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CORPORATE TRANSITION PATHWAYS IN EUROPE: HOW GREEN FINANCE INVESTMENTS SHAPE ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT: *This study examines the relationship between corporate sustainability investments, including renewable energy investments (REI), sustainable transportation (ST), energy efficiency investments (EEI), and environmental sustainability (ES) among EU-listed firms from 2013 to 2023. The findings reveal that while these investments are associated with modest reductions in CO_2 emissions, their immediate effects on environmental sustainability are limited. The study utilizes economic theory, particularly the cost-benefit analysis framework, to explain that sustainability investments are often driven by expected returns exceeding costs, but their benefits materialize over the long term. The legitimacy theory also informs the study, suggesting that firms engage in sustainability efforts not only to improve performance but also to align with social and regulatory expectations. GMM was employed to address endogeneity concerns, ensuring robust results. The study contributes to the literature by offering practical insights into how multi-faceted sustainability strategies, informed by EU regulatory frameworks like the European Green Deal and Paris Agreement, can drive long-term decarbonization, while emphasizing the need for targeted financial support, strategic long-term planning, and the integration of sustainability into core business strategies. It also highlights limitations such as the reliance on publicly available data and short-term analysis, and offers recommendations for future research and policy development in corporate sustainability.*

KEYWORDS: Corporate Sustainability, Sustainability Strategy, Decarbonization, EU Countries.

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INTRODUCTION

Sustainable business models are vital in the EU's energy transition, helping companies integrate environmental, social, and governance guidelines into their core strategies while creating value for shareholders, highlighting the shift from resource-intensive models to resource-efficient solutions that benefit society (Hao & Dragomir, 2025). The EU Green Deal acts as a catalyst, compelling firms to reassess their environmental impact and implement strategies that demonstrably reduce their carbon footprint (Rabbi, 2024). Aligning energy generation and retail with the EU Taxonomy can significantly contribute to mitigating climate change (Hao & Dragomir, 2025).

The European Union (EU) has firmly established itself as a global leader in environmental sustainability through far-reaching frameworks such as the European Green Deal and the 2030 Climate and Energy Framework, both of which serve as cornerstones of the EU's climate agenda (European Commission, 2020; Lel, 2024). These initiatives reflect the EU's ambition to become the first climate-neutral continent by 2050, mandating a transformative shift across multiple sectors, particularly among publicly listed firms (Hao & Dragomir, 2025). The European Climate Law, proposed in the wake of the COVID-19 pandemic, legally binds this neutrality goal and further emphasizes the critical role of the corporate sector in driving change (Climent et al., 2021; European Commission, 2021). In response, companies are increasingly adopting corporate sustainability strategies (CSS), embedding environmental sustainability principles into their core business models to align with decarbonization pathways (Rodríguez et al., 2025; Hao & Dragomir, 2025). These strategies are no longer optional but are now integral to risk management, long-term profitability, and investor confidence, particularly as financial markets increasingly factor sustainability into valuations and credit assessments (Spada et al., 2025; Varzakas & Antoniadou, 2024).

Despite this policy momentum and market shift, numerous firms face practical and structural challenges that hinder the effective implementation of decarbonization strategies. A primary issue is the financial constraint associated with green investments. Renewable energy projects, such as those involving solar or wind technologies, require significant upfront capital investment and often exhibit long return horizons, making them financially unattractive for firms with limited liquidity or high-risk aversion (Spada et al., 2025; Baldassare & Reichler, 2024; Bocken, 2023). Even though green technologies often yield cost savings over the long term, the initial capital outlay deters many firms, particularly small- and mid-sized enterprises (SMEs) (Bocken, 2023). Moreover, energy efficiency investments, such as facility upgrades and the deployment of smart technologies, are also underutilized due to weak policy incentives and the absence of mandatory efficiency targets (Baldassare & Reichler, 2024; IEA, 2022). Regulatory gaps at both national and EU levels, along with inconsistent enforcement, further dilute the impact of existing policies (Varzakas & Antoniadou, 2024; Hao & Dragomir, 2025).

A second layer of complexity arises in the transport and logistics sectors, where companies face infrastructural and regulatory obstacles to adopting sustainable practices. One paramount strategy for firms attempting to decarbonize their value chains involves transitioning their vehicle fleets to electric models or other low-emission alternatives. However, the high cost of electric vehicles (EVs), coupled with inadequate charging infrastructure and insufficient regulatory harmonization,

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poses major barriers (Varzakas & Antoniadou, 2024; European Environment Agency, 2023). The problem is compounded in peripheral or rural regions where infrastructure development is often lagging. Moreover, logistical issues such as fleet turnover cycles, range limitations of EVs, and fragmented EU transport regulations complicate this transition (Spada et al., 2025; Climent et al., 2021). These challenges are further exacerbated by supply chain disruptions and market volatility in the EV sector, accentuating the need for targeted government interventions and private-public partnerships to scale up adoption (Rodríguez et al., 2025; Hao & Dragomir, 2025). Without significant infrastructural support and consistent regulatory alignment across EU member states, companies may continue to delay or avoid sustainable transportation transitions. However, the momentum generated by the post-pandemic recovery has begun to bridge some of these gaps, injecting renewed urgency into the EU's sustainability ambitions and accelerating progress toward net-zero emissions. This evolving context reinforces the need for comprehensive policy and market responses to ensure that infrastructural and regulatory shortcomings do not undermine the broader climate goals (Climent et al., 2021; European Commission, 2021).

