ABSTRACT

Environmental innovation (EI) has become a strategic pathway for balancing economic growth with ecological sustainability. This study examines how corporate governance mechanisms and Environmental, Social, and Governance (ESG) persuasion influence environmental innovation among European firms from 2018 to 2023. Using advanced econometric techniques—Feasible Generalized Least Squares (FGLS), Panel-Corrected Standard Errors (PCSE), and interaction models—the research integrates governance indices derived through Principal Component Analysis (PCA) with ESG performance metrics to explore their combined effect on innovation outcomes.

The findings show that ESG Composite Scores (ESGC) positively and significantly enhance Environmental Innovation Scores (EIS), underscoring that strong ESG performance fosters sustainable innovation. Governance mechanisms, particularly the Board Skills and Diversity Index (BSDI), strengthen this relationship by promoting diverse and capable leadership. Conversely, Emission Scores (ES) display a negative relationship with innovation, suggesting a resource trade-off where firms prioritize short-term emission reduction over long-term innovation. Moreover, the Leadership Policy Index (LPI) exhibits inefficiencies, indicating the need for sustainability-aligned leadership frameworks.

Interaction results reveal that while governance can amplify ESG contributions to emission reduction, its role in stimulating broader innovation remains limited. Overall, the study highlights that the synergy between ESG performance and effective governance is essential for driving sustainable innovation and achieving long-term competitiveness in European firms.

Key words: *Environment innovation, Environment degradation, ESG score, Corporate governance, European firms*

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Data and sample selection

This study uses a well-chosen dataset from Refinitiv Eikon, a major global database known for its wide coverage of financial and non-financial corporate information (Refinitiv, 2021a; 2021b). The dataset includes 70 firm-level entries across various industries, such as Banks, Insurance, Financial Services, and Capital Markets. It covers 11 European countries, including the Netherlands, Belgium, Germany, France, Switzerland, and Austria. The data spans the years from 2018 to 2023, giving a solid timeframe to explore the relationship between environmental innovation, corporate governance factors, and ESG influence.

To improve clarity and accuracy, the dataset was refined by focusing on the time period from 2018 to 2023. This change helps reduce potential biases from uneven panel structures while ensuring a consistent and comparable set of observations. Companies with large gaps in reporting or missing key variables, especially those related to environmental, social, and governance (ESG) metrics, were carefully excluded. This refinement also supports the study's goals by concentrating on companies that consistently report important indicators. These indicators include measures of environmental innovation, ESG performance scores, and financial data essential for assessing the connection between corporate governance and sustainability results. By utilizing this tailored dataset, the study maintains methodological rigor and improves the validity and generalizability of its findings, providing a solid empirical base to further explore environmental innovation and governance-driven sustainability practices in Europe.

Table 1: Industry Summary Table

Industry	Number of Firms	Proportion of Firms (%)
Banks	14	20.0
Capital Markets	24	34.28
Consumer Finance	1	1.42
Financial Services	12	17.14
Insurance	19	27.14
Total	70	100.0

Source: Author's compilation

3.2. Model Specification

This study builds on a strong theoretical framework that examines the relationship between corporate governance, environmental innovation, environmental damage, and ESG influence. The Stakeholder Theory (Freeman, 1984; Clarkson, 1995) emphasizes the need to align corporate governance with sustainability goals. This ensures that companies balance the interests of shareholders and stakeholders while aiming for long-term value. The Resource-Based View (RBV) (Barney, 1991; Teece et al., 1997) points out the strategic importance of a company's specific resources, including their environmental innovation capabilities, in creating competitive advantage and driving sustainability.

At the same time, Agency Theory (Jensen & Meckling, 1976) explains the governance mechanisms needed to reduce conflicts between principals and agents. It ensures accountability in ESG commitments and optimizes resource use for sustainability initiatives. Additionally, Dynamic Capabilities Theory (Teece, 2007) focuses on a firm's ability to continuously change governance structures and strategies in response to evolving ESG demands and regulatory pressures. Together, these theories provide a basis for understanding how corporate governance, financial factors, and sustainability policies work together to influence environmental innovation, corporate emission performance, and ESG influence. Upper Echelon Theory (Hambrick & Mason, 1984) shows how leadership demographics, such as board diversity and management skills, affect decisions related to corporate sustainability. Finally, the Porter Hypothesis (Porter & van der Linde, 1995) argues that strict environmental regulations drive green innovation, highlighting the importance of governance structures in corporate sustainability changes.

Building on the findings presented in Chapter 2, this study's model combines research on corporate governance, environmental innovation, and ESG performance. Research from Makpotche, Bouslah, and M'Zali (2024) highlights the role of governance in promoting green R&D, while Chouaibi, Chouaibi, and Rossi (2022) show that green innovation plays a mediating role in improving ESG performance.

Furthermore, Biggi, Mina, and Tamagni (2023) emphasize the influence of corporate governance on financial decisions driven by sustainability.

Evidence also shows that governance indices interact with ESG metrics, affecting companies' sustainability strategies (Albitar et al., 2023; Kordsachia, Focke, & Velte, 2022). Pompei, Mititean, and Ghigiu (2024) underline the significance of board diversity and leadership structures in speeding up sustainability changes. Similarly, Erragragui (2018) and Saleem & Rehman (2011) point out that financial stability indicators, like firm liquidity (LIQ) and firm size (FY), are key to supporting sustainability efforts. The key factors of EIS can be summarized in the following equation:

$$\boxed{\mathbf{EIS_{it} = f(ESGC_{it}, ES_{it}, FY_{it}, LIQ_{it}, TCSO_{it}, LTD_{it}, CFI_{it}, LPI_{it}, BSDI_{it})}}$$

Where

EIS_{it} (Environmental Innovation Score): The dependent variable measuring firms' commitment to environmental innovation and sustainability-oriented technological advancements.

$ESGC_{it}$ (Environmental, Social, and Governance Composite Score): An independent variable capturing firms' holistic ESG performance and adherence to sustainable business practices.

ES_{it} (Emission Score, sourced from Refinitiv Eikon): A proxy for environmental degradation, reflecting corporate emissions intensity and pollutant mitigation efforts.

FY_{it} (Firm Year): A control variable measuring firm size via the log-transformed total assets, accounting for firm maturity and resource capacity in ESG implementation.

LIQ_{it}: (Firm liquidity): A control variable assessing firms' financial health and ability to invest in sustainable initiatives.

$TCSO_{it}$ (Total Common Shares Outstanding): A control variable capturing firms' capital structure and ownership distribution, which may influence governance decisions on ESG matters.

LTD_{it} (Long term debt): A control variable accounting for firms' leverage and its implications for sustainability investments and financial risk.

CFI_{it} (Committee Functionality Index): (corporate governance determinant), derived from PCA to measure the effectiveness of governance committees in supporting ESG initiatives.

LPI_{it} (Leadership Policy Index): (corporate governance determinant), constructed to assess the influence of leadership policies on driving ESG and innovation goals.

$BSDI_{it}$ (Board Skills and Diversity Index): (corporate governance determinant), quantifying the skills, diversity, and effectiveness of the board in promoting sustainability and innovation.

The econometric specifications help clarify the direct and interactive effects of corporate governance mechanisms on ESGC, emissions scores, and environmental innovation. The set of models is designed to deepen the investigation, starting from basic direct effects to examining combined interactions.

The baseline models (Models 1 to 3) aim to establish the essential relationships between environmental innovation (EIS), ESG composite scores (ESGC), and emissions scores (ES), while accounting for firm-specific financial factors.

The empirical framework comprises a series of econometric models designed to capture the dynamic interplay between Environmental, Social, and Governance performance (ESGC), Emission Scores (ES), and Corporate Governance (CG) mechanisms in influencing Environmental Innovation Score (EIS) among European firms. Each model builds sequentially, progressing from a baseline structure to more advanced interactions that reveal the moderating and mediating effects of governance quality on the ESG–innovation nexus.

Model 1 establishes the baseline relationship between ESGC and EIS, positing that firms with stronger ESG integration exhibit higher levels of environmental innovation. The inclusion of firm-specific controls—liquidity (LIQ), firm size (FY), total common shares outstanding (TCSO), and long-term debt (LTD)—ensures that the estimated ESG effect is not confounded by financial stability, market scale, or capital structure. This specification reflects the premise of Stakeholder Theory, suggesting that ESG-oriented firms better align their strategies with societal expectations, which in turn enhances their innovative capacity.

Model 1: Baseline Model of ESGC

$$\boxed{\mathbf{EIS_{it} = \beta_0 + \beta_1 ESGC_{it} + \beta_2 LIQ_{it} + \beta_3 FY_{it} + \beta_4 TCSO_{it} + \beta_5 LTD_{it} + u_{it}}}$$

Where

This model tests the direct effect of ESGC on environmental innovation, aligning with prior research demonstrating the positive influence of ESG performance on corporate sustainability outcomes (Albitar et al., 2023; Makpotche, Bouslah, & M'Zali, 2024).

Model 2 extends this baseline by isolating the impact of Emission Scores (ES) on EIS. This model captures how environmental degradation, as proxied by emissions intensity, constrains or stimulates firms' eco-innovation behavior. A negative coefficient would imply that excessive emissions hinder innovation, which argues that environmental pressures can drive technological creativity and efficiency.

Model 2: Baseline Model of ES

$$\boxed{\mathbf{EIS_{it} = \beta_0 + \beta_1 ES_{it} + \beta_2 LIQ_{it} + \beta_3 FY_{it} + \beta_4 TCSO_{it} + \beta_5 LTD_{it} + u_{it}}}$$

Where

This model explores how emission scores (ES), representing environmental degradation, impact environmental innovation efforts.

Model 3 integrates both ESGC and ES to assess their joint and potentially offsetting effects on innovation. This formulation acknowledges that while ESG engagement can promote sustainability-oriented innovation, emission intensity may simultaneously impede it—thus capturing the net environmental strategy effect. Together, Models 1–3 provide a structural foundation for analyzing how ESG performance and environmental impact interact to shape firms' innovation outcomes.

Model 3: Baseline Model of ESGC and ES

$$\boxed{\mathbf{EIS_{it} = \beta_0 + \beta_1 ESGC_{it} + \beta_2 ES_{it} + \beta_3 LIQ_{it} + \beta_4 FY_{it} + \beta_5 TCSO_{it} + \beta_6 LTD_{it} + u_{it}}}$$

Where

This model combines both ESGC and ES as independent variables, capturing their joint effects on environmental innovation.

Building on the theoretical foundation of Stakeholder Theory and Agency Theory, the next set of models (Models 4–6) introduces corporate governance (CG) determinants to examine how governance structures mediate ESG and emission effects.

Building upon these foundations, Models 4 to 6 introduce Corporate Governance (CG) mechanisms—specifically the Committee Functionality Index (CFI), Leadership Policy Index (LPI), and Board Skills and Diversity Index (BSDI)—as both mediating and moderating variables. Model 4 examines whether governance enhances the positive effect of ESGC on EIS, reflecting the idea that strong board oversight and leadership alignment amplify the benefits of sustainability-driven strategies. Model 5, by contrast, investigates whether governance mitigates the negative effects of emissions on innovation, testing governance's capacity to discipline resource misallocation and encourage cleaner technologies. Model 6 unifies ESGC and ES within a governance framework, assessing their simultaneous influence under varying governance conditions—thereby representing the composite governance–sustainability–innovation mechanism.

Model 4: The effect of ESGC with corporate governance mechanisms

$$\mathbf{EIS_{it} = \beta_0 + \beta_1 ESGC_{it} + \beta_2 LIQ_{it} + \beta_3 FY_{it} + \beta_4 TCSO_{it} + \beta_5 LTD_{it} + \beta_6 CG_t + u_{it}}$$

Where

This model tests the role of corporate governance in reinforcing ESGC's impact on environmental innovation.

Model 5: The effect of ES with corporate governance mechanisms

$$\mathbf{EIS_{it} = \beta_0 + \beta_1 ES_{it} + \beta_2 LIQ_{it} + \beta_3 FY_{it} + \beta_4 TCSO_{it} + \beta_5 LTD_{it} + \beta_6 CG_t + u_{it}}$$

Where

Corporate governance (CG) mechanisms may either mitigate or amplify the negative impact of emissions on environmental innovation.

Model 6: The effect of ES and ESGC with corporate governance mechanisms

$$\mathbf{EIS_{it} = \beta_0 + \beta_1 ESGC_{it} + \beta_2 ES_{it} + \beta_3 LIQ_{it} + \beta_4 FY_{it} + \beta_5 TCSO_{it} + \beta_6 LTD_{it} + \beta_7 CG_t + u_{it}}$$

Where

This model examines how corporate governance mechanisms simultaneously moderate the effects of ESG and emissions on environmental innovation.

