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Female leadership and environmental innovation: do gender boards make a difference?

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Abstract
This research investigates how female CEOs and board gender composition (BGC) influence environmental innovation. Using a panel dataset of 237 energy companies, the study reveals that female CEOs are more committed to the environment than males. Interestingly, the findings also show that the BGC positively moderates the female CEO and environmental innovation nexus. Additionally, it reveals that female CEOs have a more significant influence on promoting environmentally friendly innovation in profitable energy companies than males. The findings remain strong after various robustness tests, contributing to the ongoing debate on gender equality and offering novel insights into the green footprint.

Article Highlights

- The study reveals that female CEOs significantly drive environmental innovation strategies in energy companies.
- The presence of women on corporate boards significantly magnifies the effect of female CEOs on environmental innovation.
- Practical implications for ecological innovation highlight the necessity of female leadership in both positions.

Keywords Female CEOs · Environmental innovation · Board gender composition · Gender equality · Energy sector · Panel data · GMM

JEL Classification J16 · Q56 · G34

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1 Introduction

Because of its significant environmental impact, the global energy industry, which is considered a major emitter sector, faces many obstacles to achieving carbon neutrality. Emissions from this sector result in a high social cost [1]. Additionally, it must face many social and regulatory pressures that can enhance the sustainability of its products and production methods [2]. Thus, this sector faces societal and regulatory pressures to address climate change and environmental externalities, and reduce further social welfare loss to enhance legitimacy and competitiveness [3–5]. Research in this area revealed the need for the energy sector to enhance its public image, increase supplier satisfaction, and align with community and ecological concerns [1].

The prerequisites to engage with climate change and the eco-friendly crisis have never been more pressing, and innovation policies are critical to finding solutions [6]. While opinions differ on the financial aspects of ecological innovation, the upfront funding and higher capital costs required to pay off in a long-term [7]. According to ref. [8], environmental innovation takes longer to see results. Because of the strategic importance of ecological innovation for corporations, top management must establish relevant policies and strategies [9, 10]. In turn, the Chief Executive Officers (CEOs) have the ultimate power to decide on all essential policymaking bodies, including establishing organizational policies, particularly those related to eco-friendly concerns, and implementing eco-friendly innovation [4, 11–13].

Contextually, researchers e.g., [14, 15] claimed that companies with more female CEOs might have an advantage in achieving improved social and financial outcomes. However, scholarly research on the influence of female CEOs on green strategy remains underexplored [3]. Indeed, previous studies on the impact of women on corporate boards (WOCB) and environmental innovation cannot be ignored [16]. Still, it is difficult to generalize their findings to feminine CEOs owing to the challenges in equalizing the impact of BGC with C-suite gender diversity [10]. Relatedly, ref. [6] assert that worldwide observers, managers, and stakeholders agree that workforce diversity is helpful for businesses since diversity engenders a mindset that encourages thinking beyond conventional boundaries, cultivating an innovative environment.

However, refs. [5, 17] also submitted that female CEOs may be less open to social performance if their boards lack gender diversity. While CEOs are the primary decision-makers within particular companies, they collaborate with directors and other executives to share this duty in different firms [15, 18]. Thus, it is necessary to examine the extent to which females in both positions have complementary connections regarding eco-friendly strategies, particularly environmental innovation. Specifically, investigating the joint effect of WOCBs and female CEOs on environmental innovation would provide valuable insights. Therefore, this paper merges these two threads of the literature and analyzes how BGC may intervene in the female CEOs-Environmental Innovation nexus. From a BGC standpoint, this association is being studied for the first time to understand how it can enhance the connection between female CEOs and environmental innovation through a synergistic effect.

This article makes three significant endeavors to the current literature. First, it offers novel insights into the underexplored interrelationship between the female CEOs, board members and the green footprint of the firms they lead. Thus, this research adds value to existing scholarly works that detect the impact of BGC on eco-innovation, hence offering notable contributions to upper echelons research. Aforementioned studies primarily concentrated on monitoring women's role within the boardroom [19, 20]. This paper has undertaken a pioneering investigation into the influence of female CEOs and WOCBs of the advancement of environmental innovation. Drawing lessons from the upper echelon theory and in line with recent studies, this study explained that women are more accommodating, assertive, and communal, and they are more likely to accept innovative environmental practices that reduce harmful ecological effects than men. Hence, this paper analyzes women's dual responsibility in overseeing managerial activities and their role as decision-makers.

Second, no previous research has explored this connection within the energy industry, which holds great importance, particularly given the exhaustion of mineral fuel resources, the ecological damage resulting from fossil fuel extraction, and the pressing requirement for energy saving, and renewable energy advancement [21, 22]. Stockholders increasingly call on energy companies to reduce emissions and improve their social performance [23]. Thus, the analysis of the energy industry is warranted. The International Energy Agency's 2021 report states that oil and gas consumption and production contribute 62% of energy-related emissions [24]. Additionally, the energy industry and its by-products make up 56% of energy consumption globally and are major contributors to global warming [25, 26]. Considering these issues' significance, examining the global energy industry is critical.

Third, this exploration complements the body of knowledge on contingency theory, positing that gender inclusivity can result from the alignment between female CEOs and contextual circumstances [12, 27, 28]. The need for

this alignment highlights the promotion of gender equality in both positions and aligns with the "fifth Sustainable Development Goal" of the United Nations". Furthermore, the analysis considers the moderating effect of BGC and contributes to the ongoing literature on the contingency approach in studying the impact of women executives on business outcomes.

2 Related literature and hypothesis development

2.1 Female CEOs and environmental innovation

Even though market authorities frequently promote WOCBs, little discussion has been held about appointing women as CEOs [29, 30]. Additionally, despite the efforts of numerous companies to hire more women for their boards, the lack of female CEOs remains a prevalent issue worldwide [31]. In ref. [32] argued that women are underrepresented in top executive management roles in Australian companies. While significant scholarly devotion has been given to the nexus between WOCB and environmental innovation, there is a noticeable dearth of exploration of the role of female CEOs [3, 19]. We believe that women in CEO positions have a distinctive impact compared to those in board positions. Women actively monitor and supervise the board's actions [20, 33]. Nevertheless, they control decision-making when they serve as CEO [18].

According to literature, the CEO is the highest-ranking executive in the business, accountable for strategy development, and has considerable influence on decision-making [34, 35]. Hence, scholars assert that CEOs hold considerable sway over businesses' strategic choices and ensuing implementation, granting them the ability to exert substantial influence over ecological policies and practices [27].