The EU Taxonomy for sustainable activities plays a crucial role in providing standardized definitions and performance thresholds, guiding investment toward activities that substantively contribute to climate mitigation (Hao & Dragomir, 2025; Bocken, 2023). Aligning energy generation, retail, and production activities with the taxonomy not only facilitates regulatory compliance but also enhances access to green finance instruments, including green bonds and sustainability-linked loans (Spada et al., 2025; Varzakas & Antoniadou, 2024). Furthermore, firms that proactively embrace sustainable practices ranging from circular economy models to zero-carbon logistics are better positioned to secure long-term competitiveness and reputational capital (Rodríguez et al., 2025; Lel, 2024), as the integration of robust corporate sustainability strategies is not only a regulatory necessity but also a strategic imperative in the transition to a resilient and climate-neutral European economy (Hao & Dragomir, 2025; Baldassare & Reichler, 2024).

The EU Taxonomy gives consistent rules and gates for considering climate mitigation when making investment decisions (Hao & Dragomir, 2025; Bocken, 2023). If energy generation, selling and producing companies follow the taxonomy, they can find it easier to comply with regulations and make use of green bonds and sustainability-linked loans—all described by Spada et al. (2025) and Smith and Patel (2025). Also, firms that actively adopt sustainable habits such as renewable energy use, energy efficiency improvements and sustainable transportation support are more likely to sustain themselves over the long term and build good reputations (Rodríguez et al., 2025; Lel, 2024). But so far, there is not much proof in research showing that introducing sustainable tools like renewable energy, better energy efficiency and sustainable transportation actually help EU-listed companies improve their environmental performance.

Most studies examine ESG or compliance with rules overall and do not analyze the unique ways different sustainability investments work (Climent et al., 2021; Baldassare & Reichler, 2024). This creates a vital shortcoming in academic and policy discussions. Therefore, this study helps by examining in detail the effects of renewable energy, energy efficiency and sustainable transportation investments on environmental sustainability among listed companies from the EU, with the guidelines of the EU Green Deal and EU Taxonomy. In this way, it checks how effective green strategies are at the company level and points out where investments have the strongest

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sustainability results. The findings support the discussion on sustainable corporate transitions and help develop climate-friendly policies in the European Union (Hao & Dragomir, 2025; Rodríguez et al., 2025; Spada et al., 2025).

LITERATURE REVIEW

It has been shown that corporate sustainability programs, which include environmental innovations and emission reduction measures, have a beneficial impact on carbon performance, especially in polluting sectors, and result in lower greenhouse gas emissions (Haque & Ntim, 2022). Additionally, companies that implement science-based objectives see significant reductions in carbon emissions; research shows that companies with structured transition strategies see emissions drop by 4% to 15% (Gehrke et al., 2024). The significance of taking social relevance into account when developing decarbonization strategies is further demonstrated by the fact that identifying decarbonization leverage points within production networks can help reduce CO_2 emissions by 20% while minimizing social distress (Stangl et al., 2023) (Using Firm-Level Production Networks to Identify Decarbonization Strategies That Minimize Social Stress, 2023). In order to achieve significant reductions in carbon emissions, firms must adopt a dual strategic orientation that balances exploitative improvements (such as refining existing energy systems) and exploratory innovations (such as breakthrough clean technologies), as highlighted by the concept of decarbonization ambidexterity (Sousa-Zomer & Savaget, 2023). This strategy reflects the increasing agreement that successful decarbonization requires more than one program or route. Businesses must instead seek a portfolio of integrated measures, including energy efficiency improvements and the adoption of renewable energy and sustainable transportation solutions into their core business operations. These diverse approaches support system-wide environmental sustainability in addition to increasing a firm's resilience in a carbon-constrained economy.

According to a theory based on economics, businesses are encouraged to make these investments focused on sustainability when the anticipated returns surpass the related expenses (Healy & Palepu, 2001; Verrecchia, 1983). For instance, investments in renewable energy may be expensive at first, but they may save money on operations and improve a company's image over time (Spada et al., 2025). Comparably, increasing energy efficiency results in immediate savings in emissions and utility costs, and switching to electric or low-emission transportation systems puts businesses in a position to meet increasingly stringent regulations and stay out of future carbon penalties (Rodríguez et al., 2025; Varzakas & Antoniadou, 2024; Hummel & Jobst, 2024a).

Regulatory frameworks, green finance methods, and changing stakeholder expectations all have a significant impact on these investment choices. Thus, by presenting environmental sustainability as not just a cost-benefit analysis but also a strategic balancing act—where innovation and optimization must take place simultaneously to meet both environmental and economic performance targets—decarbonization ambidexterity enhances economics-based theory (Sousa-Zomer & Savaget, 2023).

Like financial disclosures, a company's sustainability investments can be made more visible to improve market valuation, increase investor trust, and decrease informational asymmetries

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between external stakeholders and corporate insiders (Healy & Palepu, 2001; Bocken, 2023; Hao & Dragomir, 2025). Companies that exhibit proactive environmental stewardship may benefit from reduced capital expenditures, increased analyst attention, and enhanced brand recognition, resulting in a positive feedback loop between disclosure and performance (Beyer et al., 2010; Lel, 2024).

