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Environmental-Practices, Digitalization and Financial Performance: Evidence from Industrial Firms in Eastern and Western Europe

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Abstract

This study analyzes how sustainability practices and digitalization jointly influence the financial performance of European industrial firms, emphasizing differences between Western and Eastern Europe. The empirical analysis relies on a large multi-country panel dataset and employs fixed effects regression models with robust standard errors to account for unobserved firm-specific heterogeneity and common time shocks. Environmental sustainability is captured by the environmental component of ESG scores, digitalization is measured by digital investment intensity, and financial performance is proxied by return on equity (ROE). The findings indicate that stronger environmental practices are positively associated with profitability across the full sample. Digital investment intensity also has a positive and statistically significant effect on ROE. Importantly, the interaction term between environmental performance and digitalization is positive and significant for Western European firms but not for the full sample, suggesting that the relationship between environmental practices and financial performance may vary with the level of digital investment under specific regional conditions. However, the results reveal substantial regional heterogeneity. The positive effects of environmental practices, digitalization, and their interaction are primarily driven by firms in Western Europe, whereas the relationships are weaker and statistically insignificant in Eastern Europe. These findings underline the complementary role of digital transformation and the importance of institutional and technological readiness.

Keywords: environmental practices; digitalization; industrial firms; financial performance; Western and Eastern Europe



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1. Introduction

Industrial and cross-sector industrial firms are core to the European economy, providing high-added-value and acting as structural links within broader production networks [1,2]. Industrial production, however, remains one of the most resource-demanding and environmentally intensive forms of economic activity, relying heavily on raw materials and energy consumption, thereby contributing significantly to pollution and climate change. The European Union's State of the Digital Decade 2025 report highlights that, despite progress toward common digital targets, substantial gaps persist in digital infrastructure,

digital skills, and business digitalization across member states, reflecting uneven technological development within Europe [3]. Such regional variation in digital capacity conditions firms' ability not only to adopt but also to economically leverage environmental practices supported by digital technologies, making comparative analysis between Eastern and Western Europe particularly relevant for understanding sustainability–performance dynamics.

While digitalization may offer particularly strong upgrading potential in Eastern Europe, its financial returns cannot be assumed to materialize uniformly across regions. In industrial firms, the performance effects of digital investment depend not only on the scale of investment but also on the surrounding enabling environment, including the quality of digital infrastructure, firms' capacity to integrate advanced technologies into production processes, managerial and organizational capabilities, and the level of institutional support for innovation and sustainability transitions [4,5]. Empirical evidence suggests that the productivity and profitability benefits of digital transformation tend to materialize when firms possess complementary assets such as organizational capital, technological readiness, and access to innovation ecosystems [6,7]. In regions where these complementary conditions are less developed, digitalization may enhance operational potential and process modernization but may not immediately translate into stronger financial performance or sustainability-related value creation [8]. This institutional and technological asymmetry makes the Eastern–Western European comparison particularly important for identifying when digitalization can reinforce the financial effectiveness of environmental practices.

Digital transformation and sustainability practices are interrelated and mutually reinforcing strategic directions [9], especially for industrial firms, distinguishing between East and West Europe. Digital technologies create conditions for more effective environmental monitoring, resource optimization, and transparency in sustainability reporting, thereby supporting operational efficiency improvements [10]. Therefore, digitalization can act as an important mechanism that allows firms to more effectively implement ESG principles and improve operational efficiency. At the same time, sustainability practices can strengthen firms' reputation, increase stakeholder trust, and improve access to financing [11]. The shift to sustainability must be accompanied by a primary shift in industrial production systems, making sustainability practices for industrial firms one of the main research and policy targets to be implemented [12,13].

This is an environment where sustainability practices—measured in terms of environmental, social, and governance (ESG) factors—emerged as a strategic concern among industrial firms in their entirety [14]. ESG actions represent a reaction on the part of firms to these pressures: those of investors, regulators, customers, and employees.

However, ESG engagement alone may not yield financial improvements without complementary internal capabilities. Digitalization through real-time monitoring, automation, and transparency may be essential to unlock the full value of sustainability initiatives. Moreover, empirical research on how digitalization complements environmental practices to influence financial outcomes remains scarce, particularly in industrial contexts.

This complementarity may be particularly sensitive to regional institutional conditions [8,15,16]. In more digitally mature environments, firms are better positioned to embed digital technologies into environmental monitoring, resource optimization, and sustainability reporting, thereby increasing the financial effectiveness of environmental practices [4,6,17]. By contrast, in regions where digital infrastructure, innovation ecosystems, and implementation support are less developed, firms may face greater difficulty in converting digital investment into measurable performance gains [5]. Thus, the financial value of combining environmental practices with digitalization is likely to depend not

only on firm-level strategic choices but also on the broader regional context in which these strategies are implemented.

Consequently, this paper empirically tests the joint effect of ESG behavior and digital transformation on the financial performance of European industrial firms. To structure the inquiry, the following research questions are posed:

RQ1: How do environmental practices affect the financial performance of European industrial firms?

RQ2: Does digital investment independently contribute to firm profitability?

RQ3: To what extent does digitalization moderate the environmental practices relationship, and how do these effects vary between Eastern and Western Europe?

This study draws on three complementary theoretical frameworks to explain how environmental practices and digitalization jointly influence firm performance in different institutional contexts. First, Stakeholder Theory [18] posits that firms respond to diverse stakeholder expectations, such as those from regulators, investors, and consumers, by aligning their strategies with societal and environmental demands. In this context, firms that adopt stronger ESG practices may improve legitimacy, reduce stakeholder conflicts [19], and ultimately enhance financial outcomes (supports H1). Second, Agency Theory explains how digitalization reduces information asymmetry between managers and stakeholders through enhanced transparency, monitoring, and data traceability [20]. This can reduce agency costs, increase operational efficiency, and improve financial performance (supports H2). Third, Ecological Modernization Theory [21,22] provides a macro-level lens by suggesting that digital technologies serve as enablers of cleaner production, allowing firms to decouple economic growth from environmental degradation. This theory underpins the hypothesis that digitalization amplifies the benefits of ESG by making sustainability more measurable and actionable (supports H3). Together, these theories offer a multi-level explanation, covering strategic, operational, and institutional layers, for the synergistic impact of sustainability and digital transformation on industrial firm performance across diverse European contexts.

Although empirical research on ESG practices and firm performance has expanded considerably, the evidence remains fragmented across sectors and institutional contexts [15,23,24]. More importantly, prior studies have largely examined environmental practices and digitalization as separate drivers of firm outcomes, leaving their joint relationship underexplored at the firm level [6,25]. This limitation is particularly important in the European industrial context, where firms operate under uneven conditions of digital maturity, institutional support, and sustainability pressure [3,26]. As a result, existing research provides limited insight into whether digitalization consistently strengthens the financial value of environmental practices, or whether its effectiveness depends on regional conditions such as infrastructure readiness, technological capabilities, and implementation support [5,8,16]. Addressing this gap is essential for understanding why similar sustainability and digitalization strategies may generate different financial outcomes across Eastern and Western Europe.

These Eastern and Western Europe disparities are not merely anecdotal. Recent evidence shows that Western European firms significantly outperform their Eastern counterparts in both ESG reporting and digital capability, particularly in capital-intensive sectors [26]. This divide reflects not only technological infrastructure gaps but also differences in regulatory enforcement and market expectations surrounding sustainability and transparency. Further, Marczewska et al. (2025) [16] found that digitalization efforts yield stronger performance outcomes in Western European firms due to better institutional support and ESG alignment. As such, the regional variation within Europe offers an ideal

empirical context to assess how institutional heterogeneity moderates the environmental practices–digitalization–performance link.

Against this backdrop, this study investigates how environmental practices and investment in digitalization jointly shape firm-level financial performance in European industrial sectors. Specifically, it examines whether sustainability engagement is associated with improved profitability, how digital investments contribute independently to performance outcomes, and whether digitalization acts as a moderator that strengthens the environmental practices relationship. In doing so, this study further explores whether these effects differ systematically between Eastern and Western European contexts, where institutional and technological conditions diverge.

By examining the intersection of environmental practices and digital transformation within the European industrial sector, this paper addresses a notable gap in the literature, where these two domains have largely been treated in isolation. Drawing on a firm-level panel dataset covering multiple European countries, the analysis incorporates regional heterogeneity, enabling a comparative perspective between Eastern and Western European institutional environments. This approach offers insights into how differences in regulatory stringency, digital infrastructure, and ESG maturity shape firm performance outcomes. This paper also develops a theoretically grounded framework that integrates Stakeholder Theory, Agency Theory, and Ecological Modernization to explain the mechanisms through which environmental initiatives and digitalization jointly influence financial performance. This conceptual synthesis captures strategic, operational, and institutional dynamics, offering a more holistic understanding of the environmental practices–digitalization–performance nexus and informing decision-making in digitally and institutionally diverse settings.

