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Original article

An examination of country participation in carbon capture projects

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ABSTRACT

Carbon capture, utilisation and storage represents an important technology for countries to address climate change challenges, achieve decarbonisation and reach net zero targets. This study examines the factors that are association with country level participation in carbon capture projects. A Poisson regression model is employed to examine the relationship between country level factors (such as GDP per capita, regional partition, trade openness, economic complexity and tax initiatives) and the number of carbon capture project initiated within a country (from 2019 up until February 2023). We find that a country's region (as defined by the World Bank), market affluence and level of CO_2 emissions is associated with a country's participation in carbon capture projects. The results indicate that nations that are more affluent and have higher CO_2 emissions are associated with increase participation in carbon capture projects. Carbon tax and Emissions Trading Systems have a positive impact on a country's participation in carbon capture projects, in particular carbon tax. This indicates that carbon tax acts as an effective incentive for industry engagement with carbon capture technologies. This study also examines the interplay between economic complexity and country level carbon capture project participation, where a negative relationship is observed.

Introduction

There is an increased need for a reduction of CO_2 emissions by countries and carbon neutrality in order to combat climate change [1,2]. Carbon capture, utilisation, and storage (CCUS) is emerging as an important technology to reduce emissions, especially in industrial sectors (that are often characterised as hard to decarbonise) [3–7]. The CCUS process involves separating and capturing CO_2 that is produced by processes using fossil fuels [8,9]. This captured CO_2 is transported and stored in geological reserves for long periods of times. An alternative to storing the CO_2 in geological reserves in the CCUS process is to use the captured CO_2 to produce chemicals, algae or building materials [10,11]. Fig. 1 provides a summary of the CCUS value chain (adapted from the work of Chen et al. [12]).

CCUS has been argued to be a necessity in reducing emissions and tackling climate change globally. Whilst there has been significant progress in recent decades in the development of solar, wind and hydro energy, these sources are unlikely to meet global energy demands [13,14]. Fossil fuel-based power generation remains a feature of the modern global economy [15], which is the activity that results in the largest emissions of CO_2. Therefore, carbon capture is a critical (even vital) solution, mitigating these CO_2 emissions along with utilising captured carbon in various industries, whilst the technology and capabilities in renewable energy continue to be developed [16].

Bowen [17] notes that wide adoption of CCUS technology could account for 20 % of required CO_2 reduction by 2050. Mahjour & Faroughi [18] note that in heavy industries the use of carbon capture and storage could result in a 25–67 % reduction in CO_2 emissions. Yet Hong [19] notes that the global deployment of CCUS technologies is still not sufficient to reach 2050 net-zero targets. The increasing importance of carbon capture technologies in addressing the climate change crisis [11,20] has acted as the motivation for this study, which seeks to examine country level features associated with participation and investment in CCUS projects. In particular we seek to understand whether there are country level features associated with carbon capture project involvement (at the country level). This can then potentially inform and discuss policy aspects that can be used to foster the involved and participation of countries in carbon capture projects in effort to tackle climate change.

Peridas & Schmidt [21] provide an overview of the current status of carbon capture technology. They note that first generation carbon capture technology is mature yet does not meet efficiency expectations.

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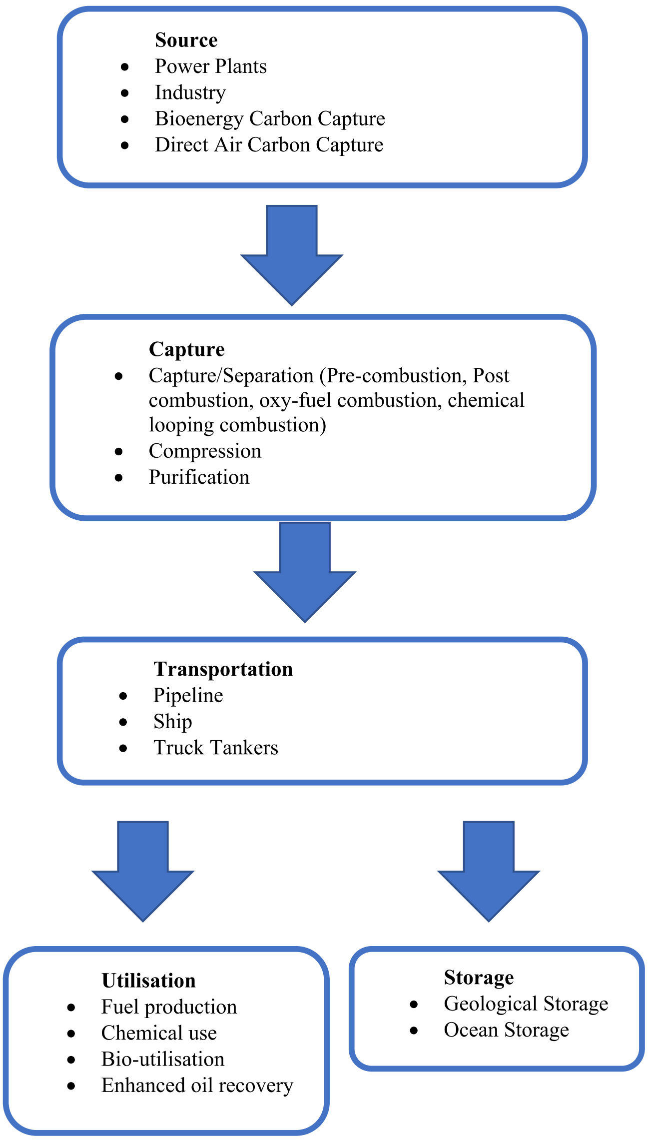