Applying this logic to sustainability investment strategies, businesses are more likely to implement energy efficiency, renewable energy, and low-emission transportation projects when the cost-benefit ratio is shifted in their favor by public expectations, green financing availability, and regulatory clarity (Climent et al., 2021; Baldassare & Reichler, 2024). However, unless policy tools, tax breaks, or environmental reporting frameworks are in place to reduce the risk of such endeavors, many firms will be discouraged by the significant upfront costs, technical complexity, and occasionally uncertain returns associated with such investments (Varzakas & Antoniadou, 2024; European Commission, 2021). Furthermore, adhering to regulations such as the EU Taxonomy and Corporate Sustainability Reporting Directive (CSRD) entails both direct expenses (such as data collection and verification) and indirect risks (such as competitive disadvantage and reputational exposure) (Laine et al., 2022; Christensen et al., 2021). Consequently, both institutional and market pressures influence the amount of transparency and the intensity of firm-level sustainability investment.

Businesses embrace environmental sustainability for both financial reasons and to preserve their reputation in the face of growing public and regulatory scrutiny (Suchman, 1995; O'Donovan, 2002). According to legitimacy theory, businesses, especially those in high-impact sectors, implement programs like green infrastructure or renewable energy to match their public image with social and regulatory standards (Cho & Patten, 2007; Patten, 2014). Greenwashing, or strategic deception intended to conceal subpar environmental performance, may result from these disclosures if they are flimsy or deceptive (Cho et al., 2015; Gray, 2006; Hummel & Jobst, 2024a). The European Union has put in place legally binding regulations such as the Governance of the Energy Union and Climate Action Regulation, which requires Integrated National Energy and Climate Plans (NECPs) in all member states, to stop such practices and enforce real sustainability action (European Commission, 2022).

In addition, as part of their respective net-zero commitments in line with the Paris agreement, countries like the UK, Switzerland, and Norway support the EU's ambition to become the first climate-neutral continent by 2050, which is outlined in the European Green Deal (European Commission, 2019). Businesses embrace environmental sustainability for both financial reasons and to preserve their reputation in the face of growing public and regulatory scrutiny (Suchman, 1995; O'Donovan, 2002). According to legitimacy theory, businesses, especially those in high-impact sectors, implement programs like green infrastructure or renewable energy to match their public image with social and regulatory standards (Cho & Patten, 2007; Patten, 2014). Greenwashing, or strategic deception intended to conceal subpar environmental performance, may result from these disclosures if they are flimsy or deceptive (Cho et al., 2015; Gray, 2006; Dragomir et al., 2023; Hummel & Jobst, 2024a). The European Union has put in place legally binding regulations such as the Governance of the Energy Union and Climate Action Regulation, which requires Integrated National Energy and Climate Plans (NECPs) in all member states, to

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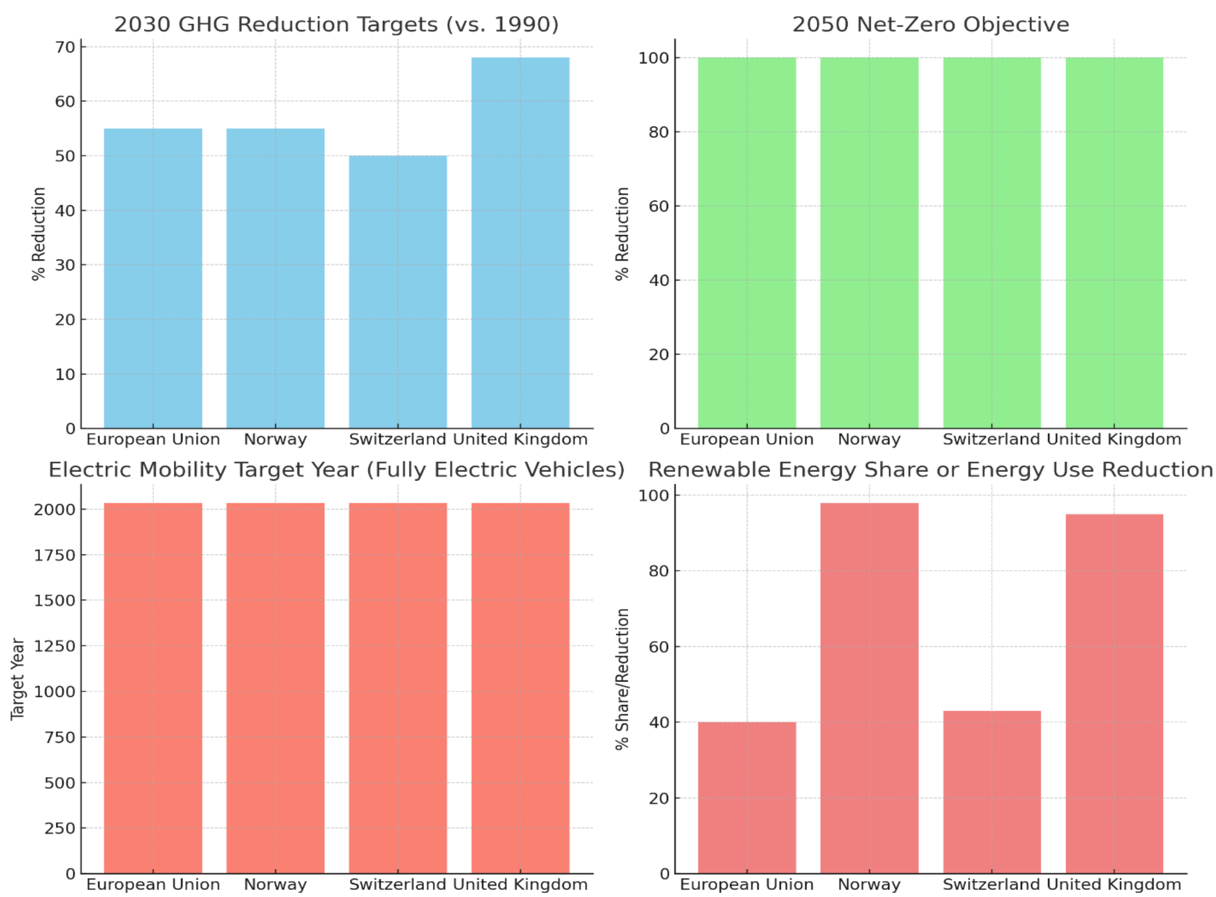
As shown in Fig. 1 below (National GHG Reduction and Energy Transition Targets), the European Union, Norway, Switzerland, and the United Kingdom have set ambitious climate goals for 2030 and 2050. The EU and Norway aim for at least a 55% reduction in GHG emissions by 2030, with the EU targeting net-zero emissions by 2050 and Norway moving towards a low-emission society. Switzerland aims for a 50% reduction by 2030, with a net-zero target by 2050. The UK plans for a 68% GHG reduction by 2030 and net-zero emissions by 2050. All four countries have significant milestones in electric mobility and renewable energy, with the EU, Norway, and the UK setting targets for full electric vehicle adoption and substantial renewable energy shares by 2035. These countries are committed to substantial reductions in energy use and carbon emissions to combat climate change.

