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CARBON EMISSION INTENSITY AND INVESTMENT EFFICIENCY IN THE EUROPEAN UNION: THE MODERATING ROLE OF ANALYST COVERAGE AND ENVIRONMENTAL INNOVATION

Avrupa Birliği'nde Karbon Emisyon Yoğunluğu ve Yatırım Etkinliği: Analist Kapsamı ve Çevresel İnovasyonun Moderatör Rolü

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Keywords: Investment Efficiency, Carbon Emission Intensity, Analyst Coverage, Environmental Innovation, European Union

JEL Codes: G14, G31, O32, Q52, Q56, Q58.

Abstract

This study examines the impact of carbon emission intensity (CEI) on investment efficiency (IE) as well as the moderating role of analyst coverage and environmental innovation in this relationship for firms operating in the European Union (EU). A panel data set consisting of 5,501 observations of 931 firms for the period 2008-2023 is used. Empirical analyses conducted using the OLS method estimated with Driscoll-Kraay standard errors show that CEI has an overall negative effect on IE, and this effect is particularly pronounced for firms that over-invest. These main findings are robust to alternative investment efficiency measures and alternative estimation methodologies. In addition, analyst coverage and environmental innovation exacerbate the negative effect of CEI on IE. Lastly, heterogeneity analyses indicate that the negative effect of CEI on IE is stronger for firms with lower levels of green revenue and those not participating in the Emissions Trading System (ETS). The study reveals that policies to increase IE should be designed by taking into account firm- and sector-level conditions.

Anahtar Kelimeler: Yatırım Etkinliği, Karbon Emisyon Yoğunluğu, Analist Kapsamı, Çevresel İnovasyon, Avrupa Birliği.

JEL Kodları: G14, G31, O32, Q52, Q56, Q58.

Öz

Bu çalışma, Avrupa Birliği'nde (AB) faaliyet gösteren firmalar için karbon emisyon yoğunluğunun (CEI) yatırım etkinliği (IE) üzerindeki etkisini ve bu ilişkide analist kapsamı ve çevresel inovasyonun moderatör rolünü incelemektedir. 2008-2023 dönemi için 931 şirketin 5.501 gözleminden oluşan bir panel veri seti kullanılmıştır. Driscoll-Kraay standart hataları ile tahmin edilen OLS yöntemi kullanılarak yapılan ampirik analizler, CEI'nin IE üzerinde genel olarak olumsuz bir etkiye sahip olduğunu ve bu etkinin özellikle aşırı yatırım yapan şirketler için belirgin olduğunu göstermektedir. Bu ana bulgular, alternatif yatırım etkinliği ölçütleri ve alternatif tahmin metodolojilerine karşı sağlamdır. Ayrıca, analist kapsamı ve çevresel inovasyon, CEI'nın IE üzerindeki olumsuz etkisini daha da arttırmaktadır. Son olarak, heterojenlik analizleri, CEI'nın IE üzerindeki olumsuz etkisinin, yeşil gelir seviyesi daha düşük olan ve Emisyon Ticaret Sistemi'ne (ETS) katılmayan firmalar için daha güçlü olduğunu göstermektedir. Çalışma, IE'yi artırmaya yönelik politikaların, şirket ve sektör düzeyindeki koşullar dikkate alınarak tasarlanması gerektiğini ortaya koymaktadır.

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1. Introduction

Global climate change is currently a major environmental problem, posing a significant threat to the sustainability of economic, social, and ecological systems (IPCC, 2018). A major driver of this threat is greenhouse gas emissions from energy consumption and industrial activities, with carbon dioxide (CO_2) accounting for most of these emissions (Abdallah et al., 2012). Carbon emissions accelerate the global warming process and have detrimental effects on human health, economic stability, and environmental sustainability (Sariannidis et al., 2013). This led the international community to set emission reduction targets through notable international treaties, including the Kyoto Protocol (1997) and the Paris Agreement (2015), which have played a pivotal role in advancing the shift toward a low-carbon economy. This transformation is now seen not only as essential for addressing environmental concerns, but also as a crucial factor in strengthening nations' economic competitiveness (Scott, 2013).

The European Union (EU) played a pioneering role in this process and introduced the Emissions Trading System (ETS) in 2005 (Action, 2013). ETS has made carbon emissions a direct cost factor for firms. Under this system, firms are given carbon permits within certain emission limits; these permits are either distributed free of charge or auctioned (Ellerman and Joskow, 2008). Furthermore, the European Union (EU) has strengthened its climate agenda by expanding upon the European Green Deal (2019) and the "Fit for 55" legislative package introduced in 2021. Through these frameworks, the EU has established legally binding targets aimed at reducing greenhouse gas emissions by 55% by the year 2030, and reaching full climate neutrality by 2050 (Scheuing and Kamm, 2022; Schlacke et al, 2022). The carbon emissions border adjustment mechanism launched in this context aims to create equal competitive conditions between producers and importers within the EU by preventing carbon leakage (López and Prego, 2019).

In the context of the EU's stringent environmental regulations, carbon emission intensity (thereafter CEI) stands out as a key metric affecting environmental and financial performance (Matsumura et al., 2014). CEI measures the amount of carbon emitted by firms per unit of output, with a high CEI signaling operating inefficiencies and an elevated risk of environmental costs (Bao and Motlagh, 2024). In particular, firms operating in carbon-intensive sectors may experience significant deviations in investment efficiency (thereafter IE) due to high compliance costs arising from the regulatory environment (Kruger et al., 2007). In this context, CEI emerges as a critical environmental and financial risk factor that exacerbates these investment inefficiencies and may adversely affect the short- and long-term financial performance of carbon-intensive firms (Oestreich and Tsiakas, 2024).

The objective of this study is to investigate the impact of CEI on IE using data from 931 firms in the EU for the period 2008-2023. Results show that CEI has a negative effect on IE, which manifests itself in the form of overinvestment. Moreover, we explore the moderating role of analyst coverage and environmental innovation for the CEI-IE relationship and show that the negative effect is more pronounced for firms with higher analyst coverage and higher levels of environmental innovation. To gain deeper insights, we also conduct heterogeneity analyses based on green revenue level, ETS participation, and sector of operation. Our findings indicate that the negative effect of CEI on IE is stronger for firms with lower levels of green revenue and those not participating in the ETS. This effect is statistically significant, particularly within the basic materials, consumer cyclicals, consumer non-cyclicals, and technology sectors, whereas a positive association is observed in the utilities sector.

This study contributes to the literature on several fronts. First, it extends classical IE models by incorporating CEI as a determinant of IE. While prior studies linked CEI to firm-level outcomes such as profitability (Ganda and Milondzo, 2018; Desai et al., 2022), market capitalization (Hardiyansah et al., 2021), and capital structure (Liu et al., 2021), none have directly examined its impact on IE in the EU. The few studies addressing the CEI-IE relationship rely on limited single-country samples, such as those focused on China (Chen et al., 2022; Wang and Zhang, 2024). Hence, we address this gap by analyzing the CEI-IE relationship with a multi-country dataset of EU firms, using agency theory, information asymmetry theory, the resource-based view, and the Porter hypothesis as our main theoretical perspectives. The EU provides a particularly relevant setting as member states are subject to some of the world's most strict environmental regulations and advanced carbon market practices such as the ETS. These policies raise compliance costs, heighten uncertainty, and increase financing constraints for high-CIE firms (Venmans, 2016; Hintermayer, 2020; Hui and Oh, 2021; Zhang et al., 2019).

Second, this study investigates how institutional and market-based mechanisms, namely analyst coverage and environmental innovation, moderate the CEI–IE relationship. Prior literature suggests that external control mechanisms, such as analyst coverage, can improve investment decisions by reducing information asymmetry and monitoring managers. However, it is not clear how these mechanisms work in high-CEI contexts, as intensified monitoring may create short-term performance pressures. Likewise, environmental innovation, viewed through the resource-based perspective as a strategic capability and through the Porter hypothesis as a regulatory response, can reduce the inefficiency caused by CEI. Yet, in practice, symbolic strategies such as greenwashing may reduce these benefits. By analyzing these moderators together, our study adds to the understanding of how institutional and market-based mechanisms shape the CEI-IE relationship.

Finally, we extend the literature by examining how the CEI–IE relationship varies across firm-level characteristics, specifically green revenue shares, ETS participation, and sector of operation, which have received limited attention in prior studies. Overall, our contributions not only advance theoretical debates on the determinants of IE but also provide policy-relevant insights into how carbon intensity interacts with market monitoring, innovation, and firm heterogeneity in the highly regulated EU setting.