Fig. 1. Carbon Capture, Utilisation and Storage (CCUS) value chain.

Next generation (second and third) carbon capture technology seeks to improve efficiency and cost when deployed at scale; yet implementation on such scales has not been realised. Pipeline transportation of CO_2 is also a mature technology, and many of the challenges associated with transportation are not technological, rather operation (especially on larger scales). Peridas & Schmidt [21] further outline that there has been progress on policy to encourage and fund CCUS initiatives, yet much work is still required. Carbon capture is a technology that is established yet the general public (in several countries) are largely unaware of it, therefore, wider, public support for the uptake of CCUS initiatives is often lacking [22–24].

CCUS is an especially attractive option, for both governments and firms, as compared to more radical low carbon initiatives, as it focuses on reducing CO_2 emission by modifying existing processes [25]. However, CCUS still experiences several barriers to widespread adoption [26]; Alcade et al. [27] note that the main barriers are the cost and lack of stakeholder support (especially from key policy makers). In line with the work of Alcade et al. [27] several scholars have noted that core challenges that carbon capture projects have faced (which in some cases has led to their failure) include high cost and design issues and unfavourable economic conditions [28,29]. Reiner [30] notes in the case of Norway, the Mongstad project costs increased dramatically, almost four times the original estimates. This resulted in government auditors shutting down the project, which did not go beyond the pilot phase [31]. The development and implementation of CCUS requires substantial investment, especially from governments in the first instance (to kick-start investment from industry) [32]. This would also allow for a spread of the costs (and risks) amongst a wider range of actors to prevent the high financial burden resting solely on one actor (such as government), which will make project implementation more likely and minimise the risk of the project failing in the pilot phase.

Although there are numerous challenges to implementing and deploying carbon capture and storage programmes, there are a number of prominent success stories. One example is the Petra Nova project in the USA, which is the largest carbon-capture retrofit at a coal plant; furthermore the project came in on time and under budget [33]. A further success story for carbon capture projects was the Quest project in Canada, which involved multiple industry actors, chiefly Shell Ltd [34]. Quest demonstrated the feasibility of large commercial scale carbon capture and storage. Wang et al. [29] suggest that a feature of successful CCUS projects is that they are not owned and operated by the public sector alone, rather are a form of public–private partnerships that share the associated risks and rewards.

Carbon capture projects occur across the globe [35]; the USA is the home to many large-scale projects, with a high level of carbon capture capacity [36,37]. Abdulla et al. [38] investigate the success and failure factors of CCUS projects in the USA, where they note that policy design was a critical factor contributing to the success (or failure) of a project. Although many CCUS projects occur in North America, several studies have examined the emergence of CCUS technologies in developing countries [39,40].

This study aims to understand what country level factors influence investment in carbon capture projects. Therefore, this paper aims to address the following research question:

RQ1: What country level features are associated with investment in carbon capture projects?

Emissions Trading Systems (ETS) can influence investment in CCUS initiatives and has been viewed more widely as a one of the lower cost options for policy makers in reducing CO_2 emissions [41,42]. ETS attempt to cap carbon emissions and allow for the trading of carbon emission credits. McLaughlin et al. [43] note that the impact of ETS on CCUS investment has been modest (due to low carbon prices in many regions [29]). However, ETS allow for trading (or purchase) of carbon emission credits in areas with low carbon fuel standards; therefore, ETS in the long term may prove to be an effective mechanism to fund CCUS initiatives. In their study of Chia's engagement with CCUS projects, Ouyang & Guo [44] note that ETS are vital for the effective deployment of carbon capture technology. They find that ETS shorten the time of CCUS investment to around 5.9 years.

