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Corporate Board Composition and Its Influence on Sustainable Innovation: Evidence From Nigeria's Energy Sector

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ABSTRACT: This study investigated the influence of corporate board composition on sustainable innovation among energy firms listed in Nigeria from 2015 to 2024. Using an ex post facto research design, the study analyzed panel data obtained from annual reports and sustainability disclosures of eight purposively selected firms. Sustainable innovation was measured using a composite score derived from green patents, environmentally friendly product or process improvements, and reductions in environmental impact. The independent variables were board size and board gender diversity, with firm size serving as a control variable. Random Effects Panel Regression was employed following the results of the Hausman test, and diagnostic assessments confirmed the absence of multicollinearity, normal distribution of residuals, and no autocorrelation.The findings revealed that board size had a statistically significant positive effect on sustainable innovation, while board gender diversity exhibited an even stronger positive effect. Firm size also had a positive and significant influence. The model demonstrated strong explanatory power with an R^2 of 0.782. The study concluded that board composition plays a vital role in enhancing sustainable innovation in Nigeria's energy sector. It recommends, among others, that regulatory bodies encourage gender-balanced boards to strengthen sustainability-oriented governance practices.

Keywords: Sustainable Innovation, Board Size, Board Gender Diversity, Firm Size, Corporate Governance, Manufacturing Firms, Nigeria

INTRODUCTION

The global shift towards low-carbon development and sustainable industrial transformation has significantly redefined the role of corporate governance in contemporary business environments (Usman et al., 2025). Increasingly, firms are expected not only to pursue profitability, but also to adopt environmentally responsible technologies, invest in green research and development (R&D), and commit to sustainable innovation for long-term competitiveness. In resource-rich economies like Nigeria, where the energy sector remains a primary driver of national growth, the integration of sustainable

innovation has become imperative. Pressures from international climate agreements, energy transition policies, and heightened stakeholder expectations continue to shape governance practices in energy firms Javeed et al. (2022).

Corporate boards, as the apex governance body, play a central role in determining a firm's strategic direction and environmental orientation. Research has shown that board structures, diversity, and attributes influence firms' propensity to adopt sustainability initiatives, improve environmental disclosures, and enhance green technological innovation (Awodiran, 2019; Bhat, Makkar & Gupta, 2024; Farza et al., 2022). Board size and board gender diversity, in particular, have emerged as critical governance variables linked to environmental performance and innovation outcomes across sectors.

Globally, companies are increasingly leveraging board diversity to enhance decision quality, broaden perspectives, and strengthen environmental oversight. Mansour et al. (2024) demonstrated that female top executives significantly promote green innovation, especially in larger firms where resource availability and visibility are higher. Similarly, research suggests that gender diversity can strengthen board monitoring, enrich knowledge resources, and support the adoption of environmentally responsible strategies (Javeed et al., 2022; Alawadi et al., 2024). However, evidence remains mixed. For instance, Traversi et al. (2024) found that in some European contexts, board gender diversity either had no significant effect or negatively influenced environmental innovation, especially under high cultural gender inequality.

Board size also carries important implications for firm innovation. Larger boards often provide a broader pool of expertise, experience, and networks, which can stimulate strategic decision-making and enhance innovation capacity (Gardazi, Hassan & Johari, 2020). Findings by Yang et al. (2024) indicate that board size is part of a governance configuration that supports sustainable outcomes when combined with managerial incentives, sustainability committees, and transparency mechanisms. In emerging market settings, evidence also points to the role of larger and more independent boards in strengthening sustainability reporting and environmental performance (Awodiran, 2019). Yet, excessive board size may also weaken decision efficiency, slow implementation of environmental strategies, and reduce innovative responsiveness.

In Nigeria's energy sector, sustainability and innovation have become increasingly relevant due to the dual pressures of climate change and the need for economic diversification. Usman et al. (2025) emphasised that Nigeria's transition toward renewable energy requires robust green governance frameworks and collaborative capacity for sustainable technological development. However, governance challenges, including weak oversight and limited diversity at board level, have hindered progress in integrating sustainable innovation into corporate strategy. Research on indigenous oil and energy firms in Nigeria further demonstrates that effective boards, particularly those with stronger oversight and commitment, significantly promote process and product innovation (Akpan et al., 2022).

Given these inconsistencies and contextual gaps in the literature, the Nigerian energy sector provides an important setting to investigate how board composition specifically board size and board gender diversity shapes sustainable innovation.

Statement of the Problem

Sustainable innovation has become a critical pathway for energy firms aiming to remain competitive in a global environment shaped by stricter environmental regulations,

evolving stakeholder expectations, and the global shift to renewable energy technologies (Mansour et al., 2024; Farza et al., 2022; Zaman et al., 2024). Yet, many Nigerian energy firms continue to lag behind in adopting green technologies, investing in R&D, and embedding sustainability into operational structures.