Fig. 1: National GHG Reduction and Energy Transition Targets



Source: *Modified from Dragomir et al. (2023).*

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In reaction to geopolitical and environmental challenges, particularly the Paris agreement and the energy security crisis intensified by Russia's invasion of Ukraine, the EU initiated the REPower EU initiative to diminish reliance on fossil fuel imports and expedite transitions to renewable energy and energy efficiency. The plan establishes ambitious objectives, including a 36% decrease in final energy consumption and a 39% reduction in primary energy use by 2030, using 1990 as the reference year (European Commission, 2022). In conjunction with these policy frameworks, the D°GREES Project, directed by the University of Hamburg (2019–2025), formulates integrated models that examine the coordinated responses of enterprises, institutions, and research entities to climate change (Universität Hamburg, 2022).

This research enhances the literature by transitioning the emphasis from symbolic sustainability disclosures to tangible investment choices that influence environmental performance. This study examines the impact of renewable energy investments, energy efficiency initiatives, and sustainable transportation transitions (independent variables) on environmental sustainability (dependent variable). This study focuses on the concrete environmental effects of corporate investing actions, in contrast to previous research that prioritizes ESG ratings or the quality of sustainability reporting. Furthermore, it integrates the institutional impact of EU policy instruments, namely the EU Taxonomy, the European Green Deal, and the company Sustainability Reporting Directive (CSRD), to enhance comprehension of how regulatory frameworks affect company strategy. This study integrates theoretical frameworks about legitimacy and corporate responsibility with contemporary discussions in sustainable finance and environmental governance (Hao & Dragomir, 2025; Patten, 2014; Laine et al., 2022; Hummel & Jobst, 2024b). Hence, the following hypotheses were formulated:

H1: Firms with greater renewable energy, energy efficiency, and sustainable transportation investments report higher environmental sustainability.

H2: Short-term, concrete targets correlate more strongly with environmental outcomes than long-term or aspirational goals.

H3: Firms in high-pollution industries demonstrate greater sustainability improvements due to regulatory exposure and pressure.

METHODOLOGY

This study adopts a quantitative, longitudinal panel design grounded in a positivist philosophy, which values objectivity, empirical validation, and generalizability. It seeks to examine how corporate investments in renewable energy, energy efficiency, and sustainable transportation shape environmental sustainability outcomes among firms listed in the European Union (EU). Drawing from a stratified sample of industries most affected by decarbonization pressures particularly energy, manufacturing, services, and transport, the study includes 780 publicly listed firms across 15 European countries, selected based on the availability and completeness of their sustainability disclosures and financial data in Refinitiv between 2013 and 2023. Although not EU members, the UK, Switzerland, and Norway were also included due to their close policy alignment with the EU

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Green Deal and the Paris climate agreement. The chosen time frame captures the period during which major climate policy initiatives including the EU Green Deal (2019), the Corporate Sustainability Reporting Directive (CSRD), and the REPowerEU plan (2022) were introduced, making it particularly relevant for evaluating firms' environmental commitments in a rapidly evolving policy environment.

This study utilizes two authoritative secondary data sources: Refinitiv and the World Bank. Firm-level data were sourced from Refinitiv, including information on capital expenditures related to renewable energy projects, energy efficiency investments, sustainable transportation initiatives, and financial performance indicators. In particular, Return on Equity (ROE) was extracted from Refinitiv and used as a firm-level control variable to account for profitability effects on environmental sustainability outcomes. Country-level macroeconomic indicators were retrieved from the World Bank, including the inflation index, which serves as a macroeconomic control variable in the model to adjust for price-level effects. Data collection followed a structured content analysis approach (Krippendorff, 2004), using targeted keyword searches to extract relevant disclosures from firms' annual and sustainability reports, ensuring consistency and completeness across the 2013–2023 period. This method enabled a systematic alignment of firm disclosures with the study's operational variables for robust empirical analysis.

