



The Governance Edge: Unlocking Renewable Energy Potential Through Board Leadership

Mujtaba Momin, Ariz Naqvi, Suzan Dsouza*

College of Business Administration, American University of the Middle East, Kuwait. *Email: suzan.dsouza@aum.edu.kw

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ABSTRACT

The present study triangulates board gender diversity and board expertise with the use of renewable energy sources. The study reveals the association between these three variables, under the regimentation of control variables. The investigation, using a final dataset of 1892 firms from the European Union, deciphers their association to be influential in renewable energy use, to the extent of a statistically significant relationship. The decadal dataset between 2013 and 2023, sourced from the Refinitiv (Datastream) database, is processed using the STATA software package. The study magnifies the positive influence that board gender diversity has on renewable energy adoption, indicating that a higher proportion of female directors contributes to improved environmental performance and strategic commitment to sustainable energy practices. Simultaneously, board-specific skills are examined to assess their contingent effect on renewable energy investments. Findings suggest that while gender-diverse boards stimulate innovation and sustainability initiatives, an overemphasis on conventional expertise may foster a risk-averse approach, limiting renewable energy projects. This study is one of the few investigations contributing to the literature in this area, paving the way for future research to explore the interplay between corporate governance, board composition, and the transition toward a low-carbon economy, thus enhancing long-term sustainable global development.

Keywords: Board Gender Diversity, Board Expertise, Renewable Energy Use, Corporate Governance, European Union

JEL Classifications: G30, G34, G39

1. INTRODUCTION

The importance of board gender diversity has been increasingly recognized for its multifaceted impact on organizational strategy, performance, and sustainability. While considerable attention has been paid to various dimensions of board diversity, an area that remains largely unexplored is its influence on the adoption of renewable energy sources. Despite its critical importance in addressing climate change and fostering sustainability, the relationship between board composition and renewable energy integration is a research avenue that has scarcely been investigated. Although some recent studies have begun to explore related themes (Almaqtari, et al., 2024; Mohy-ud-Din et al., 2025; Uyar et al., 2024), these efforts have primarily focused on broader environmental measures rather than delving specifically into

renewable energy practices. This gap in literature underscores the need for a deeper exploration of this important nexus.

Existing research has established the significance of board diversity, particularly gender diversity, in influencing strategic and sustainable organizational decisions (Bel-Oms et al., 2024). Gender diversity has been linked to improved organizational performance (Almaqtari, et al., 2024; Fouad et al., 2023) and enhanced Environmental, Social, and Governance (ESG) performance (Almaqtari, et al., 2024; Arayssi et al., 2016; Kampooale et al., 2024; Mehmood et al., 2023; Shakil et al., 2021). However, while these studies hint at an increased environmental consciousness, they seldom address the specific adoption and integration of renewable energy sources within organizations. Recent shifts in organizational performance metrics emphasize climate action

and carbon footprint reduction, making the interplay between board composition and renewable energy use pivotal. Research suggests that gender-diverse boards drive decision-making toward environmental sustainability (Mehmood et al., 2023; Shakil et al., 2021), including reducing emissions (World Economic Forum, 2022), enhancing corporate governance (Issa and Hanaysha, 2023), and fostering societal trust (Joshi and Diekmann, 2022). Notably, women in leadership roles appear to demonstrate a higher propensity for prioritizing environmental sustainability in organizational decisions (Cordeiro et al., 2020). Despite this promising evidence, the specific contribution of gender-diverse boards to renewable energy adoption remains underexplored.

This study addresses this critical research gap by examining the relationship between gender diversity and board skills in influencing the adoption of renewable energy sources within organizations. In particular, it sheds light on how the inclusion of women on boards can shape organizational commitment to renewable energy practices. Evidence suggests that gender-diverse boards are not only more inclined toward environment-conscious decisions but also foster long-term strategic value through the integration of renewable energy (Cordeiro et al., 2020; Shakil et al., 2021). Moreover, board members' functional expertise and diverse skill sets further enhance their ability to influence sustainable practices (Almaqtari et al., 2024; Ankrah Twumasi et al., 2022). Yet, empirical research on these dynamics remains scarce. By investigating the interplay between gender diversity, board-specific skills, and renewable energy adoption, this study aims to contribute to a deeper understanding of corporate governance practices that support the transition to a low-carbon economy. Ultimately, this research seeks to inform strategies that enable organizations and nations to align more effectively with global sustainability goals.

2. LITERATURE REVIEW

The rapid global push toward sustainable development and carbon neutrality has brought renewable energy adoption to the forefront of corporate strategy, particularly within the European Union (EU) (Gajdzik et al., 2024; Filipović et al., 2022). With the EU setting some of the world's most ambitious environmental targets and regulatory standards, firms are under increasing pressure to transition from conventional energy sources to renewable alternatives (Gawusu et al., 2022; Kabeyi and Olanrewaju, 2022). Although a substantial body of literature has examined the broad relationship between corporate governance and overall sustainability performance, less attention has been paid to the specific influence of board-level characteristics on renewable energy use. In this context, recent research has begun to focus on how two critical dimensions of board composition, board gender diversity (BGD) and board-specific skills (BSS) can shape a firm's commitment to renewable energy.

While earlier studies have shown that diverse boards improve overall sustainability performance by enhancing decision-making, oversight, and stakeholder responsiveness (Cordeiro et al., 2020; Joshi and Diekmann, 2022), there is a notable gap in the literature regarding the direct link between board attributes and the specific strategic investment in renewable energy. This gap is particularly

evident in the EU context, where robust regulatory frameworks, high stakeholder expectations, and strong governmental incentives create a unique setting for examining the interplay between board composition and renewable energy initiatives (Jain et al., 2022; Taneja and Ozen, 2023). The present literature review synthesizes the extant research on board gender diversity and board-specific skills, integrating firm-level factors and the EU regulatory environment, and formulates hypotheses aimed at explaining how these governance attributes drive renewable energy adoption.