The structure of the paper is as follows. The subsequent section presents a literature review and formulates the research hypotheses. The methodology section outlines the data sources, defines the variables employed in the analysis, and explains the empirical strategy. The findings are then discussed in the results section. Finally, the paper ends with a summary of the key outcomes and their broader implications.

2. Literature Review and Hypothesis Development

2.1. Carbon Emission Intensity and Investment Efficiency

IE is a key indicator that reveals the extent to which firms can correctly evaluate available investment opportunities and use capital efficiently (Stein, 2003). According to neoclassical investment theory and Modigliani and Miller (1958), firms should invest in initiatives that offer positive net returns and aim to attain the most efficient investment level, where the marginal return is balanced by the marginal cost. However, in reality, firms often deviate from this optimal level, resulting in inefficiencies such as overinvestment in low-return projects or underinvestment in profitable ones (Biddle et al., 2009).

CEI, which refers to a firm's carbon emissions per unit of revenue or output and is considered a key indicator of sustainability performance. Firms with high carbon intensity face operational risks due to increased regulatory obligations, compliance costs, carbon pricing, and public pressure (Dobler et al., 2014; Qi et al., 2022). These risks create uncertainty in the investment environment, which may influence how firms allocate their capital. Accordingly, the impact of CEI on IE can be investigated through several theoretical perspectives, most notably agency theory, information asymmetry theory, the resource-based view, and the Porter hypothesis.

From an agency theory perspective (Jensen and Meckling, 1976), CEI may impair IE. In this framework, high carbon emissions can be considered a reflection of managerial opportunism, where managers exploit free cash flows to invest in polluting sectors despite their long-run costs. This form of "empire-building" negatively impacts IE since resources that could have been used in value-maximizing projects are diverted to environmentally harmful and low-return investments. By prioritizing personal interests over shareholder value maximization, managers reduce the efficiency of investment decisions.

Similarly, information asymmetry theory (Myers and Majluf, 1984) suggests that firms with high CEI face greater uncertainty about future penalties, reputational risk, or market responses. This widens the information gap between managers and investors, increasing the firm's perceived risk and thereby raising the cost of capital (Gulen and Ion, 2016). This often results in underinvestment in profitable projects due to financing constraints or overinvestment in symbolic activities (e.g., "greenwashing") to signal environmental commitment (Lyon and Maxwell, 2011; Souguir et al., 2024). Both of these outcomes reduce efficiency.

From a resource-based view (Barney, 1991), carbon emissions reflect whether a firm has the necessary resources and capabilities, such as clean technologies, to cope with environmental challenges. Firms that are successful in lowering carbon emissions gain strategic advantages that may improve their IE. On the other hand, firms with high CEI are tied to rigid carbon-intensive production processes, leading to inefficient investment decisions.

Finally, the Porter hypothesis argues that carefully structured environmental policies have the potential to enhance not only ecological outcomes but also firms' financial performance, primarily by stimulating innovation within organizations (Porter and van der Linde, 1995). When firms are forced to decrease their carbon emissions, they often redesign production processes with cleaner and more efficient technologies. These innovations can lower long-term costs, improve competitiveness, and ultimately increase IE. Accordingly, firms with CEI are less likely to benefit from these innovations, resulting in investment inefficiencies.

Overall, the theoretical perspectives discussed above suggest that high CEI may reduce IE by amplifying agency problems, widening information gaps, constraining resources and capabilities, and limiting the innovation benefits of environmental regulation. Building on these mechanisms, empirical studies investigated the effect of carbon emissions on several firm-level outcomes. Studies in various countries and sectors show that carbon emissions and carbon intensity generally negatively affect firm value and financial performance (Lee et al., 2015; Laskar et al., 2022; Miah et al., 2021; Nguyen, 2018; Ferrat, 2021). Recent studies show that carbon-related risks and regulatory structures can significantly affect firms' investment decisions and efficiency. For example, Chen et al. (2022) show that the carbon emission trading system introduced in China increases firm IE by limiting excessive investment. Similarly, Wang and Zhang (2024) find that the pilot ETS implementation in China reduces investment inefficiency, especially for firms with high innovation capacity and institutional investor ownership. On the other hand, there are also studies focusing on voluntary carbon verification and disclosure mechanisms. Luo and Pan (2025) argue that carbon verification reduces underinvestment and improves the information environment in an international sample of CDP (formerly referred to as the Carbon Disclosure Project) participating firms, while Luo et al. (2025) argue that carbon risk negatively affects labor IE, especially for high-polluting and financially constrained firms.

Drawing upon the earlier discussed theoretical and empirical insights, the initial hypothesis of this research is formulated as follows.

H_1: CEI has a negative impact on IE for firms operating in EU.

2.2. Carbon Emission Intensity, Analyst Coverage, and Investment Efficiency

As discussed earlier, information asymmetry theory suggests that investors' lack of reliable information about the firm' environmental risks may distort capital allocation and negatively affect IE (Myers and Majluf, 1984). In this context, analysts function as external information intermediaries, providing regular information to the market by monitoring firms' financial and environmental performance (Schipper, 1991; Knyazeva, 2007). Broader analyst coverage forces firms to disclose more detailed, timely, and transparent information on their environmental risks, enabling investors to make informed decisions (Irani and Karamanou, 2024; Cheng et al., 2025). In line with that, Liu (2024) finds that broader analyst coverage contributes positively to firms' environmental investment behavior, enhances the transparency and reliability of ESG disclosures, and strengthens managerial accountability regarding environmental outcomes. Similarly, Downar et al. (2021) show that firms with increased analyst coverage after mandatory environmental regulations reduce carbon emissions more.

Beyond information provision, analysts also play a monitoring role by exerting pressure on managers for transparency and accountability (Zheng and Shen, 2024). From an agency theory perspective (Jensen and Meckling, 1976), such monitoring can limit opportunistic behavior and reduce the tendency of managers to overinvest in polluting projects.

However, the effect of analyst coverage is not always positive. Some studies emphasize that analyst pressures may lead firm management to prioritize immediate financial goals at the expense of environmental projects with long-term payoffs (Chan and Hameed, 2006; Chun and Shin, 2018); He and Tian, 2013; Guo et al., 2019). Similarly, Qian et al. (2019) show that under analyst pressure, managers tend to prioritize short-term projects with quick returns, ignoring long-term environmental issues such as carbon emission intensity. This may lead to strategic deviations that may further reduce IE in firms with high carbon emission intensity. Indeed, Zhang et al. (2023) emphasize the strategic steering power of analysts that may lead to deviations from sectoral norms.

In sum, an increase in analyst coverage can help discipline managers by reducing information asymmetry and help investors assess environmental risks more accurately. However, at the same time, it may increase market pressure by making environmental risks such as carbon emission intensity more visible, which may lead managers to postpone long-term environmental investments or avoid risky projects altogether. In this framework, analyst coverage may play both a supportive and a restraining role on IE. Accordingly, hypothesis H_2 is formulated to capture both the negative and positive effects of analyst coverage on CIE-IE relationship.

H_2: Analyst coverage has a moderating role on the negative relationship between CEI and IE.

2.3. Carbon Emission Intensity, Environmental Innovation, and Investment Efficiency

Environmental innovation involves creating or substantially enhancing products, processes, organizational models, or systems with the objective of minimizing or removing their environmental footprint (Popp et al., 2010; Kemp and Arundel 1998). Such innovations can provide both environmental and economic benefits by reducing environmental pollution and resource use and are considered a valuable tool for firms to achieve their sustainable development goals (Rennings, 2000). In their analysis of Chinese data, Zhang et al. (2017) show that environmental innovation is particularly effective in reducing carbon emissions through energy efficiency, knowledge-based innovation, and resource utilization. Similarly, Popp et al. (2010) emphasize that the impact of environmental innovation becomes stronger when these technologies are widespread and effectively implemented.

Beyond improving environmental outcomes, environmental innovation also influences firms' IE. Firms that engage in such innovation typically disclose their environmental strategies, performance indicators, and technological improvements in greater detail. This increased corporate transparency reduces information asymmetries between managers and investors, leading to more efficient investments (Rehman et al., 2024). Moreover, environmental innovation enables firms to respond strategically to regulatory requirements and stakeholder expectations, improving both environmental and financial performance (Yu et al., 2017).

From a resource-based view perspective (Barney, 1991), environmental innovation represents a unique and inimitable capability that enhances competitiveness, reduces operational costs, and strengthens reputation (Andries and Stephan, 2019). Similarly, the Porter Hypothesis (Porter and van der Linde, 1995) argues that well-designed environmental regulations encourage firms to innovate. Suh innovations not only improve ecological outcomes but also make firm more competitive and strengthen IE (Xing et al., 2024). In this sense, firms that successfully adopt environmental innovations are more likely to reduce the inefficiency risks associated with high CEI.