Other policy tools have also been found to impact CCUS investment patterns, for instance, carbon tax. Carbon tax is usually applied to all non-renewable carbon emissions; therefore, carbon tax systems create economic incentives (in both developed and developing countries) to lower emissions [45]. Carbon tax policy aims to create barriers to high emission activities and subsequently aims to act as an incentive for investment in emission lowering technologies, such as CCUS [46,47]. Many studies have considered the interplay between carbon tax systems and CCUS investment [48]. However, Zhang et al. [49] note that the relationship between the use of CCUS technology and carbon tax policy remains ambiguous. For instance, in the case of the USA, Tarufelli et al. [50] find that tax credit schemes are not sufficient to foster large scale carbon capture investment.

Given the increased focus on ETS and carbon tax on CCUS activity, this study aims to address the following (second) research question:

RQ2: Are ETS or carbon tax policy instruments in place at the country level associated with investment in carbon capture projects?

In recent years, there has been increased interest in the interplay between the Economic Complexity Index (ECI) score of a country and country level sustainability performance and green issues [51]. The Economic Complexity Index (ECI) is a metric that is used to quantify the diversification and sophistication of the export basket of a country [52]. It is calculated by using international trade data, examining the export profile of countries, focusing on the products exported (and the sophistication and complexity of these exported products). Therefore, the ECI captures the production capabilities of a country and it is often used as an indicator of the knowledge base, skill base and sophistication of production of a country [53,54]. A country with a high ECI score is capable of more sophisticated production and manufacturing [55].

There has been much debate regarding the link between ECI and CO_2 emissions [56,57]. Some argue that higher ECI results in increased environmental degradation [58], as the processes for producing diverse and sophisticated products (for export) results in higher energy demands, along with an increase in consumption-based emissions [59]. In this case, countries with high ECI and higher emissions would be well position to engage with carbon capture projects, with high level of carbon to utilised in CCUS projects, a need to reduce emissions and potentially increased capabilities to engage withe carbon capture technologies. Others argue that a higher ECI is associated with a reduction of CO_2 emissions [60–62], as they are able to produce products more efficiently [63]; and that sophisticated products are often not high-emission intensity products [64]. Some studies suggest that countries with a higher ECI are better positioned to transition to cleaner energy sources, as they have more capacity to make the transition to renewables [65]. Can & Gozgor [66] find that in the case of France, higher ECI level suppress CO_2 emissions in the long run. A range of studies suggest that the link between ECI and environmental degradation is not simple or linear, rather is characterised by a quadratic relationship [67,68].

A number of studies draw on the EKC (Environmental Kuznets Curve) hypothesis when examining the link between CO_2 emissions and ECI [69–73]. The EKC hypothesis was first developed by Grossman & Krueger [74], and it considers the link between GDP per capita and environmental quality. The EKC hypothesis states there is an inverted U-shaped relationship between market affluence and CO_2 emissions, that as a country becomes more affluent its emissions also increase, up to a certain (tipping) point, after which increases in market affluence are associated with a decrease in carbon emissions. Market affluence has also been found to shape the adoption of carbon capture technologies at the country level; given the level of finance required, western and developed countries have progressed in the implementation and piloting of CCUS projects compared to developing countries (which are more reliant on public–private partnerships) [75].

Neagu [76] identify a EKC relationship (inverted U-shaped) between ECI and carbon emission in their study of a set of EU countries. This suggests that initially pollution increases when countries expand the complexity of the products they export, but then this reaches a turning point, and the increase in complexity offsets carbon emissions. Kazemzadeh et al. [77] also find that there is an inverted U-shaped relationship between ECI and energy intensity (defined as the ratio of energy consumption to economic output).

This study aims to examine the interplay between country level ECI scores and investment in carbon capture projects,; therefore, this study addresses the following (third) research question:

RQ3: Do countries with a higher Economic Complexity Index (ECI) engage more in carbon capture project investment?

In the extant literautre, there is extensive discussion and debate regarding the link between ECI and CO_2 emissions (and environmental degradation more generally), the relationship between ECI and participation in carbon capture projects is relatively understudied by comparison. Although there is no consensus on the how ECI impacts environmental outcomes, there remains a rich literautre examining the problem [78–81]. This study aims to consider how ECI impacts participation in a key emission mitigating technology, rather than the impact on a particular environmental outcome.

Table 1 below provides a summary of the main literautre and areas relevant to the three research questions posed by this paper.

The paper is structured as follows; the next section will provide an overview of the data and methods utilised in this paper to address the research questions. This will be followed by the results, and the final section with provide a discussion and concluding comments.

Material & methods

In order to address the three research questions posed by this paper, we make use of data from the International Energy Agency (IEA) on carbon capture projects [83]. IEA data provides information covering advances in carbon capture, utilisation, and storage projects across the globe. The data contains a wide range of information on CCUS projects, including announcement date, country, project partners (the firms involved), project type, sector, fate of carbon and various other details on project status.