2.1. Effects of Board Gender Diversity on Renewable Energy Use

Board gender diversity has emerged as one of the most widely studied aspects of corporate governance. Theoretically, gender diversity enriches board deliberations by introducing varied perspectives, experiences, and value systems (Issa et al., 2024). Agency theory posits that a heterogeneous board is better positioned to monitor managerial behavior, thereby reducing conflicts of interest and mitigating managerial entrenchment (Yahaya, 2024; Boussenna and Kimouche, 2024). At the same time, stakeholder theory suggests that boards comprising directors with diverse backgrounds are more likely to consider the full spectrum of stakeholder interests, including environmental and social concerns (Cordeiro et al., 2020). In the context of renewable energy, this broader outlook is particularly valuable. Female directors, for instance, are often associated with a long-term strategic orientation, greater ethical sensitivity, and a heightened awareness of environmental risks, all qualities that are crucial for driving investments in renewable energy projects (Cosma et al., 2021; Ramon-Llorens et al., 2021; Saeed et al., 2022).

Empirical evidence supports the view that increased gender diversity on corporate boards is linked with improved sustainability outcomes. Numerous studies have found that firms with a higher percentage of female directors tend to adopt environmental policies that promote renewable energy use, invest in clean technologies, and commit to long-term environmental performance (Joshi and Diekmann, 2022; Fouad et al., 2023; Atif et al., 2021; Issa, 2023). The distinct socialization and risk perception patterns that many female directors exhibit can result in more rigorous evaluations of capital investments and a stronger commitment to renewable energy initiatives (Wiersema and Mors, 2024; Arun and Yildirim Özmütlu, 2023). Furthermore, gender-diverse boards can serve as a signal to investors and regulators that a firm is committed to progressive and responsible governance practices, a signal that is particularly potent in the EU, where transparency and accountability are heavily scrutinized (Issa and Hanaysha, 2023; World Economic Forum, 2022).

Recent studies focusing on environmental and sustainability performance have provided robust evidence in support of the positive impact of board gender diversity. For example, research indicates that firms with greater gender diversity not only exhibit higher environmental performance metrics but also tend to have more proactive policies related to renewable energy investments (Cordeiro et al., 2020). Moreover, in industries characterized by rapid technological change and increasing regulatory pressures, such as those prevalent in the EU, gender-diverse boards are likely

to be at the forefront of adopting innovative energy solutions (Issa and Zaid, 2023; García-Sánchez et al., 2025). However, the literature also cautions that simply increasing the number of female directors on a board does not automatically guarantee improved renewable energy outcomes. Several studies highlight that the mere presence of women is insufficient if they lack the requisite decision-making authority or if their contributions are diluted within a predominantly male board structure (Arayssi et al., 2016; Sierra-Morán et al., 2024; Zahid et al., 2025; Arora and Aliani, 2024). In such cases, the potential benefits of gender diversity may not be fully realized. Thus, while the preponderance of empirical evidence supports a positive link between board gender diversity and environmental initiatives, the extent of this influence is moderated by factors such as board dynamics, director empowerment, and industry-specific conditions (Nicolò et al., 2022; Kuzey et al., 2022).

Drawing on the findings, the literature suggests that a higher proportion of female directors can enhance a firm's long-term strategic focus and commitment to renewable energy. This is particularly relevant in the EU, where the interplay of strict environmental regulations and competitive market pressures necessitates innovative approaches to sustainability. Consequently, the first hypothesis is formulated as follows:

- Hypothesis 1 (H_1): There is a significant positive relationship between board gender diversity and renewable energy use.

2.2. Effects of Board-Specific Skills on Renewable Energy Use

Beyond demographic composition, the functional expertise of board members, also referred to as board-specific skills (BSS), is a critical determinant of effective corporate governance (John & Senbet, 1998). Board-specific skills encompass the specialized knowledge and experience that directors bring to the boardroom, including expertise in finance, industry operations, technology, and regulatory compliance (Agnese et al., 2024; Mousa et al., 2023; Orazalin and Mahmood, 2021). According to the resource-based view of the firm, such competencies are considered valuable assets that enable boards to evaluate complex investment opportunities more effectively (Beamish and Chakravarty, 2021; Roffia et al., 2022; Jyoti and Efraxia, 2023). In the realm of renewable energy, the ability to assess technological feasibility, navigate regulatory complexities, and manage long-term capital investments is indispensable.

Theoretical frameworks suggest that boards with a higher concentration of directors possessing relevant skills are better equipped to identify and exploit opportunities in the renewable energy sector (Yousaf et al., 2022; Mehedi et al., 2024; Karim et al., 2023). Such directors can provide critical insights into the financial and technical aspects of renewable energy projects, thereby facilitating more informed decision-making and risk assessment (Settembre-Blundo et al., 2021). In turn, this can lead to a higher propensity for the firm to invest in and adopt renewable energy technologies.

Empirical research on board-specific skills offers a more nuanced picture than that of gender diversity. On one hand, studies have

found that boards rich in technical and financial expertise are more likely to support investments in innovative technologies, including renewable energy solutions (Ankrah Twumasi et al., 2022). This is because directors with specialized skills can effectively analyze the potential returns and risks associated with such projects, leading to more sound and strategic investment decisions (Jiskani et al., 2022; Fu et al., 2023). Conversely, there is evidence that an overemphasis on traditional expertise, particularly in financial management or legacy industry practices may result in a conservative approach that stifles innovation (Settembre-Blundo et al., 2021). Boards dominated by directors with conventional skill sets may prioritize short-term financial performance over long-term strategic investments, including those in renewable energy. Such risk-averse behavior can act as a barrier to the adoption of transformative renewable energy initiatives (Arayssi et al., 2016; Mohy-ud-Din et al., 2025). Moreover, the benefits of board-specific skills in promoting renewable energy use appear to be contingent on the alignment of the board's expertise with the evolving challenges of a low-carbon economy (Settembre-Blundo et al., 2021; Fu et al., 2023). When directors possess skills that are directly related to sustainable technologies, environmental management, or energy policy, their impact on renewable energy adoption is more pronounced (Settembre-Blundo et al., 2021).