The upper echelons theory posits that top executive managers are crucial in driving environmental innovation [8]. The theory argues that the individual traits of top-level managers, such as their personality, ethical values, culture, and risk aversion, help shape companies' strategic decisions, due to variations in viewpoints and behavior between companies led by female and male executives [16, 19, 36]. Thus, the psychological and personal characteristics of CEOs significantly shape a company's strategic decision-making capacity [8]. Empirical research [37], showing that managers' idiosyncrasies impact companies' performance and decision-making, by bringing new perspectives [36]. Furthermore, recommend that the personal qualities of CEOs, such as gender, play a role in shaping a company's sustainable behavior [35, 38, 39].

Because top managers, specifically CEOs, are pivotal in shaping their firms' strategic preferences, the commitment of businesses to eco-friendly investment depends on their CEOs' decisions. This theoretical perspective argues that managers' characteristics, including demographics, help shape their decision-making and ultimately impact organizational outcomes. Thus, the personality traits of CEOs meaningfully inspire their strategic choices [36]. Because of the latent nature of these personality traits, past investigations typically relied on demographic characteristics such as age, education, and, more importantly, gender [5, 40].

Also, female CEOs are often regarded as the principal strategists and designers of a company's innovation strategy [38]. Having a female CEO importantly impacts and adds value to the triple bottom line [29]. Female CEOs prioritize eco-friendly responsibility without neglecting the economic bottom line [4]. Earlier studies have found that females contribute actively to societal betterment and strongly emphasize eco-friendliness. Women are often seen as more independent and assertive than men, and when part of a leadership team, they bring fresh and innovative ideas and practical solutions to challenging issues [41].

The gender socialization theory provides theoretical backing for the connotation between female CEOs, board feminization, and the advancement of environmental innovation [42]. Females have a stronger sense of concern and care for the environment than males [10]. Their values and communication abilities can aid boards in balancing stakeholder's interests and protecting the environment [43]. Some have found that appointing female CEOs, can promote firms' EIS, as women possess a strong ecological sensitivity and corporate social responsibility [12, 44]. Additionally, female CEOs are sometimes better able to manage ecological risks than male CEOs [37].

Despite eco-innovation's demonstrated significance in preserving a company's competitiveness, innovation is often risky, leading to failure [27]. According to ref. [19], female CEOs are more considered risk-averse compared to men [8]. Relatedly, ref. [45] said there was an inverse relationship between female managers and innovation. These gender-related arguments suggest that companies with female CEOs engage in fewer innovation initiatives [46]. Consequently, they may overlook investment opportunities with higher risks and expected value. This risk-aversive viewpoint suggests that female CEOs may be less inspired to contribute to innovative projects because of the potential risks involved.

The "glass ceiling" barrier in corporate settings results in a relative preference for men in C-suite roles, and recent show that women face bias and discrimination during leadership selection [31, 42, 46]. So, biased and prejudiced practices within organizations push female leaders to adapt and submit innovative ideas in the face of uncertainty [7]. In comparison to male CEOs, female CEOs prioritize active listening, open discussions, as well as eco-innovation ideas. Women show more masculine characteristics when taking on leadership positions in the business world. Female CEOs show more thoughtful work strategies to justify their leadership roles. Females, being frequently overlooked, are compelled to submit innovative ideas more regularly. The assertion is that females must generate creative thoughts more repeatedly since they are commonly ignored and go unnoticed [41]. Thus, women who are chosen as top executives go the extra mile to challenge stereotypes and drive innovation, resulting in increased green initiatives to break the glass ceiling [29, 45].

No clear conclusion exists on the nexus between CEOs gender and environmental innovation activities [47]. While ref. [38] argued that a female CEO does not significantly influence the eco-innovation levels. Contrarily, ref. [10] unearthed that female CEOs of publicly listed Chinese firms display a higher propensity to endorse eco-innovation when juxtaposed with their male counterparts. Recently, ref. [7] revealed that female CEOs in China show more significant levels of innovation when compared to male chief executives, and argued that female executives work smarter to defend their leadership roles against biased selection and evaluation criteria.

CEOs have various roles as they head management, act as directors, and contribute to board committees [10]. Furthermore, female CEOs are enticed to promote innovation because the CEO position is more lucrative than serving as a board member [48]. According to ref. [49], having women in top management may contribute positively to a company's green strategies. Also, ref. [46] suggest that female executives in this context are more inclined to launch in innovative capacities than male executives. This inclination is because they must beat out their male counterparts before becoming CEOs.

Based on their study of French-listed companies, ref. [29] uncovered a direct connection between diverse gender representation among executives and a boost in incorporating innovation and eco-innovation. As well, ref. [14] revealed that a higher number of females in top-management executive roles positively impacts innovation levels in French companies. In contrast, ref. [50] found no noteworthy link among female CEOs and innovation, and ref. [51] revealed that female CEOs have a detrimental influence on eco-innovation. The reason behind our motivation is the inability to generalize and the contradictory nature of conclusions drawn from existing studies on the connection among the existence of women managers and ecological innovation. Additionally, adequate research is absent on the influence of female CEOs on eco-innovation in energy companies.

Experts argue that female leaders exhibit a greater inclination towards innovation and egalitarianism in their approach to strategy-making, often venturing into uncharted territories [46]. Stakeholder well-being is a top priority for female leaders [17]. Female CEOs have a unique advantage in integrating the concerns of various stakeholders, including the environment, alongside shareholders' interests [19, 29]. Various empirical studies indicate that female leaders prioritize the ecological challenges their corporations face [36]. The sensitivity of women CEOs towards CSR issues will lead them to undertake green innovative projects [10, 25, 29, 47]. Driven by their career trajectories and socialization roles, these CEOs prioritize building relationships and promoting environment-friendly initiatives for a better community [10]. Consequently, this paper hypothesizes that female CEOs, from a gender socialization perspective, are more inclined to support and encourage green practices than male CEOs.

H1: Energy companies led by female CEOs show a greater inclination towards environmental innovation.

2.2 The BGC as a moderator

The lack of conclusive results leaves us without a definitive understanding of the connection between female CEOs and eco-innovation. Inconsistent effects can coexist depending on specific contextual thresholds, the differences in econometric methods, data, and variables measured across diverse, in-depth research investigations pose challenges in determining the interactions between female CEOs and eco-innovation [3, 5, 41]. In addition, the lack of a conclusive relationship can be attributed to moderating variables that could influence the association [10].