We examine carbon capture projects announced from 2019 onwards (up until February 2023), and the countries affiliated with these projects. We include projects at various stages, including planned, as this still reflects investment and association with CCUS technologies.

To address the research questions posed by this paper, we utilise a Poisson regression model. The Poisson regression approach was used as the outcome variable is the number of projects a country is affiliated with, and this is count data. The model specification then includes a number of country level attributes to address the research questions. Data on the country attributes was collected for 2019 (the starting year for the selection of carbon capture projects in the IEA data), in order to unpack how country features shape carbon capture investment patterns.

In the model specification, we included number of carbon capture projects before 2019, to capture existing capabilities and experience with carbon capture projects and technologies. Other country level variables include the regional partition the country belongs to (as defined by the World Bank), GDP per capita to account for market affluence, CO_2 emissions (metric tons per capita) and trade openness (as captured by level of exports as percentage of GDP). The country level attribute data was collected from the World Bank. Regional partitions are included, as regions have been noted to share characteristics linked to carbon capture potential [84], in particular political and economic

Table 1
Literature summary table.

Topic	Summary	References
Challenges associated with carbon capture projects.	Extant literautre has identified a number of challenges in implementing and deploying CCUS, yet the focal challenge is cost. These projects require substantial investment.	[46,47]
Carbon capture projects and CO_2 emissions.	Existing work has noted that countries with high levels of CO_2 are associated with carbon capture projects.	[82]
Emissions Trading Systems (ETS) and carbon capture projects.	Current impact of ETS on carbon capture investment has been modest yet may represent a long-term mechanism to fund CCUS in future.	[29,41,42]
Carbon tax and carbon capture projects.	Extant literature points towards an ambiguous relationship between carbon tax and the uptake of CCUS projects.	[45,47–49]
Economic complexity and carbon capture projects.	Whilst there is extensive debate (yet no consensus) on the link between economic complexity and CO_2 emissions (as noted in the references column), there is relatively less attention paid to the relationship between economic complexity and carbon capture.	[78–81]

factors [85]. Market affluence as captured by GDP per capita is included, given the significant relationship between income per capita and environmental quality extensively documented in the extant literautre [86,87]. It also allows for an investigation into whether more affluent countries are better positioned to participate in carbon capture projects and foster the development of this technology. Trade openness is a further measure that has received attention when examining environmental quality and carbon emissions [88–90]. Patrico et al. [82] note countries that produce high levels of CO_2 represent the highest level of potential for CO_2 utilisation and the use of carbon capture technologies. Therefore, CO_2 emissions is included in the model to examine whether carbon capture projects are in countries with high levels of CO_2; either as a results of an increased need for carbon capture technologies to combat high emission levels, or to utilise the CO_2 they are producing. To address the third research paper, we included the Economic Complexity Index (ECI) in the model specification, data on country ECI scores was collected from MIT's Observatory of Economic Complexity [91].

In order to address the second research question posed by this paper, we run two additional models, one with an ETS variable included and another with a carbon tax variable included. Details on whether a country has an ETS, or carbon tax was drawn on data compiled by Dolphin & Xiahou [92]. The ETS variable, is a binary variable, indicating whether there is an ETS in place (in at least one sector) within the country (ether at the national or sub-national level) with a 1, and 0 if there is no ETS. Similarly, the carbon tax variable is also a binary variable, with 1 if a country has carbon tax (in at least one sector at either the national or sub-national level) and 0 otherwise.

Results

This section contains two subsections, the first will provide a descriptive analysis, and this will then be followed by the regression analysis, which is used to tackle the three research questions posed by this paper.

Descriptive analysis

Fig. 2 provides a map of the number of projects affiliated with each country from 2019 up until February 2023. In line with previous studies, we observe a high level of CCUS projects associated with the USA [36,37]. Fig. 2 also shows the overall prominence of CCUS projects in North America, with a high number in both the USA and Canada. There is clear evidence of CCUS activity in Europe, most notably in the UK [93]. Inderberg & Wettestad [94] note that the UK has favourable structural capacity for CCUS, with offshore storage capacity and high levels of oil and gas industry expertise available.

There are a range of CCUS projects across the globe, including the BRIC (Brazil, Russia, India and China) nations. A number of studies have documented the CCUS progress and interest in BRIC countries [40,95,96], often focusing on the case of China [97,98]. Whilst CCUS is a part of China's carbon mitigation strategies; Jiang et al. [99] note that there is low participation of Chinese firms in CCUS projects and technologies. Jiang et al. [99] attribute this to several factors, including lack of financial subsidies and lack of public understanding in the value of CCUS technologies. India has also faced challenges regarding the uptake and deployment of CCUS technologies [100], including lack of R&D investment, political issues, lack of public support and lack of financing [101]. Examining the case of Russia, Vasilev et al. [102] note that the efforts to implement and develop CCUS have been quite limited, with level of public awareness of CCUS representing a key challenge. Public awareness of CCUS technologies represents a key challenge (and potentially) barrier to the uptake of CCUS technologies across the globe [103–107].