Given the dual-edged nature of board-specific skills, the literature indicates that the influence of these skills on renewable energy use is complex and context-dependent. In the EU, where the pace of technological innovation and regulatory change is rapid, the strategic value of relevant board expertise is particularly significant. When board members' skills align with the technical and strategic demands of renewable energy projects, a positive relationship is likely to emerge. Conversely, if traditional expertise dominates, the board may adopt a more cautious stance, potentially reducing the likelihood of investing in renewable energy. Based on these considerations, the following hypothesis is proposed:

- Hypothesis 2 (H_2): There is a significant relationship between board-specific skill percentage and renewable energy use, with the effect contingent on the relevance of the expertise to sustainable energy projects.

2.3. The EU Regulatory Environment and Industry Dynamics in Renewable Energy Adoption

The European Union represents a unique and dynamic setting for the study of renewable energy adoption. EU policymakers have implemented some of the world's most rigorous environmental regulations, including the European Green Deal and various directives aimed at reducing carbon emissions and promoting renewable energy sources (Skjærseth, 2021; Hainsch et al., 2022). These initiatives not only establish stringent performance benchmarks but also create a competitive market environment in which firms are compelled to innovate. Within this framework, corporate governance plays a pivotal role in shaping how firms respond to these external pressures.

In the EU, the interplay between regulatory mandates and market dynamics has significant implications for renewable energy investments. Firms operating in this environment must balance compliance with strict environmental standards against the need

to remain competitive in an increasingly green economy (Gajdzik et al., 2024; Rastegar et al., 2024; Xinyu et al., 2024). As a result, the composition of the board, particularly the presence of diverse and skilled directors can critically influence strategic decision-making. A gender-diverse board, for example, is more likely to be attuned to stakeholder concerns and regulatory expectations, thereby fostering an organizational culture that supports renewable energy initiatives (Abd Majid and Jaaffar, 2023; García-Sánchez et al., 2025; Adnan et al., 2025; Almaqtari et al., 2024). Similarly, a board with a strong mix of specialized skills is better equipped to interpret and act upon the complex technical and regulatory signals prevalent in the EU market (Almada and Petit, 2025).

Beyond the regulatory landscape, industry dynamics also shape the adoption of renewable energy (Gawusu et al., 2022). Different sectors face varying degrees of exposure to environmental risks and opportunities. For instance, firms in energy-intensive industries such as manufacturing or utilities may experience stronger incentives to transition to renewable energy, given the potential for cost savings and improved energy efficiency (Liu et al., 2023; Zhang & Lin, 2024; Nurdawati & Urban, 2021). Conversely, firms in less energy-intensive sectors might be less compelled to make substantial investments in renewable technologies unless driven by strategic or reputational factors (Hartmann et al., 2021; Gavkalova et al., 2024; Geels, 2022).

Firm-specific factors, including liquidity, firm size, asset tangibility, and leverage, further condition the relationship between board characteristics and renewable energy use. These factors determine a firm's financial capacity and operational flexibility to invest in renewable energy projects (Saha and Khan, 2024; Zaman et al., 2024; Kreuzer and Priberny, 2022). In the context of the EU, where market volatility and regulatory shifts are common, the ability to mobilize internal resources for long-term investments is crucial. Although the focus of this review is on board characteristics, it is important to recognize that the effect of board gender diversity and board-specific skills on renewable energy adoption is moderated by these underlying firm-level variables (Ahmed et al., 2024; Peng et al., 2025; Rehman et al., 2024). In particular, larger firms with more diversified assets and robust financial health are likely to exhibit a stronger response to the strategic signals conveyed by a diverse and skilled board.

The distinctive characteristics of the EU environment underscore the need for research that integrates board-level attributes with an understanding of external regulatory pressures and industry dynamics. In this setting, the positive effects of board gender diversity and the context-dependent influence of board-specific skills on renewable energy use are expected to be more pronounced (Atif et al., 2021; Issa, 2023). The EU regulatory framework, with its strong emphasis on sustainability and innovation, not only reinforces the strategic importance of these governance attributes but also amplifies their impact on firm-level renewable energy outcomes. Taken together, the EU context provides a fertile ground for examining how board characteristics interact with external pressures to drive renewable energy adoption. This synthesis of internal governance mechanisms and external environmental factors leads to a more comprehensive understanding of the

strategic determinants of renewable energy use, a crucial step in addressing the existing research gap.

The literature demonstrates that while considerable research has established a link between board diversity, board-specific skills, and overall sustainability performance, a significant gap remains in understanding how these board attributes specifically influence renewable energy use in the European Union (Orazalin and Mahmood, 2021; Akhter et al., 2023; Khalid et al., 2025; Gull et al., 2023). The extant studies provide compelling evidence that gender-diverse boards can enhance corporate sustainability by promoting ethical decision-making, long-term strategic planning, and effective risk management (Amorelli and García-Sánchez, 2021; Issa and Bensalem, 2023; Wu et al., 2022). Similarly, board-specific skills are recognized as critical for evaluating the feasibility of complex renewable energy projects; however, the literature also reveals that an overreliance on traditional expertise may lead to risk aversion and hinder innovation (Zhang et al., 2024; Mehedi et al., 2024; Al Frijat et al., 2024). The unique regulatory environment and industry dynamics of the EU further complicate this relationship. EU firms operate under rigorous environmental regulations and face intense market competition, which magnifies the strategic importance of aligning board composition with sustainability objectives. In this setting, a gender-diverse board not only signals a commitment to responsible governance but also enhances stakeholder trust and facilitates access to renewable energy incentives (Jizi et al., 2022; Seebeck and Vetter, 2022; Bel-Oms et al., 2025). Meanwhile, the effective deployment of board-specific skills can help firms navigate the technological and regulatory complexities associated with renewable energy adoption, provided that these skills are relevant to the emerging demands of a low-carbon economy (Saeed et al., 2023; Arora and Singh, 2023).