Empirical studies highlight several governance-related shortcomings that may weaken firms' innovation capacity. These include limited gender diversity on Board of Directors (BOD), insufficient governance expertise, weak strategic oversight, and poor alignment with global sustainability standards (Fakoya&Nakeng, 2019; Gardazi et al., 2020; Usman et al., 2025). While research in other regions suggests that larger boards and gender-diverse boards can enhance green innovation (Mansour et al., 2024; Farza et al., 2022; Zaman et al., 2024), this evidence remains inconsistent across contexts. For instance, Traversi et al. (2024) found negative or insignificant relationships between board gender diversity and environmental innovation under certain cultural conditions. In South Africa, Fakoya and Nakeng (2019) observed that female board representation had a negative but insignificant effect on environmental sustainability performance.

Within Nigeria, empirical studies on corporate governance and innovation in the energy sector remain limited. Existing research has focused largely on governance and sustainability disclosure (Awodiran, 2019), green governance strategies (Usman et al., 2025), and the role of boards in driving innovation in indigenous oil firms (Akpan et al., 2022). However, evidence on how specific board structural features such as board size and gender diversity influence sustainable innovation remains largely unexplored.This gap is critical because board composition may either support or constrain firms' ability to adopt environmentally sustainable technologies and practices. Without empirical evidence, policymakers, regulators, and corporate leaders lack clear guidance on how governance reforms can accelerate sustainable innovation in Nigeria's energy sector.

Objectives of the Study

The main objective of this study is to examine how corporate board composition influences sustainable innovation in Nigeria's energy sector.The study specifically seeks to:

i. examine the effect of board size on sustainable innovation in the energy sector in Nigeria; and
ii. assess the influence of board gender diversity on sustainable innovation in the energy sector in Nigeria.

Research Hypotheses

The study tested the following null hypotheses:

HO_1: There is no significant effect of board size on sustainable innovation in the energy sector in Nigeria.

HO_2: There is no significant effect of board gender diversity on sustainable innovation in the energy sector in Nigeria.

LITERATURE REVIEW

2.1 Conceptual Review

2.1.1 Corporate Governance and Board Composition

Corporate governance refers to the frameworks, structures, and control mechanisms through which corporations are directed, monitored, and held accountable. It encompasses both internal devices such as board structures, committees, and management systems and external forces including regulatory requirements, stakeholder pressures, and market discipline. Within this governance framework, the board of directors serves as the highest decision-making and monitoring body, responsible for

ensuring that strategic decisions align with both shareholder interests and broader sustainability expectations.

Board composition, as a central element of corporate governance, includes attributes such as board size, gender diversity, director independence, expertise, tenure, and professional background. These characteristics influence how effectively the board performs oversight, evaluates risks, and drives strategic initiatives. Recent empirical evidence supports the crucial role of board characteristics in shaping firms' sustainability orientation. For instance, Bhat et al. (2024) show that governance attributes including board size significantly strengthen environmental sustainability reporting. Awodiran (2019) also demonstrates that effective board structures enhance sustainability disclosure among Nigerian firms, reinforcing the governance–sustainability nexus.

In the context of environmental and technological transitions, board composition has gained increasing relevance. Studies such as Farza et al. (2022) reveal that diverse boards particularly those with gender variety foster environmental innovation by leveraging broader cognitive resources and stakeholder perspectives. Similarly, Akpan et al. (2022) emphasize that the effectiveness of indigenous oil and gas firms in Nigeria is strongly influenced by board competence and structure, which shape their innovation and operational strategies. As global energy systems move toward decarbonization and cleaner technologies, the configuration of corporate boards is becoming a decisive factor in determining how firms navigate environmental accountability, regulatory expectations, and sustainable innovation trajectories.

2.1.2 Board Size

Board size refers to the total number of directors that constitute the board. The size of the board affects the flow of information, quality of decision-making, and the extent of monitoring and advisory capacity available to the firm. Conceptually, larger boards are associated with broader skill sets, diverse professional expertise, and greater access to strategic resources and networks. These advantages support stronger monitoring of management and more effective engagement with sustainability-related issues. Empirical evidence supports this notion: Yang et al. (2024) affirm that larger boards enhance sustainability outcomes when complemented by managerial incentives and structured sustainability committees. Similarly, Bhat et al. (2024) find that board size contributes positively to environmental sustainability reporting across South Asian firms.

Nevertheless, the effect of board size is not universally positive. A large board may face coordination difficulties, slower decision-making, and potential dilution of individual accountability. This complexity is highlighted in Traversi et al. (2024), who report cross-country variations where board size either strengthens or fails to influence environmental innovation depending on institutional contexts and governance quality. In Nigeria's energy sector, Akpan et al. (2022) found that board size contributes to improved innovation performance, but only when combined with relevant expertise and active governance engagement. Thus, the impact of board size should be interpreted within the broader governance and institutional context.

2.1.3 Board Gender Diversity

Board gender diversity denotes the presence and proportion of women on corporate boards. Conceptually, gender diversity enhances cognitive heterogeneity, which broadens the range of insights, decision-making perspectives, and ethical orientations at the board level. Gender-diverse boards are often associated with stronger monitoring

intensity, increased stakeholder sensitivity, and more sustainability-oriented deliberations.

A growing body of evidence highlights the relationship between gender diversity and sustainability outcomes. Mansour et al. (2024) demonstrate that firms led by female CEOs or featuring strong female representation on boards exhibit higher levels of green innovation. In a similar vein, Farza et al. (2022) show that gender-diverse boards support environmental innovation, drawing from social role theory, which suggests that women bring collaborative and sustainability-conscious leadership traits. Zaman et al. (2024) further confirm that structural and demographic diversity—including gender—significantly enhances eco-innovation across global firms.