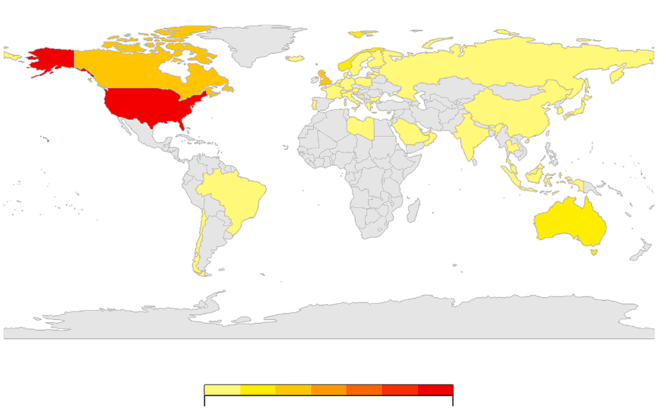

Fig. 2. World map of the number of carbon capture projects by country for 2019 to February 2023.

Some projects are associated with firms from multiple countries, representing collaboration on carbon capture projects; yet typically, many projects involve firms from a single country. These patterns can be observed in Fig. 3. We can observe projects with multiple countries associated with them tend to be in Europe. Hake & Schenk [108] argue that international cooperation is pivotal for the development and implementation of CCUS technologies; especially given that the ultimate goal of CCUS deployment is the decrease of global CO_2 emissions. They argue that international cooperation provides a number of channels for the increased uptake of carbon capture projects. Firstly, carbon capture is a capital intensive, and somewhat risky technology [109], therefore international cooperation allows for risk and burden sharing amongst partners. Secondly, international cooperation potentially allows for global learning [32]; newly industrialised and developing countries may learn from the early adoption practices and deployment of carbon capture technologies in industrialised nations.

The carbon capture projects examined as part of this study cover a range of sectors, Fig. 4 highlights the number of projects per sector. Whilst there are a number of projects that focus on transport and storage separately, a high number involve both transport and storage development. A number of hard to decarbonise sectors are included in the carbon capture projects, more notably power and heat, whilst there are far less cement and iron and steel carbon capture projects.

In addition to the sector classifications, each project is characterised as a type of carbon capture project, depending on project activities. Table 2 provides an overview of available project types.

Fig. 5 presents the number of projects by type for the projects analysed as part of this study. We observe that a high number of projects focus on capture only, and relatively less on both carbon capture and usage. The number of projects on transport and storage, and a combination of the two are at similar levels.

Table 3 provides the descriptive statistics for a range of country level attributes included in this study. We can observe that the number of projects before 2019 was rather small, and that the number has grown substantially since then, demonstrating the increased implementation of carbon capture technologies. However, there is a high level of variation in terms of the number of projects per country, as reflected by the high standard deviation. There is also a high level of variation in a number of other country level variables, most notably CO_2 emissions and ECI.

Regression analysis

The regression analysis results are presented in Table 4; where there are three models. Models 2 and 3 contain the ETS and carbon tax variables respectively. An examination of the AIC/BIC scores indicates the inclusion of the carbon tax variable improves the model fit.

We observe that, as expected, the number of previous projects is a positive predictor of country participation in carbon capture projects, as the variable is positive and significant across all three models. This previous experience with CCUS indicates capacity and potentially a