This paper argues that, while female CEOs are inclined towards more significant EIS, the broader context might shape the strategic decision process. Extensive research in recent decades supports gender equality aligned with the fifth Sustainable Development Goal of the United Nations. This paper argues that gender alone does not sufficiently account for female CEO's influence on environmental innovation. So, this study investigates whether BGC can influence the connection between female CEOs and the advancement of eco-innovation.

Managers worldwide acknowledge workforce diversity as beneficial for businesses in several aspects, as ref. [6] asserted. Promoting diversity fosters a mindset that encourages creative thinking and drives innovation. Female board

members acknowledge cooperation, collaboration, and non-hierarchical approaches [52, 53]. Including WOCB can enhance governance and board effectiveness, benefiting stakeholders. Boards with more gender diversity are linked to higher innovation, creativity levels, and knowledge positively than less gender-diverse boards [8, 19, 25, 29, 41, 54].

Eco-innovation in modern corporations often relies on the involvement of female directors because they prioritize others' interests and exhibit ecological sensitivity [48]. It enhances group decision-making, improving firm outcomes and giving a firm an additional competitive advantage [55]. Furthermore, empirical evidence from ref. [49] supports the positive impact of WOCB on active eco-friendly strategies. One underlying theme of the contemporary study is that the association between WOCBs is likely to moderate the female CEOs and environmental innovation nexus.

Women tend to be more attuned to societal issues and uphold higher moral and ethical standards than men [19]. In ref. [15] suggested that, although CEOs hold the primary role of decision-makers in specific companies, they often collaborate with directors and other executives in other firms to distribute this responsibility. In addition, women board members' distinct cognitive perspectives can foster meaningful dialogue, enhance information sharing and knowledge integration, encourage cooperation, and facilitate collaborations within and outside organizations [33, 41]. In ref. [43] found that the appointment of female CEOs and increased representation of WOCBs was associated with reduced corporate ecological violations. Indeed, refs. [5, 17] found that female CEOs may exhibit less inclination toward social performance when their boards lack gender diversity. Therefore, analyzing how females in CEO and BOD roles are connected regarding eco-friendly strategies, especially EIS, is crucial.

Aforementioned studies have primarily looked at the influence of CEOs on ecological innovation and the upshot of BGC on eco-friendly innovation [10, 49]. However, it is uncertain how female CEOs directly or indirectly influence firm environmental innovation from the BGC viewpoint, which is also an essential subject in the ongoing ecological discussion. According to these theoretical perspectives, having female leadership in both positions impacts how boards and CEOs contribute to environmental innovation within firms. However, theoretical statements lack unanimous empirical support based on studies [56]. The evidence supporting the affirmative influence of female leadership in both positions on environmental innovation capacity is scarce.

Contingency theory suggests organizational consequences, like EIS, result from the fit among different factors [27]. In line with this theory, an independent variable better justifies the outcome with a moderator variable [10]. It also recommends that the effect of an explanatory variable on an explained variable may diverge from company to company. Situation-specific factors can cause variations that lead to inconsistent results. The contingency theory suggests that the emergence of eco-friendly innovation results from the alignment between female CEOs and situational factors. The impacts of female CEOs on environmental innovation are influenced by various factors, including female board members, which should be examined as additional critical variables.

As a result, this paper expects that BGC will moderate the decisions made by female CEOs regarding corporate environmental innovation as illustrated in Fig. 1. Scholars can derive more comprehensive conclusions about gender equality by considering the interplay among all relevant attributes. Integrative methods are used to explore and formulate multiple theories. This study analyzes how female CEOs and board gender composition impact environmental innovation. Consequently, the ensuing hypothesis was developed:

H2: BGC may positively moderates the nexus between female CEOs and environmental innovation of global energy companies.

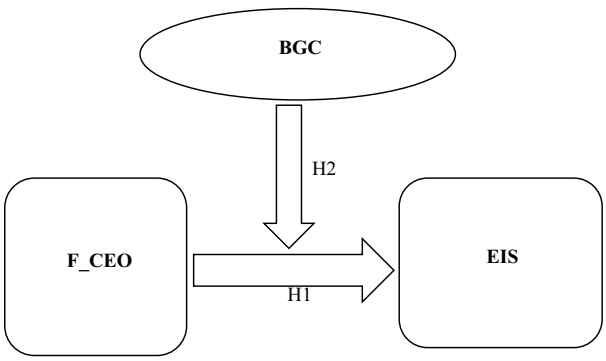

Fig. 1 Conceptual framework

3 Methodology

3.1 Sample selection

The study broadly examined a global panel dataset of energy companies to estimate proposed hypotheses about the biggest GHG emitters [57]. Shareholders and society closely scrutinize the energy industry due to the negative impacts of its operations. Activists and government institutions spotlight the energy industry to promote awareness and mitigate its harmful effects.

The study gathered all its data from the highly reliable Refinitiv Eikon database [1]. It is common knowledge that Thomson Reuters Eikon serves as a platform offering financial figures from multiple sources, encompassing annual reports for many international companies [58]. Among the various data sources, it is widely recognized as one of the most trustworthy [57, 59]. These databases have proven credible and dependable in earlier research [19]. Researchers increasingly rely on these scores [33].

The initial sample included 410 energy companies worldwide. The initial selection criteria included only companies with at least 11 years of data to achieve credible estimations. Because of the lack of eleven-year data, 173 companies were excluded to avoid confounding inferences. We initially conducted diagnostic tests and comparisons to our collected data to ensure neutrality in sample selection. The exclusion of companies that failed to provide data throughout the study period did not present any notable biases since the excluded companies did not differ systematically from the included companies, potentially affecting the study findings. To ensure the results' reliability, we also conducted a sensitivity analysis. While the missing observations have reduced our sample size, the fact that the analyzed companies represent 58% of the population ensures that our sample remains somewhat representative. However, this could potentially limit the generalizability of our results. The analysis was conducted during a period that aligned with the notable growth of female leadership in significant corporations, specifically within the energy industry, in the last decade [2]. Then, winsorization at the 1% level in both tails was applied to variables with extreme values to control for outliers [33]. Winsorization is crucial for mitigating the impact of outliers while preserving valid data points. It is the preferred choice among outlier treatment methods as it maintains all data points [60]. Thus, this approach was considered most appropriate given the nature of our data and the aims of the analysis.