However, a growing number of recent studies show that the positive effects of environmental innovation on IE are not always realized in practice. While genuine innovations improve IE, some high-CEI firms may substitute real innovation with symbolic practices such as greenwashing (Li et al., 2023; Hawn and Ioannou, 2016). These practices create the illusion of environmental innovation, without delivering real environmental and financial benefits, thereby weakening the effectiveness of environmental innovation as a mechanism for improving IE (Delmas and Burbano, 2011; Zahid et al., 2023). This problem is particularly prevalent among firms that are motivated to achieve high ESG scores without real operational transformation (Chen et al., 2021; Laufer, 2003).

The above discussion suggests that environmental innovation may weaken or strengthen the relationship between CEI and IE depending on the circumstances. While genuine innovation may mitigate the negative impact of CEI on IE, symbolic actions may mask underlying inefficiencies or even exacerbate them. Accordingly, we propose the following hypothesis.

H_3: Environmental innovation has a moderating role on the negative relationship between CEI and IE.

3. Methodology

3.1. Data and Sample

The dataset employed in this study comprises 931 publicly listed, non-financial firms operating within EU member countries over the 2008–2023 period. Information on CO_2-equivalent emissions, financial metrics, analyst following, and environmental innovation is retrieved from the London Stock Exchange Group (LSEG) database. After eliminating records with missing values, 5,501 firm-year observations remain for empirical analysis. To minimize the influence of extreme values on the results, all variables are winsorized at the 1st and 99th percentiles. Given that the number of observations varies across years, the dataset forms an unbalanced panel. All statistical procedures are performed using Stata 17. Table 1 Panel A displays the distribution of observations by country, while Table 1 Panel B shows the sectoral breakdown, including both percentage and cumulative shares.

Table 1. Country-Level and Sectoral Distribution of Observations

Panel A. Country-Level Distribution of Observations*

Country of Headquarters	Number of Observation	Number of Firm	Percent (%)
Austria	184	29	3.34
Belgium	230	41	4.18
Denmark	307	48	5.58
Finland	373	58	6.78
France	1003	138	18.23
Germany	1041	189	18.92
Greece	98	20	1.78
Ireland; Republic of	245	33	4.45
Italy	101	21	1.84
Luxembourg	153	29	2.78
Netherlands	283	43	5.14
Other*	74	21	1.35
Poland	145	26	2.64
Portugal	73	11	1.33
Spain	210	33	3.82
Sweden	981	191	17.83
Total	**5501**	**931**	**100.00**

Table 1 Continued

Panel B. Sectoral Distribution of Observations

Economic Sector Name (Classified by LSEG Database)	Number of Observation	Percent (%)	Cumulative (%)
Basic Materials	754	13.71	13.71
Consumer Cyclicals	963	17.51	31.21
Consumer Non-Cyclicals	405	7.36	38.57
Energy	258	4.69	43.26
Healthcare	489	8.89	52.15
Industrials	1,318	23.96	76.11
Real Estate	343	6.24	82.35
Technology	862	15.67	98.02
Utilities	109	1.98	100
Total	**5,501**	**100**	

***** Countries with observation counts below 1% are not included in the table. These countries are Cyprus, the Czech Republic, Hungary, Lithuania, Malta, Romania, and Slovenia.

3.2. Variables

3.2.1. Dependent Variable

The dependent variable of the study is IE, a key financial performance indicator that reflects how efficiently firms utilize existing investment opportunities. The indirect approach, suggested by Biddle et al. (2009) and widely adopted in the literature, was used as the measurement method. In the first stage, the expected investment level for each firm in the following period (t+1) is estimated with the following panel data model using the Sales Growth variable (Equation 1):

$$Investment_{i,t+1} = \alpha + \beta_1 . SalesGrowth_{i,t} + \varepsilon_{i,t+1} \quad (1)$$

$Investment_{,t+1}$ represents the total investment rate of the firm in period t+1. This rate is calculated as the sum of capital expenditures, R&D expenses, and merger and acquisition costs, minus cash inflows from the sale of fixed assets in the relevant year. The net investment amount is normalized by total assets from the previous year and expressed as a percentage. Sales Growth is calculated as the rate of change in the firm's income from year t-2 to year t-1. In the process of estimating the investment model, separate cross-sectional regressions were applied for each year and each sector. In the sectoral classification, the TRBC Industry Group Name in the LSEG database was used as the basis. This approach provides a more accurate and comparable measurement of IE by controlling the effect of structural differences between sectors.

In the second stage, the difference between expected and actual investment is calculated for each firm-year observation as the residual (ε). Following McNichols and Stubben (2008), the absolute values of the residuals are taken and multiplied by -1 to construct the IE variable. The resulting measure is presented in Equation (2).

$$IE_{i,t+1} = -\left|\varepsilon_{i,t+1}\right| \quad (2)$$

In this method, a low absolute value of the deviation indicates that a firm’s investment decisions are close to the expected level, reflecting high IE. That is, the firm allocates its capital optimally and avoids excessive or inefficient investment behavior. Conversely, a higher deviation reflects investment inefficiency, arising from suboptimal decisions such as overinvestment or underinvestment. Positive residuals indicate overinvestment, while negative residuals indicate underinvestment. This methodology allows both types of inefficiency to be captured within a single indicator, enabling a comparative and objective assessment of firms' IE.

3.2.2. Independent Variables

CEI is a variable expressed as the amount of CO_2 equivalent emitted per unit of output or activity and is considered a key indicator for assessing environmental performance and climate-related risks (Shah, 2024). In this context, Scope 1 emissions refer to greenhouse gases that are directly released from sources that are owned or controlled by the organization itself (e.g., on-site fuel use and company vehicles). These emissions, which are easier to monitor and report, are an essential element of the corporate carbon footprint. In contrast, Scope 2 emissions refer to indirect greenhouse gas emissions that result from the generation of purchased energy, such as electricity, steam, heat, or cooling consumed by the company to meet its operational requirements (Mytton, 2020; Hertwich and Wood, 2018).

CEI is measured by taking the natural log of the total emissions from both Scope 1 and Scope 2 sources (sourced from the LSEG database) to net sales revenue. This method provides a comparable and literature-consistent indicator of carbon emission intensity by reducing the effect of differences in firm size and volume of activity (Choi and Luo, 2021; Perdichizzi, 2024).

3.2.3. Moderator Variables

The moderator variables of the study are analyst coverage and environmental innovation. Analyst coverage was measured in line with To et al. (2018), and it is quantified by counting the distinct analysts providing profit projections for the company during the year leading up to the fiscal year-end. To enhance statistical validity, the raw value is log-transformed. This transformation yields the first moderator variable, AnalystCoverage. This variable represents the external monitoring role of analysts on the firm, and its effects on investment decisions are evaluated through the interaction term in the analyses.

Following prior studies (e.g., Rehman et al., 2024; Zaman et al., 2021), the second moderating variable, Environmental Innovation, is measured using the "environmental innovation score" obtained from the LSEG database. This score reflects a firm's capacity to create new market opportunities through environmentally friendly products and processes while reducing environmental costs. The score is based on a composite index of 20 quality dimensions adjusted for sectoral differences and ranges from 0 to 100, with higher scores indicating that the company attaches great importance to environmental innovation (Rehman et al., 2024).

3.2.4. Control Variables

Drawing on prior literature (e.g., Chen et al., 2022; Liu et al., 2024; Luo et al., 2025), this study incorporates a set of firm-specific control variables to better identify the influence of CEI on IE. These variables not only increase comparability with previous literature but also aim to isolate the causal relationship more accurately by reducing the biases that may be caused by the omitted correlated variables in the model.

In particular, the model includes Tobin's Q, firm size, asset tangibility, financial slack, firm age, and leverage as control variables to account for firm-specific characteristics. Detailed definitions and measurement approaches for these variables are provided in Table 2.