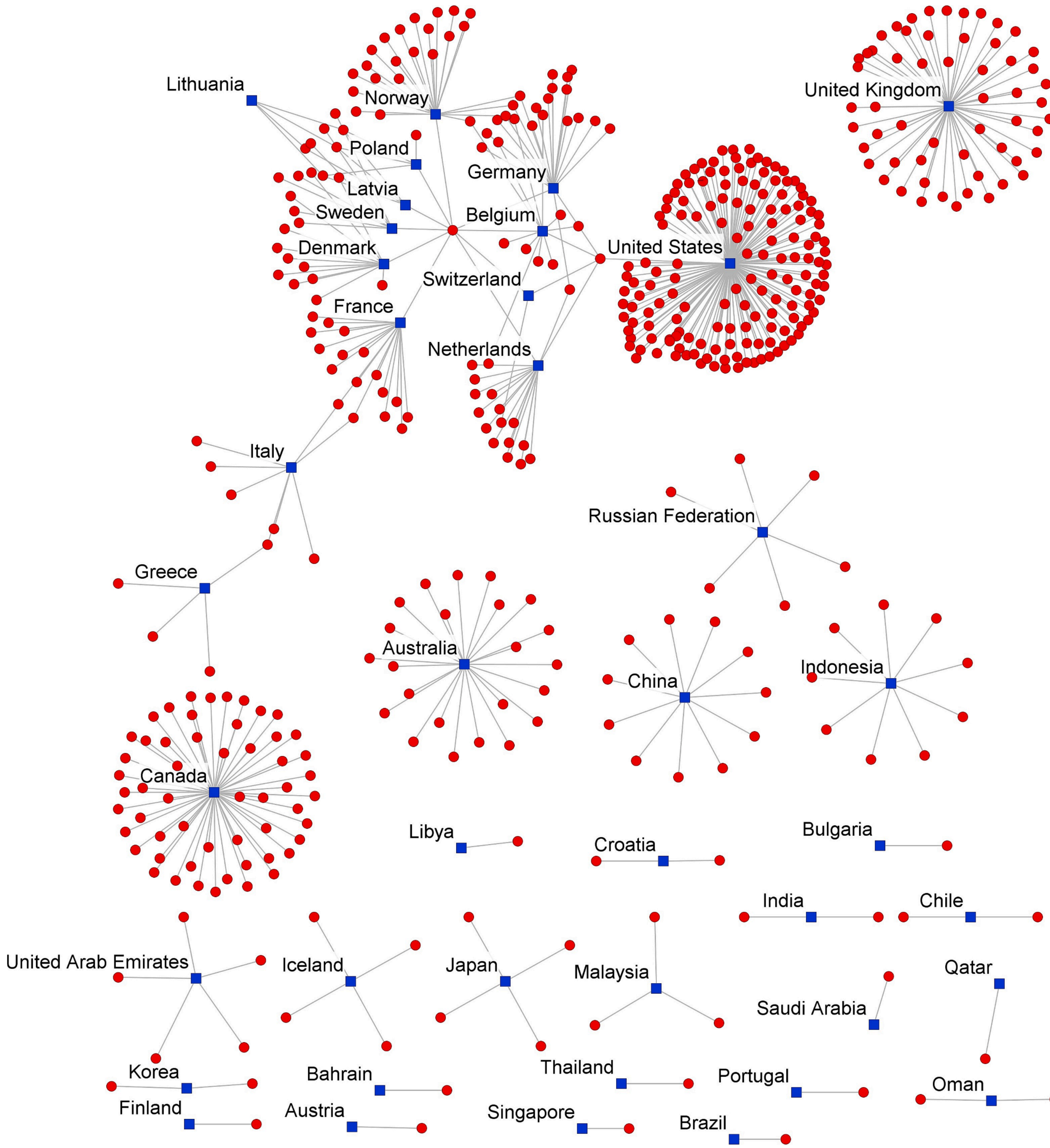

Fig. 3. Network of countries linked to carbon capture projects.

more favourable environment for CCUS.

The region results indicate whether countries from different regions participate in carbon capture projects more or less than the baseline region category, East Asia and Pacific. A positive and significant result for Europe and Central Asia and North America is observed. This indicates that projects are more likely to occur in these two region that East Asia and Pacific. This may reflect the higher level of political determination (especially in Europe) to achieve decarbonisation and net zero targets [110–112]. For Middle East and North Africa, we observe a negative and significant effect, indicating projects are less likely to be associated with countries in this region compared to East Asia and Pacific.

The GDP per capita variable allows for the examination of the relationship between market affluence and involvement in CCUS projects. We observe across the three models a positive and significant effect, which indicates that wealthier, high-income countries are more likely to invest in carbon capture projects and technology. This finding is in line with extant work that has identified that the uptake in low income countries is low; many studies note that there is a need for low cost deployment and further policy instruments in these countries to

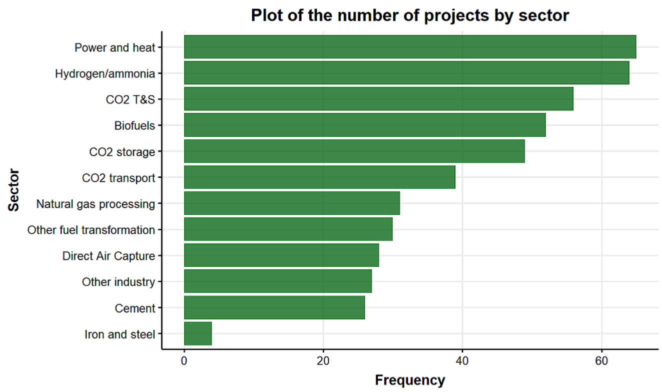

Fig. 4. Number of carbon capture projects (for the period 2019 to February 2023) by sector.