In light of these insights, the current study formulates two central hypotheses aimed at bridging the research gap. First, it is posited that there is a significant positive relationship between board gender diversity and renewable energy use (H_1). This hypothesis rests on the premise that a higher proportion of female directors enhances board deliberations, mitigates short-termism, and fosters a strategic focus on sustainable investments. Second, the study hypothesizes that board-specific skills significantly affect renewable energy use (H_2), with the effect being contingent on the alignment of the board's expertise with the technical and strategic requirements of renewable energy projects. Together, these hypotheses seek to disentangle the nuanced ways in which board characteristics drive renewable energy adoption in EU firms while accounting for the moderating influence of the region's distinctive regulatory and market environment.

Ultimately, by directly linking board attributes to renewable energy use, rather than merely examining broader environmental performance indicators, this research addresses a critical gap in the literature. It provides a more granular understanding of how corporate governance can serve as a catalyst for sustainable energy transitions in the EU. The insights derived from this investigation are expected to have important implications for both academic research and corporate practice, offering guidance for

policymakers and business leaders committed to advancing the low-carbon agenda in one of the world's most environmentally progressive regions.

3. RESEARCH DESIGN

3.1. Sample Selection and Data Collection

This study explores the connection between Corporate Governance and Renewable Energy Use using a dataset that includes only firm-year observations with complete financial information for key variables. The resulting unbalanced panel comprises 1,892 observations from 416 companies operating within the European Union between 2013 and 2023. To mitigate the effect of extreme values, selected variables were winsorized at the 5% level instead of eliminating outliers. Data processing and analysis were carried out using the STATA software package, and the dataset was sourced from Refinitiv (Datastream), a highly regarded provider of financial and economic data. The sample selection procedure, including a detailed breakdown by industry sectors, is comprehensively presented in Table 1 and illustrated in Figure 1.

3.2. Variables

This study constructs a comprehensive framework to explore the connection between corporate governance and renewable energy usage. It meticulously defines and operationalizes the primary variables, ensuring that each is measured with clarity and precision. By clearly specifying these metrics, the research establishes a robust basis for empirical analysis, which in turn facilitates a precise evaluation of how corporate governance practices relate to renewable energy adoption.

3.2.1. Dependent variable

The dependent variable, Renewable Energy Use, is quantified through the Renewable Energy Use Ratio Score. This score represents the proportion of a company's total energy consumption that is derived from renewable sources, providing a clear and measurable indicator of sustainable energy adoption. Its importance lies in its ability to capture how effectively corporate governance practices promote environmentally responsible energy choices. By using this ratio, the study can rigorously assess the impact of governance on renewable energy strategies, offering valuable insights into how corporate decisions may drive broader environmental benefits and support the transition toward a sustainable energy future.

3.2.2. Independent variable

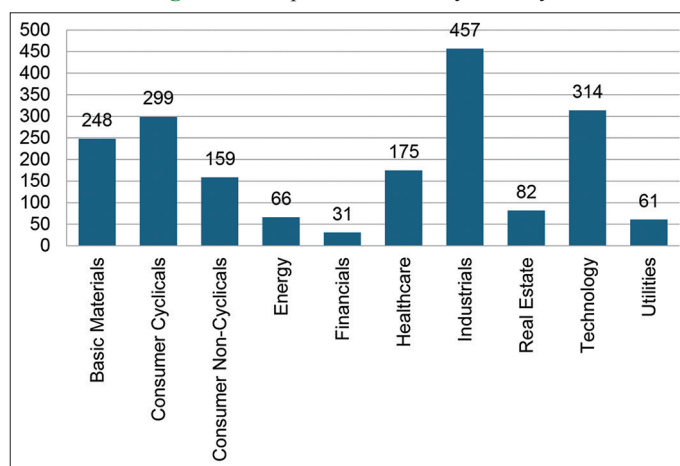
The independent variable in this study is corporate governance, which is captured through two key proxies: board gender diversity and board-specific skills. Board gender diversity is measured by the percentage of female members on the board, reflecting the inclusiveness and diverse perspectives that can influence decision-making processes. Meanwhile, board-specific skills are assessed by the percentage of board members with industry-specific or robust financial expertise, serving as an indicator of the board's capacity to guide strategic and informed decisions. Together, these measures provide a comprehensive view of corporate governance, underscoring its pivotal role in shaping effective policies and practices that can drive positive outcomes, such as enhanced

Table 1: Sample distribution by industry

Industry	Total observations
Basic materials	248
Consumer Cyclical	299
Consumer Non-Cyclical	159
Energy	66
Financials	31
Healthcare	175
Industrials	457
Real Estate	82
Technology	314
Utilities	61
Total	1892

This table provides the distributional properties of the full sample by industry. Observations are the total of the firm-years observations

Figure 1: Sample distribution by industry



renewable energy adoption.

3.2.3. Control variables

To bolster the reliability of the analysis, the study incorporates several control variables that may influence the relationship between board gender diversity and workforce score. These controls include Liquidity (Liq), Firm Size (FS), Tangibility (Tang), Leverage (L), and Sustainability Compensation Incentives (SCI). By accounting for these firm-specific factors, the research seeks to isolate the impact of corporate governance on renewable energy usage. Additionally, Table 2 provides a comprehensive overview of all variables along with their respective measurement criteria.

3.3. Regression Model

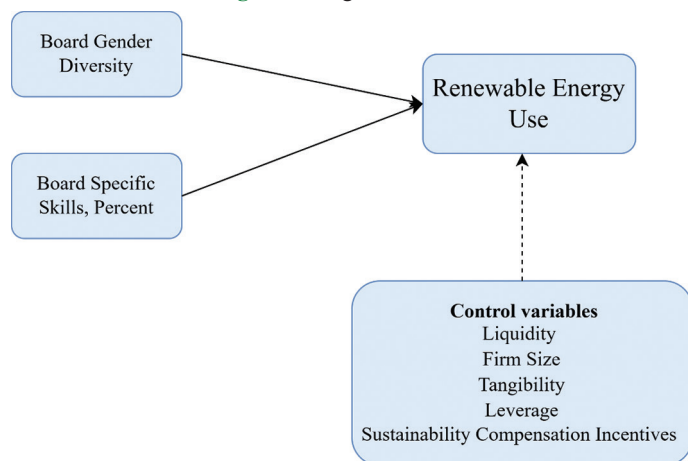
To assess the effects of Board Gender Diversity and Board Specific Skills, percentage on Renewable Energy Use, this study utilizes a regression analysis model (Figure 2) as the primary statistical method for estimating the proposed framework. The regression equations provided delineate the analytical models employed, with all variables listed in Table 2. Additionally, fixed effects for year and country are included to account for potential contextual variations.