This study contributes to theory in several ways. First, it extends Stakeholder Theory by demonstrating that the financial implications of environmental practices depend on firms' internal digital capabilities, highlighting important conditional mechanisms. Second, the findings enrich Agency Theory by showing that digital investment functions not only as a monitoring tool but also as a strategic capability influencing performance outcomes in sustainability-oriented contexts. Third, this study contributes to Ecological Modernization Theory by providing firm-level evidence that the performance benefits of sustainability and digitalization are shaped by institutional and regional conditions. By integrating these perspectives, this research offers a more comprehensive theoretical explanation of how sustainability and digital transformation jointly influence financial performance in industrial firms.

2. Literature Review

2.1. Sustainability Practices in the Industrial Sector

Industrial firms in Europe are a significant part of the economy, generating about 23 percent of the gross domestic product (GDP) [1]. The production of material products, using mechanized and automated processes, involves complex supply chains and has a huge and irreplaceable impact on firms in all other sectors. Traditional industries such as manufacturing, energy, construction, mining, and resource extraction are more characteristic of Eastern European countries. Meanwhile, Western Europe specializes in more technology-based industries such as automotive, pharmaceuticals, and aviation. Despite the differences in industrial structure and culture between East and West, all these industrial firms use raw materials and energy in production processes.

Raw materials and energy are essential factors that significantly influence environmental pollution and climate change. Sustainability practices and sustainable transitions are not possible without industrial transformation [12]. Their extraction, processing, and consumption directly affect the amount of greenhouse gases and pollutants, primarily in industry

and ultimately in the entire economy. Fossil fuels such as diesel, gas, and coal are often used in industrial firms. Due to the extraction of raw materials, forests and soil begin to disappear more quickly. By-products of production are polluting waste, which accumulates if not recycled. Air and water pollution and thermal effects cause health problems. Coordinated changes in many interconnected areas—from material preparation and production processes to waste and consumption—lead to a sustainable industrial transition towards tangible results in sustainability practices across industrial value chains and interconnected sectors [12]. Therefore, the problematic issue of sustainability practices in industrial firms is no longer debatable but represents a critical research and policy challenge.

Sustainability practices in industrial firms are an extremely complex issue, influenced by many different factors. First of all, sustainability practices depend on the strategic and operational actions of firms, which are influenced by many different stakeholders. This can be explained based on the Stakeholder Theory [18], which is the basis for many research findings examining sustainability practices in corporate activities, such as [8,27,28]. According to the Stakeholder Theory, a complex ecosystem of interest groups (managers, shareholders, customers, suppliers, and regulators) affects the activities of industrial firms; therefore, the alignment of different needs can determine the performance results. The issue of sustainability is one of the interests of all these stakeholders, since sustainable production and sustainable products meet all their needs, putting pressure on firms. Higher returns for investors, a safe environment for employees, regulatory compliance, and growing financial performance for managers can be attributed to the disclosure of sustainability practices, measured by environmental, social, and governance (ESG) scores. Business managers with environmental experience and their green attitudes based on value orientations are able to manage climate risks more effectively [29,30].

ESG refers to environmental, social, and governance practices in corporate activities [31]. Environmental practices in industrial firms are associated with more effective pollution management, more efficient energy use, and more productive waste management. Supply chain responsibility and protection of customers and employees from harmful production conditions refer to social practices in industrial firms. Governance practices include transparency in financial reporting, an independent board structure, and anti-corruption measures in industrial firms. The implementation and disclosure of sustainability practices in these types of firms can create favorable conditions for more efficient use of resources, reduce operational risks, attract cheaper capital, and ultimately increase the value of the firm.

Sustainability practices are more fragmented in Eastern Europe industrial firms. Capital markets in Eastern Europe are generally less mature. In contrast, Western European investors are more active, seeking high sustainability standards, regulatory compliance, social dialog, and demanding the same from industrial firms. However, the existing literature rarely distinguishes between Eastern and Western Europe, despite substantial differences in institutional quality, regulatory enforcement, and stakeholder pressure that may influence the ESG–performance relationship.

Clarifying sustainability priorities in industrial operations is essential for aligning stakeholder expectations and improving firm performance.

Based on several assumptions, the first hypothesis is formulated as follows:

H1. *Higher environmental practices are positively associated with the financial performance of European industrial firms.*

This assumes that industrial firms use more raw materials and resources than other sectors, which affects climate pollution, but at the same time is an important part of the economy. Stakeholders seek greater sustainability practices and cleaner production in these firms. Greater sustainability practices, responding to the interests of stakeholders, can create

conditions for achieving higher performance through cheaper sources of financing, more efficient use of resources, and better risk management mechanisms. However, achieving better sustainability practice outcomes, especially in industrial firms, requires a green transformation based on digitalization, as green technology innovation is essential to reduce the impact of climate risk and, at the same time, improve corporate performance [29]. However, existing studies focus mainly on a common set of firm data and largely ignore the role of the panel of industrial firms in different regions. Therefore, industrial firms must look for solutions to steer production towards green transformation based on digitalization.

However, environmental engagement alone may not yield optimal results without the support of enabling technologies—a role increasingly filled by digitalization.

2.2. Digitalization and Sustainability Practices

The concept of digitalization can be broadly defined as a strategic process of integrating digital and artificial intelligence technologies in firms, influencing business processes, decision-making, and competitiveness [32]. The development and implementation of modern digital technologies in production and production management processes indicate the definition of digitalization in the industrial sector [33]. Due to different economic development and access to capital, the scale of digitalization differs in maturity level, nature of investments, and strategic purpose in industrial firms in Eastern and Western Europe.

Digitalization benefits may be particularly uneven across European regions due to structural differences in technological infrastructure, institutional quality, and innovation ecosystems. Prior research indicates that firms operating in less digitally mature environments often face higher implementation costs, weaker technological complementarities, and slower capability accumulation, which may delay or reduce the financial returns to digital investments [5,8,16]. In Eastern Europe, digital transformation is frequently constrained by gaps in broadband quality, limited availability of advanced digital skills, and lower levels of public and private support for innovation diffusion [3,16,26]. As a result, digitalization may initially contribute more to operational modernization than to immediate improvements in profitability. This suggests that the performance implications of digital investment are context-dependent and may vary according to regional institutional readiness, making the Eastern–Western European comparison particularly relevant for empirical investigation.

However, digital technologies may act as a driver of manufacturing and financial transformation [20], although their impact can vary depending on the level of digital maturity and institutional support across regions. Automation and robotics, which enable the automation of production and the collection and analysis of data in real time [20], while optimizing the use of resources, form part of the digital technology toolkit used in industrial firms. The finances required for the modernization of the industrial structure can be carried out using digital finance [34], so the issue of digitalization is particularly complex, inevitably touching on the issue of sustainability through the green transformation of production.

Digitalization through digital technologies and sustainability practices through environmental, social responsibility and governance improvements in industrial firms are closely linked. Digital solutions and infrastructure can significantly promote the synergy between digitalization and sustainability practices of industrial firms. According to Kang & Shang (2025) [35], this synergy can be further promoted by the implementation of digital technologies and policies that promote diffusion. Digital technologies enable carbon emissions reduction through smart energy management systems, optimizing production processes and reducing waste. Therefore, it is an important instrument for reducing regional carbon intensity [34]. Social responsibility practices emerge through smart safety systems that improve worker safety conditions. Digitalization, through more transparent

data collection and disclosure of sustainability practices to stakeholders, ensures more reliable decision-making, which in turn enhances the governance experience. Digitalization enables lower emissions and waste volumes, which reduces energy and material costs, thus increasing the flexibility and operational efficiency of firms [17].

The theories of Agency and Ecological Modernization [17,20] are further interpreted to explain the synergy between digitalization and sustainability practices during green transformation in industrial firms. According to Agency Theory, digitalization can be a monitoring mechanism that reduces information asymmetry among stakeholders and, at the same time, increases the credibility of sustainability practices in industrial firms. Therefore, such synergy between digitalization and sustainability practices can reduce agency costs. The synergy between digitalization and sustainability practices is based on the theory of Ecological Modernization [21,22]. According to this theory, modern technologies and innovations, such as digital technologies applied to the production processes of industrial firms, can reduce environmental impact without losing long-term competitiveness. Sustainability practices based on digitalization are a key mechanism for cleaner production, reducing material intensity, energy consumption, and emissions across industrial value chains. Accordingly, the second scientific hypothesis is formulated.

H2. *Higher levels of digitalization are positively associated with the financial performance (ROE) of European industrial firms.*

This scientific hypothesis is based primarily on Agency Theory, according to which it can be stated that increasing digitalization, through digital technologies, improves monitoring and transparency and reduces agency costs. This scientific hypothesis is also based secondarily on the assumptions of the Ecological Modernization Theory that the synergy of digitalization and sustainability practices creates conditions for cleaner and more efficient production processes, thereby improving the financial performance of European industrial firms.