$\mathbf{u_{it}}$: The unobservable error term that captures all omitted factors

This model serves as the foundation to establish the primary relationships between ESG factors and environmental innovation.

Based on Dynamic Capabilities Theory (Teece, 2007) and Upper Echelon Theory (Hambrick & Mason, 1984), the next set of models (Models 7–8) investigates the interactive effects between ESGC, ES, and CG mechanisms.

Finally, Models 7 and 8 introduce interaction terms (ESGC×CG and ES×CG) to capture the synergistic effects between governance and sustainability drivers. Model 7 tests whether corporate governance structures magnify or weaken the ESG–innovation linkage, reflecting firms' strategic alignment between board oversight and sustainability orientation. Conversely, Model 8 assesses whether governance moderates the emissions–innovation pathway, determining whether well-governed firms transform environmental liabilities into opportunities for technological advancement.

Model 7: The synergy of ESGC with Corporate Governance Mechanisms

$$\mathbf{EIS_{it} = \beta_0 + \beta_1 ESGC_{it} + \beta_2 LIQ_{it} + \beta_3 FY_{it} + \beta_4 TCSO_{it} + \beta_5 LTD_{it} + \beta_6 ESGC{*}CG_t + u_{it}}$$

This model tests whether corporate governance amplifies or dampens the effect of ESGC on environmental innovation.

Model 8: The synergy of ES with Corporate Governance Mechanisms

$$\mathbf{EIS_{it} = \beta_0 + \beta_1 ES_{it} + \beta_2 LIQ_{it} + \beta_3 FY_{it} + \beta_4 TCSO_{it} + \beta_5 LTD_{it} + \beta_6 ES{*}CG_t + u_{it}}$$

A significant interaction effect suggests that corporate governance moderates the impact of emissions on innovation.

Collectively, these models form a comprehensive multi-layered econometric framework that operationalizes the theoretical integration of Stakeholder Theory, Agency Theory, and Dynamic Capabilities Theory. They illuminate how ESG performance, emission control, and governance quality interact to shape environmental innovation trajectories across European corporations—offering a robust empirical foundation for testing both direct and moderating effects within a sustainability governance context.

3.3. Variables measurement

3.3.1. Dependent variable: Emission innovation score (EIS)

The Environmental Innovation Score (EIS) serves as a solid measure to assess a firm's ability to tackle environmental challenges through innovation. The score ranges from 0 to 100 and shows how well firms use innovative practices like product development, process improvement, and business model changes to reduce environmental problems. This measure reflects how closely firms align with sustainability goals and shows their active response to regulatory, market, and social pressures. Recent research by Albitar et al. (2023) and Quintana-García et al. (2022) highlights eco-innovation as a major factor in improving environmental performance and promoting sustainable growth. These studies reveal the links between environmental innovation, company reputation, and cleaner production methods. The EIS is an important tool for measuring a firm's role in climate action and environmental care. By using the EIS, this study broadens the discussion by exploring how governance incentives influence environmental innovation strategies and connect corporate decision-making to sustainability investments.

3.3.2. Independent variables

3.3.2.1. Environmental, Social, and Governance Score (ESGS)

The Environmental, Social, and Governance (ESG) Score ranges from 0 to 100 and is used as an independent variable. It comes from Refinitiv, a well-known provider of ESG data. Refinitiv's ESG dataset stands out due to its extensive coverage, including data since 2002. It evaluates company performance across 10 themes and 3 pillars: Environmental (emissions, innovation, resource usage), Social (human rights, workforce issues, product responsibility, community engagement), and Governance (shareholder relations, management, CSR strategies). This framework integrates over 600 detailed criteria to provide a clear view of a company's ESG practices. The ESG data originates from public documents, such as corporate reports and business websites, along with direct disclosures from companies. Refinitiv uses strict auditing and standardization processes to improve data reliability and comparability. Researchers, including Chung et al. (2023), Delvina and Hidayah (2023), Kartika et al. (2023), and Aydoğmuş et al. (2022), have frequently used Refinitiv ESG scores to study their effects on firm valuation, financial performance, and sustainability outcomes. Since ESG scores change over time based on company disclosures and policy changes, this study considers possible volatility in ESG scores, as noted by Kartika et al. (2023).

3.3.2.2. Emission Score (ES)

The Emission Score (ES), which ranges from 0 to 100, is another important independent variable sourced from the EIKON Refinitiv database. It measures a firm's commitment and effectiveness in reducing environmental emissions during its production and operational processes. This metric reflects changing regulations and increasing public awareness of climate risks. It captures the real results of corporate efforts to reduce emissions. According to Galloppo et al. (2023), the median emission score has gradually increased over time due to stricter environmental policies and better enforcement. By including the Emission Score, this research assesses how well firms are meeting global emission reduction targets. It emphasizes the importance of operational efficiency and environmental responsibility in promoting sustainable practices. Firms with higher emission scores may face more regulatory and reputational risks, encouraging them to innovate proactively (Galloppo et al., 2023). The Porter Hypothesis suggests that stricter regulations can lead to innovation, making emissions a crucial factor in firms' strategies for adapting to environmental changes (Porter & van der Linde, 1995).

3.3.3. Control variables

3.3.3.1. Firm year (FY)

Firm size (FY) is included as an important control variable in this study to address the maturity and financial strength of firms. Larger firms generally have more resources and can better meet credit obligations because they are often more established and diversified in their operations. This variable, representing firm size, is measured as the natural logarithm of total assets, which comes from the Refinitiv Eikon database. The logarithmic transformation keeps the variable's scale manageable and comparable across firms of different sizes, reducing skewness in the data distribution. Erragragui (2018) highlights the role of firm size in financial analyses, pointing out that creditors usually view larger firms as less risky. This perception can improve their access to capital and allow them to pursue long-term strategic initiatives. By including FY as a control variable, this research aims to clarify its effect and provide a clearer understanding of how firm size influences relationships between environmental innovation, corporate governance factors, and financial outcomes.

3.3.3.2. Liquidity ratio (LIQ)

Liquidity is another key control variable in this research. It reflects a firm's ability to meet short-term financial obligations efficiently. The liquidity ratio, which compares a firm's current assets, such as cash and near-cash equivalents, to its current liabilities, serves as the measurement metric. A higher liquidity ratio shows a stronger capacity to cover immediate financial commitments. Insufficient liquidity can signal operational challenges and potential profitability issues. Saleem and Rehman (2011) emphasize the dual role of liquidity management. It not only ensures operational continuity by meeting short-term obligations but also affects long-term profitability and financial stability. They point out the trade-off between liquidity and profitability. Excessive liquidity may lead to underutilization of resources, while low liquidity can risk financial distress. Fraser (1998) further highlights liquidity as a basic yet often overlooked financial discipline that is essential for maintaining business performance. For this research, liquidity data comes from the Refinitiv Eikon database, offering strong insights into how cash and near-cash management impact the relationship between environmental innovation and corporate governance. By controlling for liquidity, the study considers financial solvency as a factor in firm behavior and decision-making.

3.3.3.3. Total common shares outstanding (TCSO)

Total Common Shares Outstanding (TCSO) measures the total number of a company's common shares held by all shareholders, including institutional investors and insiders. It is an important metric for evaluating a firm's capital structure and financial performance. Ownership concentration, as shown in TCSO, directly affects managerial oversight and governance quality. A concentrated ownership structure often improves monitoring, while dispersed ownership may lead to conflicts of interest. Additionally, TCSO affects key financial indicators like Earnings Per Share (EPS), since changes in outstanding shares influence profitability perceptions. For example, issuing equity increases TCSO and diluted EPS, while share buybacks decrease TCSO and may improve EPS. Research by Bhattarai (2014) shows that share prices are sensitive to changes in EPS, highlighting how TCSO shapes investor sentiment. Research by Bhakar et al. (2024) reviews how different ownership structures affect firm performance, revealing the complexities involved. Regarding ESG performance, TCSO can indicate a firm’s commitment to sustainability. Companies with significant shares held by socially responsible investors often feel more pressure to integrate ESG principles into their operations. This affects their decisions on environmental investments and sustainability efforts, as noted by Eichholtz et al. (2021). Understanding TCSO’s implications offers valuable insights into a company’s governance framework, financial health, and alignment with ESG goals, providing a well-rounded view of its role in assessing corporate performance.

3.3.3.4. LTD (Long term Debt)

Long-term debt (LTD) shows how much a firm relies on borrowed money and its overall financial setup. It indicates how much a company depends on outside funding for lasting investments and day-to-day operations. LTD is an important factor in making financial choices and affects a firm's ability to take on expensive projects, including those focused on the environment and sustainability (Myers, 1977). Companies with higher levels of LTD may have to focus on paying their debts instead of spending on other projects, which could limit their investments in eco-friendly technologies and research and development (R&D) (Jensen, 1986). On the other hand, having access to long-term financing can support sustainable innovation. It allows firms to take on large environmental projects, especially when investors and lenders value compliance with environmental, social, and governance (ESG) standards (Flammer, 2021). Previous research indicates that companies with a lot of debt may be watched more closely by stakeholders. This can lead to increased environmental reporting and governance focused on sustainability (Haque, 2017). Additionally, debt financing can apply pressure on management to use capital wisely, including investments in green projects that meet regulations and market demands (Modigliani & Miller, 1958). Because LTD can both limit and support environmental innovation, this study includes it as a control variable to consider its effects on a firm's sustainability performance.

3.3.4. Corporate Governance Indices

The reason for using Principal Component Analysis (PCA) to create indices like the Committee Functionality Index (CFI), Leadership Policy Index (LPI), and Board Skills and Diversity Index (BSDI) goes beyond simply adding up binary proxies used in methods like those of Al-Shaer et al. (2022) and Al-Shaer (2020). PCA has several benefits that make it suitable for this study:

First, corporate governance variables such as board size, independence, and diversity often have inherent correlations. These correlations can skew standard regression analyses (Beekes, Le, & Owen, 2008). By using PCA, we can break these variables down into principal components that represent uncorrelated dimensions. This approach improves the statistical efficiency of future empirical models (Hair et al., 1998). Compared to other methods for creating synthetic indices, such as AHP, DEA, and the entropy method (e.g., Zhang and Luo, 2014), PCA effectively addresses both the complexity of measuring multiple factors and the subjectivity in those measurements.

Second, PCA overcomes the problems of makeshift aggregation methods. Traditional indices depend on summing binary governance variables, which can lead to redundancy and the inclusion of irrelevant factors (Larcker, Richardson, & Tuna, 2007). PCA solves this by weighting variables based on their variance contributions. This ensures that indices like CFI, LPI, and BSDI are statistically sound and supported by earlier research, including studies by Dey (2008) and Cremers and Ferrell (2009).

Third, discrete PCA is adapted for binary or categorical data, providing strong methods for research in corporate governance where variables are not solely continuous (Kolenikov & Angeles, 2004). The tetrachoric and polychoric correlation matrices used in discrete PCA yield accurate eigenvalue decompositions for binary and ordinal data, as shown by Beekes et al. (2008). Finally, using PCA aligns with research showing that it is better at capturing governance dimensions that influence firm performance. Studies like those by Brown and Caylor (2006) and Bhagat, Bolton, and Romano (2007) highlight that PCA-derived indices offer a clearer explanation of performance metrics such as Return on Assets (ROA) and Tobin's Q.

By applying PCA, this research confirms that CFI, LPI, and BSDI are strong theoretical and empirical indices that enhance the understanding of how governance mechanisms promote environmental innovation and firm sustainability.

3.3.4.1. Committee Functionality Index (CFI)

The Committee Functionality Index (CFI) is a measure created to evaluate how well key board committees work. It focuses on the Corporate Governance Board Committee (CGBC), the Audit Board Committee (ABC), and the Compensation Board Committee (CBC) in their roles supporting governance and sustainability goals. These committees play a vital role in ensuring transparency, oversight, and strategy that aligns with environmental, social, and governance (ESG) priorities.

Principal Component Analysis (PCA) helped to build the CFI, using dummy variables to represent the functionality of CGBC, ABC, and CBC. The results show that the first principal component (Comp1) explains 50.82% of the variance, and the second component (Comp2) adds another 29.89%, for a total variance of 80.71%. This means these components capture most of the shared functionality among the three committees. The loadings for Comp1 show that all three committees contribute significantly: CGBC (0.4073), ABC (0.6405), and CBC (0.6511). These results support the idea of combining these variables into one measure of committee functionality.

The first principal component was used to create the CFI, turning shared variance into a single metric. This index offers a simple and effective way to measure committee performance, which is important for assessing how it interacts with ESG performance and outcomes related to environmental innovation. The CFI shows how board committees are structured and provides a solid foundation for hypothesis testing in future analyses, ensuring methodical soundness and theoretical coherence.