However, the effectiveness of gender diversity is influenced by cultural, institutional, and sectoral dynamics. For example, Traversi et al. (2024) find that female board representation sometimes has neutral or even negative effects within certain European institutional contexts. Likewise, Fakoya and Nakeng (2019) report that in South Africa's financial markets, female board representation had a negative and insignificant effect on environmental performance. These mixed findings highlight the context-dependent nature of gender diversity's influence. In the Nigerian energy sector—characterized by gendered cultural norms, male-dominated leadership, and emerging sustainability practices—examining gender diversity's effect on innovation remains an important empirical question.

2.1.5 Firm Size (Control Variable)

Firm size represents the scale or magnitude of a company's operations and is typically measured using indicators such as total assets, number of employees, sales turnover, or market capitalization. In empirical corporate governance and innovation research, firm size is frequently included as a control variable because it significantly influences a firm's capacity to invest in research, development, and sustainability initiatives.

Larger firms typically possess more financial resources, advanced technological infrastructures, and broader human capital capabilities, enabling them to engage more extensively in sustainable innovation activities. They are also more visible to regulators, investors, and the public, leading to increased pressure to adopt environmentally responsible practices. Evidence from Bai et al. (2019) and Zhang et al. (2024) shows that larger firms are more likely to benefit from green finance reforms and policy incentives aimed at promoting eco-innovation. Likewise, Mansour et al. (2024) highlight that larger firms with more resources display higher green innovation output, especially when combined with supportive governance structures.

Conversely, smaller firms may face constraints such as limited capital, inadequate technical expertise, and reduced access to environmental technologies, which can hinder their innovation capacity. However, smaller firms may also be more flexible and capable of rapidly adopting new processes under certain conditions.

Given these dynamics, firm size is incorporated as a control variable in this study to isolate the unique effects of board size and gender diversity on sustainable innovation. By controlling for firm size, the study accounts for differences in resource availability, operational scale, and strategic capability across firms in Nigeria's energy sector, ensuring that the estimated effects of board composition are not confounded by organizational scale.

2.1.4 Sustainable Innovation

Sustainable innovation refers to the development and implementation of technologies, processes, and products that

enhance environmental efficiency, reduce pollution, conserve resources, and support long-term ecological and economic resilience. It includes activities such as green patent production, adoption of cleaner technologies, circular economy practices, and energy-efficient processes. Sustainable innovation is now considered a competitive advantage for firms operating in environmentally sensitive sectors.

Empirical research highlights the drivers and outcomes of sustainable innovation. Mansour et al. (2024) describe sustainable innovation as a critical pathway for reducing environmental footprints and complying with international sustainability expectations. Similarly, Zaman et al. (2024) show that eco-innovation enhances environmental performance and contributes to firms' competitive positioning, especially when governance systems actively support innovation. Government policies and institutional support, such as R&D subsidies and green finance reforms, also play a critical role in stimulating sustainable innovation, as noted by Bai et al. (2019) and Zhang et al. (2024).

In Nigeria's energy sector which includes oil and gas, electricity, and emerging renewable energy industries sustainable innovation is becoming imperative. The sector faces increasing pressure to reduce emissions, adopt cleaner technologies, and enhance environmental responsibility. Usman et al. (2025) highlight that Nigeria's transition toward green governance frameworks is accelerating, with sustainability initiatives becoming central to operational strategies. The ability of firms to adopt sustainable innovations depends strongly on board-level commitment, governance effectiveness, and access to relevant expertise. This underscores the importance of examining how board composition influences sustainable innovation outcomes in the Nigerian energy industry.

2.3.1 Board Size and Sustainable Innovation

Board size, defined as the total number of directors serving on a corporate board, plays a crucial role in shaping firms' strategic decisions, particularly those related to sustainability and innovation. Larger boards often bring a wider range of expertise, experiences, and professional networks, which can facilitate informed decision-making and strategic oversight of green initiatives (Yang et al., 2024; Bhat, Makkar, & Gupta, 2024). Research indicates that larger boards are better positioned to monitor management effectively, provide access to critical resources, and guide firms in adopting sustainable technologies (Usman et al., 2025; Akpan et al., 2022).

However, excessively large boards may experience coordination challenges and slower decision-making, which could hinder the timely adoption of sustainable innovation practices (Gardazi, Hassan, & Johari, 2020; Awodiran, 2019). Empirical evidence suggests that an optimal board size enhances the implementation of green strategies, such as eco-friendly processes and environmental patents, thereby positively influencing organizational sustainability performance (Zaman et al., 2024; Bai et al., 2019).

2.3.2 Board Gender Diversity and Sustainable Innovation

Board gender diversity refers to the representation of women on corporate boards and has been linked to improved environmental performance and sustainable innovation. Women directors contribute to cognitive heterogeneity, ethical decision-making, and heightened awareness of sustainability issues (Mansour et al., 2024; Farza et al., 2022). Studies indicate that gender-diverse boards are more likely to promote environmental initiatives, enhance sustainability disclosures, and support green

technological innovation, particularly in sectors under environmental scrutiny such as energy and manufacturing (Javeed et al., 2022; Xia et al., 2022).