$$RE_{i,t} = \beta_0 + \beta_1 RE_{i,t-1} + \beta_2 BGD_{i,t} + \beta_3 BSS_{i,t} + \beta_4 Liq_{i,t} + \beta_5 FS_{i,t} + \beta_6 Tang_{i,t} + \beta_7 L_{i,t} + \beta_8 SCI_{i,t} + \text{Fixed effects}_{i,t} + \epsilon_{1i,t}$$

Table 2: Descriptions of variables

Dependent variables			
Variable	Abbreviation	Measurement	Source
Renewable Energy Use	RE	Renewable Energy Use Ratio Score	Refinitiv (Datastream)
Independent variable			
Variable	Abbreviation	Measurement	Source
Board Gender Diversity	BGD	Percentage of females on the board.	Refinitiv (Datastream)
Board Specific Skills, Percent	BSS	Percentage of board members with industry-specific or strong financial expertise.	Refinitiv (Datastream)
Control variables			
Variable	Abbreviation	Measurement	Source
Liquidity	Liq	(Current asset – current liabilities)/total assets	Refinitiv (Datastream)
Firm Size	FS	The natural log of total assets of a firm.	Refinitiv (Datastream)
Tangibility	Tang	(The ratio of tangible assets to total assets)	Refinitiv (Datastream)
Leverage	L	The ratio of total debt to total assets.	Refinitiv (Datastream)
Sustainability Compensation Incentives	SCI	Senior executive's compensation linked to CSR/H&S/Sustainability	Refinitiv (Datastream)

This table provides a summary of the chosen variables, including their calculation methods and sources

Figure 2: Regression model

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics

Table 3, presents a comprehensive set of descriptive statistics for a sample of 1,892 firm-year observations spanning 2013–2023, focusing on renewable energy use and various board characteristics alongside key control variables. In Panel A, RE has a mean value of 57.67 and a median of 60.71, with a notable range from 10.00 to 94.14. This spread indicates considerable variability in renewable energy engagement across the firms, suggesting different levels of commitment or capacity in adopting renewable practices. Panel B details the independent variables related to board composition. BGD shows an average of 33.21, with a standard deviation of 11.84 and a range that spans from complete absence (0.00) to a maximum of 66.67, hinting at a moderate but uneven gender representation across boards. Similarly, BSS has a mean of 32.09 with a larger standard deviation of 18.80, underscoring diverse levels of expertise within boards, as values vary from 0 to 100. Panel C introduces control variables like Liq, FS, Tang, L, and a binary SCI, which averages at 0.52. Collectively, these statistics provide details of the dataset, illustrating both the central tendencies and variability across key dimensions that inform further analysis of board influence on renewable energy practices.

4.2. Kernel Density Estimate

The kernel density estimation reveals distinct distribution patterns across the variables in Figure 3. For RE, the distribution is slightly bimodal with a dominant peak around 80 and a secondary one around 20, with most observations clustering in the 70–90 range. BGD exhibits a main concentration between roughly 20 and 45, with a prominent peak at 30 and a secondary bump at 40, while density falls off beyond 50. Similarly, BSS shows clustering between 20 and 50 with a noticeable peak in the 30–40 range, and values beyond 50 become progressively sparse. The Liq variable presents a unimodal distribution sharply centered around 0, tapering off towards both tails, indicating limited variability. FS is concentrated between about 20 and 24, peaking at 22 with fewer observations at the extremes. In the case of Tang, the observations are mostly between 0.2 and 0.8, with the highest density around 0.6–0.7 and declining density at the tails. Variable L is characterized by a heavy concentration around 0, evidenced by a sharp density spike, though a few outliers appear on either side. Finally, the SCI distribution shows a pronounced U-shape with high densities at both 0 and 1 and minimal density near 0.5, suggesting that observations are primarily at the extremes. Overall, the dataset displays a variety of distribution shapes from unimodal to bimodal and U-shaped highlighting the importance of selecting appropriate analytical approaches tailored to each variable's characteristics.

4.3. Correlation Matrix and VIF Values

Table 4 presents both the correlation coefficients among the study's variables and their Variance Inflation Factor (VIF) values to assess potential multicollinearity. The dependent variable RE, shows modest yet statistically significant relationships with several predictors. For instance, BGD is positively correlated with RE (0.062, $P < 0.01$), suggesting that firms with more gender-diverse boards may lean towards higher renewable energy usage. Although BSS exhibits a negligible negative correlation with RE (−0.02), the relationship is not statistically significant, indicating that board expertise might have a limited direct association with renewable energy use in this dataset. Control variables reveal additional insights: Liq is negatively correlated with RE (−0.063, $P < 0.01$) and FS (firm size) is negatively related to RE (−0.077, $P < 0.01$),

Table 3: Descriptive statistics

	Observations	Mean	Standard deviation	Median	Min.	Max.
Panel A: Dependent variables						
RE	1892	57.67	25.23	60.71	10.00	94.14
Panel B: Independent variable						
BGD	1892	33.21	11.84	33.33	0.00	66.67
BSS	1892	32.09	18.80	31.58	0.00	100.00
Panel C: Control variables						
Liq	1892	0.09	0.15	0.08	-0.48	0.81
FS	1892	22.76	1.41	22.68	17.93	26.42
Tang	1892	0.62	0.18	0.64	0.05	1.00
L	1892	1.14	2.17	0.76	-24.74	35.97
SCI	1892	0.52	0.50	1.00	0.00	1.00

This table presents descriptive statistics for the variables used in this study. The dependent variables in Panel A include Renewable Energy Use (RE). The independent variables are Board Size (BS), Board Gender Diversity (BGD), CEO Chairman Duality (CCC), and Board Specific Skills, Percent (BSS). Panel C consists of a comprehensive set of control variables. The sample consists of firm-year 1,892 observations from 2013–2023

