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Stakeholder engagement in decarbonisation and ESG strategies: Investigating global patterns of energy companies in CCUS innovation

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ABSTRACT

Formulating decarbonisation strategies with carbon capture, utilization, and storage (CCUS) technologies, as well as integration of an environmental, social, and governance (ESG) strategy into the core business of multinational companies, are highly debated research areas. The former would bring an efficient medium-term solution for industrial decarbonisation but has technological and economic difficulties. The latter would incite corporate sustainability but has concerns about its financial effects. Multinational energy companies, however, face these strategic challenges at the same time. Building on a common theoretical basis, i.e., the stakeholder view, the goal of this study is to explore the interrelations of CCUS innovation, ESG performance, and external stakeholder involvement. The research focused on the largest energy companies worldwide (n = 129). Results show that more than 75 % of companies stepped into the first CCUS technology development phase within the stage-gate innovation process model (discovery). Findings suggest that corporate strategies which include external collaborations result not only in higher CCUS innovation performance, but it also results in higher ESG performance. Nevertheless, only those companies' ESG scores benefit from CCUS innovation and external stakeholder involvement, which are at least in the first CCUS innovation phase. To the best of our knowledge, this is the first study to analyse decarbonisation strategies with CCUS innovations and ESG performance as central constructs from a stakeholder viewpoint.

1. Introduction

1.1. Decarbonisation challenges of energy companies

Fighting climate change and providing affordable and clean energy are two of the most important Sustainable Development Goals [1] which are (or should be) at the top of the corporate decision-makers' agenda in the energy sector. As multinational energy companies recognise their responsibility for the society based on external drivers (e.g., regulatory frameworks), internal drivers (e.g., risk management), or connecting drivers (e.g., branding and reporting), corporate social responsibility (CSR) activities and environmental, social, and governance (ESG) strategies are implemented [2,3]. Incorporating stakeholder perspectives into core business could be possible in several cases, e.g., in case of planning wind energy projects with public engagement [4]. Meeting stakeholder expectations with an emphasis on decarbonisation, however, represents a significant challenge for energy companies for multiple reasons.

First, ESG targets are often debated from a financial perspective, while they must be integrated into corporate strategies because of increasing investor and regulatory pressure [5]. Regarding the energy sector, recent European research found that the interrelation between ESG performance and economic performance is negative but not significant, while the negative relationship is significant if focusing on the environmental dimension and the profitability [3]. Such financial challenges make it clearly difficult to be motivated to invest in decarbonisation.

Second, shifting from CO_2-intensive technologies to sustainable technologies might conflict with other strategic responsibilities of the energy sector. For example, (1) energy transition cannot endanger the

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secure of energy supply, (2) economic stability must be maintained but rising energy costs for end-users and subsequent political instability can be a risk, (3) and societal conditions must be also considered because of potential aversions, routines to be changed, and perceived or real injustice of the transition [6].

Third, further challenges arise from the technological limitations and the costs of new technologies. One major option for decarbonisation is Carbon Capture, Utilization, and Storage (CCUS). A group of researchers argue that CCUS technologies are essential for decarbonisation, recognising the wide technological options but also the challenges, which could be solved with further developments and policy support. For example, Bajpai et al. [7] emphasise that CCUS initiatives should be supported owing to their potential, e.g., in power, industrial, or bioenergy sectors. In contrast, others consider CCUS technologies even an unrealistic option for decarbonisation, e.g., because of the currently low number of commercial-scale facilities, high costs, or questionable overall environmental impact in certain configurations [6]. In our view, the potential of further CCUS technology development projects should not be disregarded so easily in the European context, especially in EU countries with a high share in EU greenhouse gas (GHG) emissions, a high share of fossil fuels in the energy mix (e.g., Germany, Poland, the Netherlands, Italy) [8].

1.2. Research gap

Despite both decarbonisation (CCUS technologies) and corporate sustainability (ESG performance) can have strategic implications for multinational energy companies, and can directly affect society, one can hardly find any study which analyses their interrelations. Most studies only mention one of them, while focusing on the other. For example, Naims and Eppinger [9] note that CO_2 intensity is a relevant index for evaluations in ESG stock markets while exploring different strategies for CCU innovations (solutions providers, intangible value investors, passive observers, and passive sceptics). Koytsoumpa et al. [10] argue that Bioenergy coupled with Carbon Capture and Utilization (BECCU) could be a key enabler for the decarbonisation of European power, heat, and transport sectors. The authors also conclude that BECCU can be a promising investment area owing to ESG considerations. Rode et al. [11] identify the main stakeholders of CCS projects, i.e., governments and policymakers, investors and developers, the research community, regulators, and the public interface. They mention, however, that further clarification is needed in ESG policies (abandoning fossil fuels or reducing carbon emissions).

Nevertheless, to the best of our knowledge, no perspective of decarbonisation (CCUS) and corporate sustainability (ESG performance) has been empirically researched, despite the interrelations of technological innovation, energy, carbon markets and sustainable development [12]. This study aims to start filling this research gap by focusing on the largest energy companies in the world. In particular, the goal is to explore the interrelations of ESG performance, CCUS innovation, and external stakeholder involvement (e.g., R&D collaborations, and R&D platforms within industry associations), by a mixed-method approach. The main contribution of the study is that it uses quantitative and qualitative analyses to support corporate strategic decisions, affecting both environmental, social, and technical systems [13].

2. Literature review

2.1. Technological background

2.1.1. Carbon capture

For enhanced decarbonisation, fossil-fuel plants can be equipped with various carbon capture (CC) technologies with three possible strategies: post-combustion, pre-combustion, and oxyfuel combustion technologies. Post-combustion solutions are the most mature and the most suitable for already existing plants. The process consists of three main steps: (1) the flue gas from a fossil fuel power plant is directed into a CO_2 absorber; (2) the solvent containing CO_2 in the absorber is transported into the stripper for CO_2 regeneration; (3) the separated CO_2 from the stripper is compressed and transported (by pipelines, ships or trucks) to store in suitable facilities (e.g. depleted oil and gas reservoirs [14]. The main technologies for post-combustion CC are chemical absorption; physical absorption; adsorption; gas-particle reactions; membrane separation and cryogenic separation [15]. Through the pre-combustion process, the fuel is partially combusted producing CO_2/CO and H_2 (i.e., partial oxidation). Then, H_2 is separated from CO_2 by physical or chemical means and used as fuel with an ultimate combustion product of water [16]. In the oxyfuel combustion power plant, oxidation of the fuel is achieved in a nitrogen-free environment, which results in combustion products that consist of CO_2 and water vapour [17]. Additionally, Direct Air Capture (DAC), provides an option for capturing CO_2 directly from the atmosphere (or diluted gases and distributed sources of carbon) via industrial processes [18].

2.1.2. Carbon utilization or storage

CO_2 can be converted into valuable end-products for the energy sector. For example, CO_2 can be combined with green H_2 from electrolysis to form CH_4 (biomethane or synthetic natural gas) in the power-to-gas (PtG) system [19]. Power-to-liquid (PtL) systems also require CO_2 or CO [20]. The result of the PtL is raw fuel, which is further developed into a special fuel in the refining and upgrading process [21]. Another option is to store CO_2 permanently underground, often considered as a transitional or bridging technology toward a new, zero-emissions energy system [22]. CCS, however, is an important mitigation option in hard-to-abate sectors, such as cement or steel [23].

2.1.3. Stakeholder perspectives of CCUS

CCUS and hydrogen technologies could also co-exist in the future energy systems, globally. For example, the carbon-neutral synthetic fuels from the combination of CCUS and green hydrogen can support the climate-neutral vision in the EU [24]. Also, Lan et al. [25] recently proposed a carbon-gas-electricity market and a multi-energy system in the Chinese context, which involves gas-fired power plants with CCS, renewable energy power plants, and P2G operators. Despite the currently explored techno-economic promises, however, societal aspects should be also considered. For example, Seigo et al. [26] underline that CCS projects must involve conscious risk communication to ensure public acceptance, e.g., because CCS can be "seen as an end-of-pipe solution that might even displace investment in renewable energy technologies" [26, pp. 855–856]. Recent research showed that even religious beliefs and values can influence attitudes toward CCS [27]. Consequently, stakeholder perspectives and interests could significantly influence corporate governance decisions in the case of CCUS projects.