Table 2
Overview of project types.

Project Type	Description
Full chain	Full chain refers to the case where CO_2 is transported from a capture site to an injection site,
Capture	Capture refers to capture-only projects that do not include any transport and storage development.
Transport	Transport refers to CO_2 transport-only projects. Transport projects may include CO_2 shipping and pipelines (amongst other transport options).
Storage	Storage refers to CO_2 storage-only projects. These type of projects include both dedicated storage and CO_2 enhanced oil recovery (EOR).
T&S	T&S projects include both CO_2 transport and storage development.
CCU	CCU refers to a project that captures CO_2 for use an identified source for the captured CO_2.

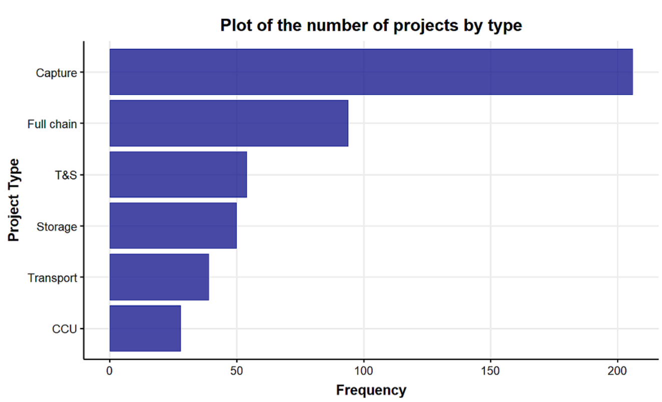

Fig. 5. Number of carbon capture projects (for the period 2019 to February 2023) by type.

Table 3
Descriptive Statistics.

Variable	Mean	Standard Deviation
Number of projects	14.73	32.05
Number of previous before 2019	1.85	4.34
GDP per capita	34584.15	22362.16
Trade Openness	48.71	29.08
CO_2 Emissions	690279.75	1837555.78
ECI	0.82	0.88

Table 4
Regression Analysis Results.

	Model 1	Model 2	Model 3
(Intercept)	−10.3047***	−11.5696***	−11.1814***
	(1.7084)	(1.8224)	(1.8483)
Number of projects before 2019	0.0449***	0.0413***	0.0726***
	(0.0116)	(0.0116)	(0.0130)
Europe & Central Asia	0.9483***	0.7164***	0.9395***
	(0.1788)	(0.2072)	(0.1772)
Latin America & Caribbean	−0.9181	−0.7214	−0.9997
	(0.6095)	(0.6168)	(0.6127)
Middle East & North Africa	−1.3109***	−1.2061***	−1.1496**
	(0.3512)	(0.3591)	(0.3547)
North America	0.9786***	0.6327**	0.6196**
	(0.2098)	(0.2431)	(0.2142)
South Asia	0.1310	0.3511	0.0533
	(0.7678)	(0.7751)	(0.7689)
GDP per capita	0.8030***	0.8492***	0.7071***
	(0.1186)	(0.1219)	(0.1261)
Trade Openness	−0.0037	−0.0033	0.0018
	(0.0032)	(0.0033)	(0.0031)
CO_2 emissions	0.3404***	0.3913***	0.4513***
	(0.0545)	(0.0598)	(0.0628)
ECI	−0.4517***	−0.5985***	−0.5639***
	(0.0867)	(0.1097)	(0.0928)
ETS		0.6121*	
		(0.2450)	
Carbon Tax			0.6768***
			(0.1403)
AIC	279.1241	274.6439	257.3787
BIC	297.7018	294.9104	277.6452
Log Likelihood	−128.5620	−125.3219	−116.6893

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

encourage CCUS projects [113].

Carbon emissions (as measured by metric tons of CO_2 emissions per capita) is positive and significant. This indicates that CCUS projects are move likely to occur in countries that have high carbon emissions. This potentially reflects where there is a strong need for mitigating carbon emissions, that carbon capture is an attractive and favourable technology.

The second research question posed by this paper aimed to examine how ETS or carbon tax policy instruments shaped country level involvement in carbon capture projects. In model 2, presented in Table 4, ETS is included in the model. The ETS variable has a positive and significant effect, yet only at the 0.05 level. In model 3, we observe a much more pronounced effect when carbon tax is included, where the carbon tax variable is positive and significant at the 0.001 level. The results from models 2 and 3 provides some evidence that policy instruments such as carbon taxes or ETS do act an incentive for firms within countries to participate in carbon capture projects [114].

