ISSN: 2029-4913 / eISSN: 2029-4921

TECHNOLOGICAL and ECONOMIC DEVELOPMENT of ECONOMY

2026
Volume 32
Issue 1
Pages 233–259

https://doi.org/10.3846/tede.2025.24455

HOW DOES GREEN INNOVATION DETERMINE CORPORATE PHYSICAL INVESTMENT? NEW EMPIRICAL EVIDENCE

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Article History:
- received 31 December 2024
- accepted 24 May 2025
- first published online 3 September 2025

Abstract. Due to the escalating issue of global warming and other environmental concerns, green innovation has garnered significant attention. However, there is a dearth of literature addressing the impact of green innovation on industrial investment. Therefore, the present study aims to investigate how green innovation affects corporate physical investment. We utilize a wide array of financial data from a panel comprising 11 Asian economies and employ the system GMM (generalized method of moments) to test the underlying hypothesis. The empirical findings reveal a positive and statistically significant effect of all proxies for green innovation, including patent registrations, the development of environmental technologies, innovation intensity, and green growth innovation, on corporate physical investment. The empirical analysis yields a crucial policy implication, emphasizing the importance of prioritizing green innovation and the adoption of modern technology. These initiatives not only boost investment volumes but also contribute to achieving environmental sustainability. By exploring the intricate relationship between green innovation and corporate physical investment, the current study introduces innovative insights to the literature on financial and environmental economics.

Keywords: corporate physical investment, green innovation, environmental sustainability, green patents registration, development in environmental technologies.

JEL Classification: G31, Q55, Q56.

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List of abbreviations

INV – physical investment;
TPR – total patent registration;
DET – development in environment related technologies;
INI – innovation intensity;
GGI – green growth innovation;
FS – firm size;
LVG – leverage,
FDI – foreign direct investment;
GDP – GDP growth rate;
CO_2 – CO_2 emissions;
CTR – carbon tax rate.

1. Introduction

In our post-modern era, endangered by global warming, climate change, and related political, military, socio-economic, and environmental crises, politicians, managers, and researchers are called upon to address and confront the challenge of sustainable economic growth (Lahane & Kant, 2022).

Due to a rapid, unbalanced and quite chaotic industrialization, these environmental issues engendered serious environmental challenges including high CO_2 emissions, climate change, and depletion of the ozone layer etc., (York & Venkataraman, 2010). The extensive exploitation of natural resources for business activities has generated environmental stresses, including anthropogenic climate change, global warming, biodiversity loss and extinction crisis and an alarming decline in available natural sources at global stage (Rosenzweig et al., 2008; Höök & Tang, 2013; Hassan et al., 2019; Magnan et al., 2021). The irresponsible (over) exploitation of natural resources reflects the inappropriateness of the present productivism, consumerist and in equalitarian business and social model as well as its fail to achieve a sustainable development. Accordingly, public authorities and policymakers are called to design, drive and, collectively, operationalize innovative (but effective), ambitious (but practicable), clever (but transformative) holistic, multi-factorial and multi-stakeholders' strategies able to promote, support and tool the spread of a "green culture" at the country-level (Bruna & Ben Lahouel, 2022). Such radical shift, from outdated production system to green innovation (Takalo & Tooranloo, 2021), not only is supposed to enhance environmental sustainability (through ecological impact mitigation) but is promised to engender monetary gains, through resource-spending, cost reduction and reinforced operational efficiency (Hizarci-Payne et al., 2021).

Consequently, persisting environmental damages have urged the environmental economist to develop pollution abatement strategies, able to ensure environmental protection and economic growth in a parallel way. Responding to this call, environmental regulations, including environmental tax and other monetary punishments on pollution emissions, have flourished worldwide to protect and preserve the natural environment (Cao et al., 2020). However, insufficiently contextualized, negotiated, progressive and efficient regulations could curb industrial growth, engendering supra-costs, business opportunities losses as well as stakeholders' resistance, with potential depreciable impacts on productivity (shortage of industrial goods) and profitability as well as social negative externalities (i.e., unemployment, job insecurity, workers 'pauperization) (Kunapatarawong & Martínez-Ros, 2016; Hu et al., 2022; Wang et al., 2022).

In such a circumstance, the exploration of green innovation can match a double expectation: preserving environment and supporting industrial growth (Töbelmann & Wendler, 2020). Following the seminal work of Fussler and James (1996), green innovation can gradually bring together better-quality products for customers and environmental degradation reduction. Convergent, Liao et al. (2021) illustrate the positive outcomes on firm performance when the industrial sector focuses on green innovation activities.

As certified by Hao and He (2022), the green innovation constitutes a pillar-instrument to enhance companies' environmental footprint and engender economic benefits, through operational optimization and prevention of socio-environmental negative impacts. It can, symmetrically, stimulate industrial competitiveness both at the domestic and international levels (Cohen & Tubb, 2018) and engender sustainable competitive advantages. Convergent, enterprises are invited to endorse green innovation to prevent business operations' negative externalities and environmental regulations' stresses as well as to stimulate green productivity (Hur et al., 2004; Li & Lin, 2017; Zhang, 2021). As explained, in their seminal book, by Carrillo-Hermosilla et al. (2009), "*the scale of environmental problems, coupled with social inequalities and competitiveness challenges within the global economy, have raised increasing awareness of the need to change and renew existing technological production and social behavioral patterns. At best, such awareness may produce innovative responses that gradually move society along a more sustainable path*". Green innovation (as a synonym of green innovation, Karakaya et al., 2014; Díaz-García et al., 2015) refers to "*new technologies that improve economic and environmental performance* [but can also…] *include organizational and social changes for improving competitiveness and sustainability and its social, economic and environmental pillars*" (Carrillo-Hermosilla et al., 2009, pp. 6–7).

Convergent, green innovation acts as a corporate financial efficiency factor, optimizing resource and energy consumption as well as minimizing unsuitable outcomes – as wastes, pollutants, greenhouse gas, environmentally induced social/health issues (El-Kassar & Sing, 2019; Cao et al., 2020). Moreover, the propulsion for green innovation remains institutionally and socially embedded. Where CSR performance (particularly within firms showing a higher transparency and a larger institutional ownership, Hao & He, 2022) acts as a precursor for green innovation, stakeholders' support to social and ecological transition (by inspiring, supporting, tooling, and assessing company's CSR programs and practices) constitute a green-innovation pillar-condition. Thus, green innovation is generally encouraged by institutional determinations, public subsidies, innovation management, transformative leadership and, obviously, technological and technical process disruption (Xiang et al., 2022; Schiederig et al., 2012; Song & Yu, 2018; Arici & Uysal, 2022; Takalo et al., 2021; Hao & He, 2022).