Table 2. Variable Definitions and Calculations

Variable	Symbol of Variables	Definition
Investment Efficiency	IE	Following Biddle et al. (2009), and as described in Section 3.2.1 Dependent Variable, it is computed as the negative of the absolute residuals from Equation (1), where higher values indicate greater efficiency.
Carbon Emission Intensity	CEI	is determined by applying the natural log to the sum of Scope 1 and Scope 2 CO_2 emissions divided by net sales revenue.
Analyst Coverage		is defined as the natural logarithm of the number of distinct analysts providing earnings forecasts for the firm.
Environmental Innovation		is measured using the environmental innovation score retrieved from the LSEG database, capturing a firm's commitment to environmental innovation.
Firm Value	TOBIN	is calculated by dividing the firm's market capitalization and total assets (after subtracting book equity) by total assets.
Firm Size	SIZE	is measured as the natural logarithm of total assets.
Firm Asset Structure	TANG	is defined as the ratio of net PPE to total assets.
Financial Slack	FINSLACK	is computed as the natural logarithm of the number of years since incorporation, calculated as ln(Fiscal Year - Year of Incorporation + 1).
Firm Age	AGE	is measured as the natural logarithm of the number of years since incorporation, calculated as ln(Fiscal Year - Year of Incorporation + 1).
Firm Leverage	LEV	is measured as the proportion of current liabilities relative to total assets.
Green Revenue Dummy		is a binary indicator equal to 1 if a firm's total green revenue surpasses the sample mean (11.6 billion), and 0 otherwise.
ETS Dummy		is a dummy variable coded as 1 if the firm is included in an ETS, and 0 if it is not.

3.3. Model Design

To empirically investigate the impact of carbon emission intensity on firm-level IE, the following baseline panel regression model is employed:

$$IE_{i,t+1} = \alpha_0 + \beta_1 CEI_{i,t} + \sum \beta_j \, Controls_{j,i,t} + Year\ FE + Industry\ FE + Country\ FE + \varepsilon_{i,t+1} \tag{3}$$

where i denotes the firm and t denotes the year. The dependent variable $IE_{i,t+1}$ indicates the IE of firm i in year t+1. The key explanatory variable, $CEI_{i,t}$, captures the firm's environmental performance and is constructed by taking the natural logarithm of the combined Scope 1 and Scope 2 carbon emissions (sourced from the LSEG database), scaled by net sales revenue. This variable reflects the amount of carbon emitted per unit of revenue, serving as a proxy for firm-level environmental risk exposure. To control for other firm-specific characteristics that may influence IE, the model includes a vector of control variables ($Controls_{j,i,t}$), such as Tobin Q, firm size, asset tangibility, financial slack, firm age, and leverage (detailed in the Section 3.2.4 and Table 2). The error term $\varepsilon_{i,t+1}$ captures unobserved firm-level shocks and omitted variables that may affect IE. The coefficient β_1 quantifies the extent to which carbon emission intensity is associated with deviations from optimal investment behavior.

In line with standard empirical practice, all explanatory variables are lagged by one period to reduce the risk of reverse causality. Furthermore, to control unobserved differences that may affect IE, the model includes fixed effects for year (Year FE), industry (Industry FE) based on the LSEG TRBC Industry Group Name classification, and country fixed effects (Country FE). These fixed effects help account for time-specific shocks, sectoral characteristics, and country-level institutional differences. The regression is estimated using Ordinary Least Squares (OLS) with Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence (Driscoll and Kraay, 1998).

Additionally, the study constructs Equation (4) to examine the moderating role of analyst coverage in the relationship between CEI and IE:

$$\begin{aligned} IE_{i,t+1} = \alpha_0 &+ \beta_1 CEI_{i,t} + \beta_2 AnalystCoverage_{i,t} \\ &+ \beta_3\left(CEI_{i,t}\ x\ AnalystCoverage_{i,t}\right) + \sum \beta_j\ Controls_{j,i,t} \\ &+ Year\ FE + Industry\ FE + Country\ FE + \varepsilon_{i,t+1} \end{aligned} \tag{4}$$

This specification extends Equation (3) by incorporating two additional terms: $AnalystCoverage_{i,t}$ which reflects the level of external monitoring by analysts for firm i, and the interaction term $\left(CEI_{i,t}\ x\ AnalystCoverage_{i,t}\right)$, which captures the moderating effect of analyst coverage on the relationship between CEI and IE. The coefficient β_3 indicates whether analyst coverage mitigates or amplifies the effect of CEI on IE.

Lastly the study constructs Equation (5) to examine the moderating role of environmental innovation in the relationship between CEI and IE:

$$\begin{aligned} IE_{i,t+1} = \alpha_0 &+ \beta_1 CEI_{i,t} + \beta_2 EnvironmentalInnovation_{i,t} \\ &+ \beta_3\left(CEI_{i,t}\ x\ EnvironmentalInnovation_{i,t}\right) + \sum \beta_j\ Controls_{j,i,t} \\ &+ Year\ FE + Industry\ FE + Country\ FE + \varepsilon_{i,t+1} \end{aligned} \tag{5}$$

This specification extends Equation (3) by incorporating two additional terms: $Environmental\ Innovation_{i,t}$, which reflects the firm's efforts toward developing or adopting environmentally sustainable technologies, and the interaction term $CEI_{i,t}\ x\ EnvInnovation_{i,t}$, which captures the moderating effect of environmental innovation on the relationship between CEI and IE. The coefficient β_3 indicates whether environmental innovation attenuates or reinforces the impact of CEI on IE.

4. Results

4.1. Descriptive statistics

The descriptive statistics of the main variables used in the analysis are presented in Table 3. The average value of IE is -4.874, with a median of -3.130, indicating significant deviations from optimal investment levels across the sample firms. When broken down into components, the mean of under-investment is -3.884, whereas the mean of over-investment is 6.536. These figures suggest that under-investment is more prevalent than over-investment in the sample, which may be attributable to market frictions and constraints in accessing external financing (Chen et al., 2011). The CEI variable has an average of -10.364, reflecting considerable variation in environmental performance among firms. The mean value of AnalystCoverage is 2.292, suggesting that, on average, listed firms in the sample are followed by approximately 9 analysts per year.

Table 3. Descriptive Statistics

Variable	Observation	Means	Std. dev.	Min	Median	Max
IE	5501	-4.874	6.135	-53.195	-3.130	-0.076
Under Invest	3343	-3.884	3.508	-26.246	-2.875	-0.076
Over Invest	2158	6.536	9.428	.0002	3.627	90.033
CEI	5501	-10.364	1.903	-14.996	-10.488	-5.594
AnalystCoverage	5324	2.292	0.897	0.000	2.485	3.891
EnvironmentalInnovation	5500	41.095	32.267	0.000	32.000	98.407
TOBIN	5501	1.828	1.643	0.406	1.333	30.424
SIZE	5501	22.239	1.567	16.566	22.298	24.949
TANG	5501	0.243	0.194	0.000	0.200	0.945
FINSLACK	5501	0.116	0.099	0.000	0.090	0.938
AGE	5501	3.286	0.934	0.000	3.332	5.142
LEV	5501	0.265	0.149	0.000	0.257	0.868

4.2. Baseline estimations

Presented here are the main estimation results analyzing how CEI affects IE. The estimations are performed using the ordinary least squares (OLS) method and Driscoll-Kraay standard errors, and the results are reported in Table 4.

Table 4. The Effect of Carbon Emission Intensity on Investment Efficiency

Variables	Baseline Model	Under-Investment	Over- Investment
CEI	-0.165***	0.008	-0.411***
	(-4.33)	(0.34)	(-3.11)
TOBIN	-0.384***	0.221*	-0.440***
	(-6.18)	(1.86)	(-3.39)
SIZE	0.304***	0.024	0.605***
	(6.10)	(1.03)	(8.10)
TANG	0.738	2.697***	1.687
	(0.98)	(10.87)	(1.14)
FINSLACK	-2.356	0.971*	-8.228**
	(-1.67)	(1.97)	(-2.96)
AGE	0.385***	0.074*	0.723***
	(5.42)	(2.06)	(3.18)
LEV	-1.244*	-1.585***	-2.245*
	(-1.86)	(-4.65)	(-1.82)
Constant	-12.707***	-4.421***	-23.061***
	(-13.64)	(-5.44)	(-9.71)
F - value	302.7***	296.1***	125.9***
R-squared	0.144	0.277	0.173
Observations	5501	3343	2158
Number of firms	931	772	647

Note: t-statistics are reported in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.10. All estimations include fixed effects for year, industry, and country.

4.3. Robustness Checks

To test the methodological robustness of our main findings, additional estimates were performed using the System GMM approach, which accounts for potential endogeneity and dynamic endogeneity issues (Arellano and Bond, 1991; Arellano and Bover, 1995; Blundell and Bond, 1998). To ensure robustness against standard error deviations in the estimates, the proposed corrections for two-stage GMM were followed (Windmeijer, 2005). According to the results presented in Table 5, the lagged dependent variable (L.IE) is positive and statistically significant across all model specifications. The coefficient of CEI is negative and statistically significant at the 5% level (β = –0.552). In the under-investment subsample, CEI shows no significant effect on IE (β = –0.116, p > 0.10), indicating that CEI does not directly influence underinvestment behavior. However, in the over-investment subsample, CEI is negative and statistically significant at the 5% level (β = –0.759), suggesting that firms with higher carbon emission intensity are more prone to overinvestment.