Despite growing evidence on environmental practices and digitalization, prior studies rarely explore their combined impact using firm-level panel data, especially in the industrial sector across diverse European regions. This limits our understanding of whether digitalization consistently contributes to financial performance in different institutional contexts. The case of European industrial firms and the Eastern–Western European divide provide a unique empirical setting to test whether the relationship between sustainability, digitalization, and performance influences financial performance. This sets the stage for a more integrative perspective on how digitalization and environmental practices interact to shape firm performance.

2.3. Interlinkages Between Sustainability, Digitalization, and Financial Performance

Corporate financial performance has long been a central outcome variable in studies examining corporate sustainability and digitalization. Financial indicators such as return on equity (ROE) and return on assets (ROA) are frequently used to evaluate whether sustainability-related strategies generate economic value for firms. A growing body of empirical research indicates that ESG engagement may enhance financial performance by improving operational efficiency, reducing risk exposure, and strengthening access to capital markets [6,15]. However, the empirical evidence remains inconclusive. While some studies report a positive relationship between ESG performance and profitability, others identify weak or insignificant effects depending on the specific ESG dimension, sectoral context, or methodological approach [23,24,36]. These mixed findings highlight the need for further research examining the mechanisms through which sustainability initiatives

translate into financial outcomes, particularly when combined with enabling capabilities such as digitalization.

ESG scores have been accepted by international financial agencies as the key factor for strategy and management of firms, which promoted researchers to search for relationships between financial performance and ESG scores [23]. This article also followed several studies, e.g., Broccardo et al. (2023) [6], Buhaya & Metwally (2024) [37], and Ukko et al. (2019) [25], that are trying to fill the existing gap in the literature by searching for the linkages between sustainability, digitalization, and financial performance.

An ambiguous discussion regarding the impact of digitalization on both the sustainability and financial performance of firms was noticed in the academic literature. On the one hand, digital technologies applied to improve business performance should increase sustainability, as the use of polluting and/or not efficient processes in the manufacturing industry should decrease. This was also discussed by researchers who state that digitalization of industry performance, which is mostly related to environmental or social aspects, might improve sustainability [6]. A positive relationship between digital technologies and sustainability (as well as each social, environmental, and economic dimension of sustainability) was found for Egyptian manufacturing firms [37]. It is also noticed that digitalization increases sustainability in terms of performance transparency, accountability, or more efficient data management [6].

Literature analysis shows that firms digitize to increase their financial performance [25]. Digital technologies also reduce costs and might increase profitability [37]. Yet, digitalization might be costly [38], which should have a negative impact on the financial performance of firms. The latter statements open further discussion about the interlinks between the dimensions analyzed in this article.

All three dimensions (i.e., digitalization, sustainability, and financial performance of Italian firms) were analyzed by Broccardo et al. (2023) [6]. Authors performed various regression models in their research and, in all cases, found the existing positive relationship between sustainability, digitalization, and financial performance [6]. Authors emphasize that digitalization has a positive direct impact on financial performance and may also interact with sustainability practices in shaping performance outcomes [6]. The findings of De Lucia et al. (2020) [23] show that there is a relationship between ESG score and returns (i.e., ROA and ROE) of firms, which allows predicting their performance. Nevertheless, the relationship between ROE and different dimensions of ESG varies across the studies analyzed. Rao et al. (2023) [24] found a negative relationship between ROE and environmental and governance scores, but Ikuta and Fujii (2025) [36] did not find a significant relationship between ROE and the environmental dimension at all and explained this finding as costly, requiring time to observe the impact of investments on the performance of firms. Yet, ROE has positive relationships with sustainable development, diversity and opportunity policies, salary gap, and employment productivity, but negative relationships were confirmed for the environmental management team and environmental management training, as well as the number of women employees from the total and the CSR board committee [23].

Moreover, the size of firms has a positive impact on performance, as larger firms have more resources to allocate, associated with more efficient sustainability [6]. Previous research suggests controlling firm size and country information when ESG-related analysis is performed, as it was noticed that high ESG performance in industries that damage the environment has a positive impact on the financial performance of firms [23]. The number of employees (measured as a percentage of total employees or natural logarithm) is used by different authors to control firm size [23,36]. Ikuta and Fujii (2025) [36] suggested using the natural logarithm of employees to reduce high variation in the number of employees among

firms. The natural logarithm of the number of employees lagged by 1 year was used by Drempeć et al. (2020) [39] to analyze the impact on ESG score, and they found a positive relationship between firm size lagged by 1 year and ESG score. Other researchers noticed that firms larger in size have a higher level of process digitalization, and the relationship between digitalization and financial performance variables exists [7].

To highlight the impact of environmental practices on firms' financial performance, it is necessary to include firm-specific control variables. Previous studies [40,41] emphasize that this effect is sensitive to financial risk control as leverage and market valuation characteristics such as price to earnings (P/E) and price to book (P/B). To avoid biased estimates of environmental impact, it is necessary to control related indicators. A higher share of tangible assets is generally associated with lower ROA, reflecting lower asset efficiency in capital-intensive firms, while the effect on ROE is ambiguous due to the collateral benefits of tangibility for leveraged firms [42]. Efficient working capital management, characterized by a shorter cash conversion cycle and optimal net working capital, enhances firm performance, whereas excessive working capital reduces profitability, implying an inverted U-shaped relationship [43]. Capital expenditures (CAPEX) tend to negatively affect near-term earnings, with this effect being particularly pronounced for loss-making firms, where short-term investment costs dominate potential benefits [44]. Revenue growth captures firms' realized growth dynamics, which directly reflect market expansion and demand-side responses to strategic investments.

Digital investment constitutes a core explanatory variable in this study and is operationalized as R&D expenditure relative to intangible assets, capturing the intensity of firms' investment in renewing and upgrading knowledge-based capital associated with digital transformation. This ratio reflects the extent to which firms actively develop new digital capabilities, such as software-driven processes, data-related technologies, and digitally enabled organizational improvements, rather than relying solely on previously accumulated intangible assets. By relating R&D spending to the existing intangible capital base, the measure captures the dynamic input dimension of digitalization, distinguishing active digital investment from the passive holding of intangible assets. Importantly, prior evidence indicates that the performance effects of technology-related investments materialize only when such investments are translated into operational improvements and revenue growth, supporting the inclusion of revenue growth as a complementary control variable [4].

In addition, intangible assets may influence firm performance through their role in knowledge intensity, innovation capability, and technological sophistication. In this study, the potential performance effect of intangible capital is partly incorporated into the empirical specification through the construction of the digital investment proxy, which reflects firms' active capability renewal relative to their existing knowledge base. Furthermore, the fixed-effects panel framework controls for time-invariant firm characteristics, including persistent differences in intangible asset structures and innovation capacity, thereby reducing the risk of omitted variable bias related to firm-specific knowledge capital.

However, previous research also shows that neither digital business strategy nor sustainability strategy alone is sufficient to achieve direct impact on financial performance, although the interaction between sustainability and capabilities to manage business digitalization strategy has a positive relationship with financial performance, while the interaction between sustainability and capabilities to perform business digitalization strategy has a negative relationship with financial performance [25]. While prior studies have examined these dimensions separately, few have explored their combined impact, particularly in the context of heterogeneous European regions with varying levels of industrial maturity and digital readiness. Therefore, a problematic question is raised, and the third scientific hypothesis is formulated.

H3. *Digitalization strengthens the positive relationship between environmental practices and financial outcomes in European industrial firms.*

Further, in Section 3.2, this study empirically examines the combined impact of sustainability practices and digitalization on financial performance by presenting a multi-country panel data analysis of European industrial firms.

3. Materials and Methods

3.1. Data

This study uses firm-level panel data covering industrial firms in Eastern and Western Europe. The sample consists of 2106 firms observed over the period 2015–2024, forming an unbalanced panel. Firms are classified into Eastern and Western Europe countries based on their country of incorporation. Firms are classified as Eastern European Union countries if they are incorporated in Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, or Slovenia, while firms from all other European member states are classified as Western European Union countries. Firms incorporated in non-EU European countries available in Bloomberg (e.g., the United Kingdom, Norway, and Switzerland) are classified as Western Europe due to comparable levels of institutional development and digital maturity. Industrial firms are identified based on the NACE Rev. 2 classification, including manufacturing and related industrial activities. Firm-level financial data are obtained from Bloomberg, while all data processing and econometric analyses are conducted using StataNow 19.5 (BE-Basic Edition) and Gretl 2025b.

Environmental ESG scores are obtained directly from the Bloomberg ESG database and range from 0 to 100, reflecting firms' relative environmental performance based on publicly disclosed information. The relatively low average environmental scores observed in the sample are consistent with the industrial focus of this study, which includes firms operating in carbon-intensive sectors and in regions with lower ESG disclosure maturity. Prior research also documents substantial cross-industry and cross-country variation in ESG ratings. The sample includes all firms with available ESG and R&D data during the study period and is not restricted to currently listed firms, thereby reducing potential survivorship bias. Observations with incomplete information for key variables were excluded. Prior to estimation, all variables were screened for extreme values and winsorized at the 1st and 99th percentiles to mitigate the influence of outliers. No additional rescaling of ESG scores was performed.