The increasing severity of global environmental challenges, including climate change, resource depletion, and rising carbon emissions has intensified pressure on businesses to adopt sustainable practices (Cao et al., 2020). International agreements such as the Paris Agreement and the Carbon Border Adjustment Mechanism (CBAM) have established stringent environmental commitments, compelling firms to transition towards low-carbon technologies and sustainable investment strategies. In this context, green innovation has emerged as a critical driver of corporate resilience and long-term competitiveness, allowing firms to comply with regulatory standards while maintaining economic viability. However, the urgency of green technology development is further heightened by the growing demand for eco-friendly products, investor preferences for sustainability-driven firms, and increasing scrutiny from global markets. Given the vital role of businesses in reducing carbon footprints and fostering economic sustainability, understanding the link between green innovation and corporate investment behavior is crucial for designing effective policies and investment strategies that balance environmental goals with financial sustainability.

While green innovation promotes corporate investment, firms face significant challenges in adopting sustainable technologies. One major contradiction is the trade-off between the high upfront costs of green technology and short-term financial returns which discourages many firms from prioritizing eco-friendly investments. Additionally, policy uncertainty, including fluctuating environmental regulations, inconsistent government incentives, and unpredictable carbon pricing mechanisms creates investment risks that may deter firms from committing to long-term green innovation strategies. Moreover, the lack of standardized frameworks for measuring green investment returns and the technological uncertainties associated with emerging green innovations further complicate decision-making (Aastvedt et al., 2021). Addressing these barriers requires clear regulatory frameworks, stable financial incentives, and well-structured market mechanisms that can mitigate investment risks and accelerate the green transformation of industries.

Meanwhile, the monetary outcomes in the shape of an early return, and low default risk engendered by green innovation can encourage investment. The emanating environmental regulation push corporate managers to explore techniques and solutions able to reduce the business-induced volume of CO_2 emissions (Shen et al., 2019). In this regard, the corporate managers are called to mitigate the pollution emissions, following green production operations as well as developing and/or adopting modern technology. Accordingly, the green innovation strategies (Chen & Ma, 2021; Zhang & Vigne, 2021) ensure win-win situations, i.e., positive business growth and green environment as stated by Porter (1991). Nevertheless, little is known in the literature how such green innovation practices protect the corporate investment decisions.

In line with this research-orientation, the present empirical study aims at exploring the impact of green innovation strategies on corporate physical investment decisions, using a large sample of financial data from 11 Asian economies (China, India, Indonesia, Japan, Malaysia, Pakistan, Philippine, Singapore, South Korea, Thailand, and Turkey). In the current study, the green innovation works as an independent variable, referring to modification in basic business operations ensuring the pollution mitigation and reduction of other negative externalities (Carrión-Flores & Innes, 2010). Similarly, the physical investment is a dependent variable, exemplifying the volume of investment in acquisition of three capital projects including property, plant, and equipment (PPE hereafter) (Phan et al., 2022).

A list of corporate-specific, macroeconomic, and environment-specific variables are endorsed as control variables. The regression analysis is supported by a GMM (generalized method of moments). The empirical analysis states that all of four proxies for green innovation endorsed in the paper (total patent registration, development in environmental technologies, innovation intensity, green growth innovation) positively determine the corporate physical investment. After controlling for endogeneity and other firm-specific and macroeconomic factors, the article provides robust evidence regarding the positive impact of green innovation on physical investment protection. Finally, it offers an empirical validation of the theoretical underpinning of Porter's win-in model and calls policymakers, corporate managers, and environmental economists for reinforced green innovation commitment.

This research holds particular significance in the context of Asian economies, which are at the forefront of industrial growth yet face mounting environmental challenges. As the region continues to expand its manufacturing and industrial sectors, the integration of green innovation into corporate investment strategies becomes increasingly urgent for achieving sustainable economic growth. Unlike developed economies, many Asian countries experience regulatory inconsistencies, limited financial incentives, and technological gaps, making it crucial to assess how green innovation can effectively drive physical investment in such an environment. By investigating the relationship between green innovation and corporate investment, this study provides policy-relevant insights for governments, investors, and corporate managers, ensuring that sustainable investment strategies align with the broader agenda of economic resilience and environmental sustainability in Asia.

The key innovation of our study lies in its direct examination of the relationship between green innovation and corporate physical investment decisions, a dimension that has remained largely unexplored in the existing literature. While prior research has extensively analyzed green innovation in the context of firm performance, environmental sustainability, and financial outcomes, no study, to our knowledge, has explicitly investigated its direct impact on corporate investment in tangible assets. By bridging this gap, our study offers novel empirical evidence on how green innovation influences firms' capital allocation strategies, shedding light on its role in shaping long-term investment decisions. Moreover, our analysis moves beyond the conventional focus on firm profitability or environmental compliance and instead positions green innovation as a strategic driver of corporate investment behavior, reinforcing its importance in sustainable business practices. This contribution not only advances academic discourse but also provides valuable insights for policymakers and corporate managers seeking to align innovation policies with long-term economic growth and sustainability objectives.

The other parts of the paper are the follows: Section 2 reports the review of previous studies and suggests the relevant hypotheses for testing, Section 3 narrates the material and methods, and Section 4 of the study presents the empirical results and discussed the empirical results while Section 5 consists of the conclusion and policy implications emanated from empirical analysis.

2. Literature review

Due to a hyperbolic, but insufficient (or ineffective) regulated, surge in economic activities (e.g., production, distribution, and consumption of industrial goods), inducing natural-resource stress and a range of human-engendered environmental damages, all the countries are called, in the times of Anthropocene, to face sustainability issues. Accordingly, business growth is threatened by multi-factorial and multi-level environmental issues (including over-exploitation and induced rarity of natural sources; air, land and water pollution; lack of clean air; scarcity of clean water; Liang & Yang, 2019). These ecological risks and threats are deeper in industry-intensive economies. In 2015, the UNO (United Nations Organization) articulated the 17 SDGs (sustainable development goals) that could be achieved by the year 2030 (commonly known as Agenda 2030). Among other goals, the goals relating to environmental sustainability and human health e.g., clean water, clean energy, sustainable production, and climate actions have attained the major attention of both the academic community and policy officials (Adebayo et al., 2022; Parmentola et al., 2022; Udemba & Tosun, 2022).

To achieve a balanced economic development, the industrial sector is called to focus on green innovation and other pollution abatement strategies. In this regard, the ecological modernization theory states that the development of environmental technologies is mandatory to achieve, parallelly, both economic and environmental performance (Liao et al., 2021). Called to ensure a green growth, green innovation (or eco-innovation) has become a pivotal policy agenda for both governments and companies (Bhupendra & Sangle, 2015). Accordingly, the literature has addressed the green innovation looking at four main avenues: 1) the key-measurement of green innovation (Cheng et al., 2014; Gomez-Conde et al., 2019), 2) its driving forces (Bhupendra & Sangle, 2015; Hojnik & Ruzzier, 2016) its main positive contributions in terms of pollution reduction and product quality (Liao, 2018) its main financial outcomes. As specified by the recent studies (Wen et al., 2022; Cao & Zhang, 2023), green innovation was measured by multiple proxies including the number of patents registered relating to environmental technologies, the percentage of expenditures made on the development of environmental technologies, the overall intensity of green innovation which informs about the intensity of total development in environmental technologies in relation to total patents registered, and green growth innovation which is a dimension of environmental technologies that ensure green growth.