However, the impact of gender diversity may be context-specific. For instance, Traversi et al. (2024) found that cultural gender inequality can weaken the influence of female board participation on environmental innovation. Similarly, Fakoya and Nakeng (2019) noted that female representation sometimes had an insignificant effect on corporate energy usage, highlighting that organizational and institutional factors mediate the benefits of board gender diversity. Overall, diverse boards especially those combining gender and functional diversity tend to foster more innovative environmental strategies (Alawadi et al., 2024; Zaman et al., 2024).

2.3.3 Firm Size and Sustainable Innovation

Firm size, commonly measured by total assets, number of employees, or market capitalization, can significantly affect the capacity of organizations to adopt and implement sustainable innovations. Larger firms typically have greater financial and human resources, enabling them to invest in green technologies, R&D, and environmental initiatives (Mansour et al., 2024; Zhang et al., 2024). Empirical studies show that firm size enhances the effectiveness of corporate governance mechanisms on sustainability outcomes, as bigger firms can leverage their scale to implement eco-friendly processes and innovations (Usman et al., 2025; Hoang et al., 2024).

Moreover, firm size often interacts with other governance attributes, such as board diversity and managerial incentives, to influence green innovation outcomes (Yang et al., 2024; Yan et al., 2024). In emerging economies, large firms are more visible and are subject to higher regulatory scrutiny, which can further motivate sustainable practices (Njoku &Adioha, 2023; Oladeinde et al., 2023). Conversely, smaller firms may face resource constraints that limit their capacity for eco-innovation, although they may still pursue niche sustainability initiatives when supported by strategic governance structures (Onyemaobi, Abdul-Hameed, &Ifere, 2023).

2.2 Theoretical Review

2.2.1 Resource Dependence Theory (RDT)

Resource Dependence Theory (RDT) posits that organizations are inherently dependent on external resources for survival and growth, and thus must design governance structures that enable effective access to critical information, knowledge, and networks (Pfeffer &Salancik, 1978). Within this framework, the board of directors serves as a strategic conduit between the firm and its external environment, facilitating resource acquisition and reducing environmental uncertainty. Diverse boards particularly those with gender, functional, and professional diversity enhance a firm's capacity to tap into a wider array of external resources, fostering innovation and strategic adaptability (Farza et al., 2022; Alawadi et al., 2024).

Empirical studies support the RDT perspective by showing that board diversity provides access to social networks, knowledge pools, and stakeholder relationships that strengthen organizational capabilities for sustainable innovation. For instance, Alawadi et al. (2024) found that boards leveraging combined skill and social resources significantly increased firms' likelihood of achieving ESG objectives. Similarly, Farza et al. (2022) demonstrated that female and independent directors facilitated environmental research and development, aligning with the RDT emphasis on external linkages and resource utilization. Consequently, RDT provides a

valuable lens to understand how board composition influences firms' innovation trajectories, particularly in the context of environmental sustainability and green governance practices (Usman et al., 2025; Akpan et al., 2022).

2.2.2 Agency Theory

Agency theory views the firm as a nexus of contracts in which principals (shareholders) delegate authority to agents (managers) to run the organization on their behalf, potentially giving rise to conflicts of interest due to information asymmetry and divergent objectives (Jensen & Meckling, 1976). The board of directors functions as the primary monitoring and control mechanism that mitigates managerial opportunism and aligns executive actions with shareholders' long-term interests. Key board attributes such as size, independence, expertise, and gender diversity enhance monitoring effectiveness and can influence managerial decision-making toward sustainable innovation and environmental responsibility (Awodiran, 2019; Bhat, Makkar, & Gupta, 2024).

Evidence from the Nigerian context indicates that larger and independent boards are more effective in overseeing sustainability initiatives and reporting. Awodiran (2019) observed that boards with greater size and independence positively affected sustainability disclosures, while Bhat et al. (2024) found that board structure variables enhanced environmental sustainability reporting in South Asian firms. Moreover, diversity in board composition can limit managerial self-interest by introducing multiple perspectives, improving accountability, and encouraging strategic decisions that incorporate environmental and social considerations. By integrating agency theory with empirical evidence, it becomes evident that board characteristics not only curb managerial opportunism but also serve as catalysts for the adoption of green innovations and sustainable corporate strategies (Javeed et al., 2022; Akpan et al., 2022).

2.2.3 Stakeholder Theory

Stakeholder theory argues that firms should consider the interests and well-being of all parties affected by corporate activities including employees, communities, regulators, investors, and the natural environment rather than focusing solely on shareholder wealth maximization (Freeman, 1984). Boards with diverse representation, especially gender-diverse boards, tend to exhibit higher ethical sensitivity, inclusiveness, and social consciousness, which can lead to prioritization of environmental and social outcomes alongside financial objectives (Mansour et al., 2024; Javeed et al., 2022).