2.1.4. Current techno-economic challenges of CCUS

Despite promising opportunities and decades-long research, development and innovation, the necessity of further breakthrough CCUS innovations is still present. This is because of the multifaceted challenges CCUS initiatives face, as presented by recent studies. Regarding economic viability, high capital costs must be mentioned, these costs could vary significantly by sector, though. From a global perspective, decarbonisation in the power system would require 1.6–3.8 million USD until 2050 to meet the goal of the 1.5 °C temperature increase [28].

Not only the volume of investment but also generating a reasonable return is problematic. For example, concerning CCUS in Chinese oil and gas reservoirs, Liang et al. [29] clearly states that "the current cost of CCUS-EOR is prohibitive to conduct demonstration projects without any policy incentives" [29, p. 15].

Considering previous upscaled CCUS facilities with post-combustion capture, such as the Boundary Dam Plant and Petra Nova Plant, their capture costs are around 70–105 USD/tCO_2, despite the effects of economies of scale. It was difficult to go below 30–50 USD/tCO_2 with oxy-fuel or pre-combustion technologies as well, even without considering the risks of lower technological readiness level (TRL) [30].

The problem is, on the one hand, these are only the capture costs, which are is the most dominant cost factor (over 50 % of total CCUS costs) but transportation, storage or utilization and maintenance costs should also be considered [28]. On the other hand, these unit costs are too high compared to the volume of capital investment and the growing but still low carbon prices (e.g., the carbon permits are currently at 73 EUR/tCO_2 [31]).

Technological concerns are also elaborated in the recent literature. For example, despite the well-known basic mechanisms of carbon capture, especially the post-combustion options, Gupta et al. [32] argues that their TRL is often only between 4 and 8. One potential reason is the scalability constraint, e.g., as seen in case of oxy-fuel combustion which is only at TRL 7 [30]. Moreover, while utilization technologies might reach TRL9, many storage technologies are at lower TRLs [32]. Another challenge is that a new transportation infrastructure should be developed for the capture CO_2, integrating several options, such as pipeline, on water, rail, and truck, at industrial scales [33].

Without overcoming these critical barriers through CCUS innovation, the viability of CCUS for being a medium-term solution for decarbonisation remains questionable. Nevertheless, ESG considerations incite multinational energy companies to address these issues and explore new CCUS pathways, and external stakeholder involvement might help them to do so.

2.2. *ESG goals and external stakeholder relationships*

ESG goals and challenges could be interpreted in several ways, depending on the applied corporate governance theory. For example, agency theory has long shaped the thinking about corporate governance [34,35] and is also relevant in an ESG context. Specifically, ESG disclosure could be important to reduce information asymmetries between principals and agents, especially between shareholders and top management, and increase transparency [36]. In contrast, according to stewardship theory, senior managers as agents do not simply pursue their self-interest [37]. Consequently, intrinsic responsibility and formal authority of senior managers would be useful to integrate stakeholder interests and improve ESG performance (e.g., through CEO duality) [38,39].

Instead of elaborating on individual behaviour, transaction costs theory argues that firms can exist at all because market mechanisms are imperfect and that certain economic activities are more efficient to be organised within a firm than to be carried out through continuous market transactions [40,41]. Thus, transaction costs theory can be useful to analyse what ESG activities should be conducted within the organization, and what activities should be outsourced [42]. According to the resource dependence theory, the main task of directors is to reduce uncertainty by building links to external resources, suppliers, customers, public decision-makers or different social groups [43]. This theory suggests that directors must be able to access and integrate key resources for sustainable development, which could increase ESG ratings [44].

Finally, the stakeholder theory deals with the fact that a company has a multi-faceted relationship with internal actors (owners, managers, employees) and external actors (e.g., suppliers, consumers, public authorities, and society) whose interests must be taken into account in decision-making. At the root of the approach is that the interests of all stakeholder groups have intrinsic value and that the interests of one stakeholder group are not more important than others [45,46]. Del Gesso & Lodhi [39] recently found that "stakeholder theory is most frequently adopted in studies using the term "ESG," [39, p. 9]. Integrating ESG aspects into the operations can be considered a challenging task from the stakeholder view, as meeting various stakeholders' interests at the same time inherently comes with tensions, which must be resolved [42,44]. Regarding the opportunities, higher ESG ratings would mean better transparency according to the stakeholder theory. This approach ultimately contrasts the agency theory, which suggests that managers might hide negative information, "creating the illusion of a high capacity for sustainable development" [47, p. 2] which increases financial risks. These assumptions were proved by empirical data in the Chinese context [47].

2.3. *Hypotheses development*

Following this dominant approach of the ESG research stream, and the societal perspective of the study, this research applies the stakeholder theory. Nevertheless, it focuses less on inter- and/or intra-stakeholder tensions and more on the opportunities deriving from the stakeholder perspective in the context of CCUS technologies and ESG performance in the energy sector.

2.3.1. *External stakeholder involvement and CCUS innovation*

Stakeholder involvement could have several goals, for example, based on moral considerations (e.g., legitimacy, CSR), strategic considerations (e.g., financial performance, knowledge creation), or pragmatic considerations (e.g., context-dependent problem-solving) [48]. Kujala et al. [48] argue that co-creation, supportive organisational structures, and collaborative and dialogic activities could be key to improving innovation performance based on broad stakeholder involvement. Loureiro et al. [49] underline that co-creation could involve many processes (e.g., co-design, co-production), while open innovation, as a form of co-creation, is more of a single process. In case of solving sustainability problems, these considerations can co-exist. In particular, stakeholder involvement activities could also include (1) giving a voice to stakeholders, (2) exploring their needs and integrating knowledge to improve the quality of the process, (3) forming networks for (social) learning, (4) strengthen engagement to establish legitimacy for the implementation [50].

Recent studies suggest that managing networks for co-creation or open innovation is relevant in many sectors, in order to reduce costs or increase innovation performance [51], including the energy sector [52]. Open innovation initiatives in the energy sector can involve different type of partners, e.g., from the industry (e.g., suppliers), academia (e.g., universities), state administration (e.g., government), or other communities (e.g., public groups, customers) [53]. These are relevant stakeholder groups in case of CCUS innovation as well, however, the dynamics of their involvement are heterogenous.

1) Regarding corporate partnerships, Yuan et al. [54] mention that prior demonstration projects were realised by energy companies and oil fields in China. Then the basic mechanism of the cooperation is providing complementary assets or capabilities to innovate together (technology, input materials, infrastructure).
2) Collaboration between industrial and academic organisations has also been advocated to increase CCUS innovation performance, e.g., as shown in the case of the Norwegian CCS Research Centre [55]. Such initiatives can be beneficial for energy companies to absorb cutting-edge technological knowledge from applied research, which can be later turned into innovation, upscaled and exploited.
3) Since the technology development and large-scale implementation of CCUS is risky and comes with high capital costs, government incentives can be introduced [56]. Thus, energy companies can initiate discussions or can be invited into discussions about the proper policies and regulatory frameworks.
4) Additionally, the perspectives of civil communities should be considered for CCUS innovation, since the economic and employment potential can be the sources of local support [57]. Nevertheless, public engagement into CCUS projects is important to manage risks as well [58]. It is because local communities can be against the deployment if they perceive safety risks or that CCUS development

happens at the expense of renewable options, e.g., in case of trust issues or insufficiently disseminated technological information [57].

Based on the above, we assume that.

