, these sectors play a pivotal role in attaining Sustainable Development Goal 13, which pertains to acting against climate change. On the other hand, the research indicates that carbon capture technology has been adopted to a lesser extent in specific industries. Therefore, these sectors must establish sustainable methodologies and innovative technologies to mitigate their carbon emissions and positively impact global climate objectives.

The findings about research question 5 indicate that private enterprises exhibit restricted participation in CCUS endeavours in developing nations owing to many constraints intrinsic to such countries, with public financing being the predominant factor. Nevertheless, developing nations are progressing in resource utilization and narrowing the gap with their northern global counterparts. The research underscores the necessity for increased commitment towards sustainable methodologies and minimizing ecological damage in developing nations. To scrutinize this research, a comprehensive examination must be carried out of diverse facets of those specific nations.

The findings of research question 6 indicate that the efforts made by oil and gas corporations toward addressing climate change and supporting sustainable development goals need to be increased. The research underscores the necessity for enhanced participation of oil and gas enterprises in the UNGC programme, particularly in developing nations. Moreover, the research analysis indicates that corporate participation may result in increased transparency and heightened stakeholder satisfaction.

The findings of research question 7 indicate a higher likelihood of participation in the UNGC programme among oil and gas companies in Europe and North America compared to those in Africa, Asia, Latin America, or MENA. However, SMEs' active participation level is notably lower than giant oil and gas corporations that possess substantial resources. This difference is of great significance. The findings of research question 8 indicate that the participation of companies in the UNGC programme is significantly influenced by factors such as their size, location, and sub-industry.

The study concludes that there are substantial obstacles in implementing Carbon Capture, Utilization, and Storage (CCUS) technology, which are crucial for addressing climate change and attaining sustainable development objectives. The primary challenges include restricted financial resources, inadequate participation from the private sector, and insufficient commitment from the oil and gas sector. Innovative solutions and prioritized resource allocation are crucial to successful implementation. The research underscores the necessity for further investigation to tackle these obstacles and establish efficacious policies. In addition, the engagement in CCUS technology varies across countries and industries, and regulatory frameworks must prioritize its implementation.

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