Table 4: Correlation matrix and VIF values

Variables	RE	BGD	BSS	Liq	FS	Tang	L	SCI	VIF
RE	1								
BGD	0.062***	1							1.07
BSS	-0.02	0.023	1						1.01
Liq	-0.063***	-0.058**	0.089***	1					1.74
FS	-0.077***	0.100***	-0.057**	-0.336***	1				1.17
Tang	0.033	-0.009	-0.056**	-0.596***	0.289***	1			1.59
L	0.023	-0.002	-0.009	-0.244***	0.070***	0.087***	1		1.07
SCI	0.045**	0.243***	0.033	-0.066***	0.158***	0.021	-0.007	1	1.09

***P<0.01, **P<0.05, *P<0.1. This table represents the correlation matrix and VIF values

implying that firms with better liquidity or larger size tend to use less renewable energy. Notably, Tang is strongly negatively correlated with liquidity (-0.596, $P < 0.01$) but shows a positive link with firm size (0.289, $P < 0.01$). Additionally, the SCI exhibits significant positive correlations with BGD (0.243, $P < 0.01$) and FS (0.158, $P < 0.01$), reinforcing its relevance. Importantly, all VIF values are close to 1, indicating low multicollinearity and confirming that the independent variables offer distinct and reliable information for further analysis.

4.4. Regression-Analyses

Table 5 provides regression results using both OLS (Column 1) and GMM (Column 2) methodologies to assess the impact of board characteristics on Renewable Energy Use (RE) over 2013–2023. In both models, the lag of RE is highly significant, underscoring persistence in renewable energy practices over time. Notably, in the more robust GMM specification which accounts for potential endogeneity and includes year and country fixed effects. BGD shows a positive and statistically significant effect (coefficient = 0.0989, significant at the 5% level). This implies that an increase in gender diversity on corporate boards is associated with higher levels of renewable energy use. In contrast, BSS exhibits a negative impact on RE (coefficient = -0.0446, significant at the 10% level), suggesting that a greater proportion of board members with specific skills may, paradoxically, correlate with lower renewable energy adoption, potentially reflecting a more risk-averse or traditional strategic outlook among skilled boards. From a corporate perspective, these findings have important implications. The significant positive association between board gender diversity and renewable energy use suggests that companies could benefit from enhancing diversity on their boards, as diverse perspectives

Table 5: Impact of BGD and BSS on RE: Regression results

Variables	(1)	(2)
	RE	RE
Lag of RE	0.841*** (0.01)	0.760*** (0.07)
BGD	0.108*** (0.04)	0.0989** (0.05)
BSS	-0.03 (0.02)	-0.0446* (0.02)
Liq	-3.18 (3.15)	-4.93 (3.73)
FS	-0.223 (0.27)	-0.438 (0.32)
Tang	-0.625 (2.34)	-0.246 (2.88)
L	-0.035 (0.17)	0.0822 (0.11)
SCI	-0.852 (0.74)	-0.593 (1.06)
Controls (Year dummies)	Yes	Yes
Controls (Country dummies)	Yes	Yes
Constant	10.31 (6.69)	24.83*** (9.51)
Observations	1404	1404
R-squared	0.77	-
AR1 P-value	-	0.0000
AR2 P-value	-	0.7440
Hansen P-value	-	0.1520
Sargan P-value	-	0.0920

The standard errors are reported in parentheses. ***, **, *Denote significance at the 1%, 5% and 10% level, respectively. This table reports the OLS and GMM regression results for model. The relationship between Renewable Energy Use (RE), and Corporate Governance proxied by Board Gender Diversity (BGD) and Board Specific Skills, Percent (BSS) as well as other control variables is analysed from 2013-2023. Columns 1 and 2 present the OLS and GMM results after controlling for the year and country fixed effect to capture heterogeneity

may drive innovation and progressive sustainability strategies. The robust GMM results, supported by acceptable diagnostic tests (AR2, Hansen, and Sargan P-values), reinforce the reliability of these findings. Consequently, firms aiming to strengthen their sustainability performance and corporate reputation might consider revising their board composition policies to foster greater gender diversity, while also critically assessing the strategic impact of board-specific skills on their sustainability initiatives.

Table 6 extends the discussion of Table 5 by breaking down the impact of board characteristics on RE across different industries using GMM regression. Consistent with Table 5, the lagged RE variable remains strongly significant across all sectors, indicating the persistence of renewable energy practices over time. However, the influence of board characteristics varies by industry. For example, BGD exhibits positive coefficients in Consumer Cyclical (0.08) and Industrials (0.11), albeit without statistical significance, suggesting that gender-diverse boards in these sectors may lean toward greater renewable energy adoption, even if the effect is not robust. In contrast, BSS has a statistically significant negative effect on the Basic Materials (coefficient = -0.0828 , significant at 5%) and Industrials sectors (coefficient = -0.0676 , significant at 10%). This implies that in these industries, a higher percentage of board members possessing specific skills could be associated with more conservative or traditional decision-making, potentially hindering proactive renewable energy investments. From a corporate governance perspective, these findings emphasize the importance of tailoring board composition to industry-specific dynamics. The overall positive impact of BGD observed in Table 5 suggests that enhancing gender diversity could

foster a culture of innovation and sustainability. In contrast, the negative association of BSS in certain industries indicates that firms in sectors such as Basic Materials and Industrials might benefit from integrating diverse competencies that go beyond traditional expertise. Consequently, corporate leaders should consider strategic board reforms that balance technical expertise with progressive perspectives to effectively drive renewable energy initiatives across varied industrial contexts.

5. DISCUSSION

This study expands our understanding of how board characteristics influence firms' renewable energy use (RE) in the European Union by testing two central hypotheses. Specifically, the study investigates (H₁) whether board gender diversity (BGD) positively impacts RE and (H₂) whether board-specific skills (BSS) affect RE in a contingent manner, depending on the relevance of the expertise to sustainable energy projects. The results, obtained via robust OLS and GMM regressions and supported by detailed descriptive and industry-wise analyses, offer nuanced insights into the interplay between board composition and sustainability initiatives.