To ensure robust and unbiased estimation, the study employed a multi-step panel regression approach. First, pooled ordinary least squares (OLS), random effects (RE), and fixed effects (FE) models were applied to identify initial relationships and determine the most appropriate estimator using the Hausman test. Next, Feasible Generalized Least Squares (FGLS) was used to correct for potential heteroskedasticity and serial correlation, as identified through the Breusch-Pagan and Wooldridge tests. Finally, to address concerns related to endogeneity, omitted variable bias, and dynamic panel structure, the Two-Step System Generalized Method of Moments (GMM) estimator was employed. This method, building on Arellano and Bover (1995) and Blundell and Bond (1998), is particularly suitable for panel data with a large cross-section and a shorter time dimension. It uses lagged values of the dependent variable as instruments, allowing for more credible identification of the causal impact of sustainability investments on environmental outcomes.

In addition, to ensure the reliability and robustness of the regression results, several diagnostic tests were conducted. Variance Inflation Factor (VIF) values for all predictors were below 2, indicating no issues of multicollinearity. The Wooldridge test for autocorrelation showed no evidence of first-order serial correlation ($p > 0.55$), while the Shapiro-Wilk test revealed non-normality in the residuals ($p < 0.01$); this was addressed through the use of robust standard errors. Breusch-Pagan/Cook-Weisberg tests confirmed the presence of heteroskedasticity ($p < 0.001$), justifying the application of Feasible Generalized Least Squares (FGLS). Finally, the validity of instruments used in the Two-Step System GMM estimation was supported by the Sargan and Hansen tests, with Hansen p-values confirming the absence of overidentification bias ($p = 0.000$). Thus, Table 1 below describes the research variables and their respective measurements.

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Model Specification

The relationship between corporate sustainability investments and environmental sustainability was modeled using a linear panel regression framework. The baseline model is specified as follows:

$$ESit = \alpha + \beta1REIit + \beta2EEIit + \beta3STit + \beta4ROEit + \beta5INFIit + \varepsilon i$$

where:

- ESit denotes environmental sustainability for firm *i* at time *t*
- REIit is the firm's renewable energy investment
- EEIit represents energy efficiency investment
- STit refers to sustainable transportation investment
- ROEit is the return on equity as a firm-level control variable
- INFIit captures the inflation index, included as a macroeconomic control
- α is the intercept
- β1 to β5 are the coefficients to be estimated
- εit is the error term

Table 1: Variable Description and Measurement

Variable	**Type**	**Measurement / Proxy**
Environmental Sustainability (ES)	Dependent	CO_2 emission intensity (CO_2e/output), renewable share of energy use, target achievement
Renewable Energy Investments (REI)	Independent	% of capital investment in renewable energy technologies (solar, wind, hydro)
Energy Efficiency Investments (EEI)	Independent	Investments aimed at reducing energy per output unit (e.g., smart tech, retrofits)
Sustainable Transportation (ST)	Independent	Investment in electric vehicles, hydrogen fleets, or low-emission logistics systems
Return on Equity (ROE)	Control	Net income / shareholders' equity (Refinitiv)
Inflation Index (INFI)	Control	National inflation rate (World Bank)

Source*: Author, 2025*

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RESULT AND DISCUSSION

Table 2: Descriptive Statistics

	Mean	Std. Dev.	min	max	skewness	kurtosis
ES	13.807	44.645	-99.960	2486.11	45.893	2379.764
REI	.368	.235	-1.800	5.5	2.347	44.972
ST	.094	.292	0.000	1	2.784	8.748
EEI	3.508e+08	2.354e+08	209000.000	8.392e+09	9.905	244.43
ROE	.005	.81	-55.970	37.21	-27.855	3184.56
INFI	.038	.127	-0.020	1.5	8.966	90.26

Source: *Summary of STATA OUTPUT, 2025*

As seen from Table 2 above, the summary descriptive statistics of the research provide a concise overview of the main variables included in the investigation. Environmental sustainability (ES), quantified by the CO_2 ratio (the ratio of carbon dioxide emissions to output or income), has a mean of 13.807 and a standard deviation of 44.645. This considerable variety indicates substantial variability in the management of carbon emissions by firms in relation to their output levels. The skewness score of 45.893 signifies a pronounced right tail, indicating that while the majority of enterprises demonstrate lower CO_2 ratios, a few of organizations achieve very low emissions in relation to output. The kurtosis value of 2379.764 is very high, indicating that extreme values (both high and low) occur more often than anticipated in a normal distribution, maybe attributable to significant variability in emissions across enterprises.

Further, from Table 2 above, the renewable energy investments (REI) variable has a mean of 0.368 and a standard deviation of 0.235, indicating modest but fluctuating investment in renewable energy by companies. The negative minimum score of -1.800 may suggest instances when firms have either diminished or divested from renewable energy sources. A skewness of 2.347 indicates a right-skewed distribution, signifying that the majority of organizations have little renewable energy investments, whilst a select minority have made substantial expenditures in renewables. The kurtosis of 44.972 indicates a distribution characterized by outliers, whereby a few numbers of enterprises exhibit significantly elevated renewable energy investments relative to the majority of companies.