The third research question posed by this paper aimed at understanding the interplay between economic complexity and carbon capture activity at the country level. In the three models, there was a negative and significant effects. This suggests that lower levels of economic complexity is associated with carbon capture projects. This result is somewhat surprising, as it is expected that countries with more sophisticated production and manufacturing capabilities would be better placed to implement and adopt carbon capture technologies. Yet Balland & Rigby [115] examine the link between patenting activity and economic complexity in the US, and they find that cities with the highest economic complexity levels were not necessarily those with the high levels of patenting activity. Therefore, this result may reflect that it is not the “productive knowledge” capabilities (as captured by the ECI [116]) that result in a country participating in carbon capture projects, rather innovative knowledge; as the ECI underestimates the country level economic complexity that is derived from participation in non-tradable sectors [117].

Conclusion

The conclusion contains two subsections; the first will discuss the three research questions posed by this paper, and the insights provided by the analysis undertaken in this study. This will be followed by a subsection discussing the policy implications of the study.

Concluding comments

This paper set out to tackle three research questions linked to country level carbon capture project patterns, chiefly through a Poisson regression analysis. The first research question asked what country level features are associated with investment in carbon capture projects? The results presented in Table 4 indicates that there a number of features that have a positive and significant influence on the number of carbon capture projects associated with a country (at the 0.001 significance level across all three models). The results indicate that region plays an important role, with more carbon capture projects occurring in North America and Europe and Central Asia, and less in the Middle East and North Africa (compared to the baseline region). GDP per capita is another country level feature that is associated with carbon capture project investment and activity; the positive and significant result in Table 4 indicates projects are more likely to occur in more affluent nations. The results presented in Table 4 also note that countries with higher levels of CO_2 emissions are more likely to participate in carbon capture projects (positive effect across all three models with 0.001 significance level), reflecting that carbon capture is viewed as a favourable technology to tackle climate change challenges. It may also reflect that there is ample carbon to utilise in carbon capture initiatives and use in relevant sectors [82]. Furthermore, previous experience with carbon capture projects (before 2019) has a positive and significant impact on country involvement in carbon capture projects (as observed in Table 4), reflecting the importance of experience with the technology.

The second research questions asked whether ETS or carbon tax policy instruments at the country level was associated with investment in carbon capture projects? Whilst we observe from Table 4 that both ETS and carbon tax have a positive and significant effect on country level carbon capture activity, we observe this effect is more pronounced in the case of carbon tax (0.6768 with 0.001 significance level, compared with the 0.6121 with 0.05 significance level for ETS). This provides some support for the argument presented by Wittneben [118], who suggests that carbon taxes are more effective in lowering emissions at a faster rate (compared to ETS) with lower costs to the public and with no upper bounds for potential carbon reduction. Wittneben [118] notes that ETS have been less successful (compared to carbon tax systems) as a policy instrument to lower carbon emissions.

The final research question posed by this paper asked whether countries with higher economic complexity (as captured by the ECI) engaged in more carbon capture projects. The results from the Poisson regression analysis presented in Table 4 indicate a negative and significant effect (at the 0.001 significance level across all three models). This suggests that countries with higher economic complexity are less likely to be associated with high numbers of carbon capture projects. One explanation for this result is economic complexity is measured by the ECI, which is calculated using international trade data. Therefore, the ECI does not necessary capture knowledge or innovation levels directly, rather indirect "production knowledge" levels [116]. Yet, the capabilities required for carbon capture facilities may not rely on sophistication in production capabilities (as captured by traded goods), rather sophisticated and complex capabilities in non-tradeable sectors [117]. Rather than "production knowledge", the R&D environment [119] and knowledge reserves (such as those represented by patents) [120], are potentially more relevant indicators of complexity" in the context of developing capabilities for participating in carbon capture projects. This highlights the need for further research to examine the interplay between a country's knowledge base and technological capabilities and carbon capture, drawing on alternative measures to the ECI or other forms of data.

Policy implications

There are a number of policy implications from the results of this study. A key policy implication is that carbon tax is positively associated with carbon capture project participation. This suggests that policy makers should employ this tool to encourage investment in CCUS projects. The implementation of any carbon tax should be administratively simple in order to be an effective policy tool in fostering CCUS projects [121]. Yet any tax employed should be higher than the operational and capital costs in order to fully encourage investment in CCUS, or involvement in a CCUS public – private partnership project [122]. The regional partition results point towards a need to consider where regionally stimulus fund to initiate carbon capture technologies should be allocated. In particular there is a need to direct fund to Middle East and North Africa, especially given the countries in this region are often fossil fuel rich [123], carbon capture deployment represents an important medium-term solution to the climate crisis, whilst these nations seek to transition to renewable energy sources [124].

CRediT authorship contribution statement

Matthew Smith: Conceptualization, Formal analysis, Methodology, Writing – review & editing, Data curation, Investigation, Writing – original draft. **Dimitris Christopoulos:** Resources, Funding acquisition, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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