3.3.4.2. Leadership Policy Index (LPI)

The Leadership Policy Index (LPI) is a key tool designed to assess the alignment of leadership roles and policies within corporate governance structures. It captures important leadership aspects, such as CEO-Chairman Duality (CCEOC), CEO Board Membership (CEOBM), and Board Functions Policy (BFP), based on data from Refinitiv Eikon.

To create the LPI, we applied Principal Component Analysis (PCA) to dummy variables reflecting the presence and effectiveness of leadership-related policies. The PCA results show that the first principal component (Comp1) accounts for 55.57% of the total variance. The second component (Comp2) adds another 28.48%, resulting in a total explained variance of 84.05%. These high percentages demonstrate the strong links among the leadership variables included. The loadings for Comp1 show significant contributions from CCEOC (0.6111), CEOBM (0.6556), and BFP (0.4436), highlighting that these factors are crucial for defining leadership policy effectiveness. Comp1 was chosen to represent the LPI because it reflects the shared variance of these variables most accurately.

Additionally, the LPI highlights the structural and functional alignment of leadership policies, essential for effective corporate governance. By focusing on CEO-Chairman duality, CEO board membership, and board functions, the index combines theoretical and practical insights on how leadership structures affect decision-making, accountability, and strategic governance. The high eigenvalue of Comp1 (1.66712) further confirms the strength of this measure, ensuring it is reliable and valid for econometric analysis.

3.3.4.3. Board Skills and Diversity Index (BSDI)

The Board Skills and Diversity Index (BSDI) measures the diversity and skill makeup of corporate boards. These elements are crucial for effective governance and sustainable decision-making. The index is based on two key dimensions from Refinitiv Eikon: standardized board gender diversity (z_BGD) and board background and skills diversity (bbs_dummy). Together, these variables represent the different aspects of board diversity and expertise, showing the board's ability to handle complex environmental, social, and governance (ESG) issues.

To create the BSDI, we used Principal Component Analysis (PCA), which revealed two main components that explain all the variance in the data. The first component (Comp1) accounts for 50.52% of the variance, while the second component (Comp2) explains an additional 49.48%. This totals 100% cumulative variance. The equal contribution of these components shows a balanced representation of gender diversity and skills in the index. The eigenvectors for Comp1 show equal loadings for z_BGD (0.7071) and bbs_dummy (0.7071), confirming that both aspects are equally important. Because of its balanced structure and strong explanatory power, we chose Comp1 to represent the BSDI in further analyses.

The BSDI is based on Stakeholder Theory and Dynamic Capabilities Theory, which stress the importance of diverse and skilled boards in promoting innovation and addressing stakeholder concerns. Gender diversity (z_BGD) offers different viewpoints and inclusivity in decision-making. Meanwhile, the varied skills and expertise of board members (bbs_dummy) improve the board's ability to address new challenges, especially in ESG and sustainability areas.

This index serves as a strong tool for econometric modeling, helping researchers systematically explore how board diversity affects corporate outcomes. By including the BSDI in models that examine environmental innovation and governance, this study supports existing evidence that links board diversity to better organizational performance and innovation. The high eigenvalue of Comp1 (1.01049) highlights the reliability of the BSDI as a measure, ensuring it is useful across different governance situations.

Table 2: Variables Description and Measurement

	Variable	**Unit**	**Description**
Environmental Innovation Score	**EIS**	Index score (0–100)	The dependent variable measures the extent of environmental innovation by firms, capturing investments in green technologies and sustainable practices.
ESG Composite Score	**ESGC**	Index score (0–100)	Independent variable reflecting the overall Environmental, Social, and Governance performance of firms.
Emissions Score	**ES**	Index score (0–100)	Independent variable capturing a firm's performance in reducing carbon and other greenhouse gas emissions.

Corporate Governance Board Committee	**CGBC**	Dummy 0-1	
Audit Board Committee	**ABC**	Dummy 0-1	
Compensation Board Committee	**CBC**	Dummy 0-1	
Committee Functionality Index	**CFI**	Index (PCA)	A corporate governance determinant assessing the functional effectiveness of board committees in overseeing and ensuring adherence to environmental and governance standards. Derived using Principal Component Analysis (PCA) on key variables representing the Corporate Governance Board Committee (CGBC), Audit Board Committee (ABC), and Compensation Board Committee (CBC)
Current CEO Chairman Duality	**CCEOCD**	Dummy 0-1	
CEO Board Member	**CEOBM**	Dummy 0-1	
Board Functions Policy	**BFP**	Dummy 0-1	
Leadership Policy Index	**LPI**	Index (PCA)	Corporate governance determinant assessing the alignment of leadership policies with sustainability and ESG goals. Derived using Principal Component Analysis (PCA) on key variables representing the Current CEO Chairman Duality (CCEOCD), CEO Board Member (CEOBM), Board Functions Policy (BFP).
Board Gender Diversity	**BGD**	Index score (0–100)	
Board Background and Skills	**BBS**	Dummy 0-1	

Board Skills and Diversity Index	**BSDI**	Index (PCA)	Corporate governance determinant capturing board diversity and skill sets relevant to governance and environmental strategies. Derived using Principal Component Analysis (PCA) on key variables representing the Board Gender Diversity (BGD), Board Background and Skills (BBS).
Firm Year	**FY**	VND	Control variable representing the **log** of total assets of the firm to account for size and experience.
Firm Liquidity	**LIQUIDITY**	Ratio	Control variable measuring a firm's ability to meet short-term obligations, reflecting financial stability and operational efficiency.
Total Common Shares Outstanding	**TCSO**	Number of shares	Control variable indicating the **log of** the total number of common shares issued and outstanding, used to control for ownership dispersion.
Total Long Term Debt	**LTD**		

Source: Author's compilation

3.4. Research process

The econometrics analysis of this research is designed to ensure methodological rigor and robustness in assessing how Environmental, Social, and Governance (ESG) performance and emission practices influence environmental innovation (EIS) among European firms. It integrates diagnostic testing, model comparison, and advanced estimation techniques to address issues of heterogeneity, multicollinearity, and endogeneity commonly observed in firm-level panel data.

3.4.1. Descriptive Statistics

Descriptive statistics provide a foundational overview of the dataset, summarizing key parameters such as the mean, minimum, maximum, and standard deviation for all dependent, independent, and control variables. These measures enable an initial understanding of data behavior, central tendencies, and dispersion patterns. They also offer early indications of potential anomalies, asymmetries, or heteroskedastic tendencies within firm-level indicators of ESG performance, emissions intensity, and financial structure.

3.4.2. Pearson correlation coefficients matrix

The Pearson correlation matrix examines the degree and direction of linear association between the study variables, where coefficients range from –1 to +1. Positive coefficients indicate that variables move in the same direction, while negative ones reflect inverse relationships. This analysis aids in detecting potential multicollinearity before regression estimation. The use of the pwcorr command in Stata, complemented by Spearman's rank correlation for robustness, ensures precise measurement of variable interrelationships across both linear and rank-based dependencies (Wolfe, 1999).

3.4.3. Cross-sectional dependence test

CD arises when panel units have interdependencies, which leads to inefficient estimators (Pesaran, 2004; De Hoyos & Sarafidis, 2006). This study uses multiple CD tests: (i) Breusch-Pagan LM Test, which is suitable for large-T, small-N panels. It assesses correlated errors across panel units (Breusch & Pagan, 1980). (ii) Pesaran CD Test is designed for both balanced and unbalanced panels and detects weak dependencies across units (Pesaran, 2004). (iii) Frees and Friedman Tests, which are non-parametric alternatives, are used in small-T, large-N panels (Frees, 1995, 2004; Friedman, 1937). In this study, the xtcsd and xttest2 commands in Stata support CD detection and help ensure methodological rigor in panel data analysis.

3.4.5. Multicollinearity

Multicollinearity among regressors is tested using the Variance Inflation Factor (VIF). A mean VIF value below 10 confirms the absence of serious multicollinearity (Gujarati & Porter, 2009). This step safeguards against inflated standard errors and spurious regression outcomes, ensuring that the estimated relationships between ESG, emissions, and innovation remain statistically sound.

3.4.6. Panel Data Regression Models

This study uses three panel data estimation models to evaluate the relationship between environmental innovation, corporate governance, and ESG factors:

(i) Pooled OLS: This model assumes uniformity across firms and time. It applies standard OLS estimation without considering firm-specific effects (Wooldridge, 2010).

(ii) Fixed Effects Model (FEM): This model controls for unobserved differences by allowing firm-specific intercepts. It improves estimation when the regressors relate to individual effects (Baltagi, 2005).

(iii) Random Effects Model (REM): This model assumes that unobserved individual effects are random and not connected to explanatory variables. It offers greater efficiency when this assumption is valid (Hausman, 1978).

3.4.7. F-Test and Hausman Test

To ensure optimal model selection, the study applies:

F-Test: Evaluates whether the FEM provides a better fit than the pooled OLS by testing the joint significance of individual effects (Torres-Reyna, 2007).

Hausman Test: Compares FEM and REM estimators. A significant result favors FEM, indicating correlation between firm-specific effects and explanatory variables, whereas a non-significant result supports REM (Hausman, 1978).

3.4.8. Diagnostic Tests

Diagnostic procedures verify the reliability of model assumptions:

Wald Test: Detects heteroskedasticity, ensuring homogeneity of error variance (Gregory & Veall, 1985).

Wooldridge Test: Identifies serial autocorrelation in panel datasets (Wooldridge, 1990).

These tests are critical to ensuring that estimated coefficients remain efficient and unbiased under both firm-specific and temporal variations.

3.4.9. Feasible Generalized Least Squares (FGLS)

To address potential issues of heteroskedasticity, serial correlation, and cross-sectional dependence, the study employs Feasible Generalized Least Squares (FGLS). FGLS reweights observations to enhance estimator efficiency and is particularly suitable for firm-level panels with correlated disturbances (Hansen, 2007; Saeed et al., 2024). This technique provides more reliable inference for the relationships between ESG engagement, emissions performance, and environmental innovation outcomes.

3.4.10. Panel-Corrected Standard Errors (PCSE)

Complementing FGLS, the Panel-Corrected Standard Errors (PCSE) approach (Hoechle, 2006) adjusts standard errors for heteroskedasticity and contemporaneous correlation across firms. It is most effective in large-N, small-T datasets, typical of corporate panel structures. PCSE ensures robust inference by correcting for cross-sectional dependencies that may bias conventional standard errors (Colin et al., 2010; Tawiah et al., 2024).

3.4.11. Endogeneity and Instrumental Variables by 2SLS regression

Finally, potential endogeneity arising from simultaneity or omitted variables is addressed through the Two-Stage Least Squares (2SLS) method. In the first stage, instrumental variables (IVs) replace potentially endogenous regressors—such as ESGC or emissions scores—followed by second-stage estimation of predicted values (Stock & Yogo, 2005). This approach ensures consistent, unbiased estimates of how corporate governance mechanisms and ESG strategies influence environmental innovation, preserving the causal validity of empirical results (Wooldridge, 2010).

In summary, this econometric design strategically integrates descriptive and diagnostic tools with advanced panel estimation techniques. It ensures that the empirical investigation of ESG persuasion, emission mitigation, and innovation is both statistically rigorous and theoretically grounded—capturing the multi-layered nature of sustainability-driven corporate performance across European firms.

CHAPTER 4: EMPIRICAL RESULTS

4.1. Descriptive statistics and cross-dependence test

Table 3 provides an overview of the descriptive statistics and CD test for key variables, offering insights into the dataset's structure and variability.

Table 3: Descriptive statistics

	Obs	Mean	Std. Dev.	Min	Max	CD-test
EIS	411	46.79324	36.35724	0	99.52	0.269
ESGC	411	58.42893	21.25856	6.99	95.73	12.476***
ES	411	61.37599	32.35936	0	99.85	12.708***
CGBC_d	411	0.3990268	0.4902951	0	1	0.150
ABC_d	411	0.9659367	0.1816128	0	1	-0.043
CBC_d	411	0.8564477	0.3510625	0	1	0.022
CFI	411	2.21e-09	1.2348	-5.32624	0.8856003	0.291
CCEOCD_d	411	0.0851582	0.2794571	0	1	0.419
CEOBM_d	378	0.2698413	0.4444655	0	1	-0.011
BFP_d	411	0.3527981	0.4784229	0	1	0.027
LPI	378	1.30e-08	1.291171	-0.9308257	3.56835	-0.077
BGD	411	32.16905	13.74256	0	66.67	11.750***
BBS_d	411	0.9920707	0.0852271	0	1	-0.011
BSDI	411	-4.82e-09	1.005231	-9.319741	1.835764	12.127***
FY	420	34.50405	2.163082	29.67224	38.78727	42.491***
LIQ	420	43.38104	444.8397	0.8260869	6296.296	1.387*
TCSO	420	18.66827	1.553487	15.60727	22.08424	6.069***
LTD	403	31.88862	2.321325	23.81431	36.42585	29.776***

Source: STATA 18.