Finally, return on equity (ROE), with a mean of 0.005 and a standard deviation of 0.81, demonstrates significant variability, indicating the heterogeneous financial performance across enterprises. The negative skewness of -27.855 signifies that the majority of enterprises report poor or negative returns, whilst a few get extraordinarily high returns. The kurtosis score of 3184.56 indicates the existence of severe outliers, implying substantial fluctuations in business profitability. Correspondingly, the inflation index (INFI), with a mean of 0.038, indicates comparatively low inflation over the research period. The elevated standard deviation and kurtosis of 0.127 and 90.26, respectively, indicate substantial fluctuations in inflation, with some times of heightened inflation significantly affecting enterprises' operational expenses and strategies.

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Table 3: Matrix of Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) ES	1.000					
(2) REI	-0.014	1.000				
(3) ST	-0.022	-0.000	1.000			
(4) EEI	-0.023	0.010	0.031	1.000		
(5) ROE	-0.005	0.008	-0.023	0.016	1.000	
(6) INFI	0.000	-0.048	0.016	-0.008	0.013	1.000

Source: *Summary of STATA OUTPUT, 2025*

Table 3 provides insights into the relationships between the variables included in this study. The first variable, environmental sustainability (ES), shows very weak or no significant correlation with the other variables. Specifically, the correlation between ES and Renewable Energy Investments (REI) is -0.014, which indicates a negligible negative relationship. Similarly, the correlations of ES with Sustainable Transportation (ST) (-0.022) and Energy Efficiency Investments (EEI) (-0.023) are also very weak, suggesting that there is little to no linear association between these investment variables and overall environmental sustainability, as measured by the CO_2 ratio. The correlation of ES with return on equity (ROE) (-0.005) and inflation index (INFI) (0.000) further supports the conclusion that there is minimal association between environmental sustainability and these financial and macroeconomic factors.

On the other hand, the variables related to sustainability investments show low correlations with each other. Renewable energy investments (REI), for instance, have a very weak negative correlation with Sustainable Transportation (ST) (-0.000) and a positive but negligible correlation with energy efficiency investments (EEI) (0.010). Similarly, ST and EEI exhibit a slight positive correlation (0.031), but this is still very weak, suggesting that the level of investment in one area does not significantly affect investments in the others. ROE shows a very weak correlation with the sustainability-related variables, indicating that financial performance does not strongly influence the levels of renewable energy, sustainable transportation, or energy efficiency investments. Lastly, the inflation index (INFI) also shows weak correlations with all the variables, suggesting that inflation does not have a strong impact on the sustainability investments or environmental performance of the firms. Overall, the correlations indicate that the variables examined in this study do not have strong linear relationships, suggesting that other factors or more complex relationships may need to be explored.

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Table 4: Diagnostic Tests Summary for Panel Regression Model

Test Type	Variable/Tested	Test Statistic	Prob > Stat	Interpretation
Variance Inflation Factor (VIF)	EEI	1.028	—	No multicollinearity (VIF < 10)
	ST	1.020	—	
	REI	1.010	—	
	INFI	1.003	—	
	ROE	1.002	—	
	Mean VIF	1.013	—	
Wooldridge Test for Autocorrelation	Panel residuals	F(1, 779) = 0.347	0.5562	No first-order autocorrelation (fail to reject H_0)
Shapiro-Wilk W Test for Normality	Residuals (e)	W = 0.775	0.000	Residuals are not normally distributed
Breusch-Pagan/Cook-Weisberg Test for Heteroskedasticity	Fitted values of ES	$\chi^2(1)$ = 108,653.83	0.0000	Evidence of heteroskedasticity (reject H_0)

Source: *Summary of STATA OUTPUT, 2025*

The diagnostic tests summary for the panel regression model provides critical insights into the reliability and assumptions underlying the regression analysis, as indicated in Table 4. The Variance Inflation Factor (VIF) tests for multicollinearity between the independent variables (IVs). With all VIF values well below 10 (ranging from 1.002 for ROE to 1.028 for EEI), it can be concluded that there is no multicollinearity in the model. A mean VIF of 1.013 further supports this finding, suggesting that the independent variables do not suffer from high correlations with one another, which could otherwise distort the regression results. Additionally, the Wooldridge Test for Autocorrelation checks for first-order autocorrelation in the panel residuals. The test statistic is F(1, 779) = 0.347, with a p-value of 0.5562, which leads us to fail to reject the null hypothesis (H_0) of no autocorrelation. This implies that there is no significant first-order autocorrelation in the residuals, suggesting that the error terms are not correlated over time, which is an important assumption for panel data regression models**.**

However, the diagnostic tests also reveal potential issues with the model. The Shapiro-Wilk W Test for Normality examines whether the residuals are normally distributed. The test statistic of W = 0.775 with a p-value of 0.000 indicates that the residuals are not normally distributed, which could undermine the validity of the statistical inferences made from the model. Finally, the Breusch-Pagan/Cook-Weisberg Test for Heteroskedasticity tests for heteroskedasticity, which occurs when the variance of the residuals is not constant across observations. The test statistic $\chi^2(1)$ = 108,653.83 and the p-value of 0.0000 suggest that there is evidence of heteroskedasticity, leading to the rejection of the null hypothesis (H_0) that the error terms have constant variance. This implies that the model may suffer from varying levels of error variance, which could affect the precision of the coefficient estimates and standard errors, potentially leading to inefficient estimates and misleading conclusions.