The final data sample comprised 237 energy firms and 2607 observations taken annually from 2012 to 2022. The time frame is essential because it covers the amendments made to the Kyoto Protocol, which aim to limit and reduce greenhouse gas emissions. It extends the second commitment period, 2013 to 2020. As early as 2015, the United Nations Climate Change Conference encouraged the adoption of environmentally friendly and energy-efficient technologies [61]. This study focused on the period from 2012 to 2022 because environmental concerns gained significant government, market, and public attention at the beginning of this decade, leading companies worldwide to prioritize eco-innovation due to adopting the Paris Agreement in 2015 [10, 62]. During this time, businesses worldwide also started to include information about their eco-innovation initiatives in their annual and social responsibility reports [63]. In addition, the analysis was conducted during a period that aligned with the notable growth of female leadership in significant corporations, specifically within the energy industry, in the last decade [1, 2, 22, 64]. Furthermore, the most recent year for which data was available when collecting for this study was 2022. The data collected throughout the study period was sufficient for the study's objectives and resulted in a balanced panel dataset.

3.2 Variables definition

3.2.1 Predicted variable/environmental innovation scores

Many studies on ecological innovation have utilized the survey methodology to assess environmental innovation because of limited data availability [6, 46, 56]. Nonetheless, this methodology may exhibit deficiencies in terms of verifiability and objectivity, given the potential impact of respondents' personal beliefs on their perspectives regarding the inquiries at hand [48]. Therefore, earlier research frequently relied on research and development costs to indicate environmental innovation [65]. However, companies are not mandated to disclose R&D expenditures for creating new eco-friendly products or services [8, 66].

Aligned with prior studies, this paper evaluates environmental innovation via an environmental innovation score using data obtained from the Thomson Reuters databases, which have been shown to be reliable in earlier research [19, 21, 33, 57]. An EIS scales a business's ability to decrease ecological expenses and burdens for its clients, generating fresh market prospects through advancements in ecological technologies, processes, or eco-friendly products [49]. The score is a weighted average industry-adjusted composite score ranging from 0 to 100, based on twenty variables related to eco-products in addition to eco-processes within an organization [21]. A score of 100 shows a strong commitment to environmental innovation. It is essential to mention that we converted the environmental innovation percentage score into fractions by dividing it by 100.

3.2.2 Predictor variable

Per earlier studies [10, 29], this paper defines female CEOs as a dummy variable that takes the value 1 when the CEO is female and 0 otherwise.

3.2.3 Contingent variable

The approach employed in this study, like [19, 50], involved assessing BGC influence by analyzing the proportion of women appointed to corporate boards.

3.2.4 Covariate variables

To prevent biased outcomes, this paper incorporates a set of covariate variables identified in previous research [10, 33, 55, 67–69], which account for board-level characteristics that may impact corporate EIS, which are CSR committee, board meetings, board tenure (BT). To sum up, the existence of a CSR committee, the frequency of board meetings, and the duration of board tenure are expected to correlate with environmental innovation positively. Furthermore, this study also accounted for company attributes that previous research has shown to influence environmental innovation the factors are profitability (ROA), leverage (LEV), company age and size [3, 13, 28, 29].

3.3 Statistical model

This paper tested the two hypotheses by employing the following analysis models. First, to determine if companies led by womanly CEOs are more likely to engage in environmental innovation than those led by male CEOs, we analyze Eq. (1):

$$\begin{aligned} EIS_{i,t} =& \beta 0 + \beta 1\ F\_CEO_{i,t} + \beta 2\ BGC_{i,t} + \beta 3 CSR\_Committee_{i,t} + \beta 4 BM_{i,t} + \beta 5 BT_{i,t} + \beta 6\ ROA_{i,t} \\ &+ \beta 7\ LEV_{i,t} + \beta 8\ AGE_{i,t} + \beta 9 SIZE_{i,t} + YEAR\ DUMMY + COUNTRY\ DUMMY + \varepsilon_{i,t} \end{aligned} \quad (1)$$

Second, to explore the potential moderating influence of the BGC, H2 is proposed to examine the nexus between female CEOs and EIS. Besides, this study includes an interaction term, F_CEO*BGC, in the second model to analyze the second hypothesis. The correlation between female CEOs and BGC is illustrated through this interaction. Therefore, the consequential regression model can be described as follows in Eq. (2):

$$\begin{aligned} EIS_{i,t} =& \beta 0\ + \beta 1\ F\_CEO_{i,t} + \beta 2\ BGC_{i,t} + \beta 3\ (F\_CEO \times BGC)_{i,t} + \beta 4\ CSR\_Committee_{i,t} + \beta 5\ BM_{i,t} + \beta 6\ BT_{i,t} \\ &+ \beta 7\ ROA_{i,t} + \beta 8\ LEV_{i,t} + \beta 9\ AGE_{i,t} + \beta 10\ SIZE_{i,t} + YEAR\ DUMMY + COUNTRY\ DUMMY + \varepsilon_{i,t} \end{aligned} \quad (2)$$

Energy companies are represented by the variable 'I', which includes a range of 1 to 237, while the variable't' denotes the study period (2012–2022). Table 1 names the variable definitions. To account for the influence of macroeconomic conditions and potential confounders on environmental innovation, we included fixed effects for the year and the country [63, 70]. By employing dummy variables, we can effectively manage unobserved discrepancies across countries and time frames. Moreover, it can eliminate biases caused by constant omitted variables within a country over time or by standardized variables across all countries in a year. Panel data analysis is more effective in econometrics compared to time-series or cross-sectional analysis, as it controls for individual heterogeneity, thus minimizing biased results [10, 71]. Panel data design is helpful because it enables fixed-effects estimation for firms, allowing researchers to account for unobservable firm-specific effects [12, 20, 72]. Furthermore, this approach tackles endogeneity by removing unobserved

Table 1 Definitions and description of the study variables

Variables of interest	Acronym	Description
Explained variable		
Environmental innovation score	EIS	A score from the Thomson Reuters database measures a firm's ability to decrease environmental expenses and burdens for its clients, generating fresh market prospects through advancements in ecological technologies, processes, or eco-friendly products
Explanatory variable		
Female CEOs	F_CEOs	A dummy variable that takes the value 1 when the CEO is female and 0 otherwise
Moderator variables		
Board gender composition	BGC	The proportion of females appointed to boards
Control variables		
CSR committee	CSR-Committee	Dummy, taking a value of 1 if the company has a CSR committee and 0 otherwise
Board diligence	BM	Total count of board meetings held annually
Board tenure	BT	The average years of service for each board member
Profitability	ROA	Net income/total assets
Leverage	LEV	Total debt to total assets
Energy company age	AGE	Measured by the number of years since it was established
Energy company size	SIZE	Measured by the natural logarithm of total firm assets

heterogeneity [73]. In addition, using the GMM estimator allows us to control the dynamic nature of eco-innovation [27]. The study utilized STATA statistical software version 14 for analyzing the data, as it is ideal for panel data analysis and known for its user-friendly interface [74].