3.2. Methodology

Following the identification of the key variables and their expected effects based on the literature, this study proceeds with the operationalization of these variables for empirical analysis. Table 1 presents detailed definitions and calculation methods for the dependent, main explanatory, and control variables used in the panel regression models. This ensures transparency and consistency in variable measurement and facilitates the interpretation and replication of the empirical results.

Digitalization at the firm level is a multidimensional process that cannot be fully captured by narrow indicators such as hardware acquisition or isolated software expenditures [5]. In industrial firms, digital transformation is closely associated with the development of knowledge-based capabilities that facilitate automation, data integration, real-time monitoring, and organizational adaptation [45]. Consistent with this capability-based perspective, this study operationalizes digital investment as R&D expenditure relative to intangible assets, capturing the intensity with which firms renew and expand their stock of knowledge-based capital related to digital transformation. This proxy is particularly rele-

vant in the industrial context, where digitalization is often embedded in process innovation, internally developed software solutions, data management systems, and organizational upgrading rather than reflected solely in separately disclosed IT expenditures [46]. Compared with alternative indicators such as IT capital expenditure, software investment, or digital patent counts, the selected measure better reflects the dynamic, cumulative, and capability-oriented nature of digitalization.

Table 1. Definition and calculation of variables.

Variable	Calculation
Main Variables	
ROE	Net profit/Equity, %
Environmental practices	Environmental ESG score (scale 0–100)
Digital investment	R&D expenditure/Intangible assets, %
Control Variables	
Cash ratio	Current assets/Current liabilities
Working capital	(Current assets – Current liabilities)/Total assets, %
Price-to-Book ratio	Market value of equity/Book value of equity
Price-Earnings ratio	Market price per share/Earnings per share
Revenue growth	(Sales(t) – Sales(t – 1))/Sales(t – 1), %
Firm size	ln(Total assets)
Leverage	Total assets/Total equity
Tangible assets	Fixed assets/Total assets, %
Capital expenditure	Capital expenditure/Total assets, %
Firm age	ln(Age)

However, alternative proxies for digitalization, such as IT capital expenditure or digital patent investments, are subject to important empirical limitations in cross-country firm-level research. IT-related expenditures are often not separately disclosed in financial statements and may be embedded in broader capital or operating costs, reducing measurement consistency across firms and countries. Similarly, digital patent indicators capture only formalized technological outputs and may overlook incremental process innovation and internally developed digital capabilities that are particularly relevant in industrial settings. Therefore, the selected proxy based on R&D intensity relative to intangible assets is considered more suitable for capturing firms' ongoing investment in digital capability development and organizational upgrading.

To account for potential endogeneity in the relationship between environmental practices, digital investment, and financial performance, the empirical analysis employs a fixed-effects panel data model. The choice of the fixed-effects specification is supported by the Hausman test, which indicates that the fixed-effects estimator is more appropriate than the random-effects alternative. Firm fixed effects control for unobserved, time-invariant firm characteristics. In addition, the models include a set of firm-level financial control variables, such as leverage, firm size, market valuation indicators, working capital, and capital expenditure. The panel structure of the dataset allows the analysis to exploit within-firm variation over time, helping to isolate the relationships between the variables examined. While this approach mitigates endogeneity arising from unobserved time-invariant heterogeneity, it does not fully eliminate the possibility of reverse causality or omitted time-varying factors; therefore, the estimated coefficients should be interpreted as conditional associations rather than strict causal effects.

Empirical analysis employs a fixed effects panel data model to examine the impact of environmental practices and digital investment on firm financial performance. The fixed effects specification controls unobserved, time-invariant firm characteristics that

may influence profitability, thereby reducing potential omitted variable bias. The baseline econometric model is formally expressed as follows:

$$ROE_{i,t} = \beta_0 + \sum_k \beta_k \cdot X_{k,i,t} + \mu_i + \varepsilon_{i,t} \quad (1)$$

To examine the direct effect of environmental practices on firm financial performance, the first fixed effects model includes the environmental score as the main explanatory variable. This specification tests Hypothesis H1, while controlling for firm-specific financial characteristics and accounting for both firm and time fixed effects:

$$ROE_{i,t} = \beta_0 + \beta_1 \cdot \text{Environmental_ESG}_{i,t} + \beta_2 \cdot \text{Cash_ratio}_{i,t} + \beta_3 \cdot \text{Working_capital}_{i,t} + \beta_4 \cdot \text{Price_to_Book}_{i,t} + \beta_5 \cdot \text{Price_Earnings}_{i,t} + \beta_6 \cdot \text{Revenue_growth}_{i,t} + \beta_7 \cdot \text{Firm_size}_{i,t} + \beta_8 \cdot \text{Leverage}_{i,t} + \beta_9 \cdot \text{Tangible_assets}_{i,t} + \beta_{10} \cdot \text{Capital_expenditure}_{i,t} + \beta_{11} \cdot \text{Firm_age}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

where i denotes firm, and t denotes time; μ_i are firm fixed effects; λ_t are time fixed effects; and $\varepsilon_{i,t}$ is the idiosyncratic error term.

The second model focuses on the impact of digital investment on firm financial performance. By including digital investment as the key independent variable alongside the same set of control variables, this specification tests Hypothesis H2 and isolates the effect of digitalization on ROE within a fixed effects panel framework:

$$ROE_{i,t} = \beta_0 + \beta_1 \cdot \text{Digital_investment}_{i,t} + \beta_2 \cdot \text{Cash_ratio}_{i,t} + \beta_3 \cdot \text{Working_capital}_{i,t} + \beta_4 \cdot \text{Price_to_Book}_{i,t} + \beta_5 \cdot \text{Price_Earnings}_{i,t} + \beta_6 \cdot \text{Revenue_growth}_{i,t} + \beta_7 \cdot \text{Firm_size}_{i,t} + \beta_8 \cdot \text{Leverage}_{i,t} + \beta_9 \cdot \text{Tangible_assets}_{i,t} + \beta_{10} \cdot \text{Capital_expenditure}_{i,t} + \beta_{11} \cdot \text{Firm_age}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (3)$$

where i denotes firm, and t denotes time; μ_i are firm fixed effects; λ_t are time fixed effects; and $\varepsilon_{i,t}$ is the idiosyncratic error term.

The third model incorporates an interaction term between environmental practices and digital investment to investigate whether digitalization moderates the relationship between sustainability practices and financial performance. This specification tests Hypothesis H3 and allows for the assessment of the joint effect of environmental practices and digital investment on firm profitability:

$$ROE_{i,t} = \beta_0 + \beta_1 \cdot \text{Environmental_ESG}_{i,t} + \beta_2 \cdot \text{Digital_investment}_{i,t} + \beta_3 \cdot \text{Environmental_ESG}_{i,t} \times \text{Digital_investment}_{i,t} + \beta_4 \cdot \text{Cash_ratio}_{i,t} + \beta_5 \cdot \text{Working_capital}_{i,t} + \beta_6 \cdot \text{Price_to_Book}_{i,t} + \beta_7 \cdot \text{Price_Earnings}_{i,t} + \beta_8 \cdot \text{Revenue_growth}_{i,t} + \beta_9 \cdot \text{Firm_size}_{i,t} + \beta_{10} \cdot \text{Leverage}_{i,t} + \beta_{11} \cdot \text{Tangible_assets}_{i,t} + \beta_{12} \cdot \text{Capital_expenditure}_{i,t} + \beta_{13} \cdot \text{Firm_age}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (4)$$

where i denotes firm, and t denotes time; μ_i are firm fixed effects; λ_t are time fixed effects; and $\varepsilon_{i,t}$ is the idiosyncratic error term.

To examine whether digitalization modifies the relationship between environmental practices and financial performance, the empirical specification includes both the main effects of environmental practices and digital investment, as well as their interaction term. This approach allows the analysis to capture potential non-additive effects, meaning that the financial impact of sustainability practices may depend on the level of firms' digital capability. Estimating models with environmental practices and digital investment separately enables the identification of their independent associations with profitability, while the interaction model tests whether the marginal effect of one variable varies conditionally on the level of the other. The use of firm fixed effects does not absorb the influence of these time-varying explanatory variables; rather, it controls for unobserved time-invariant firm characteristics that could otherwise bias the estimated relationships.

The empirical analysis is complemented by a set of panel diagnostic tests to validate the model specification. The Hausman test consistently favors the fixed effects specification over the random effects alternative. Furthermore, the presence of heteroskedasticity, serial correlation, and cross-sectional dependence is confirmed using the Breusch–Pagan test, the Wooldridge test for autocorrelation, and the Pesaran CD test, respectively. In response to these diagnostic outcomes, all estimations employ fixed effects with robust standard errors that are consistent with heteroskedasticity, autocorrelation, and cross-sectional dependence. This methodology enhances the reliability and robustness of empirical findings.