Some studies (as Aldieri et al., 2019 and Bitencourt et al., 2020) have investigated the key driving forces including company size, company capabilities, R&D, information sources, and environmental regulations etc., of green innovation and their intended role in industrial development.

Furthermore, there exists a consensus in the literature on the standpoint that green innovation engenders positive outcomes, not only reducing the negative footprint of business activities (shaping, and performativity fostering, a green(er) environment), but also boosting the overall industrial efficiency (York & Venkataraman, 2010; Cao et al., 2020; Liao et al., 2021). Based upon both qualitative and quantitative approaches, some papers identify a spillover effect of green innovation on industrial performance (Costantini et al., 2017). In facts, green innovation (i.e.: disruption in environmental technologies) not only mitigates environmental degradation but reduces the production costs, by replacing the existing, outdated technologies with disruptive, efficient ones (Doran & Ryan, 2016). Mothe and Nguyen-Thi (2017) convergent attest the persistent positive outcomes of green innovation in terms of R&D investment. Similarly, Alam et al. (2019) observe the positive impact of corporate R&D investment on the development of environmental technologies in G-6 countries. Finally, the innovation activities enhance the product quality and, thus, increase the competitiveness of industrial goods, all around the globe (Aastvedt et al., 2021; Chen & Ma, 2021; Le & Ikram, 2022). Moreover, they contribute to the matching of the product design, quality and offer to stakeholders' expectations (and not only to the consumers' ones).

Some studies suggest the leading role of green innovation in boosting industrial growth (Chen & Low, 2021; Sun & Razzaq, 2022), and enlighten the contribution of green innovation policies to sustainable economic development (Liao, 2018). Convergent, El-Kassar and Sing (2019) assess the "double externalities" (on environment and cost-efficiency) of green innovation and highlight its positive influence on companies' financial efficiency. Doran and Ryan (2016) attest the positive contribution of the green innovation on firms' competitiveness and financial efficiency. Temiz (2022) finds an inverse relationship between environmental performance and costs of debt and equity in 17 emerging economies, revealing a cost reduction effect of green innovation. In facts, the reduction of production costs acts as a financial efficiency factor, encouraging positive investment growth (Chen et al., 2020). Le and Ikram

(2022) reveals the direct influence of sustainability innovation on corporate competitiveness which further shows the positive effect on financial efficiency of enterprises, in the context of emerging economies.

In the same line, adopting a China-focused design, a stream of the literature attests the positive impact of green innovation on corporate investment and overall performance of Chinese companies. Yu et al. (2021) empirically reveal that green innovation alleviates the financing constraints of enterprises in China which further has a positive effect on corporate investment. In line, Szutowski (2021) finds a positive relationship between stock returns and all four types of green innovations regarding products, processes, marketing, and organizational issues. The study of Chen and Low (2021) reveals a U-shaped relationship between green investment and economic performance of Chinese enterprises. Huang and Huang (2022) show that green innovation stems from institutional pressure that stimulates the firm performance of Taiwanese enterprises. Later, Gu (2022) asserted that green innovation can act as a catalyst to enhance the overall economic performance of Chinese hotels.

Zhang et al. (2020) examined whether green innovation can ease corporate financing constraints using data from Chinese non-financial private enterprises (2012–2017) and regression analysis. The findings confirmed that green innovation, especially in heavily polluting firms, improves financing conditions, with corporate environmental disclosure further enhancing this effect. Farooq et al. (2024) explored how green innovation influences the relationship between environmental regulations and capital investment using a 10-year dataset (2010–2019) from publicly listed firms in 10 Asian economies. The findings revealed that while environmental regulations negatively affect investment decisions, they positively drive green innovation, which moderates this impact, supporting Porter's win-win model. Li et al. (2024) examined the impact of green innovation on corporate financing in BRICS countries using data from 2010 to 2022 and system GMM estimation. The findings revealed a positive influence, underscoring the role of sustainability in shaping corporate financial strategies.

Convergent with Porter's win-win hypothesis, the extant literature reveals that the abatement of pollution through green innovation does not impede the performance of industries but enhances the product quality and the environmental performance (Porter, 1991). In his theory of competition, Porter argued that stringent environmental regulations can stimulate the firm's green performance (Porter & Linde, 1995). This theory further stated that the implication of environmental regulations induces more R&D investment in environmental technologies and result in better performance on both product quality and pollution abatement.

Many studies (e.g., Yu et al., 2021; Li et al., 2024) primarily focus on financial constraints and firm performance but do not adequately address the trade-offs between high initial investment costs and long-term sustainability benefits. Moreover, research examining the relationship between green innovation and corporate investment remains disproportionately concentrated on China, with relatively limited cross-country comparative analysis in Asia. This leaves a critical gap in understanding how regulatory environments, institutional quality, and market dynamics influence the extent to which green innovation can drive corporate investment across diverse economies. Additionally, while Porter's win-win hypothesis suggests that stringent environmental policies can stimulate green investment, empirical evidence on its applicability in Asian economies remains inconclusive, given the policy uncertainty and varying degrees of regulatory enforcement. This study contributes to the literature by providing a broader regional perspective on Asia, examining the role of green innovation in shaping corporate investment decisions while accounting for financial, institutional, and policy-related constraints. By addressing these deficiencies, the research offers more comprehensive insights for policymakers and corporate strategists aiming to balance economic growth with environmental sustainability.

Table 1. Review of literature (source: self-review of literature)

Reference	Main commentary
Doran and Ryan (2016)	The research conjectures that green innovation engenders a positive role in firms' competitiveness and financial efficiency.
Costantini et al. (2017)	The paper identifies the spillover effect of green innovation on industrial performance.
Mothe and Nguyen-Thi (2017)	The study suggests the persistent positive outcomes of green innovations in the form of more R&D investment.
Liao (2018)	The empirical analysis shows that complying with green innovation policies can promote sustainable economic development.
El-Kassar and Sing (2019)	Analysis shows positive influence of green innovation on the financial efficiency of enterprises as it possessed the "double externalities" of environmental and cost-efficiency.
Alam et al. (2019)	Empirical analysis reveals positive impact of R&D investment on corporate concerns for the development of environmental technologies in G-6 countries.
Aldieri et al. (2019) and Bitencourt et al. (2020)	Both studies suggest the key driving forces of green innovations and their intended role in industrial development.
Aastvedt et al. (2021)	The analysis asserts the positive effect of green innovation scores on financial performance.
Yu et al. (2021)	This study empirically vows that green innovation alleviates the financing constraints of enterprises in China which further has a positive effect on corporate investment.
Szutowski (2021)	This study indicates the positive relationship between stock returns and all four types of green innovations.
Chen and Low (2021)	The study indicated the U-shaped relationship between green investment and the economic performance of Chinese enterprises.
Gu (2022)	The findings of study asserts that green innovation could act as a catalyst to enhance the overall economic performance of Chinese hotels.
Gupta and Deb (2022)	The empirical analysis discloses positive mediated impact of internationalization in nexus between environmental performance and corporate financial performance.
Temiz (2022)	This research exhibits inverse relationship between green environmental performance and costs of debt and equity, implying the cost reduction effect of green innovation.
Huang and Huang (2022)	This study shows that green innovation stems from institutional pressure that stimulates the firm performance of Taiwanese enterprises.
Le and Ikram (2022)	The study reveals the direct influence of sustainability innovation on corporate competitiveness which further shows the positive effect on the financial efficiency of enterprises.