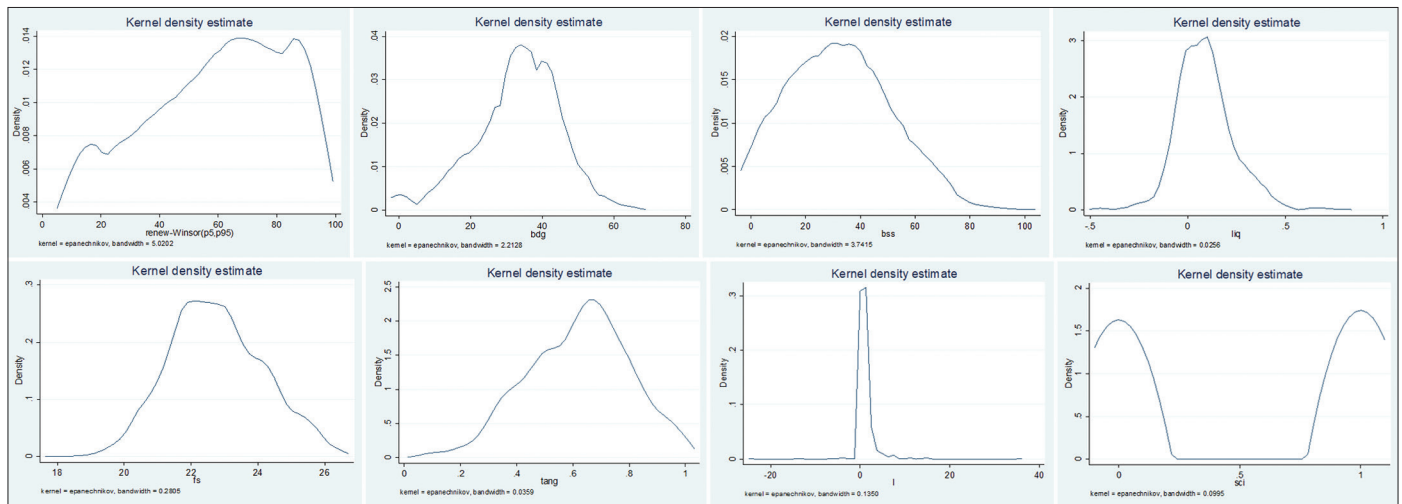
The findings provide strong support for H1. The GMM regression results indicate that an increase in BGD is significantly associated with higher renewable energy use (coefficient = 0.0989 , $P < 0.05$). This outcome reinforces the view that gender-diverse boards are not only symbolic of progressive governance but also serve as active catalysts for environmental innovation. The positive relationship suggests that female directors bring diverse perspectives, ethical sensitivity, and a longer-term strategic focus that are conducive

Table 6: Impact of BGD and BSS on RE: Industry-wise regression results

Variables	Basic materials	Consumer cyclicals	Consumer non-cyclicals	Industrials	Technology
	RE	RE	RE	RE	RE
Lag of RE	1.010*** (0.12)	0.751*** (0.14)	0.886*** (0.19)	0.849*** (0.11)	0.701*** (0.20)
BGD	0.01 (0.12)	0.08 (0.07)	-0.08 (0.30)	0.11 (0.08)	0.07 (0.17)
BSS	-0.0828** (0.04)	-0.04 (0.04)	-0.03 (0.11)	-0.0676* (0.04)	0.03 (0.06)
Liq	-19.45 (16.02)	-6.03 (11.07)	13.66 (57.34)	-0.55 (7.38)	-4.79 (16.90)
FS	0.239 (0.61)	-0.539 (0.88)	-3.518 (3.74)	0.0864 (0.48)	0.245 (1.01)
Tang	-14.1 (10.91)	-1.157 (10.98)	69.62 (78.55)	-0.572 (5.25)	-0.909 (15.19)
L	0.95 (2.76)	-0.0319 (0.16)	1.284 (0.90)	0.0867 (0.30)	-0.678 (1.76)
SCI	-1.863 (1.99)	-2.803 (3.68)	0.502 (3.72)	1.954 (1.81)	-0.361 (2.92)
Controls (Year dummies)	Yes	Yes	Yes	Yes	Yes
Controls (Country dummies)	No	No	No	No	No
Constant	12.26 (20.34)	29.96 (24.42)	44.79 (63.57)	4.569 (11.64)	16.72 (29.43)
Observations	185	217	119	344	235
AR1 P-value	0.0040	0.0010	0.0320	0.0000	0.0020
AR2 P-value	0.6080	0.0860	0.7200	0.4000	0.2690
Hansen P-value	0.1910	0.6280	0.3350	0.8470	0.2640
Sargan P-value	0.2400	0.7960	0.1840	0.7560	0.0920

The standard errors are reported in parentheses. ***, **, *Denote significance at the 1%, 5% and 10% level, respectively. This table reports the industry-wise GMM regression results for model. The selected industries, individually hold more than 10% of the total sample. The relationship between Renewable Energy Use (RE), and Corporate Governance proxied by Board Gender Diversity (BGD) and Board Specific Skills, Percent (BSS) as well as other control variables is analysed from 2013-2023

Figure 3: Kernel density estimate



to adopting renewable energy technologies. These findings are consistent with previous research demonstrating that gender diversity enhances board oversight and strategic decision-making (Joshi and Diekmann, 2022; Cosma et al., 2021). Furthermore, stakeholder theory (Freeman, 1984) supports the idea that a diversified board is better positioned to reflect a broader range of stakeholder interests, including environmental sustainability, thus prompting firms to commit more strongly to renewable energy initiatives (Cordeiro et al., 2020; Almaqtari et al., 2024).

The persistence of renewable energy practices is also notable, as evidenced by the significant lagged RE variable across models. This persistence implies that once firms embark on sustainable energy investments, these initiatives tend to be maintained over time, a dynamic that further underscores the strategic value of a gender-diverse board. The alignment of these findings with the broader literature confirms that enhancing board gender diversity can be a powerful lever for driving long-term sustainability goals (Fouad et al., 2023; Issa and Hanaysha, 2023).