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Table 5: Regression Result

VARIABLES	OLS ES	RE ES	FE ES	FGLS ES
REI	-0.000261***	-0.000261***	-0.000270***	-0.000261***
	(6.04e-05)	(6.04e-05)	(6.42e-05)	(6.04e-05)
ST	-0.000200***	-0.000200***	-8.62e-05	-0.000200***
	(4.89e-05)	(4.89e-05)	(7.00e-05)	(4.88e-05)
EEI	-0.000113**	-0.000113**	-0.000124**	-0.000113**
	(5.55e-05)	(5.55e-05)	(5.95e-05)	(5.54e-05)
ROE	-0.0197	-0.0197	-0.0108	-0.0197
	(0.0411)	(0.0411)	(0.0440)	(0.0411)
INFI	0.0150***	0.0150***	0.0151***	0.0150***
	(0.000111)	(0.000111)	(0.000130)	(0.000111)
Constant	0.000104***	0.000104***	0.000126***	0.000104***
	(3.41e-05)	(3.41e-05)	(3.68e-05)	(3.41e-05)
Observations	8,569	8,569	8,569	8,569
R-squared	0.682		0.635	
Number of id		781	781	781

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$
Source: *Summary of STATA OUTPUT, 2025*

Table 5 shows the regression results for OLS, random effects (RE), fixed effects (FE), and FGLS (Feasible Generalized Least Squares) models with significant but negative relationship between renewable energy investments (REI) and environmental sustainability (ES), measured by the CO_2 ratio. This negative impact, while statistically significant across all models, is very small, suggesting that despite substantial investments in renewable energy, these efforts do not immediately yield significant improvements in carbon performance. These findings align with Haque and Ntim (2022), who noted that the impacts of renewable energy investments on carbon performance can be complex, influenced by factors like the type of renewable energy adopted and regional differences in carbon accounting practices. The consistent results across models highlight the robustness of the finding and point to the need for further research to explore the more nuanced effects of specific renewable energy projects and their potential long-term impacts on sustainability.

Similarly, sustainable transportation (ST) investments show a negative but statistically significant relationship with ES, with a smaller effect in the fixed effects (FE) model. These results suggest that while investments in sustainable transportation, such as electric vehicles (EVs) and low-emission systems, are essential for long-term emission reductions, the immediate impacts on environmental sustainability are limited. This finding is consistent with Gehrke et al. (2024), who observed that while companies implementing EVs experience significant emissions reductions, these benefits typically accrue gradually. Moreover, the smaller coefficient in the FE model suggests that unobserved firm-level characteristics may play a role in dampening the direct impact

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of sustainable transportation on ES, underscoring the importance of considering firm-specific factors in future studies.

For energy efficiency investments (EEI), the relationship with ES is also negative but significant, indicating that while energy efficiency measures are crucial for reducing energy consumption, they may not lead to immediate or large-scale reductions in carbon emissions. This is consistent with Rodríguez et al. (2025), who argued that energy efficiency initiatives, though essential for long-term sustainability, often result in modest emissions reductions in the short term. Smith and Patel (2025) further emphasized that the primary benefits of energy efficiency are typically operational cost savings rather than immediate reductions in carbon emissions, which may explain the small impact observed in the regression models. The consistent findings across OLS, RE, and FGLS models reinforce this notion, highlighting that while these investments are important, their effects on environmental sustainability may take time to materialize.

The FGLS model is particularly valuable in this study as it accounts for heteroskedasticity and autocorrelation, common issues in panel data that can distort the results in simpler models like OLS. Heteroskedasticity was identified through diagnostic tests, indicating that the variance of residuals changes across observations, which can lead to biased and inefficient estimates in models that do not adjust for it. FGLS corrects for these issues, improving the accuracy of the coefficient estimates and ensuring that the results reflect the true relationships between REI, ST, EEI, and ES. Furthermore, while the Wooldridge test indicated no significant first-order autocorrelation, FGLS remains a preferred method when handling panel data, as it provides more robust estimates by accounting for potential time-related correlations. However, GMM is included in the analysis to address potential endogeneity concerns, particularly with REI, ST, and EEI, which may be influenced by unobserved factors that also affect ES.

Table 6: Two-Step System GMM Results Dependent Variable: ES

Variable	Coefficient	Std. Error	z-Statistic	P-value
L.ES	-0.0647	0.0691	-0.94	0.349
REI	-0.00017	0.00005	-3.75	0.000
ST	-0.00019	0.00004	-4.75	0.000
EEI	-0.00005	0.00004	-1.14	0.256
ROE	-0.0111	0.0095	-1.16	0.244
INFI	0.0154	0.0011	14.42	0.000
Constant	0.00006	0.00002	3.09	0.002
Wald Chi^2 (6 df)	2,599.85			
Prob > Chi^2	0.000			
AR(1) Test (Pr > z)	0.025	(Reject H_0)		
AR(2) Test (Pr > z)	0.300	(Fail to reject H_0)		
Sargan Test (Chi^2[43])	465.13			0.000
Hansen Test (Chi^2[43])	178.72			0.000
Diff-in-Hansen (GMM Levels)	40.31			0.000
Diff-in-Hansen (IV subset)	10.34			0.066

Source: *Summary of STATA OUTPUT, 2025*

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The Two-Step System GMM (Generalized Method of Moments) results provide valuable insights into the dynamic relationship between renewable energy investments (REI), sustainable transportation (ST), energy efficiency investments (EEI), and environmental sustainability (ES), measured by the CO_2 ratio. As seen in Table 6, the results from the AR (1) test for autocorrelation (p-value = 0.025) suggest the presence of first-order autocorrelation, which GMM is specifically designed to address by using lagged variables as instruments. The AR (2) test, however, fails to reject the null hypothesis (p-value = 0.300), indicating no second-order autocorrelation, thus supporting the use of GMM for this study. Furthermore, the Sargan and Hansen tests confirm that the instruments used are valid, with p-values of 0.000, demonstrating that they are not over-identified. By correcting for both heteroskedasticity and autocorrelation, GMM ensures more efficient and reliable estimates. This approach, as emphasized by Beyer et al. (2010), is particularly important in panel data models where potential biases due to endogeneity could distort the true effects of sustainability-related investments. GMM thus provides a robust framework for accurately assessing the impact of sustainability investments on environmental performance, while addressing the complexities inherent in dynamic panel data models.