Note: This table shows brief findings of studies arranged on similar theme.

Following the Porter's Hypotheses, the present paper manages to test the following Hypothesis.

H1: *Green innovation policies have positive and significant role in determining the corporate physical investment.*

As showed in Table 1, the state of the art underlines the positive impact of green innovation on multiple corporate issues, as alleviation of financing constraints (Yu et al., 2021), reduction of debt and equity cost (Temiz, 2022), stimulation of corporate investment (Yu et al., 2021), particularly through R&D (Mothe & Nguyen-Thi, 2017), and sustainable economic development (Liao, 2018; Hunjra et al., 2022b). These finds are convergent with the review of the literature, attesting the positive influence of green innovation on competitiveness and financial efficiency (Doran & Ryan, 2016; Le & Ikram, 2022) and performance (Aastvedt et al., 2021; Huang & Huang, 2022). In a whole, the literature advocates in favor of an green innovation spillover effect on industrial performance (Costantini et al., 2017).

3. Theoretical review

The relationship between green innovation and corporate investment decisions can be effectively understood through Stakeholder Theory, the Resource-Based View (RBV), and Institutional Theory, particularly in the context of long-term investment in tangible assets. Stakeholder Theory emphasizes that firms must respond to the growing expectations of investors, consumers, regulators, and environmental groups. As sustainability concerns intensify, companies that actively invest in green innovation strengthen their market position, build long-term stakeholder trust, and enhance financial stability, encouraging greater capital allocation to sustainable tangible assets such as eco-friendly infrastructure and clean technologies. From the RBV perspective, green innovation serves as a valuable strategic resource that enhances operational efficiency, reduces long-term costs, and fosters technological leadership (Aldieri et al., 2019). Firms integrating green innovation into their core strategies are more likely to invest in physical assets, securing a durable competitive advantage. Meanwhile, Institutional Theory underscores how regulatory frameworks and normative pressures drive firms toward sustainability-oriented investment decisions. Companies operating in stringent regulatory environments are not only compelled to comply with environmental standards but also find long-term financial incentives in green infrastructure investments, such as access to green financing, tax benefits, and improved risk mitigation. Together, these perspectives highlight that green innovation is not just a compliance-driven necessity but a catalyst for long-term investments in tangible assets, ensuring resilience, profitability, and sustainable growth.

4. Data and methods

This empirical analysis endorses secondary data for the years 2010 to 2019 of 5,014 firms from 11 economies. This span has been selected because the data regarding environment-related variables e.g., total patents registration, were available until 2019. Therefore, we are unable to expand the sample span to the recent years[1]. The selection of Asian economies and the sample of 5,014 firms from 11 economies for the period 2010 to 2019 is driven by both data availability and the increasing relevance of green innovation in the region. Asia has emerged as a global hub for technological advancements and industrial expansion, making it a crucial area for examining the relationship between green innovation and corporate investment decisions. The selected economies represent a diverse mix of developed and developing markets with varying degrees of environmental regulations, innovation policies, and industrial structures, allowing for a comprehensive analysis of green innovation's impact. The sample selection is based on data availability for key environment-related variables, particularly patent registrations as a measure of green innovation, which were consistently reported only until 2019. Expanding the dataset beyond this period was not feasible due to gaps in environmental data reporting across countries.

The exclusion of service sector firms from our study is deliberate and methodologically justified due to the fundamental differences in the nature of their investments compared to manufacturing and industrial firms. Corporate physical investment which is the primary focus of our study, predominantly involves tangible asset accumulation that are more relevant to industrial firms. While service firms do invest in sustainable initiatives, their capital allocation often prioritizes intangible assets like software, intellectual property, and human capital, rather than large-scale physical investments. Including service sector firms could have introduced heterogeneity into the dataset, making it difficult to isolate the specific impact of green innovation on physical investment. Furthermore, prior empirical studies on corporate investment behavior (e.g., studies on capital intensity and asset tangibility) also tend to focus on firms with significant physical asset structures, reinforcing our decision to limit the scope to sectors where physical investment is a core component of business operations. The data regarding firm-specific variables have been collected from Thompson Reuters's DataStream whilst the data concerning macroeconomic and environmental variables have been sourced from WDI (World Development Indicators), World Bank (n.d.), and Organisation for Economic Co-operation and Development (OECD, n.d.) Statistics, relatively. Appendix Table A1 shows the sample description.

Regarding missing data, a systematic approach was employed to ensure data integrity and avoid biases. Firms with missing data for key financial and innovation variables for a minimum of three consecutive years were excluded from the sample to maintain consistency in panel estimations. Additionally, robust data cleaning techniques, including outlier detection and winsorization were applied to prevent extreme values from distorting the analysis. For non-critical missing values, interpolation and mean imputation techniques were utilized to retain a balanced dataset where possible. This approach ensures that sample selection bias is minimized.

[1] We have excluded the service sector and financial sector (SIC 7000-8999) companies from sample because these both sectors are less concerned with physical investment in property, plan, and equipment and do not produce any industrial goods that cause the environmental degradation and therefore we exclude both sectors from sample.

4.1. Econometric models

To test underlying assumption, the undermentioned econometric equation can be developed:

$$INV_{ijt} = \beta_{\circ} + \alpha_1 INV_{ijt-1} + \alpha_2 TPR_{jt} + \alpha_3 DET_{jt} + \alpha_4 INI_{jt} + \alpha_5 GGI_{jt} + \beta_1 FS_{ijt} + \beta_2 LVG_{ijt} + \gamma_1 FDI_{jt} + \gamma_2 GDP_{jt} + \delta_1 CO2_{jt} + \delta_2 CTR_{jt} + \mu_i + \sigma_t + \varepsilon_{ijt}. \quad (1)$$

In Eq. (1), the acronym INV is used for physical investment, TPR for total patent registration, DET for development of environmental technologies, INI for innovation intensity, GGI for green growth innovation. Similarly, other abbreviations including FS, LVG, FDI, GDP, CO_2, and CTR represent the firm size, leverage, foreign direct investment, GDP growth, CO_2 emissions, and carbon tax rate relatively. The subscript i denotes the firm, j for country, and t for time. The α, β, γ, and δ are the vectors of coefficients while μ_i and σ_t illustrate the cross-section and time fixed effects relatively. Lastly, the symbol of ε_{ijt} is for residual term. Table 2 shows a brief description of these variables.