(H1). ***external stakeholder involvement has a positive effect on CCUS innovation in the case of multinational energy companies.***

2.3.2. External stakeholder involvement and ESG ratings

In related areas, recent research explores various causalities for corporate sustainability and innovation. For example, AI is proven to drive corporate sustainability based on the analysis of ESG ratings [59]. At the same time, ESG ratings can promote green innovation based on empirical data [60]. Furthermore, similar considerations appeared in the work of Lan and Zhou [61]. It states that digitalisation and ESG practices (that might positively affect ESG ratings) facilitate corporate innovation (that might include green innovation) [61]. Despite these minor differences, these studies always highlight the role of external stakeholder engagement, e.g., in getting feedback and a comprehensive understanding of relevant subject matters [61], increasing supply chain performance [59], getting green resources from them [62].

These interactions can reportedly increase ESG performance, as presented by recent studies. For example, Fan et al. [63] suggest that collaboration with external stakeholders can build social trust, which leads to increased ESG performance. Zhu et al. [64] present that ethical leadership, which encourages social responsibility practices, also positively impacts ESG performance. Likewise, strategic alliances also improve ESG performance, as found by Lin et al. [65].

Based on these recent research results, and the fundamental stakeholder perspective of ESG, we not only assume that external stakeholder involvement could help innovation for decarbonisation, but we also assume that.

(H2). ***external stakeholder involvement has a positive effect on ESG performance in the case of multinational energy companies.***

2.3.3. CCUS innovation and ESG performance

A recent stream of research focuses on the impact of ESG performance on green innovation, i.e., how ESG performance enhances green innovation [66,67]. In contrast, another research stream discusses that green technology innovation can increase ESG performance [68,69]. In our research framework, the latter approach is more relevant. It is because clean energy innovations (1) are important to improve the quality of energy services and reduce the environmental costs of energy supply [70], (2) manage carbon risks on corporate governance level, and (3) reduce emissions which influence ESG performance in the global energy sector [71].

Although the relationship between higher ESG ratings and lower GHG emissions (e.g., owing to CCUS technologies) seems to be axiomatic at first sight, recent research results suggest more ambiguity. For example, In and Schumacher [72] introduce the term „carbonwashing", drawing attention to the problem that ESG and climate-related disclosure have become dominated by long-term reduction targets instead of actual performance compared to baseline data. Treepongkaruna et al. [73] also found that high ESG-rated companies do not have lower GHG emissions, as after being recognised with a pleasing ESG score, no incentives remain to be more environmentally friendly. Carbonwashing and retaining resources from environmental actions seem to be closer to agency theory (cf., hiding information, lack of incentives). In contrast, Mneimneh et al. [74] mention that CCUS as a low-carbon technology could have importance within the environmental dimension of ESG ratings in the energy sector. Since this argument seems to be more in line with our stakeholder-based view, we assume that.

(H3). ***CCUS innovation has a positive effect on ESG performance in the case of multinational energy companies.***

2.4. Conceptual model

Based on the literature review, our underlying assumption is that CCUS innovation and external stakeholder involvement together can lead to superior ESG performance. Our conceptual model also suggests that CCUS innovation functions as a partial mediator in the relationship between external stakeholder involvement and ESG performance. Only partial mediation is relevant, since the model not only assumes an indirect effect (H1 and H3), but also a direct effect (H3) between external stakeholder involvement and ESG performance. On the one hand, this model is built on the prior literature findings presented in Sections 2.3.1. and 2.3.3. On the other hand, sustainability studies suggest that firm performance should be understood by exploring direct and indirect relationships as well, for example.

1) Concerning external stakeholder involvement and firm performance: The model of Yang and Basile [75] suggests that CSR communication productivity can partially mediate the relationship between external stakeholder involvement and firm performance, while the former also directly affects the latter.
2) Concerning innovation and ESG performance: Liu and Wang [76] articulate that digital transformation has a direct positive effect on ESG performance, and an indirect positive effect on ESG performance through innovation (i.e., innovation mediates the relationship between digital capabilities and ESG performance).

Consequently, we assume that external stakeholder involvement can directly influence and also indirectly influence ESG performance through CCUS innovation.

3. Research design

3.1. Database development

The research focuses on the largest energy companies in the world, based on 2023 data (published ESG reports or data for 2024 were not yet available at the time of conducting the research). While longitudinal data could be useful to evaluate temporal changes, our goal is to analyse structural relationships based on our theoretical model. This approach allows us to explore current patterns in the global energy sector and understand up-to-date managerial implications, which is especially important concerning the focal innovation theme.

Four data sources were used for the database development, as follows.

1) Statista: The foundation of the sample was formulated based on the Statista databases, which list the top 100 energy companies in different sub-sectors, i.e., utilities, gas, and electricity [77]. After filtering out overlaps, a list of 224 companies remained.
2) Sustainalytics: For one of the dependent variables (ESG_Rating), we chose Sustainalytics' ESG risk rating, because it provides a widely accepted *overall* score about a company's exposure to material sustainability issues [78].
3) LSEG: We integrated ESG Scores of the LSEG Data & Analytics platform into the analysis, since it provides a more *punctuated* view of the ESG performance in the three main dimensions (E, S, G) with ten subdimensions (e.g., CSR Strategy) [79].
4) Document analysis: We collected CCUS innovation and collaboration-related data from relevant formal corporate documents, e.g., ESG/Sustainability/Integrated report(s), and/or official website information.

The database development included two main phases, each with a large amount of manual data collection both in a quantitative and qualitative sense.

First, we explored whether the listed companies from the Statista database have ESG ratings in the Sustainalytics and the LSEG database [78,79]. We have analysed the availability of the ESG scores and manually collected the data for the different dimensions and sub-dimensions. As a result, this initial database development included 129 multinational energy companies, 27 data categories, and resulted in 1935 data points in total.

Second, we have explored these companies from the perspective of CCUS innovation activities by looking for available online information about their sustainability efforts and performance. During the qualitative analysis part of this phase, we extracted the relevant sentences or paragraphs from their formal documents or their official websites, along with page numbers and links to ensure reliability. After that, we applied quantitative coding to enable the involvement of these data in statistical analyses, i.e., by assigning numerical labels [80]. Similar approaches have been already applied in case of sustainability reporting, as well [81]. The coding system followed the stage-gate innovation process model of Cooper [82] to determine the CCUS innovation level of the company. Based on the patterns in the data, we combined 2-2 phases in the middle, compared to the original model.

- Code 0: No CCUS innovation-related activities are mentioned
- Code 1: Discovery (e.g., the company analyses CCUS technology development/implementation opportunities, monitors technological advancements)
- Code 2: Idea scoping and building business case (e.g., research, planning, conducting feasibility studies)
- Code 3: Development, testing, and validation (e.g., engagement with first investment in CCUS technologies, pilot projects)
- Code 4: Launch (e.g., large-scale CCUS project is under development or already implemented).

Besides, we also coded whether CCUS innovation activities were realised with the involvement of external stakeholders (Code 0: No; Code 1: Yes).

To ensure reliability, two co-authors coded the citations from the documents or websites separately, and after that, a group discussion with all the co-authors finalised the codes. Furthermore, all above-mentioned ESG and CCUS data and qualitative information were collected in an MS Excel file and made available in a supplementary material (S1).

3.2. Main indicators

On the one hand, we used the Sustainalytics ESG risk rating to measure ESG performance. On the other hand, after reviewing the available data set about the other variables (CCUS innovation, hereinafter briefly: CCUS_Innov, and External stakeholder involvement, hereinafter briefly: Stakeh_Invol), the already existing data would not have ensured validity by itself from the LSEG database, nor from the coding results. Consequently, we created new indicators by combining the LSEG data and the quantitative coding. In the case of 'CCUS_Innov', we combined the Innovation LSEG score of the company with its CCUS innovation level with the same weighting (50-50 %). In the case of 'Stakeh_Invol', those LSEG scores were selected, which are mainly related to external stakeholders, i.e., Community in the Social dimension and CSR Strategy in the Governance dimension. To ensure validity in the decarbonisation topic, these were combined with the coding results concerning the collaborative CCUS activities with the same weighting, (25 %–25 % and 50 %, respectively).