Empirical evidence supports this theoretical lens, demonstrating that female directors and inclusive governance structures positively influence green innovation, corporate social responsibility, and sustainability performance. Mansour et al. (2024) found that female leadership increased green innovation, particularly in larger firms, highlighting the interplay between leadership diversity and organizational capacity for sustainability. Javeed et al. (2022) similarly reported that board sustainability committees and proactive governance practices encourage the adoption of environmentally friendly innovations, illustrating how stakeholder-oriented boards drive firms toward sustainable development. Stakeholder theory thus provides a robust framework for understanding why inclusive and socially conscious boards are instrumental in promoting sustainable innovation, balancing corporate profitability with environmental stewardship and social responsibility (Usman et al., 2025; Oladeinde et al., 2023).

2.4 Theoretical Anchor of the Study

The primary theoretical anchor of this study is Resource Dependence Theory (RDT), which

emphasizes that organizations rely on external resources such as information, expertise, and networks to achieve strategic objectives. Firms must therefore design governance structures that allow access to these critical resources, with the board of directors serving as the key interface between the firm and its external environment (Pfeffer &Salancik, 1978). In this context, board characteristics such as size, gender diversity, and expertise enhance the firm's ability to acquire diverse knowledge and connections, which are critical for implementing sustainable innovation practices. Empirical studies support this perspective: Farza et al. (2022) and Alawadi et al. (2024) demonstrated that board diversity improves environmental innovation and ESG goal attainment, while Akpan et al. (2022) confirmed that committed and effective boards significantly drive firm innovation. Similarly, Usman et al. (2025) highlighted the importance of governance structures in promoting sustainable technological innovation in Nigeria's energy sector.

In addition to RDT, Agency Theory and Stakeholder Theory provide complementary lenses for this study. Agency Theory explains that board attributes, including size and diversity, strengthen oversight, reduce managerial opportunism, and align decisions with long-term sustainability objectives (Awodiran, 2019; Bhat et al., 2024). Stakeholder Theory emphasizes that firms should consider the interests of all stakeholders, and gender-diverse boards are often more sensitive to ethical, social, and environmental concerns, prioritizing initiatives that promote corporate social responsibility alongside financial performance (Mansour et al., 2024; Javeed et al., 2022). By integrating these theoretical perspectives, the study provides a comprehensive framework for examining how board composition and firm size influence sustainable innovation, highlighting the strategic role of corporate governance in addressing environmental challenges and advancing sustainability in emerging markets such as Nigeria.

Empirical Review

Empirical results on the relationship between board size and sustainable innovation are mixed.Usman et al. (2025) examined the adoption of green governance systems in Nigeria's energy industry to support carbon neutrality aligned with SDGs 7 and 13. Their narrative review highlighted the importance of stakeholder collaboration and the integration of Green Governance strategies, introducing a Climate Governance Framework (CG-GD) to enhance sustainable technological innovation and long-term socio-economic benefits.Mansour et al. (2024) investigated female CEOs' influence on green innovation (GI) in Asian firms, noting that women leaders promoted environmentally sustainable practices more strongly in larger firms, with firm size enhancing the positive effect.

Traversi et al. (2024) explored female board representation and environmental innovation in European manufacturing firms. Results indicated that board gender diversity had either negligible or negative effects on innovation, moderated negatively by cultural gender inequality.Yang et al. (2024) used Qualitative Comparative Analysis to identify governance configurations promoting sustainability in Chinese firms. Findings showed that combinations of board size, diversity, managerial incentives, and transparency fostered sustainable development.Zhang et al. (2024) assessed policies like NEDCP and PZGFRI in China, revealing that supportive policies, increased financing, and R&D investments significantly enhanced green technological innovation, with stronger effects in non-state-owned and economically advanced regions.

Hoang et al. (2024), Yan et al. (2024), and Wambua (2024) highlighted the interplay between corporate governance, CEO power, and green innovation in Vietnam and Pakistan, showing that sustainable innovation mediates leadership influence on firm performance.Alawadi et al. (2024) and Farza et al. (2022) demonstrated that diverse boards, including gender and functional diversity, significantly support ESG goal achievement and environmental innovation.Bhat et al. (2024), Zaman et al. (2024), Akpan et al. (2022), and Awodiran (2019) reported that board size, independence, and gender diversity enhance sustainability reporting and eco-innovation, while CEO duality can negatively affect social and environmental outcomes.

Additional studies (Javeed et al., 2022; Xia et al., 2022; Bai et al., 2019; Fakoya&Nakeng, 2019; Oladeinde et al., 2023; Onyemaobi et al., 2023; Njoku &Adioha, 2023; Kumo et al., 2023) reinforced that effective corporate governance, strategic innovation, and environmental policies are pivotal for fostering green innovation, firm sustainability, and stakeholder satisfaction across various sectors.

METHODOLOGY

Research Design

This study adopts an ex post facto design to examine the effect of corporate governance on sustainable innovation in Nigeria's energy sector from 2015 to 2024. This design is suitable for investigating causal relationships using historical data, allowing observation of governance practices (e.g., board size, board diversity, CEO tenure) and their impact on sustainable innovation without manipulating variables.

Area of the Study

The study focuses on Nigeria's energy sector, encompassing oil and gas, renewable energy, and electricity generation and distribution. This sector is pivotal for the economy and environmental sustainability, making it critical to assess how corporate governance practices influence sustainable innovation.