4. Results

4.1. Descriptive Statistics and Diagnostics

Table 2 reports the descriptive statistics for the full sample of European industrial firms. The data exhibit substantial heterogeneity across firms, as reflected in the wide dispersion of ROE, digital investment, and growth-related variables. While the median ROE is positive across all samples, the negative mean ROE for the full sample and Western Europe indicates the presence of loss-making firms, highlighting the importance of controlling for firm-specific effects. Correlation matrix presented in Appendix A.

Table 2. Descriptive statistics for the full sample.

Variable	Mean	Median	S.D.	Min	Max
All panel (n = 21,060)					
ROE	−0.856	6.280	29.000	−82.400	50.500
ROA	−2.172	2.516	17.181	−55.905	24.308
Environmental practices	25.40	22.80	19.00	4.52	100.00
Digital investment	53.400	19.000	73.900	0.615	236.000
Cash ratio	1.110	0.337	2.530	0.001	17.400
Working capital	19.600	18.100	26.700	−82.000	86.300
Price-to-Book ratio	3.250	1.570	5.470	0.048	37.700
Price-Earnings ratio	32.100	17.000	47.700	2.320	240.000
Revenue growth	12.500	4.100	42.600	−59.000	216.000
Firm size	19.200	18.900	2.580	13.700	25.700
Leverage	2.700	2.050	2.340	1.040	17.700
Tangible assets	27.000	22.800	21.600	0.057	86.800
Capital expenditure	−3.860	−2.620	4.290	−24.600	0.000
Firm age	1.950	2.080	0.749	0.000	4.640

Table 3 reports the descriptive statistics for the subsample of Western European industrial firms. Compared with the full sample, firms in Western Europe exhibit higher environmental practice scores, greater firm size, stronger liquidity positions, and higher market valuation ratios. However, the average ROE remains negative, indicating relatively weaker profitability despite higher levels of sustainability engagement and digital investment.

Table 4 reports the descriptive statistics for the subsample of Eastern European industrial firms. In contrast to Western Europe, firms in this region have higher average profitability (ROE) and greater asset tangibility, but lower environmental practices and investments in digital technologies. These patterns indicate structural differences between the two regions, reflecting inequality in technological readiness, commitment to sustainability, and financial structures.

Table 3. Descriptive statistics for the subsample of Western Europe.

Variable	Mean	Median	S.D.	Min	Max
Western Europe (n = 11,810)					
ROE	−4.310	5.840	32.600	−82.400	50.500
ROA	−4.877	2.164	19.795	−55.905	24.308
Environmental practices	27.00	26.00	19.10	4.52	100.00
Digital investment	54.200	20.000	74.100	0.615	236.000
Cash ratio	1.350	0.423	2.770	0.001	17.400
Working capital	22.800	20.500	26.000	−82.000	86.300
Price-to-Book ratio	3.830	1.980	5.850	0.048	37.700
Price-Earnings ratio	33.500	19.300	46.100	2.320	240.000
Revenue growth	14.800	5.110	46.200	−59.000	216.000
Firm size	19.600	19.300	2.650	13.700	25.700
Leverage	2.670	2.080	2.280	1.040	17.700
Tangible assets	19.700	15.300	17.200	0.057	86.800
Capital expenditure	−3.620	−2.470	4.000	−24.600	0.000
Firm age	1.940	1.950	0.785	0.000	4.640

Table 4. Descriptive statistics for the subsample of Eastern Europe.

Variable	Mean	Median	S.D.	Min	Max
Eastern Europe (n = 9250)					
ROE	4.650	6.760	20.900	−82.400	50.500
ROA	2.042	2.928	10.745	−55.905	24.308
Environmental practices	21.90	17.60	18.20	4.52	77.70
Digital investment	49.300	14.700	72.900	0.615	236.000
Cash ratio	0.751	0.222	2.060	0.001	17.400
Working capital	14.800	14.600	27.000	−82.000	86.300
Price-to-Book ratio	2.330	1.110	4.660	0.048	37.700
Price-Earnings ratio	30.100	13.900	49.700	2.320	240.000
Revenue growth	9.140	2.340	36.700	−59.000	216.000
Firm size	18.700	18.500	2.370	13.700	25.700
Leverage	2.740	2.010	2.440	1.040	17.700
Tangible assets	37.700	36.800	23.000	0.057	86.800
Capital expenditure	−4.240	−2.860	4.680	−24.600	0.000
Firm age	1.950	2.080	0.701	0.000	3.430

Figure A1 presents the correlation matrices for the full sample and regional subsamples. The correlations among the main explanatory variables are generally moderate, and no pairwise correlation exceeds conventional multicollinearity thresholds. Environmental practices and digital investment show low to moderate correlations with ROE and with each other, suggesting that they capture distinct dimensions of firm behavior. Overall, correlation patterns do not raise concerns regarding multicollinearity, supporting the suitability of the variables for multivariate panel regression analysis.

Figure 1 illustrates the evolution of average ROE over time for the full sample and for firms in Western and Eastern Europe. The figure reveals notable regional differences in profitability dynamics. Eastern European firms consistently exhibit higher ROE levels throughout the period, although with some volatility, particularly around 2020–2022. In contrast, Western European firms show persistently lower and predominantly negative ROE, especially following 2018, reflecting weaker profitability performance. The full-sample trend lies between the two regional patterns and captures the overall decline in profitability during periods of economic uncertainty, followed by partial recovery.

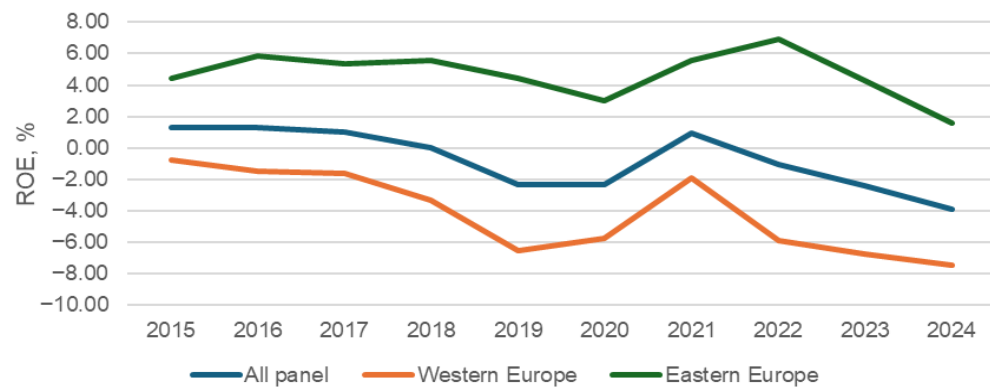


Figure 1. Dynamics of ROE across European regions.

Table 5 reports the results of the panel data diagnostic tests conducted to assess the suitability of the fixed effects specification and the validity of the underlying model assumptions. The Hausman test results strongly reject the random effects model across all specifications and samples, indicating that the fixed effects approach is appropriate. The Breusch–Pagan test provides robust evidence of heteroskedasticity in all models, while the Pesaran CD test reveals significant cross-sectional dependence in most cases, particularly for the full sample and Western Europe. Although cross-sectional dependence is weaker for the digital investment and interaction models in Eastern Europe, the overall diagnostic evidence supports the use of fixed effects models with robust standard errors to ensure reliable statistical inference.

Table 5. Panel data diagnostic tests for fixed effects models.

Models	Environmental Practices	Digital Investment	Environmental Practices (E) × Dig. Inv.
Hausman test			
All panel	<0.0001	<0.0001	<0.0001
Western Europe	<0.0001	<0.0001	<0.0001
Eastern Europe	<0.0001	0.0002	<0.0001
Breusch–Pagan test			
All panel	<0.0001	<0.0001	<0.0001
Western Europe	<0.0001	<0.0001	<0.0001
Eastern Europe	<0.0001	<0.0001	<0.0001
Pesaran CD test			
All panel	<0.0001	<0.0001	<0.0001
Western Europe	<0.0001	<0.0001	<0.0001
Eastern Europe	<0.0001	0.0546	0.447

4.2. Influence of Environmental Practices on ROE

Table 6 reports the fixed effects regression results examining the impact of environmental practices on firm profitability, measured by ROE, for the full sample and regional subsamples. For the full panel, environmental practices exhibit a positive and statistically significant effect on ROE, providing support for Hypothesis H1 and suggesting that stronger environmental practices are associated with improved financial performance. However, this relationship is not statistically significant when the sample is split into Western and Eastern Europe, indicating regional heterogeneity in the environmental practice's nexus. Among the control variables, market-based indicators such as the price-to-book ratio and revenue growth consistently display positive and significant effects across all specifications, while the price-earnings ratio is negatively associated with ROE. Firm size

shows a negative and significant effect on the full sample and Western Europe, whereas leverage and cash ratio are positively related to profitability only in Eastern Europe. Overall, the model diagnostics indicate a good explanatory power, with LSDV R^2 values ranging from 0.65 to 0.73, supporting the robustness of the estimated relationships.

Table 6. Impact of environmental practices on Return on Equity (ROE).