3.3. Statistical methods

To evaluate the hypotheses, first, the strength and direction of the relationship were analysed. As the preliminary analysis of the data set suggested that variables are not normally distributed and there are no clear linear relationships, we applied the Spearman rank-correlation test instead of the Pearson correlation test. The Spearman correlation test is more suitable for nonparametric data and robust to outliers due to its focus on orders instead of raw and actual values.

Second, in the absence of clearly linear relationships but a seemingly diminishing changing rate for the dependent variable with increasing values of the independent variable, we applied a logarithmic regression model. This method needed the partial logarithmic transformation of the data, following this formula:

$$Y = a \cdot ln(X) + b$$

where Y represents the dependent variable (ESG_Rating in H2 and H3; CCUS_Innov in H1), X is the independent variable (CCUS_Innov in H3; Stakeh_Invol in H1 and H2), a and b are the regression coefficients, while $\ln(X)$ is the natural logarithm of X. This method allowed us to analyse the nonlinear trends and gather interpretable results.

To test the robustness of our findings, address potential endogeneity, and mitigate omitted variable concerns, we have conducted additional regression analyses. This included two robustness tests with a subsample regression (Europe) and using alternative dependent variables from the LSEG database. Furthermore, we applied firm-specific control variables from the initial Statista database (Revenue in 2022 and Employee count), and regional control variables with continent-level dummy variables as fixed effects.

3.4. Additional qualitative methods

In addition to the statistical analyses, we conducted a supplementary qualitative analysis to contextualise our findings. This research part also followed a structured coding process, in three cycles, as suggested by Linneberg and Korsgaard [83]. In the first cycle, an initial test coding system was applied to the extracted information from corporate reports or websites, involving data from only 20 companies. The initial coding system aimed to inductively explore drivers and barriers of innovation in the dimension of the three main constructs of this study (ESG, CCUS technology, External stakeholders) with in vivo codes. Nevertheless, the lessons of the first cycle (i.e., unsatisfactory alignment of the data and the categories) induced the modification of the coding system, so the second cycle focused on the broader pre-conditions of CCUS innovation and related stakeholder involvement activities, analysing all the collected data. Finally, in the third cycle, we filtered and categorised the in vivo codes according to the innovation stage-gate process model [82], which was also used for quantitative coding. In line with the methodological suggestions [83], all the collected and analysed qualitative data is made accessible in the supplementary material (S1), to ensure transparency.

4. Results and discussion

4.1. Quantitative analyses

4.1.1. Descriptive results

Table 1 shows the descriptive sample statistics. Significant scaling disparities can be observed concerning several variables, especially in the case of Revenue, where right-skewed distributions with influential outliers are indicated. Consequently, the regression models will require log-transformed versions of the relevant variables. Table 2 shows that we found mention of CCUS innovation activities exactly at 100 multinational energy companies from the total 129. Results show that more than three-quarters of the companies analysed made their first steps towards CCUS innovation, and most of them (33 %) are in the second phase ('Idea scoping and building business case') with planning the investment, conducting feasibility studies, or running research projects. In line with the currently high costs and technological complexity of CCUS, however, only 19 % of the analysed companies allocated significant resources to the development, testing and validation of pilots, or

Table 1
Descriptive sample statistics with bivariate correlation coefficients.

	Obs	Mean	Std. Dev.	Median	Min	Max	2022 Revenue (in million USD)	CAGR	Employees	ESG_Rating	CCUS_Innov	Stakeh_Invol
2022 Revenue (in million USD)	125	20107.2486	32409.7567	13078.04	194.59	311175.92	1					
CAGR	127	0.90919776	7.1829326	0.21033559	−0.580375	81.166789	0.02606897	1				
Employees	120	17388.8083	30088.6332	9086.5	69	213684	0.23102536	−0.0159082	1			
ESG_Rating	129	28.8705426	10.2499726	27.4	7.9	68.7	0.03435905	−0.0013302	−0.0033888	1		
CCUS_Innov	129	84.3410853	42.5891521	84	0	199	0.25874996	0.01687599	0.24925505	−0.1747237	1	
Stakeh_Invol	129	107.131783	57.5247406	86	0,5	198	−0.0013729	0.10971516	−0.0294853	−0.2472842	0.42855244	1

Table 2
Descriptive results with CCUS innovation data (n = 129).

Sample	Companies per continent	Percentages
North-America	48	37 %
South-America	8	6 %
Europe	28	22 %
Asia	42	33 %
Oceania	3	2 %
from which	**CCUS maturity level**	**Percentages**
No CCUS activities (0)	29	22 %
Discovery (1)	33	26 %
Idea scoping and building business case (2)	43	33 %
Development, testing, and validation (3)	15	12 %
Launch (4)	9	7 %
from which	**Stakeholder involvement**	**Percentages**
Separate activities	74	57 %
Collaborative activities	55	43 %

implementing large-scale CCUS projects. Individual and collaborative CCUS innovation activities are realised to a similar extent (57-43 %, respectively) (see Fig. 1).

The CCUS innovation level shows an inverted U shape (Fig. 2), which suggests that CCUS technologies are slowly transitioning from the emerging phase to the growth phase in the technology life cycle curve [84]. Fig. 2 also shows the data with a regional comparison, indicating that no radical differences can be identified based on the headquarters' continent of the companies in their CCUS innovation level, nor their external stakeholder involvement patterns. (Similar patterns could be identified even if the percentages were used for modelling instead of the actual number of companies from a region; see Supplementary Material S1.)

In the sample, collaborations involve (1) academic partners (e.g., universities, research institutes), (2) work in associations (e.g., non-profit industrial platforms), (3) corporate partners (e.g., another utility), (4) community-based initiatives (e.g., with local civil groups, customers), (5) governmental initiatives (e.g., with local government, state funding or participation in regulatory activities). A few multi-faceted collaborations were also identified with academic and/or corporate and/or governmental partners.

Table 3 shows that corporate partners are involved most often into collaborative CCUS innovation activities in case of multinational energy companies, while academic, community-based, association-based, and governmental partnerships are less frequent. The table also presents the average ESG scores and CCUS levels in certain categories, indicating that the most dominant form of external stakeholder involvement, i.e., corporate partnerships result in better ESG performance (lower ESG risk scores), and higher CCUS levels. Nevertheless, the size of this collaborative sample is relatively small, thus, these insights only frame our regression analyses.

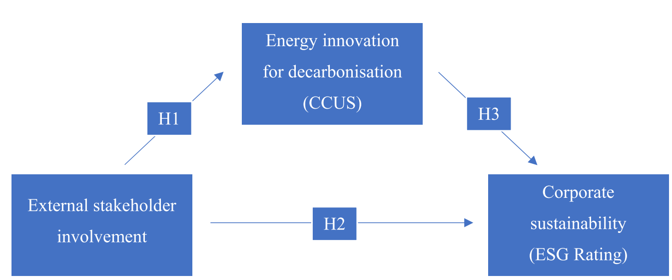

Fig. 1. Conceptual model (own construction based on Yang and Basile, 2022).