4 Results

4.1 Descriptive statistics and bivariate correlations

Table 2 provides summary statistics details. On average, 58.3% of energy companies in our dataset engage in EIS, which is quite impressive for the energy sector. Over time, the EIS of most energy firms have significantly increased, ranging from 16.7% to 91.6%. Of the energy companies in our sample, approximately 7.01% have female CEOs. The representation of women on the boards of energy firms varies, ranging from 0 to 40%, with an average of 15.891%.

The recorded Pearson correlation matrix in Table 3 demonstrates a noteworthy positive connotation between the involvement of female CEOs and board representation and the promotion of EIS. This correlation shows that greater WOCBs often lead to a higher amount of female CEOs, which is favourable. The results show that the variables have correlation coefficients less than 0.5 and mean VIFs below the critical value of 10, showing no significant correlation or multicollinearity concerns in the empirical model [10, 28, 44, 52, 75–77].

Table 2 Descriptive statistics

Variables	N	Mean	Std. Dev	Min	Max	Skewness	Kurtosis
EIS	2607	0.583	3.01	0.167	0.916	– 1.382	3.516
F_CEOs	2607	0.0713	0.4525	0	1	0.598	2.212
BGC	2607	15.891	12.209	0	0.4	0.373	2.225
CSR-Committee	2607	0.663	0.473	0	1	– 0.688	1.473
BM	2607	8.019	4.849	0	18	0.206	2.578
BT	2607	6.578	3.130	2.113	13.333	0.5735	2.507
ROA	2607	0.0834	0.0915	– 0.058	0.296	0.744	2.918
LEV	2607	0.429	0.392	0.0195	0.983	1.620	5.119
AGE	2607	26.79	14.914	12	64	1.314	3.537
SIZE	2607	21.545	1.719	14.841	26.755	– 0.1277	3.035

Table 3 Correlation matrix

Variable	GI	F_CEOs	BGC	Committee	BM	BT	ROA	LEV	AGE	SIZE
GI	1.000									
F_CEOs	0.1075* 0.0000	1.000								
BGC	0.1284* 0.0000	0.1215* 0.0000	1.000							
CSR-Committee	0.1834* 0.0000	0.0570* 0.0037	0.3387* 0.0000	1.000						
BM	0.1195* 0.0000	0.1574* 0.0000	0.3217* 0.0000	0.0123 0.532	1.000					
BT	0.0187 0.2623	0.0190 0.3324	0.2707* 0.0000	0.0927* 0.0000	0.0299 0.0742	1.000				
ROA	0.0625* 0.0014	0.0339 0.0836	0.0658* 0.0008	0.1323* 0.0000	0.035* 0.0343	0.0576* 0.0033	1.000			
LEV	-0.174* 0.0000	0.0458* 0.0194	0.102* 0.0000	-0.0238 0.1551	-0.024 0.153	-0.046* 0.0203	-0.161* 0.0000	1.000		
AGE	-0.211* 0.0000	-0.2384* 0.0000	-0.1286* 0.0000	0.0126 0.4512	0.1798* 0.0000	0.0251 0.1999	0.0241 0.2196	0.098* 0.0000	1.000	
SIZE	0.0603* 0.0021	0.2507* 0.0000	0.1194* 0.0000	0.0448* 0.0223	-0.102 0.0000	-0.003 0.8624	0.1936* 0.0000	0.1423* 0.0000	0.0448* 0.0223	1.000
VIF	_	1.54	1.30	1.12	1.13	1.92	1.39	1.78	1.64	1.77

*$P < 0.05$. (2-tailed)

4.2 Multivariate regression results

The study utilized multivariate regression analysis on panel data from energy companies to explore the relationship between female CEOs and EIS. Table 4 shows the fixed-effects (FE) models for direct and indirect linkages. In column (1), the baseline regression outcomes do not consider the interaction term (H1), but in column 2, this term (H2) is included. Since the Lagrange multiplier test can identify the superior model between OLS and random effects (RE) estimators, whereas the Hausman test determines the optimum model, either random or fixed effects [78]. Relatedly, the Lagrange multiplier test (4538.61 at $p < 0.01$) and Hausman test (104.27 at $p < 0.01$), thereby, the FE model is the preferred choice over RE and OLS shown in Table 4. Notably, the F-test values (368.45 at $p < 0.01$) demonstrate that the investigation models are accurately tailored.

Moreover, the study model showed significant predictive power, with an R-squared value of 20.54%, demonstrating its ability to account for ecological innovation fluctuations. Hypothesis 1 (H1) foresees a positive connotation between female CEOs and EIS. Consistent with H1, the outcomes of the first regression model exposed a positive and significant coefficient of F_CEOs ($\beta = 0.0323$, $t = 1.92$) at the 10% significance level, confirming the positive link between female CEOs and EIS in energy companies. In contrast to ref. [51], this outcome suggests that women executives propel environmental innovation growth. These discoveries match up with the argument of gender socialization theory, suggesting that females are more inclined to "do well" and "go green" because of their upbringing [48, 79].

The results indicate that female CEOs are highly motivated to excel in eco-friendly innovation by bringing fresh and innovative ideas and practical solutions to challenging issues [41]. While [10, 13, 29] offer evidence in favor of this finding, ref. [5] failed to demonstrate it.

Females' maternal instincts [43] that drive them to preserve nature and practice eco-friendly stewardship could explain this finding. Women's eco-responsible behaviors and ecological sensitivity make their presence in top executive management, especially as CEOs, impactful on investments in environmental innovation [13, 33]. Additionally, women-led firms are more inclined to invest in eco-innovations to address stakeholder expectations better. These findings further support Social role theory, showing that females outperform males in caretaking roles, resulting in superior green care [12].

These results confirm the common belief that women are compassionate and nurturing [10]. Hence, female CEOs prioritize safeguarding all stakeholders, including the environment, from harm caused by business operations.