Table 2. Variable's summary (source: past studies)

Sr no.	Variable	Role	Measurement	Reference
1	Physical Investment	DV	Total expenditures occurred in acquisitions of three physical assets i.e., property, plant, and equipment	Billett et al. (2011); Akron et al. (2020); Hong and Wang (2021)
2	Green innovation	IV	Total patent registration Development of environmental technologies Innovation intensity Green growth Innovation	Gomez-Conde et al. (2019); Többelmann and Wendler (2020); Guo et al. (2022)
3	Firm size	CV	Log of total assets	Adelino et al. (2017)
4	Leverage	CV	Debt/total assets	Vo (2019)
5	Foreign direct investment	CV	Net inflow of funds into capital projects of host country	Farooq et al. (2021)
6	GDP growth rate	CV	Real increment in the value of all goods and services during a specific period.	Phan et al. (2022)
7	CO_2 emissions	CV	Metric ton emissions of CO2	Wen et al. (2021)
8	Carbon tax rate	CV	Tax levy on industrial sector for environmental degradation activities	Phan et al. (2022)

Note: Abbreviations: DV – dependent variable, IV – independent variable, CV – control variables.

4.2. Methodology

In the present research, we investigate the impact of green innovation on corporate physical investment by employing several econometric techniques. As the analysis is based upon panel-data, we start with fixed-effect model (FEM). However, the existence of heteroscedasticity, as shown by the likelihood ratio test, makes it necessary to endorse the panel EGLS (generalized least square) test to treat the heteroscedasticity issues and to find out the unbiased regression.

The Hausman test examines whether the FEM or random effects model (REM) is more appropriate for the analysis. The null hypothesis (H_0) assumes that the REM is the preferred model, meaning that the individual effects are uncorrelated with the regressors. The alternative hypothesis (H_1) suggests that the FEM is more suitable, as individual effects are correlated with the regressors. In this case, the Chi-square value (18.74) and p-value (0.004) reported in Appendix Table A2 indicate that the null hypothesis is rejected at a 1% significance level, confirming that the FEM is the appropriate model for the study. Thus, the results validate the use of FEM, ensuring robust and unbiased estimations.

The transition from the FEM to Panel EGLS is motivated by the need to correct for heteroscedasticity, which can lead to inefficient estimates and biased standard errors if left unaddressed. While FEM effectively controls for time-invariant unobserved heterogeneity, it does not inherently account for heteroscedasticity. The likelihood ratio test (results reported in Appendix Table A3) confirms its presence, necessitating a methodological adjustment. Panel EGLS is chosen as it applies weighted least squares estimation, enhancing the efficiency of coefficient estimates by addressing variance inconsistencies across entities. This approach ensures that the model produces more reliable standard errors and robust inference. Additionally, EGLS is particularly useful when dealing with large panel datasets where heteroscedasticity is prevalent.

Autocorrelation in panel data arises when the error terms in one time period are correlated with those in another, leading to inefficient and biased standard errors. Addressing this issue is crucial for ensuring robust statistical inference. The Wooldridge test is widely used for detecting first-order autocorrelation in panel data models because it is simple, does not require strong assumptions, and performs well even with unbalanced panels. The results of the Wooldridge test reported in Appendix Table A4 indicate an F-statistic of 18.45, which is statistically significant at the 1% level (p-value = 0.000). This leads to the rejection of the null hypothesis (H_0), which assumes no first-order autocorrelation. The presence of autocorrelation suggests that the residuals are correlated over time, potentially distorting standard errors and leading to inefficient estimators.

In panel-data-analysis, it is further needed to check either the analysis is unbiased from the endogeneity issue (Bruna & Ben Lahouel, 2022), this problem being frequent when analysis contains both firm-specific and macroeconomic variables. Accordingly, we apply another diagnostic test named the Wald test and report the results in Appendix Table A5. The significant p-values of restriction terms imply that residuals are correlated with explanatory variables and, hence, cause the endogeneity issue. In addition, the study considers Durbin-Wu-Hausman test which is a widely used for detecting endogeneity in regression models. It evaluates whether an explanatory variable is correlated with the error term, which can lead to biased and inconsistent estimates if not addressed properly. The reported p-values (0.011 for Durbin and 0.005 for Wu-Hausman) in Appendix Table A6 confirm the existence of endogeneity. To solve the problem, this study finally employs the two-step system GMM (generalized method of moments) model as argued by Arellano and Bond (1991) commonly known as the AB model. The AB model with significant lagged values used as an instrument can resolve the problem of endogeneity in panel-analysis. Some recent studies conducted on similar topics have utilized the AB model as a regression estimation technique (Chen & Feng, 2019; Többelmann & Wendler, 2020; Chen & Ma, 2021).

As the analysis contains several macroeconomic variables, it is therefore mandatory to check the stationarity of variables for unbiased estimation. For this purpose, the unit root test was applied for all the data-series, and results were reported in Table 3. The significant probability ($p < 0.05$) values of the ADF test (Dickey & Fuller, 1979), and Im, Pesaran, and Shin (Pesaran et al., 2001) test reject the null hypothesis i.e., the data are not stationery and unit root exist.

Table 3. Unit root test (source: author's own calculation)

	ADF - Fisher Chi-square		Im, Pesaran and Shin W-stat	
Variable Name	Statistic	Prob.	Statistic	Prob.
INV (Physical Investment)	11924.800	0.000***	–10.383	0.000***
TPR (total patent reg.)	12658.200	0.000***	–24.206	0.000***
DET (dev. Of env. Tech.)	12347.600	0.000***	17.743	0.000***
INI (Innovation Intensity)	47564.500	0.000***	–188.134	0.000***
GGI (green growth innovation) (-1)	12355.499	0.000***	19.254	0.000***
FS (Firm size)	13988.500	0.000***	–22.512	0.000***
LVG (leverage)	12009.700	0.011***	–8.646	0.071**
FDI (foreign direct investment)	37653.100	0.000***	–14.356	0.000***
GDP (GDP growth rate)	32332.000	0.000***	–114.738	0.000**
CO_2 emissions (CO_2 emissions)	10631.100	0.000***	–12.433	0.000***
CTR (carbon tax rate)	11210.100	0.000***	–0.787	0.000***

Note: * significance at 10%, ** significant at 5%, *** significant at 1%. Description: Probability values of both tests speak about the stationarity of data and reject the null hypothesis i.e., unit root exists.

5. Empirical results and discussion

Tables 4–5 provide descriptive summary of data across panel and country-wise relatively. As for concern physical investment, the average value of INV is 0.381 (as shown in Table 4), depicting that corporate firms make 38.1% physical investment into fixed assets comparing with total assets. TPR has a mean value of 67.699, exhibiting the number of patents relating to environmental technologies registered during a specific year. The mean value of DET is 9.419%, indicating the % development in environment-related technology as compared to total technologies. Similarly, the INI mean reaches 0.106 or 10.6%, showing the fraction value of all technologies divided by environment-related technologies. The GGI mean reaches 3.549 which is a dollar amount addition to the total GDP at the emission of one kg CO_2 into the air. This value reflects the overall intensity of sustainable development.