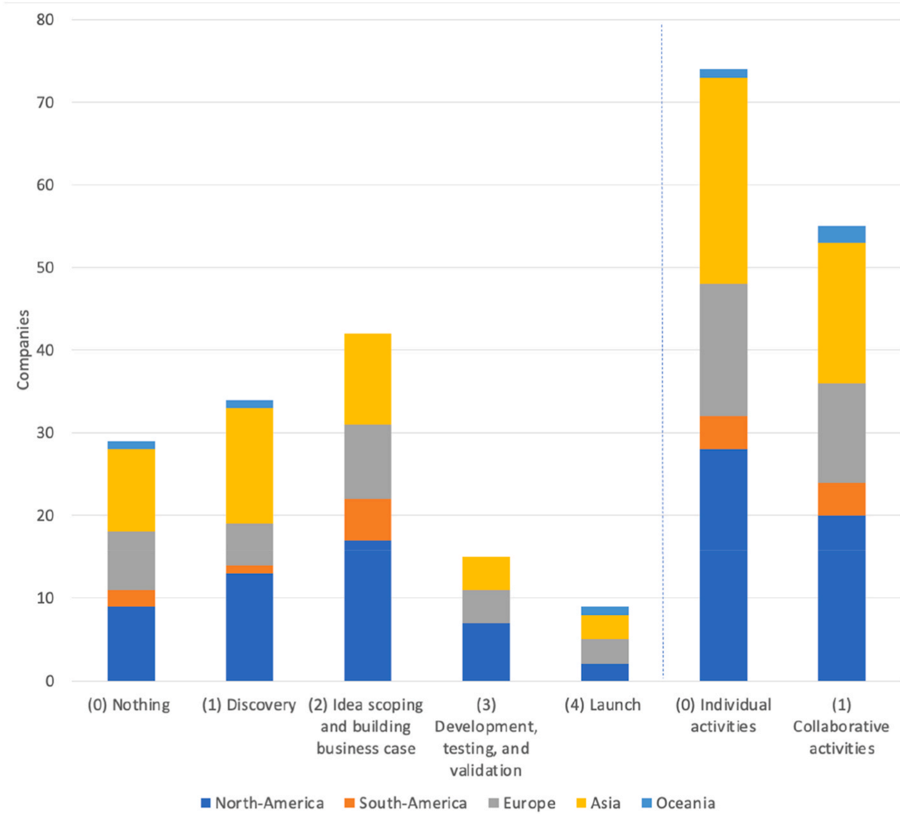

Fig. 2. Comparing regional patterns (n = 129).

Table 3
Descriptive results of the external stakeholder involvement data (n = 55).

Type of external stakeholder	Count	Percentages	Average ESG risk score	Average CCUS level
Academic	4	7 %	32.40	2.00
Association	7	13 %	25.06	2.29
Corporate	29	53 %	29.07	2.62
Community	4	7 %	23.48	1.50
Governmental	8	15 %	30.31	1,88
Multiple	3	5 %	31.60	1.67

4.1.2. *Spearman correlation analyses*

Table 4 shows the results of the Spearman correlation analyses, based on the total sample. Besides the three main constructs, relationships between revenues, employees and CCUS innovation were also analysed, based on the initial correlation results seen in descriptive statistics. Accordingly, there is a strong positive correlation between revenue and CCUS innovation (rs = 0.433), and a moderately positive correlation between employee number and CCUS innovation (rs = 0.358), both with a statistically significant p-value. Likewise, there is a statistically significant and strong positive relationship between CCUS innovation and external stakeholder involvement (rs = 0.404; $p < 0.001$), while there is a moderately negative correlation between ESG rating and external stakeholder involvement. This is also in line with the expectations since the applied ESG rating focuses on the ESG risks, and the lower rating indicates a lower risk level, i.e., better ESG performance. Nevertheless, the correlation between ESG rating and CCUS innovation, and between ESG rating and external stakeholder involvement are only weakly negative and statistically not significant ($p = 5.34$ %, $p = 0.826$, respectively). This result induced further analyses, focusing on a narrowed sample with companies already interested in CCUS innovation.

Table 5 summarises the results, concerning the three main constructs of this study, focusing on only those companies, which have reached at

Table 5
Spearman correlation analyses on the narrowed sample (n = 100).

Relationship	CCUS_Innov & Stakeholder_Invol	ESG_Rating & Stakeh_Involv	ESG_Rating & CCUS_Innov
Coefficient (rs)	0.311972061	−0.269258465	−0.260248089
N	100	100	100
T statistic	3.250599086	2.767741161	2.668268412
DF	98	98	98
p-value	0.001579041	0.006749549	0.00892314

$p < 0.05$.

Table 4
Spearman correlation analyses on the total sample (n = 129).

Relationship	Revenue & CCUS_Innov	Employee & CCUS_Innov	CCUS_Innov & Stakeholder_Invol	ESG_Rating & Stakeh_Involv	ESG_Rating & CCUS_Innov
Coefficient (rs)	0.433335337	0.357631523	0.404116172	−0.289862023	−0.170498894
N	125	120	129	129	129
T statistic	5.332608389	4.160003814	4.978812492	3.413109186	1.949976778
DF	123	118	127	127	127
p-value	0.00004 %	0.00607 %	0.000204 %	0.08623 %	5.34 %

$p < 0.05$.

Table 6
Results of the logarithmic regression – Regression statistics.

	Model 1	Model 2	Model 3
Independent variable	**Stakeh_Invol**	**Stakeh_Invol**	**CCUS_Inn**
Dependent variable	**CCUS_Inn**	**ESG_Rating**	**ESG_Rating**
Multiple R	0.30205767	0.29537889	0.2259913
R Square	0.09123883	0.08724869	0.05107207
Adjusted R Square	0.08187016	0.07783888	0.04128931
Standard Error	37.9277738	9.65796192	9.84749731
Observations	99	99	99

Note: Logarithmic forms of the independent variables were used in the regression models.

least the first CCUS innovation level. The correlation coefficient between ESG rating and CCUS innovation is −0.260, which indicates a moderate negative correlation. The t-statistic is 2.67 with a 0.009 p-value, which suggests that this relationship is statistically significant. Likewise, a negative moderate relationship can be identified between ESG rating and stakeholder involvement, which is also statistically significant (t-statistic = 2.77; p-value: 0.007). This means that companies with more efforts to involve external stakeholders might have lower exposure to ESG risks. Finally, the results suggest that the correlation between CCUS innovation and external stakeholder involvement is positive (0.312) and statistically also significant with a t-statistic of 3.25 and a p-value of 0.0016. In sum, these correlation analyses suggest that the relationship between CCUS innovation and ESG rating is stronger and more significant in case companies, which have already expressed their interest in allocating resources to discover or exploit CCUS opportunities (see Table 6).

4.1.3. Regression results

As the empirical data did not present clear linear relationships between the variables, non-linear regression models were only relevant. While tests with polynomial regression showed poor alignment with the empirical data pattern, the logarithmic regression model was more appropriate to evaluate the hypotheses. Given the problematic significance level of the 'ESG rating & CCUS innovation' relationship in the total sample, we narrowed our scope to those multinational energy companies, who have already reached at least the "Discovery" phase of CCUS. Of course, this affects the evaluation of our hypotheses. Table 5 shows regression statistics and Table 7 presents the coefficients, according to the three models (Model 1, 2, 3) based on our three hypotheses.

In sum, all three models are statistically significant ($p = 0.0023$ in Model 1; $p = 0.0029$ in Model 2; $p = 0.0244$ in Model 3), however, they have a weak explanatory power ($R^2 = 0.0912$ in Model 1; $R^2 = 0.0872$ in Model 2; $R^2 = 0.0510$ in Model 3). In particular, external stakeholder involvement seems to be contributing to CCUS innovation activities, concerning the highest (but still weak) R^2 value (0.0912) in Model 1, with clear statistical significance ($p = 0.0023$). This result reinforces prior research findings, which quantitatively demonstrated the positive role of open innovation in industrial contexts [51] or qualitatively explored open eco-innovation results in the energy sector [52]. Since the Spearman correlation test also showed a significant relationship on the total sample, and the logarithmic regression model was also statistically significant, H1 can be supported, i.e., external stakeholder involvement has a positive effect on CCUS innovation.

Results suggest that external stakeholder involvement has a significant role also in reducing ESG exposure, with a similar p-value in Model 2 ($b = -4.8379$; $p = 0.0029$). This is in line with the fundamentally stakeholder-based view of ESG integration into firm activities [42]. Nevertheless, H2 could not be accepted in its original form, since the Spearman correlation test did not show a significant relationship between these two variables in the total sample, only in the narrowed sample. Consequently, results suggest that external stakeholder involvement in decarbonisation has a positive effect on the ESG performance in the case of those multinational energy companies, which have already decided to start the discovery of CCUS opportunities.