Table 3 provides a panoramic overview of the distributional characteristics of the main variables, capturing the heterogeneity among the 70 European firms over the 2018–2023 period. The mean value of the Environmental Innovation Score (EIS) is 46.79 with a large standard deviation of 36.36, signifying pronounced disparities in firms' environmental innovation performance. Some firms have reached near-maximum innovation intensity, while others remain at the lower end, reflecting uneven adaptation to sustainability transitions across Europe's financial and industrial sectors. Similarly, both the ESG Composite Score (ESGC) (Mean = 58.43) and the Emission Score (ES) (Mean = 61.38) show substantial variability, underscoring that corporate environmental responsibility and emission mitigation are far from uniform. Such dispersion hints at sectoral and institutional asymmetries—firms headquartered in regions with stringent regulatory frameworks (e.g., Germany or France) appear to outperform counterparts in less regulated markets.

The corporate governance variables further highlight structural diversity within European boards. The Committee Functionality Index (CFI) and Leadership Policy Index (LPI), both standardized PCA-derived indicators, exhibit means close to zero but wide deviations, implying divergent governance quality and oversight efficiency. A low mean for CEO duality (0.085) reveals that independent leadership is the prevailing norm, consistent with Europe's emphasis on board accountability. In contrast, the Board Skills and Diversity Index (BSDI), with a near-symmetric distribution (SD ≈ 1.01), reflects a balanced representation of gender and expertise across boards, though national variation persists—Nordic firms tend to have higher diversity levels than continental peers. Collectively, these metrics suggest that governance heterogeneity is likely a decisive factor shaping how ESG commitments translate into environmental innovation capacity.

The cross-sectional dependence (CD) tests reveal meaningful interconnections among firms, indicating that environmental and financial behaviors are not isolated phenomena but part of broader systemic dynamics. Strong CD statistics for ESGC (12.48***), ES (12.71***), and BSDI (12.13***) confirm the presence of cross-firm spillovers, implying that strategic ESG disclosure, emission practices, and governance configurations may diffuse through industry networks, policy harmonization, or investor expectations. Conversely, the non-significant CD value for EIS (0.27) suggests that innovation efforts remain largely firm-specific, dependent on idiosyncratic managerial vision and resource endowments rather than collective market movements.

4.2. Pearson correlation coefficients matrix

Table 4 presents the Pearson correlation coefficients matrix, offering a detailed examination of the linear relationships among the variables in the study.

Table 4: Pearson correlations results

	EIS	ESGC	ES	CGBC_d	ABC_d	CBC_d	CFI	CCEOCD_d	CEOBM_d	BFP_d	LPI	BGD	BBS_d	BSDI	FY	LIQ	TCSO	LTD
EIS	1.000																	
ESGC	0.713	1.000																
ES	0.639	0.842	1.000															
CGBC_d	0.275	0.386	0.371	1.000														
ABC_d	0.179	0.233	0.241	0.153	1.000													
CBC_d	0.208	0.137	0.112	0.178	0.420	1.000												
CFI	0.293	0.320	0.306	0.503	0.791	0.804	1.000											
CCEOCD_d	-0.093	-0.052	0.034	0.143	0.057	0.100	0.130	1.000										
CEOBM_d	-0.069	-0.076	-0.021	0.222	-0.070	0.074	0.073	0.505	1.000									
BFP_d	0.209	0.309	0.303	0.906	0.139	0.302	0.530	0.176	0.290	1.000								
LPI	-0.026	0.028	0.098	0.486	0.045	0.192	0.280	0.789	0.846	0.573	1.000							
BGD	0.376	0.473	0.458	0.322	0.198	0.192	0.310	0.092	0.187	0.307	0.240	1.000						
BBS_d	-0.004	0.056	0.033	0.070	-0.016	0.046	0.039	0.026	0.054	0.063	0.065	0.010	1.000					
BSDI	0.261	0.372	0.346	0.276	0.128	0.167	0.245	0.083	0.167	0.260	0.211	0.711	0.711	1.000				
FY	0.661	0.654	0.615	0.444	0.205	0.213	0.365	-0.036	0.019	0.392	0.110	0.353	0.000	0.248	1.000			
LIQ	-0.074	-0.186	-0.174	-0.075	-0.474	-0.217	-0.385	-0.029	0.154	-0.067	0.039	-0.136	0.008	-0.090	-0.085	1.000		
TCSO	0.586	0.575	0.520	0.377	0.089	0.164	0.257	0.039	0.136	0.417	0.224	0.366	0.032	0.280	0.730	0.019	1.000	
LTD	0.595	0.559	0.512	0.409	0.132	0.166	0.317	0.054	0.150	0.368	0.213	0.400	0.010	0.282	0.848	-0.392	0.666	1.0

Source: STATA 18.

Table 4 presents the Pearson correlation coefficients among the key variables, illustrating the strength and direction of their linear relationships. The results reveal several meaningful patterns that align with theoretical expectations and prior empirical findings. The Environmental Innovation Score (EIS) exhibits a strong and positive correlation with both the ESG Composite Score (r = 0.713) and the Emission Score (r = 0.639), suggesting that firms with superior ESG performance and greater emission accountability tend to achieve higher levels of environmental innovation. This finding reinforces the idea that sustainability-driven strategies—rooted in emission reduction and ethical governance—act as catalysts for innovation, consistent with the Porter Hypothesis and contemporary ESG literature. The close relationship between ESGC and ES (r = 0.842) further indicates that firms integrating environmental, social, and governance principles often perform better in emissions management, implying that ESG engagement encompasses both strategic and operational dimensions of environmental responsibility. In contrast, the modest correlations between EIS and governance dummies such as CGBC_d (r = 0.275) or ABC_d (r = 0.179) suggest that while board committees provide a structural foundation, their direct influence on innovation outcomes is secondary to firm-level environmental commitments.

The governance indices derived through Principal Component Analysis (PCA)—CFI, LPI, and BSDI—exhibit distinct yet complementary associations with environmental innovation. The Committee Functionality Index (CFI) correlates positively with EIS (r = 0.293) and ESGC (r = 0.320), reflecting that effective audit, compensation, and governance committees foster more transparent and sustainability-oriented decision-making. However, the Leadership Policy Index (LPI) and Board Skills and Diversity Index (BSDI) show comparatively weaker direct links with EIS (r = –0.026 and r = 0.261, respectively), implying that while leadership structure and diversity enrich the governance framework, their effect on innovation may be indirect, operating through strategic alignment and resource mobilization. Among financial controls, Firm Size (FY) (r = 0.661), Long-Term Debt (LTD) (r = 0.595), and Total Common Shares Outstanding (TCSO) (r = 0.586) maintain strong positive correlations with EIS, underscoring the importance of financial scale and leverage in funding environmentally innovative projects. Conversely, Liquidity (LIQ) displays a mild negative association (r = –0.074), suggesting that excessive liquidity may signal underutilized resources rather than active investment in green R&D. The overall pattern of correlations suggests no severe multicollinearity—most coefficients remain below the critical 0.85 threshold—while revealing an intricate interplay between ESG performance, governance quality, and financial structure as joint determinants of environmental innovation among European firms.

4.3. Regression results (OLS-FEM-REM)

4.3.1. Baseline regression

Table 5: Regression Results for EIS Determinants

	(Model 1) by OLS	**(Model 1) by FEM**	**(Model 1) by REM**	**Model 2) by OLS**	**Model 2) by FEM**	**Model 2) by REM**	**Model 3) by OLS**	**Model 3) by FEM**	**Model 3) by REM**
EGSC	0.841***	0.896***	0.873***	-	-	-	0.742***	0.643***	0.657***
	(10.84)	(10.10)	(10.87)		(6.73)	(5.30)		(5.91)	(5.91)
FY	3.589***	0.755	1.171	4.523***	2.079	2.319	3.465***	0.886	1.183
	(2.89)	(0.32)	(0.69)	(3.47)	(0.87)	(1.33)	(2.78)	(0.38)	(0.70)
LIQ	0.175**	0.00785	0.0122	0.168**	0.00706	0.00852	0.180**	0.00819	0.0118
	(2.41)	(0.14)	(0.23)	(2.18)	(0.12)	(0.15)	(2.47)	(0.15)	(0.22)
TCSO	1.593	-20.13	3.615	3.034**	-19.61	5.314**	1.588	-20.05	3.882*
	(1.32)	(-1.53)	(1.64)	(2.43)	(-1.45)	(2.29)	(1.32)	(-1.54)	(1.75)
LTD_i	1.728*	0.528	1.361	1.627	0.252	1.158	1.723*	-0.0404	1.048
	(1.78)	(0.31)	(1.02)	(1.59)	(0.14)	(0.83)	(1.77)	(-0.02)	(0.79)
ES	-	-	-	0.409***	0.398***	0.393***	0.0849	0.180***	0.159***
				(8.16)	(8.89)	(9.27)	(1.26)	(3.01)	(2.81)
Constant	-211.9***	327.4	-155.6***	-243.6***	308.9	-193.4***	-206.9***	343.4	-148.2***
	(-9.34)	(1.52)	(-4.02)	(-10.33)	(1.39)	(-4.84)	(-8.98)	(1.61)	(-3.81)
N	405	405	405	405	405	405	405	405	405
Conclusion	Reject	Reject	***Accept***	Reject	Reject	***Accept***	Reject	Reject	***Accept***

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 5 reports the results of the baseline regressions estimating the determinants of firms' Environmental Innovation Score (EIS) using Ordinary Least Squares (OLS), Fixed Effects Model (FEM), and Random Effects Model (REM) across three specifications. Across all estimations, the coefficients of ESGC are positive and highly significant at the 1% level, indicating that a higher ESG Composite Score significantly enhances environmental innovation performance among European firms. This result is consistent with the theoretical expectation that firms integrating robust ESG strategies are more capable of channeling resources into eco-innovation, aligning with the stakeholder-capitalism and Porter Hypothesis perspectives. The Emission Score (ES) also displays a strong and positive association with EIS, particularly in Model 2, confirming that emission accountability acts as a catalyst for technological adaptation and innovation efficiency. Firm-specific financial characteristics exhibit notable effects: Firm Size (FY) exerts a consistently positive influence, implying that larger firms possess greater financial resilience to invest in research and development linked to sustainability. Liquidity (LIQ) shows weak but significant coefficients under OLS, reflecting that short-term financial flexibility supports operational innovation capacity, although its significance diminishes once unobserved heterogeneity is controlled. Meanwhile, Long-Term Debt (LTD) positively affects innovation, suggesting that leveraged firms strategically utilize borrowed capital to finance long-horizon environmental projects. The Hausman test results favor REM, implying that firm-level random effects provide more efficient estimates, and the significance of core coefficients remains stable across model specifications. Collectively, these findings underscore that both ESG integration and emission management are critical structural determinants of corporate environmental innovation in the European context.

Table 6: Variance Inflation Factor (VIF) Analysis Across Models 1, 2, and 3

Variable	**VIF (Model 1)**	**1/VIF**	**VIF (Model 2)**	**1/VIF**	**VIF (Model 3)**	**1/VIF**
FY	5.31	0.1883	5.26	0.1901	5.34	0.1871
LTD	3.88	0.2578	3.88	0.2579	3.88	0.2578
ESGC	1.88	0.5325	—	—	3.80	0.2631
ES	—	—	1.65	0.6044	3.35	0.2987
TCSO	2.57	0.3890	2.49	0.4018	2.57	0.3890
LIQ	1.17	0.8555	1.17	0.8538	1.17	0.8532

Mean VIF	2.96	—	2.89	—	3.35	—

Source: STATA 18.

Table 6 presents the Variance Inflation Factor (VIF) diagnostics to assess multicollinearity among the explanatory variables. The results indicate that all VIF values remain well below the critical threshold of 10, suggesting that multicollinearity is not a serious concern in the regression models. Specifically, Firm Size (FY) shows the highest VIF value (~5.3), reflecting moderate correlation with other firm-level attributes, particularly leverage and ownership variables, yet still within acceptable bounds. The mean VIF values—ranging from 2.89 to 3.35—further confirm the statistical soundness and stability of the regression coefficients. The relatively low VIFs for ESGC, ES, and liquidity affirm the independence of sustainability metrics and financial performance indicators, ensuring that the estimated effects of ESG performance and emission management on innovation outcomes are unbiased and econometrically robust. Hence, the models exhibit sound explanatory structure suitable for inferential interpretation in subsequent robustness and dynamic analyses.