Nonetheless, the mean values across the countries as shown in Table 5 reveal that Pakistani corporate firms make highest investment as 0.503 or 50.3% as compared to other companion countries. Relating to green innovation activities, the highest number of patent registration reaches 94.700 and is achieved by South Korea. The highest development in environmental-related technologies has made by Philippines (14.635%). Similarly, the Pakistan enjoys highest innovation intensity of 14.7% while highest green growth innovation is made by Singapore (9.628%).

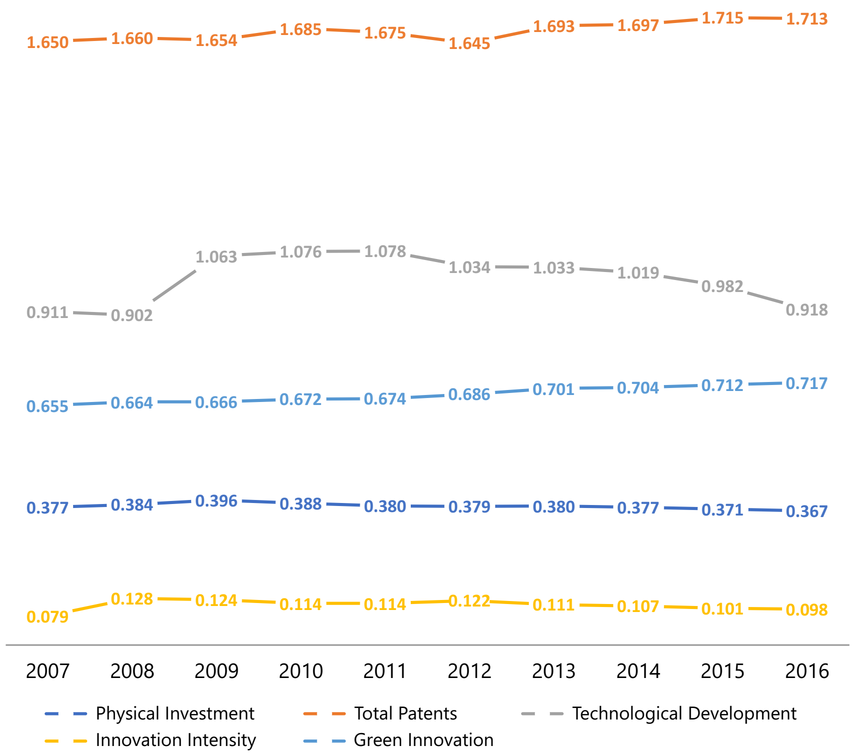

Figure 1. Co-variation of variables (source: self- estimation)

Figure 1 indicates the co-movement of main variables. It enhances the understanding on how main variables co-changed. Table 6 presents the correlation analysis among the variables. The most variables are below 0.70 (a benchmark value), implying that there is no multicollinearity issue.

Table 4. Descriptive summary (source: author's own calculation)

	Mean	Median	Std. dev.	Maximum	Minimum	Observations
INV	0.381	0.359	0.183	0.909	0.010	50140
TPR	67.699	81.000	0.030	95.000	0.000	50140
DET	9.419	9.090	0.165	26.890	1.710	50140
INI	0.106	0.104	0.025	0.271	0.033	50140
GGI	3.549	3.322	0.041	10.767	1.418	50140
FS	2.390	2.335	0.076	5.677	0.012	50140
LVG	0.285	0.270	0.175	0.909	0.010	50140
FDI	10.362	10.335	0.065	11.463	8.059	50140
GDP	4.549	4.831	0.086	14.525	–5.416	50140
CO2	6.804	7.543	0.087	12.111	0.807	50140
CTR	1.856	1.900	0.129	3.976	0.238	50140

Note: Abbreviations: see the list of abbreviations.

Table 5. Country-wise average values of main variables of study (source: self-estimation).

	INV	TPR	DET	INI	GGI
China	0.374	77.700	7.488	0.084	1.678
India	0.416	30.900	9.959	0.095	3.318
Indonesia	0.414	2.800	9.588	0.099	5.349
Japan	0.348	93.800	9.938	0.119	4.271
Malaysia	0.383	36.500	7.835	0.077	3.207
Pakistan	0.503	7.400	12.124	0.147	5.561
Philippines	0.389	37.600	14.635	0.145	7.151
Singapore	0.345	43.700	10.160	0.103	9.628
South Korea	0.379	94.700	10.260	0.134	3.172
Thailand	0.437	27.000	12.270	0.120	4.271
Turkey	0.393	73.700	7.358	0.077	5.270

Note: This table shows the mean trend of main variables of study of all under-analysis countries.

Table 6. Correlation statics (source: author's own calculation)

	INV	TPR	DET	INI	GGI	FS	LVG	FDI	GDP	CO2	CTR
INV	1.000										
TPR	–0.140	1.000									
DET	0.040	–0.125	1.000								
INI	–0.029	0.276	0.579	1.000							
GGI	–0.012	–0.158	0.348	0.324	1.000						
FS	–0.059	0.320	–0.041	0.081	0.004	1.000					
LVG	0.325	–0.145	0.011	–0.046	–0.099	0.013	1.000				
FDI	–0.047	–0.020	–0.466	–0.513	–0.516	0.039	0.087	1.000			
GDP	0.059	–0.346	–0.259	–0.561	–0.492	–0.139	0.132	0.577	1.000		
CO2	–0.135	0.743	–0.037	0.350	0.022	0.276	–0.187	–0.193	–0.450	1.000	
CTR	0.091	–0.476	–0.286	–0.550	–0.656	–0.193	0.184	0.638	0.706	–0.624	1.000

Note: Abbreviations: see list of abbreviations.

Furthermore, we adopt the GMM model to test our research-model, and we report the results in Table 7. The statistical analysis reveals that all proxies of green innovation including TPR (total patent registration), DET (development in environmental technologies), INI (innovation intensity), and GGI (green growth innovation) enjoy a positive and statistically significant relationship with corporate physical investment. From an economic perspective, green innovation enhances firms' productive efficiency, reduces operational costs, and strengthens their market competitiveness, thereby encouraging greater capital expenditure on tangible assets. As stated by the literature, the innovation in environmental technologies engenders benefits in terms of cost efficiency (optimization of the productive process), production quality, competitiveness increase, and sustainable development (Cheng et al., 2014; Aastvedt et al., 2021; Hizarci-Payne et al., 2021; Gu, 2022). Firms that actively engage in green innovation are better positioned to meet evolving regulatory standards and consumer preferences, which reduces uncertainty and strengthens investment incentives. Additionally, green innovation can improve access to financing by signaling lower environmental risks to investors and financial institutions, as evidenced by Aloui et al. (2023), who found that green finance policies in European banks have strengthened investor confidence in sustainable investments. These mechanisms collectively reinforce managerial preferences for capital investments, as firms anticipate long-term financial and strategic benefits from green innovation.

Following the Porter's win-win hypothesis, the development of environmental technologies seems an effective and valuable way to achieve the dual aim of industrial development and green environment protection (Porter, 1991). Stimulating green innovation and ensuring green productivity contribute, in facts, to an efficient use of existing sources with minimization of both productions cost and undesirable outputs (Cao et al., 2020). Such production cost reduction engenders positive spillover effect on physical investment. Moreover, the green innovation reflects, contributes, and put in acts a firm's CSR concern and commitment (Pan et al., 2021), enhancing company's reputation and, thus, easing the financing acquisition even at low financing costs (Mondosha & Majoni, 2018; Zhang & Vigne, 2021).