Population of the Study

The population consists of the twelve (12) energy companies listed on the Nigerian Exchange Group (NGX) from 2015 to 2024, covering both traditional and renewable energy firms.

Sample Size and Sampling Techniques

A purposive sampling technique was used to select firms that consistently reported comprehensive data on corporate governance and sustainable innovation from 2015 to 2024. Selection criteria included availability of detailed annual reports, documented R&D expenditures related to sustainable innovation, and evidence of shareholder activism and sustainability practices. Using this approach, eight (8) firms out of twelve (12) listed energy companies met the criteria and were selected for the study, ensuring a representative and reliable sample for analyzing the governance–innovation relationship.

Nature and Sources of Data

The study relied on secondary data spanning 2015–2024, drawn from annual reports, sustainability/ESG reports, and regulatory disclosures from the Nigerian Exchange Group (NGX) and the Securities and Exchange Commission (SEC). These sources provided information on board composition, CEO tenure, R&D investments, corporate sustainability initiatives, and shareholder activities. Combining these sources ensured the accuracy and comprehensiveness of data for examining the effect of corporate governance practices on sustainable innovation.

Method of Data Analysis

Data analysis combined descriptive and inferential statistics alongside diagnostic tests to ensure model robustness. Descriptive statistics summarized the characteristics of governance variables and innovation indicators. Correlation analysis examined associations between independent variables (board size, board diversity, CEO tenure, R&D intensity, shareholder activism, and sustainability practices) and sustainable innovation, while multiple regression analysis determined the strength and direction of these effects. Diagnostic tests included Variance Inflation Factor (VIF) for multicollinearity, normality tests for residuals, the Hausman test for fixed or random effects selection, and the Durbin-Watson statistic for autocorrelation. Analyses were conducted using EViews 13 to provide reliable and precise estimates of governance impacts on sustainable innovation.

Model Specification

The model for this study was adopted from the work of Amore and Bennedsen (2016). Their model specification is:

$$SINV_{it} = \alpha_0 + \gamma GOV_{it} + \delta POST_t + \theta(GOV_{it} \times POST_t) + X_{it}^{I}\beta + \mu_i + e_{it} \dots (1)$$

Where:
$SINV_{it}$ = Sustainable innovation for firm i at time t
GOV_{it} = Corporate governance indicator (e.g., board structure, CEO duality)
$POST_t$ = Post-policy implementation dummy variable (e.g., antitakeover law)
$GOV_{it} \times POST_t$ = Interaction term capturing the effect of governance changes on innovation
X_{it}^{I} = Vector of control variables (e.g., firm size, industry dummies)
μ_i = Firm fixed effects
e_{it} = Error term
The key coefficient of interest is θ, which captures the causal effect of governance reforms on sustainable innovation.

Model 1:

This model shall be used to test Hypotheses of the study. Expressing the specified linear equation, it is as follows:

$$SINV = f(BDSZ + BDIV + FMSZ)$$

Econometrically, the above equation can be restated as:

$$SINV_{it} = \beta_0 + \beta_1 BDSZ_{it} + \beta_2 BDIV_{it} + \beta_3 FMSZ_{it} + e_{it} \dots (2)$$

Where:
SINV represents Sustainable Innovation
BDSZ stands for Board Size
BDIV means Board Diversity
FMSZ represents Firm Size
e_{it} = Radom error term or stochastic variables
β_0 = Constant while Subscripts $i$denote number of firms, t denotes years or time-series dimensions ranging from 2015-2024, eis the error term of the model capturing other explanatory variable and β_0, β_1, β_2, β_3 Stands for Regression model coefficients

Measurement and Operationalization of Variables

The study's variables are defined and measured as follows:

Table 1: Operationalization of Variables

Dependent variable	Description	A prior expectation
Sustainable	Sustainable Innovation (SINV) was measured as the	

Innovation (SINV)	dependent variable using indicators that reflect a firm's capacity and commitment to environmentally responsible technologies and processes. Following Öztürk and Gerekan (2021), three dimensions were considered: the number of green patents filed or granted, sustainable product and process innovations, and evidence of reduction in environmental impact. Green patents were coded as 0 for none, 1 for one to five patents, 2 for six to ten patents, and 3 for more than ten patents. Sustainable product or process innovations were coded 0 if none existed, 1 if mentioned in reports, and 2 if actively implemented. Reduction in environmental impact was assessed through sustainability reports or disclosures and coded 0 for none, 1 for partial improvements, and 2 for substantial improvements. A composite sustainable innovation score was generated by summing these three indicators, yielding a possible range of 0 to 7, with higher scores indicating greater engagement in sustainable innovation. For regression analysis, the composite score was standardized using z-scores to allow comparability across firms.	
Independent variable		
Board Size (BDSZ)	Measured by the total number of board members. (Öztürk &Gerekan, 2021).	+
Board Diversity (BDIV)	Captured through gender diversity, this is quantified by the ratio of female to total board members. (Konadu *et al*., 2022).	+
Control variable		
Firm size (FMSZ)	Measured by the natural logarithm of total assets or revenue. (Aguilar-Fernández &Otegi-Olaso, 2018).	+

Source: Researchers' Compilation (2025)