Finally, CCUS innovation has a significant but weak negative effect on the ESG risk rating ($b = -4.5824$ in Model 3). This weak effect could not be motivating for companies to engage in CCUS innovation at first sight, however, one must recognise that ESG scoring systems (including Sustainalytics) apply complex methodologies. These methodologies consider not only green innovation activities, but also other environmental issues (e.g., biodiversity), social issues and governance mechanisms, in line with global reporting frameworks, e.g., GRI standards [85], or regional reporting frameworks (e.g., European Sustainability Reporting Standards – ESRS [86]. Since progress in CCUS innovation cannot be a single dominant explanator of ESG performance increase, even the weak but statistically significant result can be considered relevant. From a theoretical perspective, this also extends prior knowledge about the relationship between ESG ratings and green innovation: while a recent study found that even the existence of ESG ratings positively impacts corporate green innovation [87], we found that the existence of green (CCUS) innovation positively affects the ESG rating of the company. Like H2, H3 can be accepted only with restrictions because of the results of the Spearman analysis on the total sample. So, CCUS innovation has a positive effect on ESG performance in the case of those multinational energy companies, which have already decided to start the discovery of CCUS opportunities.

4.2. Robustness and control variable analyses

4.2.1. Robustness tests

Because of the relatively small sample size, two types of robustness tests were employed, which supported our findings.

First, we made a subsample regression, focusing on European-based multinational energy companies. This solution is in line with prior research applying subsampling methods to improve reliability in case of finite samples [88]. Concerning the relationship between external stakeholder involvement and CCUS innovation (Model 1), the relationship remained positive and is close to significance ($p = 0.0704$, $R^2 = 0.17$) despite the even smaller subsample size ($n = 20$). Model 2 in the full sample showed a significant negative relationship between

Table 7
Results of the logarithmic regression – Coefficients.

		Coefficients (b)	*Standard Error*	*t Stat*	*P-value*	*Lower 95 %*	*Upper 95 %*	*Lower 95.0 %*	*Upper 95.0 %*
Model 1	Intercept	4.52691845	29.2152094	0.15495074	0.87718212	−53.457185	62.5110219	−53.457185	62.5110219
ln_Stakeh_Invol & CCUS_Inn	5.16478597	19.4712108	6.23938969	3.12069157	0.00237699	7.08774944	31.8546722	7.08774944	31.8546722
Model 2	Intercept	51.5876588	7.43938679	6.93439664	4.5541E-10	36.8225354	66.3527823	36.8225354	66.3527823
ln_Stakeh_Invol & ESG Rating	5.16478597	−4.8379273	1.58880372	−3.0450126	0.00299563	−7.9912628	−1.6845917	−7.9912628	−1.6845917
Model 3	Intercept	49.5082753	8.97429309	5.51667689	2.8676E-07	31.6967877	67.3197629	31.6967877	67.3197629
ln_CCUS_Inn & ESG Rating	4.36944785	−4.5824978	2.00558603	−2.2848673	0.02449913	−8.5630309	−0.6019648	−8.5630309	−0.6019648

external stakeholder involvement and ESG risks, and this relationship remained negative and became marginally non-significant ($p = 0.0562$, $R^2 = 0.19$) in the European sub-sample. Nevertheless, the relationship between CCUS innovation and ESG performance became even stronger in the European sub-sample ($p = 0.0245$, $R^2 = 0.25$).

Second, we analysed our findings using alternative dependent variables, as often suggested in the literature (see e.g., Refs. [89,90]). Based on the data from the LSEG ESG database, we focused on a specific component of the ESG performance, the Emissions score, since this would be the strategic goal of both CCUS innovation and external stakeholder involvement according to the theoretical and industrial background of this research. Based on the analysis, both external stakeholder involvement and CCUS innovation positively and significantly impact the Emissions score (the higher score means better performance in the LSEG scoring system) ($p = 0.0132$, $R^2 = 0.062$; $p = 0.0036$, $R^2 = 0.084$, respectively).

4.2.2. *Firm-specific controls*

To further address potential endogeneity and omitted variable bias of the theoretical model, we have also conducted regression analyses with control variables. Based on the results of Spearman correlation analyses (Section 4.1.2.) and the prior ESG literature [91], first, firm-level control variables, i.e., revenue and employee number, were relevant for this purpose. Regarding CCUS innovation, stakeholder involvement is a significant predictor even when revenue and employee number is considered as controlling variables ($p = 0.012$, $R^2 = 0.259$). Nevertheless, the impact of revenues should be also underlined, which is in line with the cost-intensive nature of CCUS. The contribution of higher stakeholder involvement is also shown for better ESG performance by the regression analysis with these control variables ($p = 0.0025$, $R^2 = 0.0995$), without significant dependence on revenue or employee number.

4.2.3. *Regional controls*

Potential omitted variable bias can be also present due to unobserved geographic heterogeneity, especially because recent research found significant regional differences in ESG risks [92]. To address this issue, continent-level dummy variables as fixed effects were included, in line with Fig. 2, which compared regional patterns descriptively. Concerning Model 1, the relationship between stakeholder involvement and CCUS innovation remained significantly positive ($p = 0.0089$, $R^2 = 0.216$), however, Asia and North America have lower CCUS innovation levels compared to Europe (reference group). The relationship between stakeholder involvement and ESG performance in Model 2 was also reinforced by the regional analysis ($p = 0.0133$, $R^2 = 0.241$). In Model 3, however, the impact of CCUS innovation on ESG rating became less significant, but the explanatory power of the model, however improved ($p = 0.110$, $R^2 = 0.212$). This result suggests that regional differences might mediate the relationship between CCUS innovation and ESG ratings, which can be the subject of future research.

4.3. *Additional qualitative analysis*

To contextualise the most significant statistical finding, i.e., the supportive role of external stakeholder involvement in CCUS innovation, supplementing qualitative analysis was conducted. Specifically, disclosed corporate information about CCUS innovation and external stakeholder involvement activities was qualitatively coded in line with the innovation stage-gate process model [82]. The coding focused on the referred pre-conditions of stepping into the next phase in the process model and the related external stakeholder involvement activities which companies do implement to explore and exploit CCUS opportunities or overcome CCUS challenges. Table 8 presents the categorisation of the in vivo codes. The synthesis of corporate communications can be summarised as follows.

Table 8
Qualitative summary of the CCUS innovation-related information of large energy companies (with in-vivo codes).

Phase	Pre-conditions to step into the next phase	External stakeholder involvement
Discovery	Emerging technologies, external innovations Internal research Firm commitment (e.g., for innovation and environmental leadership) Strategic orientation (e.g., creating future business opportunities, mitigating uncertainties, managing risks by diversification, enhancing core business, repurposing assets)	Partnership, collaborative research with universities, research centres, or other companies Dialogue within multi-stakeholder initiatives Participation in working groups at an industry association level
Idea scoping and building business case	Multiple pathways for operational improvements Combination opportunity with other technologies (e.g., renewable hydrogen and e-methane) Strategic positioning (e.g., solidify positioning in CCUS/a lower carbon future, strategic partnership with a CCUS startup) Win-win situations in the production system/supply chain	Inter-organizational working group, partnership, collaboration with universities, research centres (e.g., exploring options, conducting feasibility studies) Strategic investment into a technology developer startup
Development, testing, and validation	Current resource portfolio (e.g., clean energy assets, previous internal technology developments, cross-functional expert team) Infrastructural feasibility (e.g., opportunity for retrofitting) Reaching not only technological maturity but cost-effectiveness and environmental benefits; overcoming technical, technological, operational and economic challenges Supportive/pressuring regulatory framework Multiple possible technology suppliers Not implementable or not profitable alternatives (e.g., offsetting, reforestation) Available external technologies for commercial deployment	Inter-organizational technical teams Winning grants, governmental support Partnership, collaboration with universities and technological partners (e.g., pilot/small-scale test plant development)
Launch	Overall techno-economic goals: - Reducing GHG emissions (own or clients' emissions) - Addressing sustainable electricity consumption needs - Switching to natural gas as a low-emission fuel - Enabling transition/cleaner fuel production	Winning grants, governmental support, collaboration with a municipality Partnership, collaboration/joint venture with other industrial companies (e.g., LNG shipping company, peer utilities, natural gas infrastructure developers, CCUS at a cement plant)

(1) In the discovery phase, both external and internal pre-conditions appeared in corporate reports and websites. For example, many companies mentioned the monitoring activity about emerging technologies from the external environment, while others emphasised that CCUS development would be important for them because of their mission-like commitment (e.g., environmental leadership) or their strategic orientation (e.g., repurposing assets

for a lower-carbon future). During this discovery phase, collaborative research activities, dialogue with stakeholders, and participation in non-profit organisational events inform corporate decision-makers about new opportunities.