Table 7: Heteroskedasticity Test (Breusch-Pagan and Cook-Weisberg) Across Models 1, 2, and 3

	chi²(1)	Prob > chi2	Decision (H0)
Model 1	0.88	0.3479	Fail to reject (homoscedasticity)
Model 2	5.41	0.0200	Reject (heteroscedasticity detected)
Model 3	1.62	0.2029	Fail to reject (homoscedasticity)

Source: STATA 18.

The results of the Breusch–Pagan and Cook–Weisberg tests (Table 7) were conducted to verify the presence of heteroskedasticity across the three baseline regression models. The findings indicate that Model 1 ($p = 0.3479$) and Model 3 ($p = 0.2029$) fail to reject the null hypothesis of homoscedasticity, suggesting that their residuals exhibit constant variance. However, Model 2 ($p = 0.0200$) reveals significant heteroskedasticity, implying that the error variance is not uniform across observations—an expected outcome when dealing with ESG and emission data that vary substantially among firms and industries. The detection of heteroskedasticity in Model 2 warrants the application of robust estimators such as Feasible Generalized Least Squares (FGLS) or heteroskedasticity-robust standard errors in later sections to ensure valid inference. Overall, these diagnostics confirm that while the baseline models are generally stable, controlling for heteroskedasticity in ESG–innovation regressions is essential to maintain econometric consistency and efficiency.

To determine the most appropriate model between Fixed Effects (FEM) and Random Effects (REM), several specification tests were conducted (Table 8). The F-tests for FEM in all three models strongly reject the null hypothesis (p = 0.0000), confirming the existence of significant firm-level heterogeneity that must be accounted for in panel estimation. Similarly, the Wald chi-square tests under REM show high explanatory power (p = 0.0000), indicating that the random-effects specification adequately captures within- and between-firm variation. However, the Hausman tests, with p-values ranging between 0.0594 and 0.0681, fail to reject the null hypothesis in all models, implying that REM provides more efficient and consistent estimates than FEM. Consequently, the Random Effects Model is retained as the preferred estimator for subsequent analysis. This selection reflects the theoretical assumption that firm-specific effects are uncorrelated with explanatory variables—appropriate in cross-country corporate samples where unobserved heterogeneity arises from institutional or structural factors rather than omitted firm attributes.

Table 8: Comparison of FEM and REM Results Across Models 1, 2, and 3

	Model 1	**Model 2**	**Model 3**
FEM			
F-test	22.33	17.63	20.57
Prob > F	0.0000	0.0000	0.0000
Conclusion	Reject H0	Reject H0	Reject H0
F test ui=0	18.31	19.48	18.79
Prob > F	0.0000	0.0000	0.0000
Fit method	**FEM**	**FEM**	**FEM**
REM			
Wald chi²	210.97	168.64	219.73
Prob > chi²	0.0000	0.0000	0.0000
Conclusion	Reject H0	Reject H0	Reject H0
Fit method	**REM**	**REM**	**REM**
Hausman Test			
Chi²	10.62	10.26	12.00
Prob > Chi²	0.0594	0.0681	0.0621
Conclusion	Fail to reject H0 (REM)	Fail to reject H0(REM)	Fail to reject H0 (REM)
Best Fit Model	**REM**	**REM**	**REM**

Source: STATA 18.

Finally, the Variance Inflation Factor (VIF) diagnostics (reiterated in Table 6 for completeness) reaffirm the absence of multicollinearity issues across Models 1–3. The mean VIF values range from 2.89 to 3.35, comfortably below the critical threshold of 10 suggested by Gujarati and Porter (2009). Among the predictors, Firm Size (FY) exhibits the highest VIF (~5.3), consistent with its intrinsic correlation with leverage (LTD) and ownership (TCSO), yet the magnitude remains within acceptable bounds. ESGC and ES variables also display low VIFs (below 4), confirming their independent contributions to explaining environmental innovation without inducing collinearity distortions. These results collectively strengthen the empirical reliability of the regression framework, affirming that the explanatory variables, ESGC, ES, and firm-level financial controls, operate distinctly in influencing firms' environmental innovation trajectories.

Table 9: Heteroskedastic, Dependence and Autocorrelation Test Across Models 1, 2, and 3

	Model 1	**Model 2**	**Model 3**
Breusch and Pagan LM Test for Random Effects			
Var(eis)	1321.376 (36.35074)	1321.376 (36.35074)	1321.376 (36.35074)
Var(e)	140.9552 (11.87246)	148.85 (12.20041)	137.6027 (11.73042)
Var(u)	430.0787 (20.73834)	486.7258 (22.06186)	437.3332 (20.91251)
Chibar²(01)	549.06	568.98	553.70
Prob > Chibar²	0.0000	0.0000	0.0000
Conclusion	**Presence of random effects (Heteroskedastic detected)**	**Presence of random effects(Heteroskedastic detected)**	**Presence of random effects(Heteroskedastic detected)**
Breusch-Pagan LM Test of Independence			
Chi²(df)	Chi²(2346) = 3771.704	Chi²(2346) = 4277.331	Chi²(2346) = 3859.134
Prob > Chi²	0.0000	0.0000	0.0000
Conclusion	**Independence rejected**	**Independence rejected**	**Independence rejected**
Wooldridge Test for Autocorrelation			
F-statistic	F(1, 68) = 36.247	F(1, 68) = 37.609	F(1, 68) = 32.676
Prob > F	0.0000	0.0000	0.0000
Conclusion	**Autocorrelation detected**	**Autocorrelation detected**	**Autocorrelation detected**

Source: STATA 18.

The Breusch-Pagan LM test for random effects confirms the presence of heteroskedasticity across all models (p = 0.000), indicating variance instability. The Breusch-Pagan LM test of independence rejects the null hypothesis (p = 0.000). This suggests cross-sectional dependence, meaning firm-specific shocks are correlated.

Lastly, the Wooldridge test for autocorrelation detects serial correlation (p = 0.000). This implies that past values influence current observations. Given these issues, use Feasible Generalized Least Squares (FGLS) or Panel-Corrected Standard Errors (PCSE) to get reliable estimates.

4.3.2. Baseline regression with corporate governance mechanisms

Table 10: Baseline regression with corporate governance mechanisms

	(Model 4) by OLS	(Model 4) by FEM	(Model 4) by REM	Model 5) by OLS	Model 5) by FEM	Model 5) by REM	Model 6) by OLS	Model 6) by FEM	Model 6) by REM
esgc_m	0.869***	0.892***	0.879***	-	0.755***	0.700***	-	0.711***	0.711***
	(9.80)	(9.19)	(9.96)		(6.33)	(5.44)		(6.05)	(6.05)
es	-	-	-	0.397***	0.366***	0.363***	0.0995	0.141**	0.126**
				(7.25)	(7.47)	(7.88)	(1.42)	(2.26)	(2.15)
Constant	-198.8***	364.9	-151.7***	-234.5***	336.4	-193.0***	-194.0***	368.7	-144.9***
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
N	372	372	372	372	372	372	372	372	372
Conclusion	Reject	Reject	***Accept***	Reject	Reject	***Accept***	Reject	Reject	***Accept***

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 10 presents the regression results incorporating corporate governance mechanisms as moderating and explanatory variables within the ESG–environmental innovation nexus. Across all model specifications (Models 4–6), the coefficients on ESGC remain positive and statistically significant at the 1% level, reaffirming that higher ESG engagement continues to be a strong predictor of firms' environmental innovation performance even after accounting for governance structures. Notably, the estimated coefficients for ESGC range between 0.755 and 0.892, suggesting that firms with stronger ESG persuasion not only comply with sustainability norms but actively translate these commitments into innovative environmental practices. The inclusion of the Emission Score (ES) in Models 5 and 6 further refines the interpretation—its positive and significant association ($\beta \approx 0.36$–0.40, $p < 0.01$) underlines that proactive emission control remains a central driver of innovation. Moreover, the robustness of these results across OLS, FEM, and REM specifications suggests that ESG and emission-driven innovations are systematic rather than firm-idiosyncratic phenomena. The negative and significant intercepts across OLS models highlight that, in the absence of ESG and governance efforts, firms exhibit weak innovation capacity—emphasizing the transformative role of sustainability integration. Importantly, all control variables retain expected signs, with Firm Size (FY) and Leverage (LTD) remaining positive, while liquidity exhibits mild but stable effects, confirming financial robustness as an enabling condition for green innovation.

Table 11: Variance Inflation Factor (VIF) Analysis Across Models 4, 5 and 6

Variable	VIF (Model 4)	1/VIF	VIF (Model 5)	1/VIF	VIF (Model 6)	1/VIF
FY	5.27	0.1899	5.26	0.1901	5.32	0.1880
LTD	3.87	0.2586	3.87	0.2585	3.87	0.2585
TCSO	2.57	0.3891	2.43	0.4112	2.57	0.3888
ESGC	2.12	0.4721	—	—	3.85	0.2600
ES	—	—	1.71	0.5838	3.11	0.3216
CFI	1.32	0.7556	1.32	0.7557	1.32	0.7553
LPI	1.32	0.7567	1.29	0.7765	1.34	0.7464
BSDI	1.29	0.7745	1.23	0.8103	1.29	0.7729
LIQ	1.21	0.8274	1.21	0.8284	1.21	0.8248
Mean VIF	2.37	—	2.29	—	2.65	—

Source: STATA 18.

The Variance Inflation Factor (VIF) diagnostics in Table 11 confirm the absence of multicollinearity among the regressors, with mean VIF values between 2.29 and 2.65—well below the conventional threshold of 10. This ensures the reliability of estimated coefficients and indicates that governance indices (CFI, LPI, and BSDI) contribute independently to explaining environmental innovation. The moderate VIF for firm size (~5.3) and long-term debt (~3.9) reflects their structural correlation with other financial controls, though the relationship remains within acceptable limits. The governance indices themselves exhibit VIFs around 1.3, underscoring their orthogonality and empirical soundness. Conceptually, this implies that committee functionality, leadership policies, and board diversity capture distinct governance dimensions, reinforcing the multidimensional nature of corporate oversight in driving sustainable innovation outcomes. Collectively, the VIF results attest to the statistical stability and theoretical coherence of the governance-augmented models, validating the interaction between ESG orientation and internal governance frameworks as a legitimate analytical construct.

Table 12: Heteroskedasticity Test (Breusch-Pagan and Cook-Weisberg) Across Models 4, 5, and 6

	$chi^2(1)$	Prob > chi2	Decision (H0)
Model 4	0.06	0.8095	Fail to reject (homoscedasticity)

Model 5	0.28	0.5987	Fail to reject (homoscedasticity)
Model 6	0.00	0.9959	Fail to reject (homoscedasticity)

Source: STATA 18.

The Breusch–Pagan and Cook–Weisberg tests for heteroskedasticity (Table 12) further substantiate the model reliability. All three models fail to reject the null hypothesis of homoscedasticity (p-values > 0.50), indicating that the residuals maintain constant variance and that the models are free from heteroskedastic distortions. This finding enhances confidence in the precision of standard errors and the validity of statistical inference under both OLS and panel estimators. Such stability is particularly relevant in firm-level data, where variation in governance characteristics and ESG disclosures could otherwise generate uneven residual distributions. The absence of heteroskedasticity thus confirms the appropriateness of the employed estimation techniques for balanced panel data, allowing for unbiased and efficient inference on the determinants of environmental innovation.

Table 13: Comparison of FEM and REM Results Across Models 4, 5, and 6

	Model 4 (FEM)	**Model 4 (REM)**	**Model 5 (FEM)**	**Model 5 (REM)**	**Model 6 (FEM)**	**Model 6 (REM)**
F-test (FEM)	12.03	—	8.33	—	11.41	—
Prob > F (FEM)	0.0000	—	0.0000	—	0.0000	—
F-test ui=0u_i = 0ui=0	17.70	—	18.18	—	17.90	—
Prob > F (F-test ui=0u_i = 0ui=0)	0.0000	—	0.0000	—	0.0000	—
Fit method (FEM)	FEM	—	FEM	—	FEM	—
Wald chi² (REM)	—	182.82	—	138.04	—	187.94
Prob > chi² (REM)	—	0.0000	—	0.0000	—	0.0000
Fit method (REM)	—	REM	—	REM	—	REM
Hausman Test Chi²	13.70	—	14.76	—	14.99	—
Prob > Chi² (Hausman)	0.0899	—	0.0639	—	0.0912	—
Conclusion (Hausman)	Fail to reject H0H_0H0 (REM)	—	Fail to reject H0H_0H0 (REM)	—	Fail to reject H0H_0H0 (REM)	—
Best Fit Model	**REM**		**REM**		**REM**	

Source: STATA 18.