Table 5. Robustness Checks

Variables	**System GMM**		
	Baseline Model	**Under-Investment**	**Over- Investment**
L.IE	0.209*	0.095***	0.241***
	(1.77)	(3.52)	(4.22)
CEI	-0.552**	-0.116	-0.759**
	(-2.10)	(-1.05)	(-2.10)
TOBIN	-0.394***	0.264**	-0.463**
	(-2.93)	(2.36)	(-2.40)
SIZE	0.336***	0.032	0.590*
	(3.53)	(0.28)	(1.87)
TANG	0.956	2.919***	3.434
	(0.80)	(3.02)	(1.17)
FINSLACK	-2.261	1.695	-15.158***
	(-1.11)	(1.18)	(-2.99)
AGE	0.276*	0.167	0.068
	(1.96)	(1.33)	(0.19)
LEV	1.058	-1.753*	-6.308**
	(0.97)	(-1.71)	(-2.02)
Constant	-16.325***	-7.031**	-20.552**
	(-3.42)	(-2.12)	(-2.42)
Observations	5,399	3,287	2,112
Number of Firms	925	767	639
F - value	54.50***	85.53***	54.13***
AR(1) test (p value)	0.000	0.000	0.000
AR(2) test (p value)	0.103	0.332	0.102
Hansen test of over-identification (p value)	0.550	0.469	0.713

Note: t-statistics are reported in parentheses. Significance levels: *** p<0.01, ** p<0.05, * p<0.10. All estimations include fixed effects for year, industry, and country.

Model validity is supported by diagnostic tests: AR(1) tests were significant (p = 0.000) in all models, while the insignificant p-values in AR(2) tests (p = 0.103, 0.332, 0.102) indicate the absence of second-order autocorrelation (Arellano and Bond, 1991). Hansen's over-specified model test p-values are 0.550, 0.469, and 0.713, respectively, confirming the validity of the selected instrument set (Hansen, 1982). These results show that the direction and significance level of the relationship obtained in the basic analysis are similarly preserved in the System GMM estimates, thus demonstrating that the negative effect of CEI on IE is methodologically sound and reinforces the overall robustness of the findings.

To further ensure robustness, we employ three alternative measures of IE, with the corresponding results presented in Appendix Table A1. The findings remain consistent across all specifications. Moreover, we separately examine the effects of Scope 1 and Scope 2 emissions using both the OLS model and the System GMM method. The results, shown in Appendix Table 2, reveal a negative and significant effect of both Scope 1 and Scope 2 emissions on IE. Overall, these analyses corroborate our baseline results and demonstrate robustness

4.4. Moderation Analysis

This section presents the results of moderation analyses conducted to examine the possible regulatory effects of analyst coverage and environmental innovation variables on the CEI–IE relationship (Table 6).

Table 6. The Moderating Role of Analyst Coverage and Environmental Innovation in the CEI-IE Relationship

Variables	**IE (1)**	**IE (2)**
CEI	-0.176*** (-3.58)	-0.185*** (-4.91)
AnalystCoverage	0.034*** (3.40)	
CEI * AnalystCoverage	-0.012* (-1.83)	
EnvironmentalInnovation		0.006*** (5.95)
CEI * EnvironmentalInnovation		-0.003*** (-4.45)
TOBIN	-0.422*** (-7.89)	-0.383*** (-7.27)
SIZE	0.166** (2.51)	0.255*** (4.52)
TANG	0.643 (0.88)	0.627 (0.93)
FINSLACK	-2.464* (-1.83)	-2.439* (-1.91)
AGE	0.390*** (5.17)	0.374*** (5.75)
LEV	-1.179* (-1.90)	-1.258* (-1.89)
Constant	-7.921*** (-7.02)	-9.832*** (-10.64)
Observations	5,432	5,500
R-squared	0.149	0.145
Number of groups	907	931
F - value	559.6***	359.2***

Note: t-statistics are reported in parentheses. Significance levels are denoted as follows: ***p < 0.01, **p < 0.05, p < 0.10. All estimations include fixed effects for year, industry, and country.

The results of the regressions, which include analyst coverage and its interaction with CEI to investigate a potential moderating effect of analyst coverage on the CEI-IE relationship, are reported in column 1 of Table 6. In these analyses, CEI and analyst coverage have been mean-centered to prevent multicollinearity issues. Table 6 shows that analyst coverage has a positive effect on IE (β=0.034, p<0.01). On the other hand, the coefficient of the interaction term CEI*AnalystCoverage is negative and statistically significant (β=-0.012, p<0.10), meaning that analyst coverage amplifies the negative effects of CEI on IE. This finding suggests that external monitoring by analysts may increase market pressure and increase the visibility of environmental risks, thereby exacerbating IE in carbon-intensive firms.

The results of the regressions which include environmental innovation and its interaction with CEI to investigate a potential moderating effect of environmental innovation on CEI-IE relationship are reported in column 2 of Table 6. In the analysis, CEI and environmental innovation have been mean-centered to prevent multicollinearity issues. Table 6 shows that environmental innovation has a positive effect on IE (β=0.006, p<0.01). In addition, the interaction term (CEI*EnvironmentalInnovation) is negative and significant at 1% level (β=-0.003), suggesting that for firms with high levels of environmental innovation, the deterioration in IE becomes more pronounced as CEI increases.

Additionally, separate moderation analyses were conducted at the Scope 1 (direct emissions) and Scope 2 (indirect emissions) levels, which are subcomponents of CEI. In these analyses, the moderating effects of analyst coverage and environmental innovation variables on the CEI–IE relationship were examined separately for each emission type. The findings obtained are generally consistent with the basic models and are presented in Appendix Table A3.

Morever, figure 1 provides a visual representation of how environmental innovation influences the relationship between CEI and IE, offering a clearer understanding of this interaction.

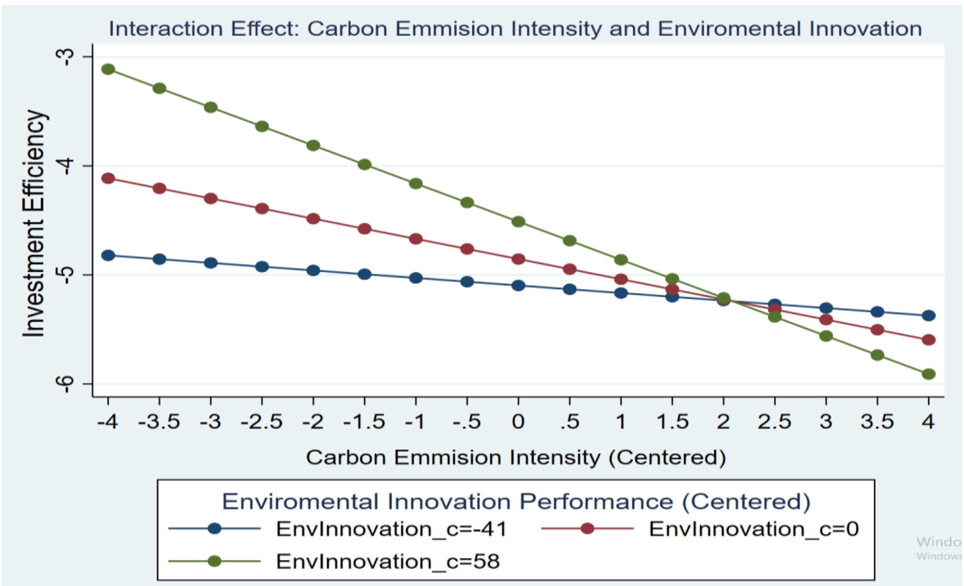

Figure 1. Heterogeneous Effects of Environmental Innovation on the Carbon Emission Intensity–Investment Efficiency Relationship

Figure 1 shows that firms with high levels of environmental innovation initially have a more advantageous position on IE. Especially up to a threshold point where the centralized value of CEI is approximately 2, these firms perform relatively more efficiently in their investment decisions. However, once this threshold is exceeded, meaning that CEI reaches very high levels, a notable decline in IE is observed among firms with high environmental innovation.

4.5. Heterogeneity Analysis

The impact of CEI on IE may vary across firms. Accordingly, we consider green revenue and ETS participation as potential factors that may influence this relationship, and the results are presented in Table 7. The first column indicates that for firms with high green income (i.e., firms with green income levels above the sample median) CEI does not have a significant effect on IE. However, the second column shows that for firms with low green income, the relationship between CEI and IE is significant and negative (β=-0.253 and p<0.01). This finding indicates that green income mitigates the negative impact of CEI on IE. Regarding ETS participation, column 3 of Table 7 shows that for firms participating in ETS, CEI does not have a significant effect on IE. However, column 4 shows that for firms that are not participating in ETS, the association between CEI and IE is negative and significant (β=-0.187 and p<0.01).