Table 4 Results of panel-data estimation (FE regression)

Variables	Model 1		Model 2	
	Coef.	t	Coef.	t
Constant	0.257	14.30*	0.703	4.97*
F_CEOs	0.0323	1.92***	0.0822	1.82***
BGC	0.479	5.071*	0.449	5.87*
F_CEOs* BGC	–	–	0.795	7.72*
CSR-Committee	0.0913	2.39**	0.596	3.30*
BM	0.331	4.22*	0.244	5.85*
BT	0.0363	2.13**	0.044	1.92***
ROA	0.0212	3.28*	0.0708	3.77*
LEV	− 0.0298	− 2.23**	− 0.0455	− 1.99**
AGE	− 0.0147	− 3.04*	− 0.0132	− 1.73***
SIZE	0.128	6.70*	0.0997	5.46*
Year dummies	Included		Included	
Country dummies	Included		Included	
F-Test	368.45*		238.42*	
R-squared	20.54%		22.96%	
Breusch & Pagan test for RE	4538.61*		5010.07*	
Hausman Test	104.27*		85.60*	
BP / Cook-Weisberg test	68.17*		36.03*	
Observations	2607		2607	
COMPANIES	237		237	

*P < 0.01
**P < 0.05
***P < 0.1

Furthermore, women naturally favor aesthetically pleasing activities, which is why female CEOs endorse eco-friendly initiatives. Promoting female leadership drives efforts to combat global warming through energy efficiency, green building, and climate change policies.

Concerning the control variables, we discovered that the Committee, BM, BT, and SIZE positively influenced EIS, suggesting that energy companies of greater magnitude, equipped with a CSR committee operating at the board level, allocate a larger proportion of their budget to ecological preservation and exhibit a greater propensity to embrace green initiatives [28]. Interestingly, the largest energy companies possess greater resources than smaller ones, incentivizing their participation in innovative endeavors. This aligns with arguments on resource dependence [49] and public visibility. The finding showed that energy companies with a board-level CSR committee promote EIS. In addition, profitable energy companies with diligent boards and longer tenures for their board members show more remarkable dedication to eco-friendly consciousness. Thus, directors adhere to stakeholder theory by prioritizing society, stakeholders' interests, and the environment [48].

On the other hand, financial leverage (LEV) and company age (AGE) significantly hinder EIS. EIS. The inverse relationship between AGE and EIS demonstrates that, as time progresses, institutional inertia intensifies, impeding corporate eco-friendly innovation [28]. Mature companies might innovate, excluding green matters, as they perceive such investments to be unrelated to boosting business performance [29]. Finally, high leverage in energy firms is strongly linked to a lack of EIS, while lower leverage is associated with higher levels of innovation.

4.3 Moderating variable—board gender composition (BGC)

Table 4 also displays the regression results for moderating factors in column (2), indicating that the Lagrange multiplier test (5010.07 at $p < 0.01$) and the Hausman test (85.60 at $p < 0.01$) both support the preference of the FE model over RE and OLS. Table 4 highlights a significant link between female CEOs and eco-friendly innovation in energy companies. The F-test values for the second model were 238.42. The sets of values were statistically significant ($p < 0.01$), implying

a good fit for the second model of moderating factors. Additionally, the moderator model's R-squared values of 22.96% demonstrate a substantial influence of the explanatory variables in explaining the observed changes in EIS.

H2 argues that the link between female CEOs and corporate EIS is contingent on female board members' presence. Model 2 is shown in Table 4, illustrating the interaction between female CEOs and BGC (F_CEOs* BGC). The positive coefficient values for F_CEOs and BGC in Table 4 show their positive impact on EIS in energy companies. Additionally, the statistical analysis has unveiled the significant influence of the interactive terms in determining EIS in the second model. As an illustration, when examining Model 2, the interaction figure exhibited a significantly positive moderating influence on EIS between BGC and F_CEOs ($\beta = 0.795$, $t = 7.72$) at a 1%. Interestingly, the interaction term has a noteworthy marginal effect on EIS, thus confirming H2.

The view held by scholars, including [6], is that modifying a board's composition affects the connection between top management and shareholders. To be precise, BGC exerts an ample and positive impact on promoting EIS. It is widely accepted among scholars, including [8], that feminine traits in top management and the board influence their decision-making to prioritize environmentally friendly options. This rationale aligns with the core argument of the upper-echelon theory, where the demographic characteristics of CEOs and the BGC are posited to impact their decision-making abilities significantly [45]. According to refs. [19, 29], female directors can have joint effects with female CEOs in shaping firms' decisions by endorsing and promoting investments in innovative initiatives. This argument also aligns with ref. [49] claim that women possess tremendous potential to drive green development. Consequently, including women on energy firms' boards supports female CEOs in making more informed investment choices and prioritizing ecological innovation.

This study's empirical evidence demonstrated that female directors had a crucial role in moderating the connection between female CEOs and EIS, aligning with the expectations outlined in the theoretical portion of this research. Increasing the Board Gender Composition (BGC) by one unit on average amplifies the influence of female CEOs (F_CEOs) on the Environmental Innovation Score (EIS). Hence, the complementary association between BGC and F_CEOs was confirmed through the synergistic effects of the interaction term. Additionally, our findings align with the theoretical perspectives of human capital and resource dependency, suggesting that including women in a company impacts its ability to innovate, including EIS [29, 47]. This relationship also aligns with gender socialization theory [10] in that businesses with a greater representation of women on their boards are more inclined to address external pressures related to eco-friendly concerns [48, 80]. Consequently, addressing external pressures leads to a stronger emphasis on eco-friendly innovation, which brings positive ecological change by introducing innovative and sustainable production methods [49, 70].

4.4 Endogeneity concern

Previous studies primarily relied on pooled OLS or fixed-effect models and neglected to tackle endogeneity concerns [46]. Many studies widely criticize the OLS model for its inability to estimate consistently the coefficient of a lagged dependent variable because of heterogeneity and its tendency to produce biases [44]. Omitted variable bias is also present in this case [30]. The fixed effect model can consider the variables that were not included and address the endogeneity problem to some extent [64, 69, 73]. The bias in our existing firms' fixed-effects results on the connection between female CEO and EIS may be due to endogeneity issues. In order to deal with this problem, we make use of alternative model specifications. The potential presence of reverse causality might have skewed our findings. Companies with low environmental performance, which can be enhanced through green initiatives, may consider appointing a female CEO as it is seen as a way to establish legitimacy. To clarify, the gender of the CEO is not the sole factor influencing the EIS; the reverse is also valid.