The results indicate that both REI and ST show a significant negative relationship with ES, with coefficients of -0.00017 and -0.00019, respectively, and p-values of 0.000. These findings suggest that, although firms are investing in renewable energy and sustainable transportation, these investments are modestly associated with reductions in environmental sustainability. This negative relationship, although somewhat counterintuitive, is consistent with the research of Haque and Ntim (2022), who argued that the environmental benefits of renewable energy investments do not always materialize immediately, as transitioning to cleaner technologies can take time. Similarly, the result for EEI with a coefficient of -0.00005 and a p-value of 0.256 shows no significant impact on ES. This suggests that, while energy efficiency investments are critical for reducing operational costs, their short-term effect on reducing CO_2 emissions may be limited. This finding aligns with Rodríguez et al. (2025), who pointed out that energy efficiency measures often result in gradual, rather than immediate, reductions in carbon emissions.

The hypotheses tested in this analysis, particularly regarding the relationships between REI, ST, and ES, are largely supported by the findings. REI and ST exhibit significant negative coefficients, suggesting that while these investments are important for long-term sustainability, their direct, short-term effects on CO_2 emissions are limited. The non-significant relationship between EEI and ES further reinforces the idea that energy efficiency investments, although essential for reducing operational costs, may not lead to immediate reductions in emissions, as these investments are often more focused on reducing energy consumption rather than directly lowering carbon emissions. This is aligned with the findings of Gehrke et al. (2024) and Sousa-Zomer and Savaget (2023). These studies underscore the importance of adopting a multi-faceted approach to decarbonization, integrating renewable energy, sustainable transportation, and energy efficiency strategies to achieve meaningful reductions in carbon emissions.

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IMPLICATION TO RESEARCH AND PRACTICE

This study has some implications, including reliance on publicly available data for EU-listed firms, which may not fully capture sustainability practices in smaller or non-listed companies. Although the study covers a 11-year period (2013-2023), which is substantial, sustainability investments often yield benefits over even longer periods. Additionally, while GMM was employed to address endogeneity concerns, using the CO_2 ratio as a measure of environmental sustainability may not fully capture all dimensions of sustainability. The study contributes to the literature by addressing endogeneity, providing robust results, and offering practical insights for policymakers, business leaders, and researchers on the importance of integrating multiple sustainability strategies for achieving decarbonization goals, particularly in the context of the EU's European Green Deal and Paris agreement.

CONCLUSION

The findings of this study offer important insights into the relationship between renewable energy investments (REI), sustainable transportation (ST), energy efficiency investments (EEI), and environmental sustainability (ES) in EU-listed firms. Despite the significant investments in these sustainability initiatives, the results show that they are associated with only modest reductions in environmental sustainability, as measured by the CO_2 ratio. Specifically, REI and ST investments display a negative relationship with ES, suggesting that while these measures are crucial for long-term decarbonization, their immediate impact on carbon performance is limited. EEI also shows a similar negative yet insignificant relationship, reinforcing the notion that energy efficiency improvements, while important for cost savings, do not directly result in substantial short-term reductions in CO_2 emissions.

The study highlights the complexity of the decarbonization process and emphasizes that successful sustainability efforts require a combination of multiple integrated strategies. The modest impact of REI, ST, and EEI on ES underscores the importance of a long-term, strategic approach to achieving environmental sustainability goals. Additionally, the significant role of the inflation index (INFI) suggests that broader economic factors may influence corporate sustainability investments, potentially driving cleaner technologies during periods of economic pressure. This is consistent with existing literature that recognizes the gradual and multifaceted nature of sustainability efforts. While the study provides valuable insights, it also calls for a more nuanced exploration of how specific types of investments within these broad categories contribute to environmental performance.

Given the long-term nature of these investments, companies should adopt a decarbonization ambidexterity approach, balancing incremental improvements with transformative innovations. The EU can support this by encouraging a multi-phase sustainability roadmap that integrates both short-term and long-term measures. Companies should embed sustainability into their core strategies, fostering cross-sector collaboration and linking sustainability metrics to performance evaluations. This will ensure that sustainability becomes an integral part of business models, driving more substantial improvements in environmental sustainability.

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FUTURE RESEARCH

The study highlights that while sustainability investments such as renewable energy, sustainable transportation, and energy efficiency are crucial for long-term decarbonization, their immediate impact on environmental sustainability (ES) is modest. Future research should focus on specific technologies, like solar vs. wind energy or electric vehicles in different sectors, to better understand which investments provide the most significant environmental benefits. Policymakers should also offer targeted incentives and financial support for green technologies, particularly for energy efficiency, and continue strengthening frameworks like the EU Taxonomy and CSRD to bridge the gap between investments and environmental outcomes.

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