Table 7. Heterogeneous Effects of Green Revenue and ETS on the CEI–IE Relationship

Variables	**Green Revenue**		**Emission Trading System Green Revenue**	
	High	**Low**	**Included**	**Not Included**
CEI	0.054	-0.253***	-0.153	-0.187***
	(0.33)	(-3.21)	(-1.29)	(-4.94)
Constant	-9.202**	-13.816***	-9.981	-10.972***
	(-2.72)	(-6.78)	(-1.05)	(-8.64)
Control Variables	Included	Included	Included	Included
Observations	1,951	3,550	1,123	4,356
R-squared	0.146	0.168	0.192	0.150
Number of firms	397	617	191	856
F - value	393.7***	576***	114.8***	210.5***

Note: t-statistics are reported in parentheses. Significance levels are denoted as follows: ***p < 0.01, **p < 0.05, p < 0.10. All estimations include fixed effects for year, industry, and country. The table presents coefficients of the main explanatory variables only; control variable coefficients are excluded for clarity.

Finally, the impact of CEI on IE is analyzed in the context of sectoral differences. Table 8 shows that this relationship varies significantly across sectors. The negative and statistically significant effect of CEI on IE is observed across several sectors, including Consumer Non-Cyclicals (β=-0.658 and p<0.01), Consumer Cyclicals (β=-0.244 and p<0.10), Basic Materials (β=-0.204 and p<0.10), and Technology (β=-0.300 and p<0.10). In contrast, the relationship is positive and significant in Utilities (β=0.947 and p<0.05), suggesting that the regulatory structure and investment dynamics of the sector operate differently. The effects are not statistically significant in the Healthcare, Industrials, Real Estate, and Energy sectors. These results suggest that CEI may affect sector-specific investment decisions at different levels and that policy recommendations should be developed on a sectoral basis.

Table 8. Sectoral Heterogeneity in the Effect of CEI on IE

Variables	Basic Materials	Consurmer Cyclicals	Consumer Non-Cyclicals	Energy	Healthcare
CEI	-0.204*	-0.244*	-0.658***	-0.351	-0.197
	(-1.95)	(-2.06)	(-7.56)	(-1.30)	(-1.10)
Constant	-8.620**	-14.250***	-13.378***	-29.843***	-9.525**
	(-2.54)	(-3.07)	(-3.50)	(-3.36)	(-2.18)
Control Variable	Included	Included	Included	Included	Included
Observations	754	963	405	258	489
R-squared	0.131	0.084	0.203	0.391	0.110
Number of Firms	100	157	70	39	88
F - value	27.87	188.9	1160	3421	2255
Variables	**Industrials**	**Real Estate**	**Technology**	**Utilities**	
CEI	0.070	-0.190	-0.300*	0.947**	
	(0.84)	(-1.20)	(-2.03)	(2.52)	
Constant	-9.512***	6.406	-25.947***	-90.296***	
	(-10.16)	(1.21)	(-8.93)	(-3.37)	
Control Variable	Included	Included	Included	Included	
Observations	1,318	343	862	109	
R-squared	0.098	0.106	0.143	0.831	
Number of Firms	219	73	168	17	
F - value	271.1	75649	983.3	537.7	

Note: t-statistics are reported in parentheses. Significance levels are denoted as follows: ***p < 0.01, **p < 0.05, p < 0.10. All estimations include fixed effects for year and country. The table presents coefficients of the main explanatory variables only; control variable coefficients are excluded for clarity.

5. Conclusion

5.1. Discussion of Main Findings

This study investigated the impact of CEI on IE and the moderating role of analyst coverage and environmental innovation in this relationship using data from 931 European firms for the period 2008-2023. Our analysis consistently showed that CEI has a negative impact on IE and that this negative effect manifests itself in the form of overinvestment. This result supports the agency theory, which suggests that managers in carbon-intensive firms tend to direct their free cash flows to low-return projects as a form of empire building or to symbolic environmental investments (Jensen and Meckling, 1976; Cariola et al., 2005; Lyon and Maxwell, 2011; Souguir et al., 2024). Moreover, our main finding is in line with the information asymmetry theory, which suggests that heightened uncertainty surrounding high-CIE firms leads to a higher cost of capital, thereby reducing IE (Myers and Majluf, 1984; Bao and Motlagh, 2024; Gulen and Ion, 2016). Supporting this interpretation, recent studies reveal that the increase in Scope 1 and 2 emissions encourages excessive investments that lead to inefficient use of resources, and that this process is closely related to agency problems between managers and shareholders (Jebri et al., 2024). Furthermore, the negative impact of carbon risk on IE appears to be amplified by the intensity of environmental uncertainties, deficiencies in corporate governance, and ineffective climate strategies (Luo et al., 2025).

Building on these baseline findings, our results show that an increase in the number of analysts following a company strengthens the negative relationship between CEI and IE. While analysts are important information intermediaries that increase efficiency in capital allocation by reducing information asymmetry (To et al., 2018), this role may operate differently in high-risk contexts. Greater analyst coverage may increase the market visibility of carbon risks, creating pressure on managers to focus on short-term performance, which can lead to the postponement of long-term environmental investments (Chan and Hameed, 2006; He and Tian, 2013; Qian et al., 2019). This interpretation is in line with prior studies linking greater analyst coverage to "short-termism" (DesJardine, 2015) and "greenwashing" (Gao and Chen, 2024). However, because our study does not directly measure managers' intentions, these interpretations should be regarded as tentative rather than definitive.

In addition to analyst coverage, we found that the adverse effect of CEI on IE is more pronounced among firms with higher levels of environmental innovation. A possible explanation is that some firms employ environmental innovation as a symbolic legitimacy strategy rather than as a real transformation of production processes (Jebri et al., 2024). This pattern is also consistent with the literature on greenwashing, which suggests that firms highlight their environmental initiatives merely to improve their image while avoiding costly operational transformations (Delmas and Burbano, 2011; Hawn and Ioannou, 2016). While such strategies may create positive impressions among investors, they do not necessarily deliver real improvements in efficiency or reductions in carbon emissions (Jebri et al., 2024). From a theoretical perspective, this finding contradicts the resource-based view and the Porter Hypothesis, which suggest that innovation should increase efficiency. Our evidence shows that when environmental innovation is not supported by real technological changes, its potential to improve efficiency is constrained and can even be counterproductive.

Beyond these institutional mechanisms, our study reveals that the negative impact of CEI on IE is less pronounced for firms with higher levels of green revenue. This can be explained by the fact that firms with high green income levels can more easily adapt to both regulatory pressures and investor expectations, gain strategic flexibility, and act more rationally in capital allocation. On the other hand, firms with low green income levels face higher environmental risk perception, regulatory uncertainty, and external financing costs in the face of increasing CEI, which significantly weakens IE. This result is consistent with previous studies showing a positive relationship between green revenue and financial performance (Guo and Zhong, 2023; Kruse et al., 2020; Klausmann et al., 2025; Yan and Yin, 2023). Indeed, Matsumura et al. (2014) and Bolton and Kacperczyk (2021) show that carbon emissions have negative effects on firm value and cost of capital, while firms with high environmental performance gain advantages in investor confidence and market value. In this context, companies with a high green revenue ratio are perceived by the market as lower risk and can maintain their investment activities thanks to more favorable financing conditions.

Consistent with this line of evidence, the findings show that the negative impact of the CEI on IE is only significant for companies operating outside the ETS scope; conversely, this effect is weakened for companies included in the ETS. This finding is consistent with the literature suggesting that the market-based structure of the ETS improves firms' resource allocation and makes investment decisions more rational by incorporating carbon costs into the price mechanism. Indeed, Sun et al. (2022) and Ren et al. (2022) show that ETS implementation increases firms' financial performance and innovation capacity, while Vu et al. (2025) show that

ETS participation strengthens firms' resilience to carbon transition risks. Similarly, Chen et al. (2022) and Wang and Zhang (2024) show that ETS increases IE by limiting excessive and insufficient investment, while Ma et al. (2023) demonstrate that regulation improves the efficiency of labor investments. Additionally, the long-term positive effects of market-based environmental policies on energy and IE also support these findings (Dai and Li, 2023).