This paper employs the generalized method of moments (GMM) system to effectively rule out the possibility that endogeneity drives our main results when examining the connection between female CEOs and EIS. Addressing endogeneity has been a significant obstacle in previous studies [29, 48]. Among the approaches considered, the system-GMM estimator is the most favorable option because it can estimate the equation concurrently at both differences and levels [3]. Additionally, it addresses the issue of weak instrument problems commonly encountered in the instrumental variables approach [75]. To ensure the accuracy of our GMM estimations, we perform various standard tests. To begin, the test for AR (1) and AR (2) autocorrelation must be conducted [81]. According to the results in Table 5, all models reject the null hypothesis of no first-order [AR (1)] autocorrelation. The null hypothesis that there is no [AR (2)] second-order autocorrelation is supported. The tests conclude our models are unaffected by serial correlation and that the instruments used are appropriate. Additionally, we conduct the Hansen test to assess model over-identification [82-84]. According to Table 5 the null hypothesis of valid "exogenous" instruments remains unchallenged in the models, showing no correlation between the instruments and the residuals and that the models are accurately specified [85]. Moreover, as Table 5 states,

Table 5 Dynamic panel-data estimation: two-step system GMM regression

Variables	Model 1		Model 2	
	Coef.	t	Coef.	t
Constant	0.0695	3.70*	0.019	2.27**
EIS(t−1)	0.424	4.50*	0.651	4.20*
F_CEOs	0.0363	2.34**	0.0423	3.84*
BGC	0.425	3.06*	0.547	3.81*
F_CEOs* BGC	–	–	0.451	4.69*
CSR-Committee	0.0104	4.66*	0.0811	3.55*
BM	0.0363	4.0*	0.0547	3.81*
BT	0.179	1.815***	0.1331	3.98*
ROA	0.0459	3.26*	0.0956	3.6*
LEV	− 0.0597	− 3.06*	− 0.0372	− 2.16**
AGE-	− 0.0585	− 4.42*	− 0.0711	− 2.81*
SIZE	− 0.628	5.37*	0.449	4.72*
Year dummies	Included		Included	
Country dummies	Included		Included	
Hansen J. test	0.279†		0.385†	
AR (1)	0.007		0.009	
AR (2)	0.659		0.752	
Observations	2607		2607	
Company	237		237	
Instrument	89		93	

*P < 0.01

**P < 0.05

***P < 0.1

†P-insignificant. (Regression with robust standard errors)

the number of instruments must be kept below the number of groups [27, 30]. As depicted in Table 5, the β of lagged EIS [EIS (t−1)] was positive and significant at the 1% level. This means that the prior EIS values had essential influences on the contemporary EIS. The data in column (1, 2) of Table 5 show a positive and significant correlation between female CEOs and corporate EIS. Moreover, the statistical analysis showed that interaction terms were crucial in determining EIS. The signs in Table 5 are consistent with the coefficient cues' overall trend. Even after addressing the concern about endogeneity, our results remain unchanged.

4.5 Further analyses

This study conducts further analyses to validate our primary conclusions, following the approach of [21]. This study conducts sub-sample analyses to identify the channels through which female CEOs impact EIS. Profitability is the primary focus. Energy companies with higher profits can allocate more resources to environmentally friendly innovation. Since environmentalism is expensive and demands significant resources and long-term dedication, profitable energy companies may be better equipped to create and execute policies related to ecological innovation [7].

Some argue that highly profitable businesses may disregard environmentalism in favor of compiling wealth [86, 87]. In contrast, less profitable companies might aim to cut costs, optimize resource utilization, attract customers with eco-friendly policies, and prioritize ecological innovation [88, 89]. Levels of profitability may influence our baseline results. Thus, we divide our sample into high-profitability and low-profitability energy companies to assess the interaction between female CEOs and EIS links. The findings are displayed in Table 6. Supporting the previous viewpoint, a stronger association exists between female CEOs and EIS in more profitable energy companies. Additionally, when there is a higher proportion of female board members, the connection between female CEOs and EIS becomes more pronounced, especially in energy companies with greater profitability. The direction of the indications in Table 6 is consistent with the coefficient cues, showing a coherent pattern. Nevertheless, the strong and noteworthy correlation between the two groups emphasizes the importance of eco-innovation for all energy companies.

Table 6 Regression analysis based on sub-samples with high and low profitability

Variables	Model 1				Model 2			
	Low-profitability		High-profitability		Low-profitability		High-profitability	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	0.173	2.56**	0.098	2.59**	0.464	10.35*	0.097	12.3*
F_CEOs	0.0587	1.76***	0.0254	3.62*	0.0575	2.58*	0.155	3.73*
BGC	0.0812	3.56*	0.0104	4.67*	0.077	3.34*	0.271	4.74*
F_CEOs* BGC	–	–	–	–	0.012	2.29**	0.118	6.06*
CSR-Committee	0.0304	2.17***	0.0494	2.46**	0.0489	2.37*	0.271	4.74*
BM	0.045	1.78***	0.048	2.41**	0.073	2.64*	0.091	3.71*
BT	0.0451	2.48**	0.0481	2.31**	0.0475	3.37*	0.128	4.25*
ROA	0.0111	2.22***	0.0732	2.53**	0.0742	3.33*	0.055	4.00*
LEV	− 0.179	1.83***	− 0.133	3.97*	− 0. 304	2.47**	− 0.076	2.19**
AGE	− 0.0124	2.09**	− 0.015	2.96**	− 0.0719	3.02*	− 0.011	2.32**
SIZE	0.0818	5.07*	0.098	6.14*	0.0569	4.91*	0.149	5.86*
Year Dummies	Included				Included			
Country Dummies	Included				Included			
F-Test	58.54*				7.01*			
R-squared	13.67%				10.07%			
Observations	1540				1067			
COMPANIES	140				97			

*P < 0.01

**P < 0.05

***P < 0.1

4.6 Robustness checks

To assess the robustness of our findings, we perform a sensitivity check in this section. Building upon [13, 63] work, this study adopted an alternative indicator to assess environmental innovation. Relatedly, [13, 30, 49] employed ISO 14001 standards to gauge eco-innovation endeavors. Thus, this study assesses environmental innovation, assuming that the energy company has passed ISO 14001 certification; the value is 1; otherwise, it is 0. The sensitivity analysis results presented in Table 7 align with the earlier results reported in Table 4.