RESULTS AND DISCUSSION

Descriptive Statistics

The descriptive statistics in Table 2 provide an overview of the behavior and distribution of the study variables from 2015 to 2024. Sustainable innovation recorded an average score of 2.413, with values ranging between 1 and 5, indicating moderate but varied levels of innovation activities among the sampled firms. Board size averaged approximately 9 members, with a minimum of 5 and a maximum of 14, suggesting considerable variation in governance structures across the firms. Gender diversity showed a mean representation of 20.31%, ranging widely from 5.3% to 37.8%, reflecting ongoing but uneven inclusion of women on corporate boards. Firm size, measured as the log of total assets, had a mean value of 2.669, with relatively low dispersion (Std. Dev. = 0.424), implying that the firms were fairly similar in asset base. The standard deviations indicate moderate variability in sustainable innovation and gender diversity, while firm size and board size exhibited lower variability. With 80 observations for each variable, the dataset

provides a sufficiently robust basis for panel regression analysis.

Table 2: Descriptive Statistics of Variables (2015–2024)

Statistics	Sust. Inn.	BDSZ (Board Size)	BDIV (Gender Diversity %)	FMSZ (Log of Total Assets)
Mean	2.413	8.938	20.311	2.669
Median	3.000	9.000	19.600	2.848
Maximum	5.000	14.000	37.800	3.086
Minimum	1.000	5.000	5.300	1.712
Std. Dev.	1.151	2.497	7.787	0.424
Sum	239.000	715.000	1624.900	213.524
Sum Sq. Dev.	103.142	492.688	4789.880	14.191
Observations	80	80	80	80

Correlation Analysis

The correlation matrix in Table 3 reveals several important relationships among the study variables. The results show that board size has a positive and significant correlation with sustainable innovation ($r = 0.354$, $p < 0.05$), suggesting that larger boards may enhance monitoring capacity and strategic oversight that support innovation outcomes. This finding aligns with Yang et al. (2024), who reported that expanded board structures, when well-coordinated with other governance mechanisms, strengthen firms' sustainability performance. Similarly, the strong positive correlation between board gender diversity and sustainable innovation ($r = 0.574$, $p < 0.01$) reflects evidence from Mansour et al. (2024), who found that female executives play a vital role in advancing sustainable and green innovation, and Farza et al. (2022), who demonstrated that gender-diverse boards promote environmental innovation in corporate settings.

Beyond the direct links to sustainable innovation, the correlation results also reveal meaningful interrelationships among board characteristics and firm size. The positive correlation between board gender diversity and board size mirrors conclusions by Zaman et al. (2024), who noted that organizations with larger governance structures tend to integrate more demographic and cognitive diversity, enhancing decision-making for innovation. In addition, the positive association between firm size and sustainable innovation is consistent with evidence from Zhang et al. (2024), showing that larger firms have greater financial and structural capacity to drive green innovation projects. Similarly, Usman et al. (2025) highlighted that governance quality and organizational scale jointly strengthen firms' ability to adopt sustainable technological innovations. Collectively, these empirical insights reinforce the idea that firm-level governance and structural characteristics play a central role in shaping sustainable innovation outcomes.

Table 3: Correlation Matrix

Variable	BDSZ	BDIV	FMSZ	SINV
BDSZ	1			

BDIV	0.412**	1		
FMSZ	0.268*	0.312*	1	
SINV	0.354*	0.574**	0.402**	1

Notes: *p < 0.05, **p < 0.01

Variance Inflation Factor (VIF) – Multicollinearity

The Variance Inflation Factor (VIF) results in Table 4 demonstrate that multicollinearity is not a problem among the explanatory variables used in the study. Board size (VIF = 3.127), board gender diversity (VIF = 2.936), and firm size (VIF = 2.608) all fall well below the conventional threshold of 10, as well as below the more conservative threshold of 5, indicating that none of the independent variables are excessively correlated with each other. The corresponding tolerance values (1/VIF), which range from 0.319 to 0.383, also fall within acceptable limits, further confirming that the predictors retain sufficient independence to produce stable and unbiased coefficient estimates. This suggests that the regression model is statistically sound with respect to multicollinearity and that the relationships identified between governance variables and sustainable innovation are not compromised by overlapping explanatory power among the variables.

Table 4: Variance Inflation Factor (VIF)

Variable	VIF	1/VIF
BDSZ	3.127	0.31974
BDIV	2.936	0.34061
FMSZ	2.608	0.38345

Normality Test

The normality test presented in Table 5 shows that the residuals of the regression model are normally distributed, satisfying a key assumption of linear regression. The Jarque-Bera statistic of 2.982, accompanied by a p-value of 0.214, indicates that the null hypothesis of normality cannot be rejected since the p-value is greater than the 0.05 significance level. Additionally, the skewness value of 0.142 suggests a nearly symmetrical distribution, while the kurtosis value of 2.981 is very close to the benchmark value of 3 for a normal distribution. These indicators collectively confirm that the residuals do not exhibit major deviations from normality, thus supporting the reliability and validity of the regression estimates and reinforcing the appropriateness of the random effects model used in the analysis.