Finally, the sectoral analysis indicates that the impact of CEI on IE varies across sectors, with this effect being more pronounced in the consumer goods, basic materials, and technology sectors. This situation is closely related to the structural characteristics of the sectors. In the consumer goods sector, brand reputation and consumer sensitivity (Delmas and Burbano, 2011; Krüger, 2015) show that high CEI increases market and reputation risks, thereby raising capital costs. In the basic materials sector, high capital intensity and process emissions (Dechezleprêtre and Sato, 2017) restrict low-carbon transition investments, and in the technology sector, energy-intensive digital infrastructures become more vulnerable under increasing regulatory pressures.

5.2. Policy Implications

The evidence of a negative relationship between CEI and IE suggests that a comprehensive green policy framework is needed to mitigate the negative effects of carbon risk on IE and increase the efficiency of capital allocation. A central priority should be the integration of carbon pricing mechanisms (such as carbon taxes, ETSs, or border carbon adjustments) into the market structure. Such an approach could redirect capital flows to low-carbon investments and make high-CIE projects less attractive (Iovino et al., 2021). In parallel, the widespread adoption of green financing instruments is critically important. Green bond issuances, in particular, facilitate the financing of environmentally friendly projects and alleviate companies’ overinvestment problems (Jebri et al., 2024). Encouraging the financial system in this direction will strengthen not only environmental sustainability but also the quality of long-term investments. At the policy level, the EU Clean Industry Deal announced by the European Union in 2025 exemplifies this approach by providing tools such as accelerated depreciation, targeted tax credits, and green transition funds that support investments in low-carbon technologies (European Commission, 2025). Such policies have the potential to indirectly increase firms' IE by internalizing carbon costs and lowering financing costs. Extending similar policies to candidate or neighboring economies, such as Turkiye, could facilitate alignment with the EU green taxonomy, reduce firms' cost of access to capital markets, and facilitate diffusion of sustainable investment practices.

In line with these system-wide measures, it is equally important to address how external monitoring influences corporate investment behavior. Given our finding that broader analyst coverage intensifies the negative impact of CEI on IE, policymakers should develop regulatory mechanisms that limit short-term market pressures while preserving the information-providing role of analysts. First, standardized, forward-looking sustainability reporting, aligned with the EU's Corporate Sustainability Reporting Directive (CSRD), should be promoted. Such reporting would shift analysts’ focus from short-term profits to long-term environmental performance (Zhang and Wu, 2023) and increase investor confidence by reducing capital costs (Dhaliwal et al., 2011). Second, subjecting disclosures to independent verification can help analysts distinguish symbolic claims from genuine environmental progress (Simnett et al., 2009; Christensen et al., 2021; Gao and Chen, 2024). Third, regulators and exchanges should encourage guidance based on long-term environmental metrics (e.g., emissions intensity, energy efficiency, green investment ratio) rather than quarterly earnings guidance (He and Tian, 2013; Qian et al., 2019). At the corporate level, linking managerial incentives to verified decarbonization targets and institutionalizing environmental expertise in investment committees will enhance the sustainability of long-term investments even under analyst pressure (Guo et al., 2019; Zhang et al., 2023). Finally, methodological transparency should be provided regarding how environmental metrics used in analyst reports (e.g., CEI, Scope 1–3 emissions, transition plan quality) are modeled. This will enable assessments to be free from short-term pricing pressures and more aligned with sustainability goals (Qian et al., 2019; Zhang et al., 2023).

Extending these considerations to the domain of environmental innovation, firms should build their environmental innovation strategies on concrete practices that provide measurable carbon reductions, not just image-oriented ones, and should rely on transparency and impact-based reporting in this process. To achieve this, policymakers must ensure that innovation-related incentives and disclosures are designed to distinguish real operational transformations from symbolic actions. For example, tax credits, subsidies, or R&D grants should be tied to verified emission reductions and technological improvements, rather than self-reported innovation announcements. In addition, sustainability reporting frameworks should require firms to disclose the carbon impact of their innovation activities, enabling investors to assess whether environmental innovations result in measurable efficiency gains. Finally, corporate governance mechanisms are needed to align environmental innovation with efficiency gains. Measures such as establishing sustainability committees within boards or linking executive compensation to reduced carbon emission targets may ensure that environmental innovation becomes a tool for real transformation rather than a symbolic legitimacy tool.

Our finding that firms with higher levels of green revenue are less negatively affected by CEI highlights the importance of coordinated implementation of comprehensive mechanisms aimed at increasing the share of green revenue at the policy level. First, the introduction of financial incentives such as accelerated depreciation or tax breaks for low-carbon investments can accelerate the transition of businesses to clean production technologies (Brühl, 2021). Second, the allocation of approximately €38 billion by the EU Innovation Fund during the 2020–2030 period to support the commercialization of innovative low-carbon technologies (European Commission, 2025) demonstrates the importance of developing similar green R&D grants and credit mechanisms at the national level. Third, the public sector's creation of demand for low-carbon products and services through Green Public Procurement (GPP) policies can strengthen the private sector's motivation to invest in these areas (OECD, 2023). In conclusion, strengthening the green revenue structure will both increase companies' resilience to carbon risk and contribute to sustainable growth by supporting IE.

Our evidence that the adverse impact of CEI on IE is weaker for firms covered by the ETS highlights the importance of gradually expanding the scope of the ETS, maintaining a predictable and stable carbon price signal, restructure allocation and auction mechanisms based on efficiency principles, and effectively coordinating complementary policy instruments such as innovation funds and green R&D programs. The inclusion of new sectors such as shipping, aviation, and buildings under the EU's Fit for 55 reform package enhances the comprehensiveness of the carbon price signal in the economy, thereby strengthening emission reductions and capital allocation (European Council, 2023). The predictability of the carbon price signal reduces the financial risk of low-carbon investments, facilitating the mobilization of private capital; indeed, the literature shows that price uncertainty delays companies' decarbonization investments (Flues and van

Dender, 2020; Fuchs et al., 2024; van der Ploeg, 2021). Furthermore, directing ETS revenues toward green R&D and clean technology investments through mechanisms such as the Innovation Fund contributes to accelerating the low-carbon transition (European Commission, 2024). Therefore, this integrated policy approach will strengthen companies' resilience to carbon transition risks while limiting CEI-related inefficiencies and encouraging sustainable investment decisions.

Finally, the sectoral heterogeneity we identified in the CEI–IE relationship indicates the necessity of a sector-based transition policy framework that will increase IE while also supporting progress toward carbon reduction targets. In the basic materials sector (e.g., steel, cement, and chemicals), given the high capital requirements and uncertainty risks associated with first-generation low-carbon technologies, scaling up the Carbon Contracts for Difference (CCfD) mechanism across Europe and providing demand assurance through Green Public Procurement (GPP) are of great importance. These tools can encourage companies to accelerate their investment decisions, thereby directing capital towards low-carbon and efficient areas (Richstein and Neuhoff, 2022; Lösch et al., 2022; Economics, 2019). In consumer sectors (Consumer Cyclicals and Non-Cyclicals), eco-design standards, carbon footprint labeling, and extended producer responsibility (EPR) applications must be made mandatory to enable the tracking of environmental impacts at every stage of the product life cycle. Such regulations can steer companies away from superficial “green” marketing strategies and toward real emission reductions and innovative production processes (Poore & Nemecek, 2018). In the technology sector, particularly regarding energy-intensive data centers, it is important to effectively implement the KPI-based reporting obligations defined under the revised Energy Efficiency Directive (EED 2023/1791) and to disseminate the European Commission Joint Research Center's (JRC) “EU Code of Conduct on Data Center Energy Efficiency” guide (CODES, 2022; Avgerinou et al., 2017). This framework can increase transparency in energy consumption and encourage renewable energy investments, enabling companies to allocate resources more efficiently and strengthen IE (Masanet et al., 2020). This policy framework offers a comprehensive approach with the potential to increase IE based on the structural differences between sectors. However, more detailed empirical and sectoral analyses are needed to gain a deep understanding of each sector's unique dynamics and institutional response mechanisms. This study discusses the impact mechanisms related to these sectors at a general level. Future research examining how the CEI–IE relationship differs at the sector and sub-sector levels, the level of interaction between policy instruments, and how factors such as firm size, technology intensity, and market structure shape this relationship could constitute an important research agenda.