(2) Even though internal and external interactions are usually themed around not only CCUS but multiple energy topics, such as energy efficiency, hydrogen, etc., they might incite companies to organise the formal idea scoping and business case building. As presented in the descriptive statistics, more than 50 % of the analysed companies have reached this second phase or higher. Regarding idea scoping and business case building, multinational energy companies mentioned continuous work within inter-organisational working groups and joint research activities with universities, and research centres. A few companies also disclosed their interest in CCUS technology developer start-ups. Based on the corporate documents, finding multiple pathways for improvements, including combination opportunities with other solutions, such as e-fuels, win-win situations with partners in the supply chain, or the overall importance of CCUS technologies within the corporate strategy could induce resource allocation to technology development.

(3) In the development, testing, and validation phase, sustainability reports and website information suggest that inter-organisational collaborations are usually continued. Nevertheless, disclosures also imply more operative opportunities and challenges before large-scale CCUS implementation. Specifically, the current resource portfolio, for example, prior investments into clean energy-related assets or CCUS projects, and the infrastructural feasibility (e.g., for retrofitting) could be a foundation for upscaling. In contrast, many of the analysed companies state relatively clearly (by the standards of such reports) that technological maturity and environmental performance are necessary but not enough for large-scale CCUS investment – they aim to develop or find technologies which are economically feasible, or at least better than the alternatives (e.g., offsetting, reforestation). There are, however, further pre-conditions to go forward. Namely, companies highlight that a supportive or pressuring regulatory framework could also speed up the development process (i.e., investments). If internal research and development were not present, companies mentioned searching external CCUS technologies for commercial deployment, preferably from multiple possible suppliers.

(4) Finally, companies sometimes mentioned that winning grants and governmental support induced their technological development work on pilot plants, but also on large-scale plants. This finding is in line with the above-mentioned statistical analysis, which suggested that there is a strong positive correlation between revenues and CCUS innovation, i.e., CCUS innovation in a real industrial environment requires significant financial resources. Besides the general goal to reduce GHG emissions by CCUS technologies, other techno-economic goals are also mentioned in the ESG reports, for example, ensuring sustainable electricity generation or enabling the production of low-carbon fuels.

5. Conclusion

This study aimed to explore the interrelations of ESG performance, CCUS innovation, and external stakeholder involvement in related corporate strategies. The quantitative analyses confirmed that external stakeholder involvement can accelerate CCUS innovation in the case of multinational energy companies. The supplementary qualitative analysis of corporate sustainability reports and websites highlighted many pre-conditions of transitioning from the discovery of CCUS development opportunities to launching a large-scale CCUS facility. Nevertheless, the empirical data also underlined the constant opportunity to collaborate with external stakeholders in different innovation phases, especially with corporate partners. Exploiting collaboration opportunities comes not only with a higher CCUS innovation level but also with higher ESG performance. This is, however, only present in the case of those companies, which are at least in the first phase of the CCUS innovation process (discovery).

5.1. Managerial implications

From a practical perspective, the main contribution is that the findings encourage corporate decision-makers to implement inter-organisational strategies, for example, with universities, start-ups, or other actors in their supply chain to explore CCUS development opportunities together. The underlying rationale is that external stakeholder involvement can support both CCUS innovation and ESG performance. Interestingly, the empirical data suggests, however, that especially those multinational energy companies should continue the work on CCUS innovation, which have already started searching for these opportunities. This is in line with the transition on the technological life cycle curve: since the majority of multinational energy companies have already engaged in discovering CCUS, and most of them are in the 'Idea scoping and business case building' phase, technology development competition might be strengthened in the future. Besides the adequate policy frameworks, the role of CCUS in the future energy systems largely depends on these innovative activities of multinational energy companies to address the critical technical, economic, and infrastructural barriers of large-scale CCUS deployment.

5.2. Theoretical contributions

To the best of our knowledge, this study is the first to analyse and bridge relationships between research topics which are separately dominating in different fields, i.e., ESG performance in business and finance research, and CCUS technologies in environmental and energy research. We integrated these topics by involving their common point, i.e., external stakeholder involvement, which is fundamental in ESG strategies and is useful in energy innovation due to complementary resources. Besides the novelty of the research scope, the study revealed the contributing role of external stakeholder involvement in CCUS innovation. Nevertheless, both the quantitative and the qualitative data suggested that financial resources (companies with larger revenue levels, government support, grants) still play a crucial role in stepping into the 'Development, testing, and validation phase' and the 'Launch' phase, owing to the economic challenges and technological complexity of CCUS. Furthermore, while it was previously proven that the existence of ESG ratings positively affects green innovation, this study found the reverse: the existence of green (CCUS) innovation positively affects the ESG rating.

5.3. Limitations and future research

This study focused only on the largest energy companies worldwide, which enabled us to gather an overall understanding of global trends but limited the scope of recommendations. For example, regional characteristics (e.g., policies, regulations, carbon tax systems, investor behaviour, green financing trends, socio-cultural background) could also affect investment in CCUS technologies, the importance of ESG scores, and the extent and nature of external stakeholder involvement. Future studies might focus on certain continents to generate a more punctuated picture and evaluate the conclusions of this study in a specific context. Moreover, this study focused only on recent data, providing a snapshot about stakeholder involvement, CCUS innovation, and ESG performance in the global energy sector. Using data from other years and conducting longitudinal studies in the future could also help understand how CCUS innovation rises, stagnates, or backslides, matching or differing from the change in ESG performance, even by region. Since this research was focusing on the largest multinational energy companies, a relatively small sample was used. Future research could widen the scope, which would allow to differentiate the contributions of the different external stakeholder groups as well (e.g., corporate, academia, etc.). From a methodological perspective, logarithmic transformation was applied in the regression models to mitigate skewness and scale issues in the raw data. In this regard, another limitation is that the applied regression models resulted in only weak explanatory power, being statistically significant though. This is because ESG performance and CCUS innovation can depend on many heterogeneous variables. Future research might integrate other independent variables into the analysis. Finally, CCUS technologies could be relevant for other GHG-intensive industries, as well (e.g., cement), so switching the industrial scope of the research could be also relevant.

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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esr.2025.102013.

Appendix

Table A1
Results of the robustness tests (part 1)

	European sub-sample			Alternative dependent variables	
	Model 1	Model 2	Model 3	Alternative 1	Alternative 2
Independent variable	Stakeh_Invol	Stakeh_Invol	CCUS_Inn	Stakeh_Invol	CCUS_Inn
Dependent variable	CCUS_Inn	ESG_Rating	ESG_Rating	Emissions	Emissions
Multiple R	0,41287633	0.43356015	0.50066777	0.2483537	0.29032919
R Square	0.17046687	0.1879744	0.25066821	0.06167956	0.08429104
Adjusted R Square	0.12438169	0.14286187	0.20903867	0.05200615	0.07485074
Standard Error	0.5439847	0.53821361	0.47292765	22.4994923	19.743842
Observations	20	20	20	99	99

Note: Logarithmic forms of the independent variables were used in the regression models.