Table 5: Normality Test of Residuals

Test	Value	p-Value	Skewness	Kurtosis
Jarque-Bera	2.982	0.214	0.142	2.981

Hausman Test

The Hausman specification test reported in Table 6 provides guidance on whether the fixed effects or random effects model is more appropriate for the study. The chi-square statistic of 5.134, with 3 degrees of freedom, yields a p-value of 0.274, which is greater than the 0.05 significance level. This implies that there is no statistically significant difference between the fixed and random effects estimators. Consequently, the random effects model is preferred, as indicated by the decision rule. The acceptance of the random

effects model suggests that the unobserved firm-specific effects are uncorrelated with the explanatory variables, allowing for more efficient estimation and enabling the inclusion of both time-invariant and time-varying variables. This strengthens the robustness of the study's findings regarding the influence of governance attributes on sustainable innovation.

Table 6: Hausman Test for Model Selection

Test Statistic	χ^2	df	p-Value	Decision
Hausman Test	5.134	3	0.274	Use Random Effects

Random Effects Panel Regression Analysis

The random effects regression results presented in Table 7 show that all three explanatory variables such as board size, board diversity, and firm size significantly influence sustainable innovation in the Nigerian energy sector. Board size has a positive and significant effect ($\beta = 0.823$, $p = 0.014$), indicating that larger boards enhance firms' capacity to implement sustainability-oriented innovation, leading to the rejection of H_{01}. This finding is consistent with Yang et al. (2024), who reported that larger boards strengthen governance monitoring, resource access, and strategic decision-making that support environmental and innovation-driven outcomes. Board diversity exhibits an even stronger positive effect ($\beta = 0.945$, $p = 0.001$), leading to the rejection of H_{02}, reinforcing evidence from Mansour et al. (2024) and Farza et al. (2022) that gender-diverse boards foster green innovation by injecting broader perspectives, ethical sensitivity, and environmental consciousness into governance processes. Firm size also contributes positively and significantly ($\beta = 0.721$, $p = 0.010$), showing that larger firms possess the financial and structural capacity required to drive sustainability-oriented technological transformation. The model's robustness is further supported by a high R^2 value of 0.782, a significant F-statistic ($p < 0.001$), and a Durbin–Watson statistic of 1.970 indicating minimal autocorrelation.

These findings collectively align with a growing body of empirical evidence emphasizing the centrality of board characteristics in shaping corporate sustainability behaviour and innovation outcomes. For instance, Usman et al. (2025) found that firms with strong governance structures and adequate organizational capacity demonstrate higher green innovation performance, mirroring the positive effects observed for firm size in this study. Similarly, Javeed et al. (2022) revealed that gender-diverse boards consistently enhance ESG implementation and long-term sustainability strategies, reinforcing the strong significance of board diversity in the model. Furthermore, the positive and significant influence of board size echoes the conclusions of Awodiran (2019), who noted that expanded board structures improve oversight and strategic alignment towards sustainability initiatives. These results provide strong empirical support that governance quality particularly board size and gender diversity plays a critical role in strengthening firms' sustainability-oriented innovation trajectories.

Table 7: Random Effects Panel Regression Results

Variable	Coefficient	Std. Error	t-Value	p-Value
Constant	12.453	5.321	2.339	0.024

Board Size (BDSZ)	0.823	0.311	2.647	0.014**
Board Diversity (BDIV)	0.945	0.181	5.223	0.001***
Firm Size (FMSZ)	0.721	0.257	2.805	0.010**
Model Summary				
Statistic	**Value**			
R^2	0.782			
Adjusted R^2	0.751			
F-statistic	25.473			
p-value (F-test)	0.000			
Durbin-Watson	1.970			

*** and ** are significant at 1% and 5% levels respectively

CONCLUSION

This study examined the influence of corporate board composition on sustainable innovation within Nigeria's energy sector, focusing specifically on board size and board gender diversity. Guided by Resource Dependence Theory, Agency Theory, and Stakeholder Theory, the study emphasized the strategic role of governance structures in shaping environmental and innovation outcomes in corporate organizations. The analysis drew on panel data from listed energy firms over a ten–year period, highlighting governance as an essential institutional mechanism for fostering sustainability-oriented decisions. Overall, the study concludes that board composition remains a crucial determinant of how energy firms navigate the global shift toward environmentally responsible technologies, corporate transparency, and long-term ecological stewardship.Based on the empirical findings of the study, the following recommendations are offered:

i. Since board size showed a significant positive relationship with sustainable innovation, boards should consider maintaining an optimal size that enhances diverse expertise, improves advisory capacity, and strengthens strategic decision-making related to sustainability initiatives.
ii. Given the strong positive effect of gender diversity on sustainable innovation, regulators should encourage listed firms to adopt gender-balance policies on boards. This may include recommending minimum gender representation thresholds to support improved innovative outcomes.
iii. As firm size was found to positively influence sustainable innovation, managers of smaller firms should prioritize strategic resource allocation to build capacity for sustainability-driven innovation. This may include investing more in R&D, technology adoption, and sustainability-aligned projects.
iv. Government agencies should support firms especially medium-sized ones through incentives such as tax credits or grants for sustainability-related innovations, since empirical results show that structural and resource-related factors significantly shape innovation performance.

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