Variable Segment	Coefficient All Panel	<i>p</i> -Value	Coefficient Western Europe	<i>p</i> -Value	Coefficient Eastern Europe	<i>p</i> -Value
Constant	89.7543 **	0.0012	92.9047 **	0.0041	68.2832	0.1381
Environmental practices	0.0455 **	0.0349	0.0348	0.1831	0.0527	0.1241
Cash ratio	0.5252	0.5201	−0.241	0.8229	2.2926 **	0.0403
Working capital	0.1743 **	0.0002	0.2029 **	0.0004	0.1032	0.1249
Price-to-Book ratio	0.7480 **	0.0001	0.7313 **	0.0001	0.8166 **	0.0001
Price-Earnings ratio	−0.1002 **	0.0001	−0.0996 **	0.0001	−0.0978 **	0.0001
Revenue growth	0.0731 **	0.0007	0.0706 **	0.0143	0.0761 **	0.0012
Firm size	−3.4950 **	0.0084	−3.6023 **	0.0177	−2.7088	0.2220
Leverage	0.6688	0.2544	0.413	0.5264	2.0312 **	0.0020
Tangible assets	−0.1541 **	0.0023	−0.0955	0.1566	−0.2232 **	0.0101
Capital expenditure	0.5195 **	0.0001	0.5417 **	0.0002	0.4117 **	0.0014
Firm age	−1.2994	0.2143	−1.6535	0.1864	−0.184	0.9006
Model information:	LSDV R^2 = 0.668, F-test = 24.66, Welch test— <i>p</i> = 0.000, mean ROE = 13.19, SD = 10.91, Durbin–Watson = 1.68.		LSDV R^2 = 0.651, F-test = 20.85, Welch test— <i>p</i> = 0.000, mean ROE = 13.34, SD = 11.30, Durbin–Watson = 1.67.		LSDV R^2 = 0.731, F-test = 10.88, Welch test— <i>p</i> = 0.000, mean ROE = 12.83, SD = 9.94, Durbin–Watson = 1.82.	

Note: ** denote statistical significance at the 5% levels, respectively.

4.3. Influence of Digital Investment on ROE Performance

Table 7 presents the fixed effects regression results examining the impact of digital investment on firm financial performance, measured by ROE. For the full sample, digital investment exhibits a positive and statistically significant effect on ROE, providing support for Hypothesis H2 and suggesting that higher levels of digital investment are associated with improved profitability. This positive relationship is also observed for Western European firms, whereas the coefficient for Eastern Europe is positive but statistically insignificant, indicating regional differences in the effectiveness of digital investments. Consistent with the previous model, market-based variables such as the price-to-book ratio and revenue growth are positively and significantly related to ROE across all samples, while the price-earnings ratio remains negatively associated with profitability. Firm size is negatively related to ROE in the full sample and Western Europe, whereas leverage and cash ratio do not exhibit statistically significant effects. Overall, the model demonstrates strong explanatory power, with LSDV R^2 values around 0.65, confirming the robustness of the estimated results.

Table 7. Impact of Digital Investment on Return on Equity (ROE).

Variable Segment	Coefficient All Panel	<i>p</i> -Value	Coefficient Western Europe	<i>p</i> -Value	Coefficient Eastern Europe	<i>p</i> -Value
Constant	56.1877 **	0.0007	67.5888 **	0.0002	−24.7789	0.4863
Digital investment	0.0300 **	0.0001	0.0384 **	0.0001	0.0065	0.4455
Cash ratio	0.6474	0.1863	0.8145	0.1138	−0.7275	0.5047
Working capital	0.0919 **	0.0253	0.0771 **	0.0465	0.1242	0.2335

Table 7. Cont.

Variable Segment	Coefficient All Panel	p-Value	Coefficient Western Europe	p-Value	Coefficient Eastern Europe	p-Value
Price-to-Book ratio	0.7324 **	0.0001	0.6973 **	0.0001	1.2501 **	0.0001
Price-Earnings ratio	−0.0921 **	0.0001	−0.0930 **	0.0001	−0.0859 **	0.0001
Revenue growth	0.0983 **	0.0001	0.1007 **	0.0001	0.0852 **	0.0001
Firm size	−2.0922 **	0.0084	−2.6257 **	0.0022	1.8517	0.2916
Leverage	0.2581	0.4401	0.3045	0.3866	−0.1084	0.8995
Tangible assets	−0.1684 **	0.0007	−0.1458 **	0.0126	−0.2381 **	0.0063
Capital expenditure	0.4198 **	0.0001	0.4576 **	0.0001	0.3000 **	0.0025
Firm age	−0.0359	0.9430	−0.1887	0.7389	1.0916	0.3836
	LSDV R ² = 0.651, F-test = 47.67, Welch test— <i>p</i> = 0.000, mean ROE = 13.76, SD = 11.92, Durbin–Watson = 1.45.		LSDV R ² = 0.654, F-test = 41.44, Welch test— <i>p</i> = 0.000, mean ROE = 14.00, SD = 12.32, Durbin–Watson = 1.47.		LSDV R ² = 0.650, F-test = 12.77, Welch test— <i>p</i> = 0.000, mean ROE = 12.70, SD = 9.92, Durbin–Watson = 1.34.	

Note: ** denote statistical significance at the 5% levels, respectively.

4.4. The Joint Influence of Environmental Practices and Digital Investments on ROE

Table 8 reports the fixed effects regression results examining the joint effect of environmental practices and digital investment on firm profitability. The interaction term between environmental practices and digital investment is positive but statistically insignificant for the full sample, indicating that the complementary effect between sustainability initiatives and digital investment is not uniform across all firms. However, the interaction coefficient is positive and statistically significant for Western European firms, indicating that the association between environmental practices and ROE becomes more favorable at higher levels of digital investment in this region. In contrast, the interaction term is negative and statistically significant for Eastern Europe, indicating that the joint implementation of environmental practices and digital investment does not produce complementary performance effects and may even weaken profitability outcomes in this regional context. These findings highlight substantial regional heterogeneity in how sustainability and digital transformation jointly influence firm performance. The control variables largely maintain their expected signs and levels of significance. Market-based indicators, such as the price-to-book ratio and revenue growth, consistently show positive and significant associations with profitability, whereas the price-earnings ratio and firm size remain negatively related to ROE. The relatively high explanatory power of the models, particularly for Eastern Europe (LSDV R² = 0.81), further supports the reliability of the estimated relationships.

To assess the robustness of the baseline results, the empirical models were re-estimated using return on assets (ROA) as an alternative measure of financial performance. The findings reported in Tables A1–A3 are broadly consistent with the main results obtained using ROE. Environmental practices remain positively associated with firm profitability for the full sample and particularly for firms in Eastern Europe, while the effect remains statistically insignificant in Western Europe. Similarly, digital investment shows a positive and statistically significant relationship with ROA for the full sample and Western European firms, whereas the effect is not significant for Eastern European firms. The interaction model further confirms the presence of regional heterogeneity: the interaction between environmental practices and digital investment is positive for Western Europe and negative for Eastern Europe. Overall, these results indicate that the main conclusions of this study are robust to the use of an alternative profitability measure.

Table 8. Joint Impact of Environmental Practices and Digital Investment on Return on Equity (ROE).

Variable Segment	Coefficient All Panel	p-Value	Coefficient Western Europe	p-Value	Coefficient Eastern Europe	p-Value
Constant	111.277 **	0.0002	113.643 **	0.0005	50.8678	0.4051
Environmental practices (E)	0.0347	0.1571	0.0150	0.5796	0.1446 **	<0.0001
Digital investment	0.0062	0.668	0.0036	0.7951	0.0571 **	0.0217
Environmental practices (E) × Dig. Inv.	0.0004	0.1796	0.0007 **	0.0361	−0.0022 **	<0.0001
Cash ratio	0.5787	0.5226	0.4965	0.5976	1.0716	0.714
Working capital	0.1472 **	0.0072	0.1463 **	0.0119	0.0797	0.4969
Price-to-Book ratio	0.7422 **	<0.0001	0.7387 **	<0.0001	1.1141 **	0.0032
Price-Earnings ratio	−0.1124 **	<0.0001	−0.1134 **	<0.0001	−0.1051 **	<0.0001
Revenue growth	0.1036 **	<0.0001	0.1005 **	<0.0001	0.1273 **	<0.0001
Firm size	−4.5151 **	0.001	−4.5672 **	0.0021	−2.2187	0.4311
Leverage	0.8544	0.2029	0.6698	0.3445	2.4410 **	0.0014
Tangible assets	−0.1155	0.1412	−0.0802	0.4069	−0.1276 *	0.0829
Capital expenditure	−0.6344 **	<0.0001	−0.6221 **	0.001	−0.5645 **	0.0334
Firm age	−0.6871	0.5329	−0.8827	0.4863	−0.4619	0.7537
Model information:	LSDV R ² = 0.694, F-test = 22.50, Welch test p = 0.000, mean ROE = 13.89, SD = 11.08, Durbin–Watson = 1.59.		LSDV R ² = 0.682, F-test = 19.86, Welch test p = 0.000, mean ROE = 13.91, SD = 11.20, Durbin–Watson = 1.60.		LSDV R ² = 0.807, F-test = 13.16, Welch test— p = 0.000, mean ROE = 13.74, SD = 10.34, Durbin–Watson = 1.66.	