Table A2
Results of the robustness tests (part 2)

European sub-sample		*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95 %*	*Upper 95 %*	*Lower 95.0 %*	*Upper 95.0 %*
Model 1	Intercept	4.12159704	0.30707096	13.4222952	8.15E-11	3.4764649	4.76672918	3.4764649	4.76672918
ln_Stakeh_Invol & CCUS_Innov	79	0.00475465	0.00247217	1.92326608	0.07041162	−0.0004392	0.00994849	−0.0004392	0.00994849
Model 2	Intercept	5.30166113	0.33482693	15.8340343	5.195E-12	4.59821585	6.00510641	4.59821585	6.00510641
ln_Stakeh_Invol & ESG_Rating	20	−0.0275983	0.01352015	−2.0412714	0.05616368	−0.0560031	0.00080649	−0.0560031	0.00080649
Model 3	Intercept	5.29362886	0.29421202	17.992565	5.9306E-13	4.67551234	5.91174537	4.67551234	5.91174537
ln_CCUS_Inn & ESG_Rating	20	−0.0291521	0.01188014	−2.4538545	0.02454717	−0.0541114	−0.0041929	−0.0541114	−0.0041929
Alternative dependent variables		***Coefficients***	***Standard Error***	***t Stat***	***P-value***	***Lower 95 %***	***Upper 95 %***	***Lower 95.0 %***	***Upper 95.0 %***
Alternative 1	Intercept	26.6516947	17.3310298	1.53780214	0.12735275	−7.7456019	61.0489913	−7.7456019	61.0489913
ln_Stakeh_Invol & Emissions	5.16478597	9.34627125	3.70132718	2.52511351	0.01318733	2.00016139	16.6923811	2.00016139	16.6923811
Alternative 2	Intercept	13.7217801	15.2083927	0.90225051	0.36915879	−16.46267	43.9062298	−16.46267	43.9062298
ln_CCUS_Inn & Emissions	5.16478597	9.70541834	3.24800303	2.98811862	0.00355555	3.25903141	16.1518053	3.25903141	16.1518053

Table A3
Results of the regression analyses with firm-specific control variables (part 1)

	Model 4	Model 5
Independent variables	Revenue, Employees, Stakeholder involvement	Revenue, Employees, Stakeholder involvement
Dependent variable	CCUS Innovation	ESG Rating
Multiple R	0.50890578	0.31549627
R Square	0.25898509	0.0995379
Adjusted R Square	0.23372322	0.06884032

(*continued on next page*)

Table A3 (*continued*)

	Model 4	Model 5
Standard Error	34.9520241	9.88598885
Observations	92	92

Note: Logarithmic forms of the independent variables were used in the regression models.

Table A4
Results of the regression analyses with firm-specific control variables (part 2)

Model 4	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95 %*	*Upper 95 %*	*Lower 95.0 %*	*Upper 95.0 %*
Intercept	−108.26617	38.01193	−2.8482157	0.00547253	−183.8069	−32.725451	−183.8069	−32.725451
ln_Revenue	11.6318383	4.2086543	2.76379039	0.00695783	3.26802226	19.9956543	3.26802226	19.9956543
ln_Employee	2.53891843	3.59536804	0.70616371	0.48195175	−4.60612	9.6839569	−4.60612	9.6839569
ln_Stakeholder_Invol	15.5548186	6.07311904	2.56125699	0.01213249	3.48577069	27.6238665	3.48577069	27.6238665
Model 5	***Coefficients***	***Standard Error***	***t Stat***	***P-value***	***Lower 95 %***	***Upper 95 %***	***Lower 95.0 %***	***Upper 95.0 %***
Intercept	49.4984367	10.7514665	4.60387768	1.3883E-05	28.1321563	70.8647171	28.1321563	70.8647171
ln_Revenue	0.9247403	1.19039485	0.77683493	0.43933934	−1.4409193	3.29039993	−1.4409193	3.29039993
ln_Employee	−0.436058	1.01693019	−0.4287984	0.66911782	−2.4569931	1.58487705	−2.4569931	1.58487705
ln_Stakeholder_Invol	−5.3434544	1.7177485	−3.1107315	0.00251575	−8.7571185	−1.9297902	−8.7571185	−1.9297902

Table A5
Results of the regression analyses with regional control variables (part 1)

	Model 1_R	Model 2_R	Model 3_R
Independent variables	Stakeh_Invol and regions (Europe, North America, South America, Asia, Oceania)	Stakeh_Invol and regions (Europe, North America, South America, Asia, Oceania)	CCUS_Inn and regions (Europe, North America, South America, Asia, Oceania)
Dependent variable	CCUS_Inn	ESG_Rating	ESG_Rating
Multiple R	0.46451751	0.49110438	0.45993426
R Square	0.21577652	0.24118351	0.21153953
Adjusted R Square	0.1740625	0.20082093	0.16960014
Standard Error	35.8202699	8.9825404	9.15631577
Observations	100	100	100

Note: Logarithmic forms of the independent variables were used in the regression models.

Table A6
Results of the regression analyses with regional control variables (part 2)

Model 1_R	Coefficients	Standard Error	t Stat	P-value	Lower 95 %	Upper 95 %	Lower 95.0 %	Upper 95.0 %
Intercept	40.9989665	29.7452472	1.37833672	0.17137119	−18.060919	100.058852	−18.060919	100.058852
ln_Stakeh_Invol	16.1393262	6.03915038	2.6724498	0.00887714	4.14845158	28.1302009	4.14845158	28.1302009
Asia_D	−31.928419	10.5575946	−3.0242134	0.00321386	−52.89077	−10.966067	−52.89077	−10.966067
N_America_D	−27.282079	10.1673924	−2.6832917	0.00861453	−47.469675	−7.0944834	−47.469675	−7.0944834
S_America_D	2.98774091	16.889023	0.17690431	0.85996416	−30.54581	36.5212919	−30.54581	36.5212919
Oceania_D	17.0732007	26.7996072	0.63706907	0.5256284	−36.138048	70.2844491	−36.138048	70.2844491
Model 2_R	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95 %*	*Upper 95 %*	*Lower 95.0 %*	*Upper 95.0 %*
Intercept	42.3509529	7.45912538	5.6777371	1.5121E-07	27.5406846	57.1612212	27.5406846	57.1612212
ln_Stakeh_Invol	−3.823241	1.51441942	−2.5245589	0.01325995	−6.8301563	−0.8163258	−6.8301563	−0.8163258
Asia_D	9.53391392	2.64749596	3.60110613	0.00050848	4.27724863	14.7905792	4.27724863	14.7905792
N_America_D	2.12987975	2.54964614	0.83536289	0.40563168	−2.9325024	7.19226193	−2.9325024	7.19226193
S_America_D	2.4645576	4.23520905	0.58192112	0.56201286	−5.9445492	10.8736645	−5.9445492	10.8736645
Oceania_D	10.6753563	6.72045619	1.58848685	0.11553435	−2.668267	24.0189796	−2.668267	24.0189796
Model 3_R	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95 %*	*Upper 95 %*	*Lower 95.0 %*	*Upper 95.0 %*
Intercept	38.9232928	9.32621709	4.17353493	6.6913E-05	20.4058702	57.4407155	20.4058702	57.4407155
Asia_D	9.44377191	2.75167343	3.43201043	0.00089224	3.98025981	14.907284	3.98025981	14.907284
N_America_D	1.3373158	2.6361548	0.5072979	0.61313394	−3.8968314	6.57146296	−3.8968314	6.57146296
S_America_D	2.64517888	4.31636124	0.61282611	0.54147115	−5.9250575	11.2154153	−5.9250575	11.2154153
Oceania_D	10.0510421	6.84483111	1.46841345	0.14533044	−3.5395306	23.6416147	−3.5395306	23.6416147
ln_CCUS_Innov	−3.1466537	1.95161081	−1.6123367	0.11024127	−7.0216227	0.72831529	−7.0216227	0.72831529

Data availability

Data will be made available on request.

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