Moreover, the green lending enhances banks' financial efficiency and, symmetrically, encourage bank-financing of CSR/green-conscious companies (Gaudio et al., 2022). An increased availability of external funds can surge the volume of physical investment. Specifically, the analysis of Liu et al. (2022) vowed that the enterprises benefiting from an environmental governance enjoy a higher investment efficiency even during the COVID era, showing the significance of green environmental efforts in investment.

The reported statistics in Table 7 provide crucial insights into the validity of the System GMM estimation. The Arellano-Bond test for first-order (AR(1)) and second-order (AR(2)) serial correlation is essential for assessing the correctness of the GMM model. The AR(1) p-values (0.001, 0.002, and 0.010) are statistically significant, indicating the expected presence of first-order serial correlation in the differenced residuals, which is typical in dynamic panel models. However, the AR(2) p-values (0.221, 0.138, and 0.167) are all above conventional significance thresholds, suggesting no significant second-order serial correlation. This is a necessary condition for the validity of System GMM, as the presence of AR(2) would indicate that the instruments used are not exogenous. Additionally, the Sargan and Hansen tests assess the validity of the overidentifying restrictions and the overall instrument specification. The Sargan test p-values (0.144, 0.231, and 0.222) and Hansen test p-values (0.159, 0.222, and 0.362) are all above the conventional 0.05 significance level, indicating that the null hypothesis of instrument validity cannot be rejected. This suggests that the chosen instruments are appropriate and do not overfit the model. Collectively, these results confirm that the GMM estimation is correctly specified, with no evidence of instrument proliferation or serial correlation issues, thereby strengthening the robustness of the empirical findings.

As usual, statistical analysis contains control variables. As the coefficient values show, the firm-size has a positive association with physical investment in non-OECD countries. The larger firms always require more investment, specifically in physical projects, due to increasing demand for products (An et al., 2016). Similarly, the positive role of leverage can be explained as the availability of enough funds boosts the managerial confidence to make capital investment (Mondosha & Majoni, 2018). Additionally, more funds have positive connectivity with physical investment because enterprises need external financing to invest in long-term projects.

Table 7. Effect of green innovations policies on physical investment (source: author's own calculation)

	Outputs of System GMM model					
	Panel Analysis (1)		Non-OECD countries (2)		OECD countries (3)	
	Coefficients	Prob.	Coefficients	Prob.	Coefficients	Prob.
C	–1.115***	0.000	–0.758***	0.002	1.053***	0.000
INV (-1)	0.928***	0.000	0.118***	0.000	1.109***	0.000
TP	0.008***	0.038	0.001***	0.003	0.001***	0.035
DET	0.009***	0.000	0.002**	0.051	0.020***	0.000
INI	1.310***	0.000	2.126***	0.000	0.679***	0.003
GGI	0.035***	0.000	0.067***	0.001	0.004***	0.007
FS	–0.002	0.720	0.0313***	0.047	–0.011	0.118
LVG	0.201***	0.000	0.044***	0.000	0.184***	0.000
FDI	–0.121***	0.000	0.045***	0.047	–0.065***	0.000
GDP	0.007***	0.000	0.009***	0.030	0.003***	0.002
CTR	–0.045***	0.000	–0.006	0.187	0.014***	0.001
CO2	0.024***	0.000	–0.008	0.522	–0.073***	0.079
Adj. R-square	0.616		0.649		0.672	
S.E. of regression	0.078		0.075		0.057	
AR (1)	0.001		0.002		0.010	
AR (2)	0.221		0.138		0.167	
Sargan Test	0.144		0.231		0.222	
Hansen Test	0.159		0.222		0.362	

Note: *** indicate the significance at 1% level, ** at 5%, and * at 10% level. Abbreviations: see list of abbreviations. Instrument specification: CI (–1) TPR (–1) DET (–1) INI (–1) GGI (–1) FS (–1) LVG (–1) FDI (–1) GDP (–1) CTR (–1) CO2 (–1) CI (–2) FS (–2).

Looking at macroeconomic level, the research-findings reveal that foreign direct investment (FDI) engenders positive impact on physical investment in domestic firms within non-OECD countries, including China, India, Indonesia, and Pakistan, etc. Such economies are called to welcome FDI and benefit from the technology shift due to the inflow of FDI which further leads to more exploration in existing business ventures. Next, the GDP growth rate positively determines the corporate physical investment. A higher GDP growth-rate indicates prosperous economic conditions in which the industrial sector may flourish rapidly due to elevated demand for industrial products. This factor encourages corporate firms to increase their business operations and, thus, make more physical investment

Table 8 shows the robustness of empirical findings across an alternative estimation technique. The estimated coefficient values imply that the main variables of the study (green innovation proxies) show the consistent relationship (as shown in Table 8) with corporate physical investment.

Furthermore, we have considered some environment-specific variables i.e., carbon emissions and carbon taxations, as control variables. The research-outcomes show that the CTR (carbon taxation), called to recover the social cost and to restrict the industrial sector from

Table 8. Robustness check

	PI (Physical Investment as a dependent variable)			
	Fixed effect model (1)		Panel GLS (2)	
	Coefficients	Prob.	Coefficients	Prob.
C (constant)	0.413***	0.000	0.383***	0.000
TPR (total patent register.)	–0.069	0.158	–0.001***	0.0354
DET (dev. Env. Tech.)	0.002	0.4029	0.007***	0.003
INI (innovation intensity)	0.064***	0.037	0.087***	0.000
GGI (G. grow. Innovation)	0.002	0.353	–0.002***	0.046
FS (firm size)	–0.037***	0.000	0.025***	0.000
LVG (leverage)	0.148***	0.000	0.175***	0.000
FDI (foreign direct invest.)	0.001	0.211	–0.006***	0.031
GDP (GDP grow. Rate)	–0.001	0.456	–0.002*	0.081
CTR (carbon tax rate)	–0.002	0.221	–0.170***	0.003
CO2 (CO2 emissions)	–0.006	0.358	0.002***	0.024
Adj. R-square		0.541		0.147
S.E. of regression		0.071		0.898
Prob (F-statistics)		0.000		0.000

Note: *** indicate the significance at 1% level, ** at 5%, and * at 10% level.

CO_2 emissions, produces a negative impact on physical investment (because of an induced arbitrage between tax payment ad investment). According to Phan et al. (2022), the high carbon risk has a negative effect on corporate physical investment. High carbon emissions urge environmental authorities to impose more carbon taxation. Hence, it enhances the cost of doing business and creates a shortage of funds for physical investment. Conversely, CO_2 emissions have a positive link with physical investment suggesting the simultaneous relationship between industrial activities increase and CO_2 production (Wen et al., 2021). Summarizing, the empirical findings suggest the acceptance of underlying hypothesis i.e., physical investment enjoys a positive relationship with green innovation policies that was proposed in study.