5.3. Limitations and Further Study

Although the findings of this study offer important insights, certain limitations may guide future research. First, it was found that the negative impact of CEI on IE is more pronounced in companies with high levels of environmental innovation. A possible explanation is that some companies use environmental innovation as a form of greenwashing to gain legitimacy rather than as a real transformation to reduce carbon emissions. However, since greenwashing was not directly measured in the study, it remains unclear whether this relationship reflects symbolic legitimacy strategies or the delayed returns typically associated with R&D investments. To fill this gap, future research could employ more direct indicators of greenwashing based on the difference between companies' environmental statements and their actual carbon emission performance, or methods that examine the discourse-action inconsistencies in sustainability reporting. Such an approach would reveal whether the impact of environmental innovation on IE reflects a genuine emission reduction process or a perceived green legitimacy strategy, thereby providing deeper and policy-relevant contributions to the literature on CEI–IE interactions.

Secondly, the findings reveal that the impact of CEI on IE varies across sectors. However, this study has addressed these differences at a broad, sectoral level. More detailed sectoral and sub-sectoral analyses are needed to better understand each sector's unique dynamics, institutional responses, and capital structure. In particular, future research could investigate how the CEI–IE is shaped by sub-sector characteristics as well as by factors such as technology intensity, market competition, and firm size that shape this relationship. Such an approach would allow deeper and context-sensitive contributions to the literature.

Finally, this study is limited to companies operating in the EU and does not include comparisons between countries that differ in corporate structures, investor profiles, and levels of environmental regulation. Research examining how the CEI–IE relationship varies across countries and under different market-based and rule-based environmental policies. Such an approach could contribute to a more comprehensive understanding of the impact of environmental risks on investment decisions. Furthermore, exploring the interactions between market mechanisms, sustainability reporting practices, and corporate governance structures at the country level could enable the development of more targeted and contextual policy recommendations aimed at improving investment quality in carbon-intensive sectors.

Declaration of Research and Publication Ethics
This study which does not require ethics committee approval and/or legal/specific permission complies with the research and publication ethics

Researcher's Contribution Rate Statement
The authors declare that they have contributed equally to the article.

Declaration of Researcher's Conflict of Interest
There is no potential conflicts of interest in this study.

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APPENDIX:

Table A1. Robustness Analyses with Alternative Measures of Investment Efficiency

Variables	**Firm-Level Controls**	**Interaction Model with NEG**	**PPE-Based Investment**
CEI	-0.150***	-0.190***	-0.119**
	(-5.07)	(-5.66)	(-2.66)
TOBIN	-0.304***	-0.360***	-0.007
	(-7.86)	(-6.12)	(-0.38)
SIZE	0.146***	0.288***	0.246***
	(6.22)	(7.20)	(8.25)
TANG	0.092	0.815	-6.389***
	(0.22)	(1.06)	(-6.52)
FINSLACK	-3.331**	-1.982	-1.614**
	(-2.78)	(-1.57)	(-2.86)
AGE	0.297***	0.322***	0.203**
	(5.82)	(4.42)	(2.92)
LEV	-0.759***	-0.902	-0.022
	(-3.41)	(-1.62)	(-0.03)
Constant	-8.829***	-12.638***	-7.814***
	(-11.28)	(-16.89)	(-8.00)
Year Effect	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes
Observations	5,501	5,501	5,320
R-squared	0.130	0.144	0.198
Number of groups	931	931	932
F - value	417***	444***	32.87***

Notes: This table reports the results of robustness analyses using three alternative approaches to measure investment efficiency (IE). In Model (1), financial control variables are added to the baseline specification to account for firms’ financial characteristics (Biddle et al., 2009). Model (2) employs an alternative estimation that differentiates investment behavior based on the sign of sales growth, following Bilyay-Erdoğan et al. (2024). Model (3) defines investment as the ratio of the annual change in tangible and intangible fixed assets to total assets in the previous year (Biddle et al., 2009; Benlemlih and Bitar, 2018). t-statistics are reported in parentheses. Significance levels are denoted as follows: ***$p < 0.01$, **$p < 0.05$, $p < 0.10$.

Table A2. Robustness Tests with Scope 1–2 Emission Intensities: Driscoll–Kraay and System GMM

Variables	Driscoll-Kraay Standard Errors		System GMM	
	IE	IE	IE	IE
L.IE			0.240*	0.275*
			(1.73)	(1.85)
Scope1	-0.121**		-0.753**	
	(-2.72)		(-2.02)	
Scope2		-0.106***		-0.809*
		(-3.10)		(-1.68)
TOBIN	-0.405***	-0.347***	-0.522***	-0.338***
	(-5.49)	(-5.58)	(-3.39)	(-2.77)
SIZE	0.353***	0.311***	0.394***	0.400***
	(5.53)	(5.68)	(3.12)	(3.52)
TANG	0.584	0.387	1.342	1.218
	(0.71)	(0.45)	(0.85)	(0.73)
FINSLACK	-1.766	-2.811	-1.286	-3.737
	(-1.10)	(-1.55)	(-0.54)	(-1.57)
AGE	0.318**	0.317**	0.244	0.069
	(2.96)	(2.89)	(1.50)	(0.44)
LEV	-0.949	-1.016	2.609*	3.558*
	(-1.23)	(-1.52)	(1.83)	(1.70)
Constant	-13.118***	-11.552***	-24.877***	-19.065***
	(-11.05)	(-15.34)	(-3.31)	(-2.63)
Year Effect	Yes	Yes	Yes	Yes
Industry Effect	Yes	Yes	Yes	Yes
Country Effect	Yes	Yes	Yes	Yes
F - value	610.1***	493.8***	55.55***	36.25***
R-squared	0.136	0.140	-	-
Observations	4952	4914	4,864	4,829
Number of firms	875	880	871	876
AR(1) test (p value)	-	-	0.000	0.000
AR(2) test (p value)	-	-	0.100	0.104
Hansen test of over-identification (p value)	-	-	0.752	0.557

Notes: This table presents the results of additional robustness analyses examining the effects of Scope 1 (direct) and Scope 2 (indirect) emission intensities on IE using both the OLS model with Driscoll–Kraay standard errors and the System GMM estimator. The findings indicate that both emission types have a negative and statistically significant impact on IE, confirming the robustness of the baseline results. t-statistics are reported in parentheses. Significance levels are denoted as follows: ***p < 0.01, **p < 0.05, p < 0.10.

Table A3. The Moderating Role of Analyst Coverage and Environmental Innovation on the Relationship Between Scope 1–2 Emission Intensity and Investment Efficiency

Variables	Independent Variable: Investment Efficiency			
	Scope-1	Scope-2	Scope-1	Scope-2
CEI	-0.090*	-0.158**	-0.105**	-0.153***
	(-2.12)	(-2.75)	(-2.86)	(-5.45)
AnalystCoverage	0.027**	0.033**		
	(2.39)	(2.62)		
CEI_ AnalystCoverage	-0.010**	-0.017		
	(-2.45)	(-1.70)		
EnvironmentalInnovation			0.005***	0.005***
			(3.59)	(3.70)
CEI _EnvironmentalInnovation			-0.004***	-0.004***
			(-4.17)	(-4.00)
TOBIN	-0.451***	-0.414***	-0.410***	-0.371***
	(-6.35)	(-6.74)	(-5.64)	(-5.79)
SIZE	0.208**	0.180*	0.284***	0.278***
	(2.31)	(2.14)	(4.29)	(5.08)
TANG	0.487	0.661	0.376	0.599
	(0.57)	(0.77)	(0.50)	(0.79)
FINSLACK	-1.761	-1.884	-1.795	-1.979
	(-1.05)	(-1.23)	(-1.13)	(-1.35)
AGE	0.336***	0.320**	0.312***	0.306**
	(3.05)	(2.73)	(3.12)	(2.99)
LEV	-1.008	-1.065	-1.110	-1.185
	(-1.40)	(-1.61)	(-1.45)	(-1.70)
Constant	-8.549***	-7.630***	-10.193***	-9.725***
	(-6.01)	(-4.81)	(-10.25)	(-12.01)
Observations	4,828	4,812	4,889	4,873
R-squared	0.144	0.146	0.141	0.143
Number of groups	846	849	868	872
F - value	386.9	534.9	1430	588.6

Notes: This table analyzes the impact of carbon emission intensity (CEI) on investment efficiency separately based on direct (Scope 1) and indirect (Scope 2) emissions. Scope 1 emission intensity is calculated as the natural logarithm of the ratio of direct CO_2 emissions from the company's own activities to net sales revenue. Scope 2 emission intensity is defined as the natural logarithm of the ratio of CO_2 emissions from indirect energy sources such as purchased electricity, heat, or steam to net sales revenue. The models test the moderating effects of analyst coverage and environmental innovation variables on the CEI–IE relationship. Values in parentheses indicate t-statistics, while ***, **, and * denote significance levels of 1%, 5%, and 10%, respectively. Year, industry, and country fixed effects were controlled for in all models, and standard errors were estimated using the Driscoll–Kraay method.