In contrast, the effect of board-specific skills on renewable energy use is more complex. The results indicate that a higher proportion of board members with specialized technical or financial expertise is associated with a statistically significant decrease in RE (coefficient = -0.0446 , $P < 0.10$). This counterintuitive finding suggests that while technical proficiency is essential for evaluating complex renewable energy projects, an overemphasis on traditional expertise may foster a risk-averse culture. Such conservatism can lead boards to prioritize short-term financial performance rather than pursuing the longer-term, transformative investments required for a sustainable energy transition.

These findings resonate with earlier studies that caution against a narrow focus on conventional skills. Settembre-Blundo et al. (2021) and Fu et al. (2023) have argued that when board expertise is not explicitly aligned with emerging sustainability challenges, it may inhibit the bold strategic decisions necessary for renewable energy adoption. In other words, the potential benefits of board-specific skills in fostering innovative investments are contingent on whether the expertise is directly relevant to sustainability. This

nuance underlines the importance of not only increasing technical skills on boards but also ensuring that these skills are updated to include competencies in renewable energy technologies and green finance (Agnese et al., 2024; Mousa et al., 2023).

The descriptive statistics reveal substantial variability in both renewable energy use and board composition across the sample. With the Renewable Energy Use Ratio Score ranging widely, from 10.00 to 94.14, firms clearly differ in their commitment to sustainable energy practices. Similarly, the distributions of BGD and BSS underscore the heterogeneous governance practices across the EU. The strong persistence of renewable energy practices, as evidenced by the significant lagged RE variable, suggests that once a firm commits to renewable energy, the underlying strategic orientation tends to endure.

Moreover, the rigorous diagnostic tests, such as the AR1, AR2, Hansen, and Sargan tests support the reliability and validity of the GMM estimations, mitigating concerns about endogeneity. The robustness of these results reinforces the empirical link between board composition and renewable energy use. In particular, the sustained positive effect of BGD across different econometric models provides compelling evidence that gender-diverse boards drive innovative and proactive sustainability initiatives (Boussenna and Kimouche, 2024).

An additional layer of complexity emerges when examining the industry-wise regression results. The positive impact of BGD on RE is more pronounced in industries such as Consumer Cyclical and Industrials, where competitive pressures and technological dynamism are particularly intense. In these sectors, the broad range of perspectives brought by female directors appears to be especially effective in fostering the adoption of renewable energy. Conversely, in sectors like Basic Materials, the negative influence of board-specific skills is more evident, suggesting that in industries with higher operational risks or stringent regulatory frameworks, a board dominated by traditional expertise may lean towards conservative strategies that limit bold sustainability investments.

These industry-specific variations align with previous findings that the effectiveness of governance mechanisms in driving sustainability is contingent on the external regulatory environment and sector-specific dynamics (Issa and Hanaysha, 2023; World Economic Forum, 2022). Such insights underscore the need for tailored governance approaches that consider both the internal board composition and the external market and regulatory conditions influencing renewable energy adoption.

Overall, the study's findings illuminate the dual role of board composition in influencing renewable energy use. On one hand, gender diversity on boards emerges as a robust driver of renewable energy adoption, reinforcing the idea that diverse boards contribute significantly to the strategic orientation toward sustainability (Cosma et al., 2021; Almaqtari et al., 2024). On the other hand, the negative association between board-specific skills and renewable energy use suggests that the benefits of specialized expertise are highly contingent on its alignment with sustainability objectives. This complex interplay calls for a balanced approach: firms should not only strive to enhance gender diversity but also ensure that the technical expertise on their boards is attuned to the demands of a low-carbon economy.

6. CONCLUSION, FUTURE SCOPE AND PRACTICAL IMPLICATIONS

In summary, the study's findings have far-reaching implications that extend beyond the immediate context of EU firms. Academically, the research advances theoretical debates on corporate governance and sustainability by revealing how board diversity and the specificity of board skills interact to shape renewable energy adoption. Practically, the results offer a roadmap for firms and policymakers aiming to foster sustainable energy practices through strategic board composition reforms. Future research should continue to explore these dimensions, addressing emerging challenges and opportunities in an increasingly dynamic global landscape. By doing so, scholars and practitioners alike can contribute to the broader agenda of driving the transition toward a low-carbon, sustainable future.

Future research can extend the geographical focus beyond EU firms to include emerging markets and other developed regions with distinct regulatory environments. Researchers could also incorporate additional board attributes such as board independence, tenure, and educational diversity to develop a more holistic understanding of how various dimensions of board composition influence renewable energy adoption (Joshi and Diekmann, 2022; Almaqtari et al., 2024). Additionally, exploring mediating and moderating variables like firm size, financial constraints, and industry-specific dynamics through longitudinal studies would provide further insights into the causal relationships between board characteristics and sustainability outcomes (Settembre-Blundo et al., 2021).

Academically, this study advances theoretical frameworks by integrating stakeholder theory (Freeman, 1984), resource dependence theory (Pfeffer and Salancik, 1978), and agency

theory (Jensen and Meckling, 1976) with the emerging literature on renewable energy adoption. The nuanced findings, where board gender diversity robustly drives renewable energy use while traditional board-specific skills may hinder innovation challenge conventional views on technical expertise. This contributes to ongoing debates about the multifaceted role of board composition in sustainability performance, emphasizing that diverse perspectives are crucial for long-term strategic decision-making (Cosma et al., 2021; Joshi and Diekmann, 2022).

From a practical standpoint, the findings suggest that firms should actively promote gender diversity on their boards while also updating board-specific skills to include competencies in sustainability and renewable energy technologies. Such governance reforms not only signal a strong commitment to sustainable practices to investors and stakeholders but also enhance the firm's ability to navigate environmental challenges and regulatory pressures, facilitating a smoother transition to a low-carbon economy (Issa and Hanaysha, 2023; World Economic Forum, 2022). Policymakers can also leverage these insights by designing incentives that encourage corporate governance structures aligned with sustainability goals, ultimately supporting a more resilient and environmentally responsible business landscape (Mousa et al., 2023).

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