6. Conclusions and policy recommendations

The present article aims at providing empirical insights on how various green innovation practices affect corporate physical investment. The GMM statistical outputs show that the development of environmental technologies engenders a positive impact on corporate physical investment. These findings are robust even after inclusion of several control variables and resolving endogeneity concerns. They offer evidence (for the considered sample) on the validity of theoretical prescriptions from Porter's theory of competitive advantage.

The contribution of the current study can be regarded as follow: first, it adds new shreds in the literature by highlighting the merit of green innovation in enhancing corporate physical investment. Second, this study empirically advocates the significance of various green innovation practices in boosting the investment. The current empirical analysis evaluates the significance of various green innovation policies for corporate investment decisions and gives a new theoretical and empirical framework to boost industrial investment through focusing on innovation practices. Finally, this study provides robust evidence even after controlling the endogeneity issues and other firm-specific and macroeconomic factors.

This study offers valuable policy recommendations for both corporate managers and public authorities while acknowledging the broader debates surrounding green innovation. First, corporate managers are encouraged to integrate green innovation into their investment strategies as a sustainable pathway to enhance investment volumes while mitigating environmental challenges. However, we recognize that green innovation can also impose compliance and transition costs, which firms must strategically manage to achieve long-term benefits. Despite these initial costs, green innovation fosters corporate sustainability, strengthens competitiveness, and enhances reputational value through credible CSR commitments and disclosures (Bruna & Nicolò, 2020).

Second, this study calls for governmental support in promoting green innovation investments through targeted financial policy incentives such as subsidies, tax reliefs, R&D tax credits, and innovation-based rewards. However, we acknowledge the importance of regulatory stringency differences across economies, which may influence firms' responsiveness to these incentives. Therefore, policymakers should adopt a context-specific approach that aligns green innovation policies with each country's regulatory and economic framework to avoid disproportionate compliance burdens on firms operating in highly regulated environments. By addressing both the benefits and challenges of green innovation, this study offers a more balanced perspective, ensuring that policy recommendations remain practical and adaptable to varying industrial and regulatory conditions.

In addition, the study proposes a multi-tiered approach tailored to different firm sizes and industries. For large enterprises, governments can introduce green tax credits and accelerated depreciation allowances for investments in sustainable technologies, encouraging long-term capital allocation toward green innovation. Additionally, green bonds and preferential interest rates on sustainability-linked loans can be expanded to facilitate large firms' access to green financing. For small and medium-sized enterprises (SMEs), which often face financial constraints in adopting green technologies, targeted subsidies, low-interest green credit lines, and public-private partnerships (PPPs) can help bridge the funding gap. Governments can also establish green innovation incubators to provide SMEs with technical support, R&D grants, and access to sustainable supply chains. From an industry perspective, sectors with high environmental impact (such as manufacturing and energy) should be prioritized for mandatory green investment quotas and stricter regulatory incentives, while technology-driven industries (such as IT and biotech) can benefit from R&D tax credits and intellectual property protections for eco-friendly innovations. Additionally, region-specific policies should consider the varying levels of institutional development and economic structure across different economies. For instance, in emerging markets, capacity-building programs and knowledge-sharing initiatives can facilitate the diffusion of green technologies, ensuring a smoother transition toward sustainable industrial practices. By aligning these targeted policies with firms' financial incentives and industry dynamics, governments can effectively enhance corporate engagement in green innovation while promoting long-term investment in sustainable physical assets.

Nevertheless, despite the rigorousness of its design and the robustness of its empirical evidence, the current article suffers from limitations, regarding both the data-sample and the ability of the model to encapsulate each country individual effect. The research is unable to consider the financial stringency of a specific firm as some companies may face high financial constraints and are unable to disseminate green innovation activities. Green innovation requires a strong motivation regarding the availability of funds. Therefore, financially distress companies are unable to explore green innovation. Accordingly, future investigations could address the moderating/mediating role of financial stringency on the relationship between green innovation-investment volume. Subsequent studies could also be conducted including the potential role of financial development on the nexus, as many recent studies, like Wen et al. (2021), Hunjra et al. (2022a), and Udeagha and Breitenbach (2023), recommend investigating the empirical relationship between financial development and sustainable economic development on the light of companies' environmental efficiency. Additionally, it might be useful to test the circular relationship among R&D investment, green innovation, sustainable development, and financial performance.

Funding

The authors extend their appreciation to the Deanship of Research and Graduate Studies at King Khalid University for funding this work through Large Research Project under grant number RGP2/457/46.

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APPENDIX

Table A1. List of countries

Sr no.	Countries	No. of Selected Firms	Percentage Contribution
1	China	1,503	22.611%
2	India	1,154	17.361
3	Indonesia	138	2.076%
4	Japan	1,961	29.502%
5	Malaysia	366	5.506%
6	Pakistan	112	1.685%
7	Philippines	55	0.827%
8	Singapore	171	2.572%
9	South Korea	821	12.351%
10	Thailand	256	3.851%
11	Turkey	110	1.654%
	Total	6,647	

Note: This table shows the number of companies selected from under-analysis countries.

Table A2. Hausman test results (source: self-calculation)

Test Statistics	Chi-Square (χ^2)	Degrees of Freedom	p-value	Decision
Hausman Test	18.740	6	0.004	FEM Preferred

Note: This Table shows that LR exists.

Table A3. Likelihood Ratio (LR) test for heteroscedasticity (source: self-calculation)

Test Statistics	Chi-Square Value	Degrees of Freedom	p-value	Decision
Likelihood Ratio (LR) Test	45.720	10	0.000	Heteroscedasticity Exists

Note: This Table shows that LR exists.

Table A4. Wooldridge test for autocorrelation in panel data (source: self-calculation)

Test Statistics	F-Statistics	P-value	Decision
Wooldridge Test	18.450	10	Autocorrelation Exists

Note: This Table shows that autocorrelation exists.

Table A5. Endogeneity identification (source: author's own calculation)

	Wald Test		
Test Statistic	Value	D.f.	Probability
Panel Investigation			
F-statistic	21665.530	(11, 46877)	0.000***
Chi-square	238320.800	11	0.000***
Individual Analysis			
Coefficient Restriction		Probability	Std. Error
C (1)		0.414	0.020
C (2)		–0.005	0.005
C (3)		–0.003	0.005
C (4)		0.280	0.046
C (5)		–0.001	0.001
C (6)		–0.008	0.001
C (7)		0.328	0.004
C (8)		–0.009	0.001
C (9)		0.002	0.003
C (10)		–0.002	0.005
C (11)		0.001	0.002

Note: Description: All the restriction terms carry the significant probability values, implying that residual term is correlated with independent variables.

Table A6. Durbin-Wu-Hausman Test for endogeneity (source: self-calculation)

Test Statistics	Chi-Square (χ^2)	P-value	Decision
Durbin Test	6.450	0.011	Endogeneity Exists
Wu-Hausman Test	7.890	0.005	Endogeneity Exists

Note: This Table shows that endogeneity exists.