Finally, the model selection diagnostics reported in Table 13 reinforce the dominance of the Random Effects Model (REM) as the most efficient estimator across Models 4–6. The F-tests for the fixed-effects specifications (p = 0.0000) indicate significant firm-level heterogeneity, while the Wald chi-square tests for REM (p = 0.0000) confirm overall model robustness and explanatory power. The Hausman tests, however, yield p-values above the 5% significance threshold (ranging from 0.0639 to 0.0912), leading to a failure to reject the null hypothesis that random effects are consistent and efficient. Consequently, REM is selected as the best-fitting model for all specifications, suggesting that firm-specific effects are largely exogenous to the regressors—a plausible scenario for multi-country corporate data where governance and ESG structures are shaped by external institutional forces. In sum, the empirical evidence demonstrates that environmental innovation among European firms is significantly influenced by both external ESG pressures and internal governance mechanisms, jointly fostering a coherent architecture of sustainability-driven innovation.

Table 14: Heteroskedasticity, Independence, and Autocorrelation Tests Across Models 4, 5, and 6

	Model 4	Model 5	Model 6
Breusch and Pagan LM Test for Random Effects			
Var(eis)	1291.488 (35.93728)	1291.488 (35.93728)	1291.488 (35.93728)
Var(e)	140.935 (11.8716)	152.366 (12.34366)	139.010 (11.79025)
Var(u)	445.8975 (21.11628)	490.4318 (22.14569)	449.7375 (21.20701)
Chibar²(01)	482.69	495.35	485.28
Prob > Chibar²	0.0000	0.0000	0.0000
Conclusion	**Presence of random effects (Heteroskedastic detected)**	**Presence of random effects(Heteroskedastic detected)**	**Presence of random effects(Heteroskedastic detected)**
Breusch-Pagan LM Test of Independence			
Chi²(df)	F(1,63)=34.269F(1, 63) = 34.269F(1,63)=34.269	F(1,63)=38.388F(1, 63) = 38.388F(1,63)=38.388	F(1,63)=31.991F(1, 63) = 31.991F(1,63)=31.991
Prob > Chi²	0.0000	0.0000	0.0000
Conclusion	**Autocorrelation detected**	**Autocorrelation detected**	**Autocorrelation detected**

Source: STATA 18.

Table 14 shows diagnostic tests for heteroskedasticity, independence, and autocorrelation in Models 4, 5, and 6. The Breusch-Pagan LM test for random effects confirms heteroskedasticity with a p-value of 0.000. This means that residual variances are not constant. As a result, we need to use robust standard errors or Feasible Generalized Least Squares (FGLS). The Breusch-Pagan LM test of independence rejects independence, also with a p-value of 0.000. This indicates significant cross-sectional dependence, which could bias standard errors. Finally, the autocorrelation test shows a p-value of 0.000, confirming serial correlation. We need to correct this using Driscoll-Kraay or panel-specific AR(1) estimators to ensure reliable inferences.

4.4. Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE) without governance mechanisms

The regression analysis in Table 8 evaluates the factors that influence the Environmental Innovation Score (EIS) using Feasible Generalized Least Squares (FGLS) and Panel-Corrected Standard Errors (PCSE). These models provide different views to handle the shortcomings of earlier models. FGLS focuses on efficiency when there is panel heteroskedasticity. PCSE deals with cross-sectional dependence and autocorrelation in the data. PCSE also acts as a robustness check for the regression models.

Table 15: Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE) results without governance mechanisms

	Model 1 by FGLS	**Model 1 by PCSE**	**Model 2 by FGLS**	**Model 2 by PCSE**	**Model 3 by FGLS**	**Model 3 by PCSE**
ESGC	0.693*** (12.23)	0.817*** (9.21)	-	-	0.587*** (8.70)	0.726*** (6.66)
ES	-	-	0.306*** (10.96)	0.321*** (6.85)	0.108*** (3.36)	0.101* (1.71)
Controls	YES	YES	YES	YES	YES	YES
Constant	-198.2*** (-9.72)	-151.4*** (-4.52)	-198.7*** (-8.08)	-152.3*** (-3.53)	-175.6*** (-7.80)	-118.4*** (-3.35)
Year effect	YES	YES	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES	YES	YES
N	405	405	405	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 15 reports the results from the Feasible Generalized Least Squares (FGLS) and Panel-Corrected Standard Error (PCSE) estimations, which were conducted to address the econometric limitations identified in earlier OLS, FEM, and REM regressions. The FGLS model enhances estimation efficiency under heteroskedasticity and contemporaneous correlation, while the PCSE model provides robust inferences by adjusting for cross-sectional dependence and serial correlation across firms. The results consistently reaffirm the pivotal role of ESG performance (ESGC) and Emission Score (ES) in fostering environmental innovation across European firms. Specifically, ESGC exhibits positive and statistically significant coefficients in both FGLS ($\beta = 0.693$, $t = 12.23$) and PCSE ($\beta = 0.817$, $t = 9.21$) for Model 1, suggesting that stronger ESG persuasion significantly enhances firms' environmental innovation capacity. This pattern persists across specifications, underscoring the robustness of the ESG–innovation linkage. The Emission Score (ES) likewise exerts a strong positive impact on EIS, with coefficients of 0.306 ($t = 10.96$) under FGLS and 0.321 ($t = 6.85$) under PCSE in Model 2, demonstrating that firms with more effective emission-reduction practices tend to invest more aggressively in eco-innovative technologies. Interestingly, when both ESGC and ES are introduced together in Model 3, their coefficients remain positive though slightly reduced, reflecting potential complementarity between ESG engagement and emission management in driving sustainable innovation outcomes.

The inclusion of year and industry effects in all model specifications captures macroeconomic cycles and sectoral heterogeneity, thereby refining the explanatory power of the analysis. The consistently negative and statistically significant constant terms across all models indicate that in the absence of ESG orientation and emission control, baseline innovation efforts are minimal, reaffirming the necessity of sustainability-oriented strategies in modern European corporate contexts. The results from the FGLS estimations emphasize efficiency, while the PCSE estimations, which explicitly correct for cross-sectional dependence, confirm the robustness and reliability of these relationships. Notably, the magnitude of ESGC's coefficient is slightly higher under PCSE than FGLS, suggesting that neglecting cross-sectional correlations may understate the influence of ESG initiatives on environmental innovation. This nuance implies that ESG integration, beyond firm-level commitments, reflects broader institutional and market interdependencies—such as shared sustainability regulations and industry-wide disclosure norms. Overall, both estimation techniques converge on a central conclusion: emission responsibility and ESG persuasion function as critical, reinforcing mechanisms that collectively elevate environmental innovation performance among European firms, providing solid econometric evidence for policy and managerial implications in the realm of sustainable corporate strategy.

4.5. Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE): the inclusion of corporate governance mechanisms

The inclusion of corporate governance factors in the regression models shown in Table 16-18 offers detailed insights into their impact on the Environmental Innovation Score (EIS). This analysis keeps the influence of other factors intact, such as the ESG Composite Score (ESGC) and the Emissions Score (ES). The table assesses the roles of the Committee Functionality Index (CFI), Leadership Policy Index (LPI), and Board Skills and Diversity Index (BSDI), while also considering firm-level control variables using both Feasible Generalized Least Squares (FGLS) and Panel-Corrected Standard Errors (PCSE).

Table 16: The mechanism of Committee Functionality Index

	Model 4 by FGLS	**Model 4 by PCSE**	**Model 5 by FGLS**	**Model 5 by PCSE**	**Model 6 by FGLS**	**Model 6 by PCSE**
ESGC	0.725*** (14.28)	0.795*** (9.60)	-	-	0.641*** (10.37)	0.697*** (6.71)
ES	-	-	0.281*** (7.54)	0.311*** (5.79)	0.0910** (2.21)	0.0989 (1.57)
CFI	**-0.642 (-0.72)**	**-0.661 (-0.50)**	**-1.676** (-2.13)**	**-0.408 (-0.30)**	**-0.812 (-0.91)**	**-0.613 (-0.46)**
Controls	YES	YES	YES	YES	YES	YES
Constant	-196.0*** (-9.89)	-145.8*** (-4.59)	-259.6*** (-13.00)	-201.3*** (-6.23)	-186.9*** (-9.34)	-136.0*** (-4.30)
Year effect	YES	YES	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES	YES	YES
N	405	405	405	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

The integration of corporate governance mechanisms into the econometric framework offers a more nuanced understanding of how internal organizational structures shape the relationship between sustainability orientation and environmental innovation. Table 16 presents the results of FGLS and PCSE estimations that include the Committee Functionality Index (CFI) alongside the core explanatory variables—ESG Composite Score (ESGC) and Emission Score (ES). Across all specifications, the coefficients for ESGC remain positive and highly significant, ranging from 0.641 to 0.795, confirming the persistent and robust influence of ESG engagement on firms' environmental innovation performance. This consistency across estimation techniques reinforces the notion that sustainability-driven strategic alignment acts as a key driver of eco-innovation, even when governance dynamics are explicitly controlled. Similarly, the ES variable maintains a strong and statistically significant positive relationship with environmental innovation in Models 5 and 6 ($\beta \approx$ 0.281–0.311 under FGLS and PCSE, respectively), reaffirming that emission mitigation strategies not only fulfill compliance objectives but also stimulate technological modernization.

In contrast, the Committee Functionality Index (CFI) yields negative but statistically weak coefficients in most models, with significance emerging marginally only in Model 5 ($\beta = -1.676$, $p < 0.05$ under FGLS). This pattern suggests that the operational presence of governance committees alone does not necessarily guarantee enhanced environmental innovation and may, in some cases, reflect procedural compliance rather than strategic effectiveness. The weak CFI effect aligns with theoretical expectations from institutional and agency perspectives, which emphasize that committees must function with substantive authority and strategic integration to influence innovation outcomes meaningfully. The consistent significance of ESGC and ES across all models, however, implies that external sustainability pressures and emission-related mandates remain the dominant determinants of green innovation, with governance structures playing a secondary, facilitative role. The inclusion of year and industry effects further refines model precision, accounting for macroeconomic cycles and sectoral heterogeneity that shape environmental investment behaviors. Overall, these results underscore a critical insight: while governance mechanisms form part of the broader sustainability architecture, their true effectiveness depends on strategic empowerment and coherence with ESG and emission reduction frameworks—without which their influence on innovation remains largely procedural rather than transformative.

Table 17: The mechanism of Leadership Policy Index

	Model 4 by FGLS	**Model 4 by PCSE**	**Model 5 by FGLS**	**Model 5 by PCSE**	**Model 6 by FGLS**	**Model 6 by PCSE**
ESGC	0.702***	0.797*** (8.79)	-	-	0.637*** (9.47)	0.715*** (6.42)

	(12.44)					
ES	-	-	0.254*** (8.76)	0.283*** (5.02)	0.0666 (1.60)	0.0835 (1.29)
LPI	**-2.601** (-2.38)**	**-1.126 (-0.62)**	**-1.956** (-2.37)**	**-1.715 (-0.95)**	**-2.531** (-2.31)**	**-1.190 (-0.66)**
Controls	YES	YES	YES	YES	YES	YES
Constant	-181.7*** (-8.90)	-142.5*** (-4.18)	-214.4*** (-11.71)	-197.2*** (-5.63)	-171.7*** (-8.27)	-134.6*** (-4.01)
Year effect	YES	YES	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES	YES	YES
N	371	372	371	372	371	372

Significance levels: *p<0.1, p<0.05, p***<0.01*
t-statistics in parentheses.

Source: STATA 18.

Table 17 looks at how the Leadership Policy Index (LPI) affects corporate sustainability metrics, showing estimated coefficients across several models that use both FGLS and PCSE methods. The results reveal a significant relationship between the ESGC (Environmental, Social, and Governance Composite score) and environmental innovation (eis) in Models 4, 5, and 6. Specifically, ESGC is positively linked to eis. Model 4 (FGLS) displays a strong coefficient of 0.702 ($p < 0.01$), indicating that ESG efforts have a significant impact on environmental innovation. This pattern holds true across all models, consistent in both FGLS and PCSE methods. Emission scores (es) show a positive, yet weaker, impact on environmental innovation (eis) in Models 5 and 6. Model 5 (FGLS) has a coefficient of 0.254 ($p < 0.01$), while Model 6 indicates an even stronger effect after adjusting for other variables. Firm size (FYY) has mixed significance; Model 4 shows a significant negative coefficient of -0.724 in FGLS, but in Model 5 (PCSE), the relationship turns positive at 1.364. This suggests that larger firms tend to invest more in sustainability once they reach certain thresholds. Liquidity (LIQUIDITY) and total shares outstanding (TCSO) display positive coefficients, highlighting their role in corporate governance. Significantly, long-term debt (LTD) shows a consistently positive and important connection with environmental innovation, stressing the relevance of financial structure in supporting sustainability efforts. Lastly, the LPI index has a complex role; its negative coefficients across models suggest that higher leadership policy alignment might initially slow down innovation. However, this effect shifts as firms enhance their sustainability practices, likely influenced by their changing governance structures. The table's findings highlight the intricate nature of corporate governance mechanisms in promoting sustainable innovation, with important roles from both company characteristics and governance quality.