Note: * and ** denote statistical significance at the 10% and 5% levels, respectively.

Overall, the empirical results provide consistent evidence that both environmental practices and digital investment contribute to firm financial performance, although their effects vary across regions. While environmental practices and digital investment individually enhance profitability in the full sample and Western Europe, the interaction results suggest that the association between environmental practices and profitability may vary with the level of digital investment, particularly in Western Europe. In contrast, the weaker and insignificant effects observed for Eastern Europe suggest regional differences in institutional conditions, digital readiness, and the effectiveness of sustainability-related investments. These findings underscore the importance of considering regional heterogeneity when assessing the financial implications of sustainability and digital transformation strategies.

5. Discussion

Environmental practices and digital investment are jointly associated with firm financial performance, although the interaction results differ across regions. Digitalization may act as a mechanism through which the relationship between environmental practices and financial performance varies, particularly in more digitally mature environments. The results show that sustainability and digital transformation should be viewed as interconnected strategic aspects and not separate strategic dimensions. A positive correlation between environmental practices and ROE in the full sample also supports Stakeholder Theory. This theory posits that when there is a connection between a firm's strategies and stakeholder expectations, legitimacy is enhanced, conflict is reduced, and firms achieve higher financial performance [18]. This is also in line with previous empirical evidence showing that sustainability involvement enhances access to capital, operational efficiency, and risk management [28,31].

The digital investment that enhances financial performance, particularly in Western Europe, fits with Agency Theory. This theory stresses the influence of digital technologies

on reducing information asymmetry and agency expenditure through increased monitoring, transparency, and data traceability [20]. This finding is in line with previous research, which argues that digitalization enhances managerial efficiency and profitability [7,25,47]. At the same time, it strengthens the claim that digital investment pays out financially where digital maturity and institutional support are available. The relationship between environmental practices and digitalization is of high significance, and it offers strong empirical evidence for a theory underpinned by Ecological Modernization [21,22]. The findings show how digital technologies convert sustainability initiatives into actual financial returns through cleaner production methods, resource use optimization, and better emissions tracking and sustainable transparency. This complementary effect is consistent with recent findings that reinforce the performance benefits of sustainability strategies and digitalization [6,17].

The results provide tentative evidence of regional differences in the joint association between environmental practices and digital investment. Although Eastern European firms exhibit relatively higher average ROE, the estimated interaction effects are not consistently significant across specifications, suggesting that the financial implications of sustainability and digital investment may depend on broader institutional and market conditions. These findings should therefore be interpreted cautiously and not as definitive evidence of structural institutional constraints or the absence of complementarities. Consistent with Marczevska et al. (2025) [16] and Li and Zhu (2024) [8], this study indicates that, without conducive institutional environments, economic returns to sustainability and digital transformation will be muted.

From a policy perspective, the findings suggest that weaker complementarities between environmental practices and digital investment in Eastern Europe should not be interpreted as structural inefficiency, but rather as an indication of uneven institutional readiness and technological infrastructure. Prior research emphasizes that digital transformation outcomes depend on the availability of innovation support systems, digital skills, access to finance, and regulatory stability. Strengthening broadband infrastructure, promoting industrial digital upgrading programs, and facilitating collaboration between firms and innovation ecosystems may enhance the effectiveness of sustainability-related investments. In this sense, public policy plays a critical role in shaping the conditions under which digitalization can translate into stronger financial and environmental performance in less digitally mature regions.

The weaker financial association of digital investment in Eastern Europe may reflect transitional digital capability accumulation rather than the absence of strategic value. Prior research suggests that in less digitally mature environments, firms often experience an initial phase in which digital investments primarily support process modernization, data integration, and operational restructuring, while measurable profitability effects materialize only after complementary organizational capabilities and institutional support mechanisms are sufficiently developed. In such contexts, limited access to advanced digital infrastructure, fragmented innovation ecosystems, and lower diffusion of managerial digital competencies may slow the translation of digital initiatives into financial outcomes. Consequently, the results highlight the temporal and contextual nature of digital transformation benefits and support the view that regional institutional readiness plays a critical role in shaping the sustainability–digitalization–performance nexus.

Overall, the findings suggest that the financial implications of environmental practices are conditional rather than universal and depend on firms' digital capability development and the institutional context in which strategic investments are implemented. By adopting an interaction-based perspective, this study contributes to the literature by showing that digitalization functions not only as a direct performance driver but also as a strategic mechanism shaping how sustainability engagement translates into financial outcomes.

This highlights the importance of integrating technological capability building with environmental strategy, particularly in institutionally heterogeneous regions.

6. Conclusions

6.1. Main Conclusions

This study provides empirical evidence on the relationship between environmental practices and digital investment in the industrial sector across Europe. Drawing on a multi-country panel dataset and fixed effects regression models, the findings demonstrate that both environmental practices and digital investment are positively associated with firm profitability, as measured by return on equity. The results provide preliminary indications regarding the interaction between environmental practices and digital investment; however, due to the sensitivity of interaction estimates to model specification, these findings should be interpreted cautiously.

The results are consistent with the theoretical framework underpinning this study. The positive relationship between environmental practices and financial performance confirms the central premise of Stakeholder Theory, suggesting that firms which align with stakeholder expectations can achieve superior financial outcomes. The role of digital technologies in improving transparency, monitoring, and accountability supports Agency Theory, while the moderating effect of digitalization on the sustainability–performance link is broadly consistent with the principles of Ecological Modernization Theory, which positions technological advancement as a catalyst for sustainable industrial growth.

A key contribution of this study lies in uncovering substantial regional disparities. The positive impacts of environmental practices and digital investment are predominantly driven by firms operating in Western Europe, where institutional quality, regulatory enforcement, and digital infrastructure are more developed. In contrast, these effects are weaker and statistically insignificant in Eastern Europe, underscoring the importance of institutional context in shaping the efficacy of sustainability and digital transformation strategies. At the same time, these regional patterns should not be interpreted as evidence of direct causal policy effects.

6.2. Practical and Policy Implications

The implications of these findings are twofold. For corporate decision-makers, the results suggest that integrating sustainability and digitalization strategies may contribute to improved financial outcomes, particularly in more digitally advanced environments. For policymakers, the evidence indicates the potential relevance of strengthening institutional frameworks and digital capabilities in Eastern Europe to facilitate effective sustainability adoption and digital transformation.

6.3. Limitations and Future Research

By combining firm-level financial analysis with a regional comparative perspective and a multi-theoretical approach, this research contributes to a deeper understanding of how environmental practices and digital investment jointly influence industrial firm performance. Future studies may extend this work by employing causal inference methods or by examining similar dynamics in non-European emerging markets with comparable institutional heterogeneity.

Research limitations include the use of proxy measures for environmental practices performance and the aggregation of firms into Western and Eastern Europe, which may not fully capture within-region institutional and technological heterogeneity. In addition, future research could explore alternative specifications of interaction effects and additional measures of digitalization to further validate the robustness of the findings.