5 Conclusion

This study delves into the context between female CEOs and EIS in the global energy industry, considering the role of female board members as a moderating factor. By examining 2607 firm-year observations from the Eikon database (2012–2022), we determined that femininity is among the most critical factors motivating firms to prioritize eco-innovation. This discovery emphasizes the significance of female CEOs, along with other essential elements such as organizational culture, regulatory environment, and market pressures, all working together to boost green innovation. Therefore, a framework of relationships and catalysts must promote and facilitate eco-innovation within companies. The drivers of eco-innovation stem from the interplay of internal capabilities, governmental policies, and market dynamics. Moreover, our findings indicate that female CEOs in energy firms have a more significant impact on driving green innovation than male. The results suggest that a one-point increase in female CEOs corresponds to a 3.23% increase in the environmental innovation score in the same direction. Findings support the upper-echelon theory. The gender socialization theory also backs up these results, stating that females are inherently inclined toward eco-friendly endeavors. Additionally, the study highlights the crucial role of BGC in influencing female CEOs to prioritize eco-innovation. By merging two literature threads, this paper explored BGC's potential intervention in the nexus

Table 7 Robustness checks by using an alternative proxy for GI

Variables	Model 1		Model 2	
	ISO 14001			
	Coef.	t	Coef.	t
Constant	0.1271	9.31*	0.1246	8.67*
F_CEOs	0.0291	2.59*	0.0487	3.34*
BGC	0.0263	2.37**	0.0612	4.63*
F_CEOs* BGC	–	–	0.126	6.26*
CSR-Committee	0.0213	1.98**	0.184	2.64*
BM	0.066	4.20*	0.0821	4.93*
BT	0.122	4.16*	0.218	3.84*
ROA	0.405	2.94*	0.0525	2.0**
LEV	− 0.095	2.07**	− 0.0551	3.21*
AGE	− 0.014	2.8*	− 0.0177	3.49*
SIZE	0.124	4.28*	0.118	4.51*
Year dummies	Included		Included	
Country dummies	Included		Included	
F-test	121.74*		465.56*	
R-squared	13.26%		14.85%	
Observations	2607		2607	
COMPANIES	237		237	

*P < 0.01

**P < 0.05

***P < 0.1

between female CEOs and environmental innovation. They are likelier to promote eco-innovation in energy corporations with more female directors than in those with less. Additionally, our research enhances our comprehension of how the gender of top executives influences ecological innovation by examining the distinct moderating impact of WOCBs. These results provide evidence for the contingency perspective, which suggests that the impact of a female CEO on eco-friendly innovation depends on various factors, such as BGC. These findings lend credence to the gender socialization theory, indicating that companies with a higher representation of WOCBs are more inclined to address ecological concerns because of external pressures. Thus, our findings contribute to understanding the dynamics of BGC and its effect on female CEOs' responses to change by providing a broad picture of whether, how, and under what conditions gender equality influences environmental innovation.

5.1 The study implications

The study findings have important practical implications. First, it shows that BGC and female CEOs play a significant role in driving environmental innovation. Ensuring gender diversity at all levels of their management structure is an important goal that companies should consciously work towards. To support their eco-innovation strategy, they are actively working to recruit and advance women into both leadership positions. Second, our findings have social implications, highlighting the importance of hiring women in diverse managerial positions. This practice promotes an inclusive workplace culture that empowers women, encourages professional development, and challenges the glass ceiling phenomenon. This study also provides insights into the factors influencing the board of directors' choices to appoint female CEOs. Third, the results also emphasize the importance of policymakers promoting workplace gender equality and diversity. Governments can implement quotas requiring a certain percentage of women in leadership positions within companies. Regulatory bodies can enforce the enabling approach to prioritize gender diversity, which usually involves companies following guidelines or giving reasons for not complying. In addition, governments can provide tax incentives to companies to prioritize gender diversity in leadership roles or grants supporting eco-innovation led by diverse teams, enabling women to access high-level positions. Moreover, customers and civil society organizations can apply normative pressure on firms to encourage the adoption of environmental innovation procedures.

5.2 Limitations and future suggestions

Despite the valuable contribution of this study to the literature, it is crucial to recognize its limitations. First, this study solely concentrated on the global energy sector, which may have many limitations. By focusing all our attention on the energy sector with strict regulations that are subject to the energy market this study found favorable results regarding environmental innovation [1]. However, as we advance, researchers must dedicate their attention to diverse industries across international borders to acquire further insights and effectively compare the findings to raise the generalizability of study conclusions. Thus, the generalizability of study findings to other industries is limited because of industry-specific factors in the energy sector that differ vigorously from different industries.

Second, the scope of this investigation was limited to analyzing the level of gender diversity among high-ranking executives and their representation on corporate boards. Therefore, there is still a significant amount of work to be done to explore further how the personal characteristics of female CEOs, such as their age, experience, level of education, and qualifications, impact eco-innovation. Third, both internal and external factors play a role in shaping energy sector decisions related to environmental innovation. Future expansion on studying regional eco-friendly policies or other governance mechanisms, such as board size and board independence, to examine how they affect ecological innovation would be interesting. Forth, variables from the Thomson Reuters database are employed as proxies for EIS. While the Thomson Reuters database is a trusted source for the companies' environmental innovation, patent applications can be a valuable alternative to EIS. Standard certifications in environmental management can serve as a reliable indicator of environmental innovation in this context. In addition, patent applications could be employed in future research to reinforce the earlier findings. Fifth, investigation may be necessary to explore any potential missing confounding variables in our analysis. Factors such as economic conditions, regulatory changes, or technological advancements may influence energy companies' operations and GHG emissions. Addressing these issues in future studies would increase the validity of our findings. Finally, further investigation is needed to explore additional contextual factors, like firm size and capital structure, for a more comprehensive understanding of the relationship between female CEOs and environmentally friendly innovation. Notwithstanding these limitations, our results can be considered robust and reliable because of the unique multi-dimensional panel dataset and the GMM approach. Our data is well-suited for the fixed-effects and GMM approach, guaranteeing that all fundamental assumptions for our regression model are fulfilled. We have also conducted rigorous checks to ensure the reliability of our findings and implications.

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Data availability Data will be made available if required.

Declarations

Competing interests The authors declare no competing interests.

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