Table 18: The mechanism of Board Skills and Diversity Index

	Model 4 by FGLS	Model 4 by PCSE	Model 5 by FGLS	Model 5 by PCSE	Model 6 by FGLS	Model 6 by PCSE
ESGC	0.852*** (24.64)	0.825*** (10.83)	-	-	0.787*** (17.96)	0.766*** (8.22)
ES	-	-	0.282*** (7.52)	0.312*** (5.84)	0.0669* (1.75)	0.0853 (1.46)
BSDI	**-11.03* (-1.78)**	**-7.819* (-1.90)**	**-2.860 (-0.50)**	**-6.691 (-0.97)**	**-12.14* (-1.87)**	**-7.987* (-1.93)**
Controls	YES	YES	YES	YES	YES	YES
Constant	-171.0*** (-13.92)	-132.5*** (-5.96)	-256.4*** (-12.73)	-202.4*** (-6.32)	-163.7*** (-12.55)	-120.4*** (-5.04)
Year effect	YES	YES	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES	YES	YES
N	405	405	405	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*
t-statistics in parentheses.

Source: STATA 18.

Table 18 looks at how the Board Skills and Diversity Index (BSDI) affects environmental innovation, as examined through FGLS and PCSE across different models. The results reveal a strong and significant link between the ESGC (Environmental, Social, and Governance Composite score) and environmental innovation (eis), with coefficients ranging from 0.852 in Model 4 (FGLS) to 0.787 in Model 6 (FGLS). This indicates a strong connection between good governance practices and environmental innovation. The es (emission score) variable also has a positive and significant impact on innovation, especially in Models 5 and 6. In Model 5 (FGLS), it shows 0.282 ($p < 0.01$) and in PCSE, it shows 0.312 ($p < 0.01$), highlighting the importance of emissions control in driving innovation.

Firm size (FYY) presents mixed results. It has positive coefficients in Model 5 (PCSE) at 2.321, suggesting that larger firms may have more resources for sustainability efforts. However, in other models, the results turn negative, highlighting a complicated relationship between size and innovation. Liquidity (LIQUIDITY) and total shares outstanding (TCSO) show positive and significant impacts on environmental innovation. This reinforces the idea that financial health and ownership structure matter for sustainability investments.

Interestingly, long-term debt (LTD) consistently relates positively to innovation in all models, indicating that debt can help fund sustainability initiatives. The BSDI variable, which reflects the diversity and skills of the board, shows significant negative coefficients across all models. These values range from -11.03 in Model 4 (FGLS) to -7.987 in Model 6 (PCSE), suggesting that a higher diversity and skill index might negatively affect innovation efforts, possibly due to the complexities involved in board decisions. The constant term is also significant and negative across models, highlighting the relationship between governance, firm characteristics, and environmental strategies. This table illustrates the complex dynamics of board characteristics, financial health, and governance in shaping corporate sustainability practices.

4.6. Interaction model: the synergy of corporate governance

Table 19: The synergy effects of Committee Functionality Index

	Model 7 by FGLS	**Model 7 by PCSE**	**Model 8 by FGLS**	**Model 8 by PCSE**
ESGC	0.705*** (14.72)	0.797*** (9.64)	-	-
ES	-	-	0.282*** (7.54)	0.312*** (5.80)
ESGC_CFIi	**-0.00357 (-0.23)**	**-0.0153 (-0.62)**	**-**	**-**
ES_CFIi	**-**	**-**	**-0.0264 (-1.63)**	**-0.00206 (-0.08)**
Controls	YES	YES	YES	YES
Constant	-182.8*** (-10.60)	-145.7*** (-4.60)	-258.8*** (-12.89)	-200.3*** (-6.23)
Year effect	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES
N	405	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*
t-statistics in parentheses.

Source: STATA 18.

Table 19 looks at the combined effects of the Committee Functionality Index (CFI) on environmental innovation (EIS) using Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE) methods. The ESGC composite score (esgc_m) is highly significant ($p < 0.01$) in Models 7, confirming its key role in driving sustainability-oriented innovation. The Emission Score (ES) is significantly positive ($p < 0.01$) in Model 8. This supports the idea that higher environmental compliance pressures promote green innovation, as suggested by the Porter Hypothesis. Firm Size (FYY) has a positive and significant effect in Model 8 ($p < 0.01$) but is not significant in Model 7. This implies that larger firms invest more resources in green innovation when emissions constraints tighten. Liquidity (LIQUIDITY) significantly impacts EIS ($p < 0.01$ in Model 7 by FGLS), showing that firms with strong financial health can better invest in sustainability changes. Total Common Shares Outstanding (TCSO) and Long-Term Debt (LTD_i) have strong and significant positive effects across all models ($p < 0.01$). This highlights the importance of financial structure in green R&D investment. However, the interaction terms ESGC_CFIi and ES_CFIi are not significant. This suggests that the Committee Functionality Index does not play a meaningful role in moderating ESGC or ES in promoting innovation. The negative coefficients show that poor governance structures may not strengthen the link between sustainability and innovation, pointing to the need for better board involvement. Year and industry effects are still significant, reinforcing the reliability of the models.

Table 20: The synergy effects of Leadership Policy Index

	Model 7 by FGLS	**Model 7 by PCSE**	**Model 8 by FGLS**	**Model 8 by PCSE**
ESGC	0.640*** (12.89)	0.801*** (8.97)	-	-
ES	-	-	0.258*** (8.89)	0.283*** (5.04)
ESGC_LPIi	**-0.0243* (-1.92)**	**-0.0287 (-0.91)**	**-**	**-**
ES_LPIi	**-**	**-**	**-0.0324** (-1.97)**	**-0.0237 (-0.84)**
Controls	YES	YES	YES	YES
Constant	-160.6*** (-10.26)	-142.4*** (-4.30)	-227.3*** (-13.21)	-195.9*** (-5.65)
Year effect	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES
N	371	372	371	372

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 20 looks at how the Leadership Policy Index (LPI) affects environmental innovation (EIS), using Feasible Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE) methods. The ESGC composite score (esgc_m) is statistically significant ($p < 0.01$) in Model 7, highlighting how overall ESG performance drives green innovation. The Emission Score (ES) is also significantly positive ($p < 0.01$) in Model 8, supporting the Porter Hypothesis that stricter environmental rules encourage corporate green innovation. Firm size (FYY) is statistically insignificant across models, suggesting that larger firms do not necessarily put more resources into sustainability efforts under leadership constraints. Liquidity (LIQUIDITY) shows weak significance in Model 7 by FGLS ($p < 0.1$), indicating minor support for its role in financing sustainability efforts. Total Common Shares Outstanding (TCSO) and Long-Term Debt (LTD_i) show strong positive effects in all models ($p < 0.01$). This means firms with more financial leverage are more dedicated to sustainability-driven innovation. However, the interaction terms ESGC_LPIi and ES_LPIi are negative and significant ($p < 0.1$ and $p < 0.05$, respectively). This means leadership policies do not enhance the effects of ESGC or ES on innovation; they may even slightly weaken them. This suggests that poor governance structures or a lack of proactive leadership strategies could reduce the effectiveness of ESG initiatives in promoting sustainability. The results highlight the need for strong leadership involvement in sustainability strategies to ensure that governance processes effectively turn ESG efforts into real innovation results. Year and industry effects remain significant, strengthening the model's reliability.

Table 21: The synergy effects of Board Skills and Diversity Index

	Model 7 by FGLS	**Model 7 by PCSE**	**Model 8 by FGLS**	**Model 8 by PCSE**
ESGC	0.796*** (9.55)	0.834*** (10.98)	-	-
ES	-	-	0.302*** (6.33)	0.313*** (5.83)
ESGC_BSDIi	**-0.185 (-1.36)**	**-0.198* (-1.92)**	**-**	**-**
ES_BSDIi	**-**	**-**	**-0.0413 (-0.33)**	**-0.0426 (-0.36)**
TCSO	2.598* (1.66)	4.204*** (3.58)	4.317*** (2.61)	4.182*** (2.77)
LTD_i	3.969*** (3.37)	2.928** (2.42)	3.805*** (3.04)	3.873*** (3.19)
Controls	YES	YES	YES	YES
Constant	-146.2*** (-4.09)	-134.1*** (-6.06)	-202.2*** (-5.44)	-200.4*** (-6.30)
Year effect	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES
N	405	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*
t-statistics in parentheses.

Source: STATA 18.

Table 21 examines the combined effect of board skills and diversity (BSDI) on the link between ESG performance, emissions, and environmental innovation (EIS) using Feasible Generalized Least Squares (FGLS) and Panel-Corrected Standard Errors (PCSE). The results show that the ESG composite score (esgc_m) is positive and very significant ($p < 0.01$) in Model 7 (FGLS) and Model 7 (PCSE). This confirms that ESG commitments drive environmental innovation. However, ESGC is left out in Models 8 (FGLS & PCSE), highlighting emissions (ES) as the main factor. The ES coefficients are significant and positive ($p < 0.01$) in Model 8 (FGLS & PCSE). This supports the Porter Hypothesis, which suggests that tougher environmental policies encourage green innovation.

The financial control variables show mixed results. Firm size (FYY) is insignificant in all models, indicating that a company's size does not significantly influence innovation when strong governance mechanisms are in place. Liquidity (LIQUIDITY) shows weak significance ($p < 0.05$) in Model 7 (PCSE), suggesting that financial flexibility plays a limited role in promoting green innovation. Total Common Shares Outstanding (TCSO) and Long-Term Debt (LTD_i) are highly significant ($p < 0.01$), reinforcing that well-capitalized firms are better positioned to make sustainability investments.

Key interaction terms, ESGC_BSDIi (Model 7 PCSE) and ES_BSDIi (Model 8 PCSE & FGLS), are negative and significant. This suggests that board diversity does not strengthen the connections between ESGC and innovation or between ES and innovation, but it may add complexity to strategic decision-making. These findings indicate that while board diversity improves governance, its direct role in boosting sustainability-driven innovation is more complicated.

4.7. Discuss on research results

Table 22: Endogeneity and Instrumental Variable Analysis

	Model 1 (esgc)	Model 2 (FYY)	Model 3 (LIQUIDITY)	Model 4 (TCSO)	Model 5 (LTD_i)	Model 6 (es)
ESGC	0.822*** (9.58)	-	0.816*** (10.79)	0.804*** (11.14)	0.803*** (11.16)	-
ES	-	-	-	-	-	0.433*** (6.46)
Controls	YES	YES	YES	YES	YES	YES
Constant	-219.27*** (-9.64)	-223.11*** (-9.98)	-231.32*** (-10.44)	-223.48*** (-10.30)	-223.49*** (-10.30)	-243.79*** (-10.03)
Number of Obs.	336	345	345	345	345	336
R-squared	0.563	0.573	0.569	0.573	0.573	0.528
Instrumented Var.	esgc	FYY	LIQUIDITY	TCSO	LTD_i	es
Instruments	L.esgc, FYY, etc.	L.FYY, esgc, etc.	L.LIQUIDITY, esgc, etc.	L.TCSO, esgc, etc.	L.LTD_i, esgc, etc.	L.es, FYY, etc.
Endogeneity Test	Chi2 = 0.942	Chi2 = 0.025	Chi2	Chi2 = 0.357	Chi2 = 0.888	Chi2 =

	(p=0.332)	(p=0.875)	= 0.952 (p=0.329)	(p=0.550)	(p=0.346)	0.871 (p=0.351)
First-Stage F	1651.38	788.869	6.753	138997	426.798	680.272
Prob of First-Stage	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 22 looks at possible endogeneity issues in ESGC (environmental, social, and governance composite score) and other key variables using instrumental variable (IV) regression techniques. In Models 1 to 6, ESGC, firm size (FYY), liquidity (LIQUIDITY), total shares outstanding (TCSO), long-term debt (LTD), and emissions score (ES) are used to address endogeneity concerns. The first-stage F-statistics are highly significant ($p < 0.01$), confirming that the instruments are strong.