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Appendix A

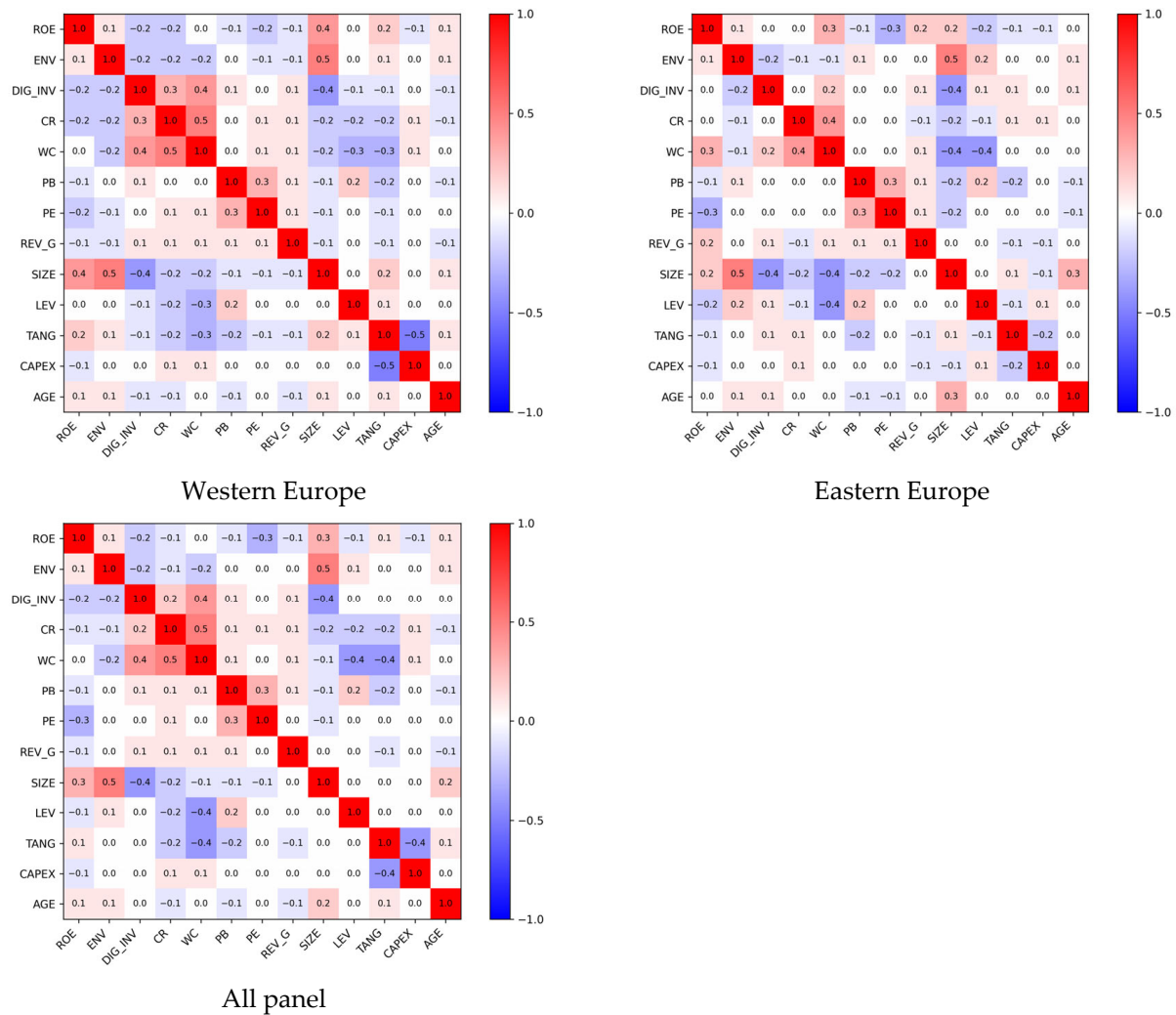


Figure A1. Correlation matrices for the full sample, Western Europe, and Eastern Europe.

Table A1. Impact of environmental practices on Return on Assets (ROA).

Variable Segment	Coefficient All Panel	p-Value	Coefficient Western Europe	p-Value	Coefficient Eastern Europe	p-Value
Constant	51.6330 ***	<0.0001	50.7863 ***	<0.0001	57.9437 ***	0.0067
Environmental practices	0.0179 **	0.0453	0.0110	0.3146	0.0394 ***	0.0034
Cash ratio	0.2781	0.4918	−0.0961	0.8533	1.3316 **	0.0178
Working capital	0.0920 ***	<0.0001	0.0996 ***	<0.0001	0.0653 **	0.0304
Price-to-Book ratio	0.2946 ***	<0.0001	0.2761 ***	<0.0001	0.3818 ***	0.0012
Price-Earnings ratio	−0.0378 ***	<0.0001	−0.0376 ***	<0.0001	−0.0379 ***	<0.0001
Revenue growth	0.0357 ***	<0.0001	0.0362 ***	<0.0001	0.0343 ***	0.0011
Firm size	−2.0410 ***	0.0001	−2.0081 ***	0.0009	−2.2272 **	0.0278
Leverage	−0.2615 **	0.0149	−0.2275 **	0.0454	−0.7388 ***	0.0008
Tangible assets	−0.0836 ***	0.0002	−0.0555 *	0.051	−0.1531 ***	0.0012
Capital expenditure	−0.2294 ***	<0.0001	−0.2328 ***	0.0002	−0.2234 ***	0.0007
Firm age	−0.3019	0.4577	−0.3416	0.489	−0.2463	0.6679
Model information:	LSDV R ² = 0.752, F-test = 23.19, Welch test p = 0.000, mean ROA = 5.78, SD = 5.06, Durbin–Watson = 1.69.		LSDV R ² = 0.739, F-test = 20.44, Welch test p = 0.000, mean ROA = 5.81, SD = 5.17, Durbin–Watson = 1.70.		LSDV R ² = 0.794, F-test = 6.69, Welch test p = 0.000, mean ROA = 5.70, SD = 4.79, Durbin–Watson = 1.68.	

Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A2. Impact of Digital Investment on Return on Assets (ROA).

Variable Segment	Coefficient All Panel	p-Value	Coefficient Western Europe	p-Value	Coefficient Eastern Europe	p-Value
Constant	35.0733 ***	<0.0001	42.2574 ***	<0.0001	−12.7344	0.5306
Digital investment	0.0129 ***	0.0001	0.0162 ***	0.0002	0.0044	0.2854
Cash ratio	0.3600 *	0.0869	0.3752 *	0.0892	0.5965	0.2006
Working capital	0.0659 ***	<0.0001	0.0612 ***	0.0002	0.0604 **	0.0334
Price-to-Book ratio	0.3078 ***	<0.0001	0.2878 ***	<0.0001	0.5943 ***	0.001
Price-Earnings ratio	−0.0381 ***	<0.0001	−0.0385 ***	<0.0001	−0.0354 ***	<0.0001
Revenue growth	0.0429 ***	<0.0001	0.0441 ***	<0.0001	0.0372 ***	<0.0001
Firm size	−1.3746 ***	0.0002	−1.7147 ***	<0.0001	0.9982	0.3238
Leverage	−0.3988 ***	0.0005	−0.3718 ***	0.0051	−0.5850 ***	0.0087
Tangible assets	−0.0748 ***	0.0004	−0.0745 ***	0.0048	−0.0866 **	0.0153
Capital expenditure	−0.1734 ***	<0.0001	−0.1849 ***	<0.0001	−0.1523 ***	0.0012
Firm age	0.1858	0.3432	0.2815	0.1859	−0.1842	0.6849
Model information:	LSDV R ² = 0.747, F-test = 57.28, Welch test p = 0.000, mean ROA = 6.28, SD = 5.68, Durbin–Watson = 1.46.		LSDV R ² = 0.746, F-test = 48.74, Welch test p = 0.000, mean ROA = 6.29, SD = 5.79, Durbin–Watson = 1.49.		LSDV R ² = 0.767, F-test = 11.42, Welch test p = 0.000, mean ROA = 6.24, SD = 5.14, Durbin–Watson = 1.38.	

Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A3. Joint Impact of Environmental Practices and Digital Investment on Return on Assets (ROA).

Variable Segment	Coefficient All Panel	p-Value	Coefficient Western Europe	p-Value	Coefficient Eastern Europe	p-Value
Constant	65.7620 ***	<0.0001	63.8866 ***	<0.0001	73.2787 **	0.0129
Environmental practices (E)	0.0141	0.1538	0.0032	0.7663	0.0773 ***	<0.0001
Digital investment	0.0028	0.6217	0.0027	0.6121	0.0234 *	0.0926
Environmental practices (E) × Dig. Inv.	0.0002	0.2668	0.0003 *	0.0671	−0.0010 ***	0.0048

Table A3. Cont.

Variable Segment	Coefficient All Panel	p-Value	Coefficient Western Europe	p-Value	Coefficient Eastern Europe	p-Value
Cash ratio	−0.0394	0.9343	0.0365	0.9413	−0.5008	0.7633
Working capital	0.0885 ***	0.0001	0.0830 ***	0.0007	0.0718	0.1428
Price-to-Book ratio	0.2890 ***	<0.0001	0.2815 ***	<0.0001	0.5632 *	0.0505
Price-Earnings ratio	−0.0413 ***	<0.0001	−0.0420 ***	<0.0001	−0.0382 ***	0.0013
Revenue growth	0.0439 ***	<0.0001	0.0433 ***	<0.0001	0.0485 ***	<0.0001
Firm size	−2.7203 ***	<0.0001	−2.6221 ***	<0.0001	−3.1111 **	0.0206
Leverage	−0.1423	0.1465	−0.1363	0.1809	−0.4671 *	0.0532
Tangible assets	−0.0382	0.1687	−0.0351	0.3139	−0.0475	0.2543
Capital expenditure	−0.2557 ***	0.0003	−0.2529 ***	0.0023	−0.1902	0.1106
Firm age	−0.0356	0.9314	0.0459	0.9233	−0.5691	0.3647
	LSDV R ² = 0.772,		LSDV R ² = 0.764,		LSDV R ² = 0.844,	
	F-test = 21.04, Welch test		F-test = 18.65, Welch test		F-test = 6.44, Welch test	
Model information:	p = 0.000, mean ROA = 5.95,		p = 0.000, mean ROA = 5.94,		p = 0.000, mean ROA = 6.04,	
	SD = 5.13,		SD = 5.16,		SD = 4.92,	
	Durbin–Watson = 1.61.		Durbin–Watson = 1.65.		Durbin–Watson = 1.38.	

Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

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