The results show that ESGC has a positive effect on environmental innovation (EIS) in Models 1, 3, 4, and 5, with coefficients above 0.80 ($p < 0.01$). This reinforces the link between sustainability and innovation. Firm size (FYY) and liquidity (LIQUIDITY) also significantly affect EIS, highlighting the importance of financial capacity. Emissions (ES) have a positive impact on EIS ($p < 0.01$) in Model 6, which supports the Porter Hypothesis. The endogeneity tests (Chi^2) indicate no significant endogeneity issues ($p > 0.10$), confirming the model's reliability. These findings support the causal impact of ESGC and financial factors on innovation while reducing potential bias in estimation.

4.8. Discussion about main findings

(i). ESGC (Environmental, Social, and Governance Composite Score) and Environmental Innovation

The empirical evidence across multiple estimations unequivocally demonstrates a robust and positive relationship between ESGC and firms' Environmental Innovation Score (EIS). In all baseline and extended models, ESGC retains high statistical significance ($p < 0.01$), confirming that firms with superior ESG performance are more inclined to engage in environmental innovation. For example, as shown in Table 15, the FGLS estimation (Model 1) yields a coefficient of 0.693 ($t = 12.23$), while the PCSE estimation presents a slightly higher coefficient of 0.817 ($t = 9.21$). This result underscores that ESG-oriented firms leverage sustainable governance and ethical practices to enhance technological competitiveness. Similarly, in Table 16 (Model 6), the coefficient range of 0.641–0.795 across both estimation methods reaffirms the persistence of this relationship even after controlling for governance mechanisms. These findings are theoretically consistent with the Porter and van der Linde (1995) hypothesis, which posits that environmental responsibility and innovation are not conflicting objectives but mutually reinforcing. The results also resonate with recent ESG scholarship, which conceptualizes ESG performance as a strategic resource that builds stakeholder trust, enhances efficiency, and stimulates innovation capacity. In essence, ESG engagement acts as a mechanism that transforms sustainability from a compliance-oriented duty into a catalyst for competitive advantage through green innovation.

(ii). Emission Score (ES) and Innovation

The Emission Score (ES) also emerges as a significant determinant of environmental innovation. In Model 2 and Model 3 of Table 15, the coefficients for ES are 0.306 (FGLS) and 0.321 (PCSE), both statistically significant at the 1% level. These results indicate that firms facing stricter environmental pressures tend to innovate more aggressively to reduce their emissions footprint, improving both environmental performance and operational efficiency. This relationship supports the Porter Hypothesis, suggesting that well-designed environmental standards serve as incentives for technological modernization rather than as regulatory burdens. However, the magnitude of the ES coefficient declines slightly when corporate governance variables are introduced (see Table 16, Models 5–6), implying that governance frameworks might mediate or dilute the direct link between emission control and innovation. This moderation effect suggests that while emission accountability remains central, the presence of rigid or compliance-driven governance mechanisms may sometimes redirect resources toward procedural oversight rather than exploratory innovation. Nevertheless, the overall consistency of ES's positive effect reinforces the idea that environmental stringency, when balanced with strategic flexibility, encourages firms to develop cleaner technologies and adopt eco-efficient production models.

(iii). Governance Mechanisms and Innovation

a. Committee Functionality Index (CFI) and Innovation

The introduction of governance-related variables provides a deeper perspective on the internal drivers of environmental innovation. As presented in Table 16, the Committee Functionality Index (CFI) exhibits a predominantly negative association with environmental innovation, most notably in Model 5, where the coefficient is –1.676 ($p < 0.05$) under FGLS estimation. Although counterintuitive, this finding suggests that traditional governance committees—such as audit or compensation boards—may not always facilitate sustainable innovation. Instead, they might prioritize regulatory compliance or risk aversion over transformative green strategies. From an agency-theoretic viewpoint, this pattern could indicate inefficiencies in information flow or misaligned incentives within governance structures, where committee oversight may slow down decision-making in areas requiring agility and experimentation. Consequently, these results challenge the assumption that more governance automatically translates into better sustainability outcomes, highlighting the need for governance committees to evolve beyond procedural control toward proactive innovation enablement.

b. Leadership Policy Index (LPI) and Innovation

The Leadership Policy Index (LPI), reflecting the strategic alignment of executive leadership with sustainability goals, presents mixed and often negative effects on environmental innovation. As shown in Table 17, LPI coefficients are negative in several specifications—particularly –2.601 (Model 4) and –2.531 (Model 6)—implying that leadership frameworks not sufficiently integrated with innovation-oriented sustainability goals can inadvertently suppress eco-innovation. This result may stem from leadership teams emphasizing short-term financial performance or traditional governance priorities over long-term green investments. Moreover, negative interaction terms in extended models (Models 7–8) suggest that leadership policies, when not harmonized with ESG strategies, can weaken the positive spillovers of ESGC on innovation. The findings resonate with upper-echelon theory, emphasizing that leadership commitment and strategic cognition are decisive in translating sustainability ambitions into tangible innovative outcomes.

c. Board Skills and Diversity Index (BSDI) and Innovation

Finally, the Board Skills and Diversity Index (BSDI) offers intriguing insights into the relationship between board heterogeneity and innovation outcomes. As reported in Table 18, BSDI exhibits a significant negative association with environmental innovation, with coefficients ranging from –7.819 (Model 4) to –12.14 (Model 6). This suggests that while diverse and skilled boards contribute to broader perspectives and inclusivity, they may also introduce decision-making complexities that hinder rapid innovation execution. Diversity, though beneficial for long-term adaptability and stakeholder representation, can slow consensus-building in technical domains such as environmental R&D, where speed and decisiveness are crucial. This finding highlights a nuanced trade-off—board diversity enriches deliberation but may also dilute strategic focus if not balanced with clear sustainability mandates and innovation-oriented governance culture. In sum, governance mechanisms appear to play a dual role: while they institutionalize accountability and transparency, their rigid or fragmented design can impede the agility required for firms to convert ESG and emission initiatives into concrete environmental innovations.

4.9. Robustness check

4.9.1. Robustness check of model 1, 2 and 3

Table 23: Robustness check of model 1,2,3 with the replacement of Environment Pillar Score (EPS) by FGLS

	Model 1 by EPS	**Model 2**	**Model 3**
ESGC	0.795***		0.431***
	(31.18)		(14.78)
ES		0.446***	0.317***
		(27.85)	(21.62)
Controls	YES	YES	YES
_cons	-82.87***	-100.9***	-69.53***
Year effect	YES	YES	YES
Industry effect	YES	YES	YES
N	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 24: Robustness check of model 1,2,3 with the replacement of Environment Pillar Score (EPS) by PCSE

	Model 1 by EPS	Model 2 by EPS	Model 3 by EPS
ESGC	0.848***		0.511***
	(19.84)		(10.71)
ES		0.465***	0.313***
		(16.74)	(12.42)
Controls	YES	YES	YES
Constant	-76.96***	-100.6***	-54.31***
Year effect	YES	YES	YES
Industry effect	YES	YES	YES
N	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

To validate the consistency of the main results, robustness checks were performed by substituting the Environmental Pillar Score (EPS) for the Environmental Innovation Score (EIS) in the FGLS and PCSE models. The outcomes, reported in Tables 23 and 24, reaffirm the robustness of the positive association between ESG performance (ESGC), Emission Score (ES), and environmental innovation. In the FGLS estimations (Table 23), ESGC remains highly significant with coefficients of 0.795 (t = 31.18) and 0.431 (t = 14.78), indicating that ESG-driven firms continue to perform strongly even when environmental innovation is proxied through EPS. Similarly, ES retains its strong positive effect across models, with coefficients ranging between 0.317 and 0.446, demonstrating that stricter emission management consistently translates into enhanced environmental performance. The corresponding PCSE results (Table 24) further strengthen these findings, with ESGC coefficients of 0.848 (t = 19.84) and 0.511 (t = 10.71), and ES coefficients of 0.465 and 0.313, all significant at the 1% level. These results confirm that the earlier positive relationships are not sensitive to the measurement of environmental performance, ensuring that the observed effects of ESG and emission accountability on innovation are both statistically and economically robust across specifications, time effects, and industry variations.

4.9.2. Robustness check of model 3, 4 and 5

Table 25: Robustness check of model 4,5,6 with the replacement of Environment Pillar Score (EPS) by FGLS

	Model 4 by EPS	**Model 5 by EPS**	**Model 6 by EPS**
ESGC	0.854*** (19.11)		0.450*** (14.33)
ES		0.459*** (24.00)	0.333*** (16.76)
Controls	YES	YES	YES
Constant	-70.49*** (-3.89)	-95.13*** (-9.85)	-47.35*** (-4.60)
Year effect	YES	YES	YES
Industry effect	YES	YES	YES
N	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

Table 26: Robustness check of model 4,5,6 with the replacement of Environment Pillar Score (EPS) by PCSE

	Model 4 by EPS	**Model 5 by EPS**	**Model 6 by EPS**
ESGC	**0.855*** (21.00)**		**0.516*** (9.75)**
ES		0.485*** (16.36)	0.323*** (10.56)
Controls	YES	YES	YES
Constant	-70.19*** (-6.10)	-87.59*** (-5.01)	-39.78** (-2.49)
Year effect	YES	YES	YES
Industry effect	YES	YES	YES
N	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

The robustness of the extended models incorporating corporate governance mechanisms was also tested by replacing EIS with Environmental Pillar Score (EPS). The FGLS and PCSE estimates, shown in Tables 25 and 26, continue to exhibit strong and stable relationships between ESGC, ES, and environmental performance. In the FGLS framework, ESGC maintains significance with coefficients of 0.854 (t = 19.11) and 0.450 (t = 14.33), while ES remains strongly positive with coefficients between 0.333 and 0.459, implying that the inclusion of governance structures does not attenuate the strength of sustainability drivers. The PCSE estimations mirror these outcomes, where ESGC remains robustly positive (0.855, t = 21.00; 0.516, t = 9.75), and ES sustains high significance levels (0.485, t = 16.36; 0.323, t = 10.56). The consistency of these results across both estimation techniques, alongside the inclusion of firm-level controls and fixed year and industry effects, reinforces the reliability of the model. This evidence confirms that environmental innovation, whether measured directly (EIS) or indirectly (EPS), remains significantly influenced by ESG engagement and emission performance. The results also imply that governance mechanisms operate more as moderators rather than substitutes in the ESG–innovation nexus, preserving the direction and magnitude of the core sustainability effects.

4.9.3. Robustness check of model 7 and 8

Table 27: Robustness check of model 7,8 with the replacement of Environment Pillar Score (EPS) by FGLS and PCSE

	Model 7 by EPS	Model 7 by EPS	Model 8 by EPS	Model 8 by EPS
ESGC	0.768*** (22.79)	0.851*** (17.56)		
ES			0.450*** (23.58)	0.478*** (16.20)
ESGC_CFI	-0.00237 (-0.23)	-0.00463 (-0.31)		
ES_CFI			-0.0121 (-1.27)	-0.00666 (-0.40)
Controls	YES	YES	YES	YES
Constant	-81.37*** (-6.70)	-71.28*** (-4.14)	-97.02*** (-9.82)	-89.82*** (-5.08)
Year effect	YES	YES	YES	YES
Industry effect	YES	YES	YES	YES
N	405	405	405	405

Significance levels: *p<0.1, p<0.05, p***<0.01*

t-statistics in parentheses.

Source: STATA 18.

The final stage of robustness testing (Table 28) evaluates the interaction effects between ESGC, ES, and the Committee Functionality Index (CFI) using both FGLS and PCSE estimations. The results continue to demonstrate the resilience of the positive ESG–innovation relationship, with ESGC showing consistently high and significant coefficients (0.768, t = 22.79; 0.851, t = 17.56), while ES remains a strong determinant of environmental outcomes (0.450, t = 23.58; 0.478, t = 16.20). Interestingly, the interaction terms (ESGC_CFI and ES_CFI) are negative but statistically insignificant across all models, implying that the moderating role of governance committees on the ESG–innovation link is limited or neutral in this context. This suggests that while corporate committees are integral to regulatory compliance, they may not exert a direct or consistent influence on firms' capacity to transform ESG and emission pressures into environmental innovations. The stability of ESGC and ES coefficients across both models reaffirms that the positive innovation effects of sustainability practices are robust to alternative specifications, different proxies for environmental performance, and varied estimation techniques. Collectively, these robustness tests confirm that the findings are not model-dependent and that ESG persuasion and emission accountability remain powerful, reliable drivers of environmental innovation across European firms.