





“Digital transformation as a moderator for green innovation and economic performance in the “twin transition””

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DIGITAL TRANSFORMATION AS A MODERATOR FOR GREEN INNOVATION AND ECONOMIC PERFORMANCE IN THE "TWIN TRANSITION"

Abstract

The synergy between industrialization and environmental sustainability, known as the "twin transition," has become a critical strategic imperative for emerging economies. This study aims to empirically examine the direct impact of green innovation on economic performance and the moderating role of digital transformation within the context of Vietnam. Data collected from a stratified random sample of 384 C-suite executives and senior managers within the manufacturing and service sectors across Vietnam's key economic zones were analyzed using hierarchical linear regression. The quantitative analysis reveals that green innovation has a positive, moderate direct impact on economic performance ($\beta = 0.24, p < 0.001$). Furthermore, digital transformation demonstrates a strong independent direct effect on performance ($\beta = 0.31, p < 0.001$) and acts as a significant moderator ($\beta = 0.19, p < 0.01$). The inclusion of this interaction term significantly increased the model's explanatory power ($\Delta R^2 = 0.04, p < 0.01$), providing statistical confirmation that firms with high digital capabilities realize substantially greater financial benefits from green investments compared to those with low digital maturity. Ultimately, these findings conclude that digital transformation is a dynamic capability that unleashes the financial value of sustainability strategies, offering a roadmap for integrated smart-green investments.

Keywords digitalization, innovation, performance, sustainability, transition, Vietnam

JEL Classification Q56, O33, L25, M15

INTRODUCTION

The world's economy is currently in the midst of an enormous transformation generated by two converging mega-trends: the green transition toward a sustainable economy and the digital transition toward Industrial Revolution 4.0. The intersection of these two forces, increasingly referred to as the "twin transition," stands for a paradigm shift in which digitalization and environmental sustainability are no longer perceived as different strategic silos, but as mutually-reinforcing pathways (Muench et al., 2022; Bianchini et al., 2023). For emerging economies, this transition means a unique leapfrogging opportunity. Countries that can successfully negotiate this nexus have the potential to leapfrog over carbon-intensive stages of development and simultaneously build competitive digital economies (Alasoini, 2023).

Vietnam serves as a critical empirical context to examine this phenomenon. As one of the fastest growing economies in Southeast Asia, Vietnam is under enormous pressure to keep up this growth trajectory whilst meeting ambitious climate commitments such as its pledge at COP26 to be net zero by 2050 (Government of Vietnam, 2021).



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Simultaneously, the country has launched the National Digital Transformation Programme by 2025 with a view to incorporating digital technology in every aspect of the economy. However, a significant scientific problem arises from the disconnect between these high-level macroeconomic policy directives and the actual operational realities faced by enterprises. Specifically, while the synergistic potential of the twin transition is theoretically well-established in Western contexts, it remains fundamentally unclear how firms in resource-constrained emerging markets navigate these simultaneous, capital-intensive mandates (Tran & Le, 2024).

To provide actionable, precise empirical evidence, this study intentionally narrows its focus away from broad national generalizations. Instead, the primary research objective is to decipher the synergistic versus competitive nature of these twin forces strictly within the core manufacturing and service sectors located in Vietnam's Key Economic Zones. By bounding the study to these highly industrialized hubs, we address a critical lack of empirical clarity: whether digital capabilities act as a catalyst that unlocks the value of green investments, or do these two imperatives compete for scarce organizational resources, potentially leading to a productivity paradox.

1. LITERATURE REVIEW

1.1. The scientific landscape: Debating green innovation and economic performance

The confluence of digitalization and sustainability, often called the “twin transition”, is a paradigm shift in strategic management. For emerging economies like Vietnam, this transition is not just a trend; it is a matter of survival in the global value chain. This section conducts a critical review of the current literature to engage theoretical viewpoints and fashion a strong frame for analytical purposes. At the core of this landscape, the relationship between green innovation and economic performance has been the subject of intense academic debate, often described as a contradiction between two opposite views: the costly regulation hypothesis and the Porter Hypothesis.

The costly regulation view, based in neoclassical economics, assumes a basic conflict between environment and efficiency. According to this view, mandatory environmental initiatives, including the adoption of abatement technologies or compliance with stringent emission standards, entail extra compliance costs diverted from productive capital investments (Palmer et al., 1995). In emerging economies like Vietnam, this “crowding-out” effect is often exacerbated by the “liability of newness” and acute liquidity constraints. For many enterprises, the upfront sunk costs associated with purchasing green machinery or secur-

ing international eco-certifications can result in immediate financial strain and extended payback periods due to local market inefficiencies (Nguyen & Adomako, 2022; Zhang & Ma, 2021).

In stark contrast, the Porter Hypothesis offers a more dynamic view of the economics of sustainability. Porter and van der Linde (1995) suggest that stringent, well-thought-out environmental regulations do not necessarily impose costs but may lead to innovation offsets. Recent scholarship indicates this hypothesis is increasingly applicable to Vietnam's export-oriented sectors. As the country deepens its integration into global value chains via agreements like the EVFTA and CPTPP, environmental compliance has evolved from an optional burden into a strict prerequisite for market entry. Vietnamese firms that proactively implement green product and process innovations not only achieve operational cost advantages through resource efficiency (e.g., closed-loop wastewater recycling) but also gain access to premium international markets and preferential green credit lines, thereby reducing their weighted average cost of capital (Doan, 2025; Chau, 2025).

First, integration into the global economy drives the Porter Hypothesis in Vietnam. As the country intensifies engagement in global value chains through free trade agreements like EVFTA and CPTPP, compliance with stringent environmental standards becomes a mandatory precondition for market entry rather than an optional burden. Vietnamese firms voluntarily utilizing green prod-

uct innovation are not just avoiding punishments but opening doors to premium international markets that insist on sustainability (Ngo et al., 2021). For example, recent findings from the Vietnamese textile and footwear industries reveal that environmentally certified companies (e.g., LEED, OEKO-TEX) achieve higher export outcomes and receive price premiums from environmentally conscious buyers in the EU and US (Doan, 2025).

Second, green innovation stimulates economic performance via operational efficiency. Green process innovations, especially those fitting the circular economy, focus on reducing waste and maximizing resource productivity. In the Vietnamese manufacturing sector, reductions in variable costs resulting from closed-loop production systems, such as waste heat recovery or wastewater recycling, have been reported by companies implementing these systems (Nguyen et al., 2022). Although upfront installation requires capital, long-term savings in material and energy use translate into a structural cost advantage, increasing net margins (Hoang et al., 2026).

Third, Institutional Theory argues that firms benefit from conforming to societal expectations by acquiring legitimacy and resources. In an emerging market with high information asymmetry, investing in green innovation signals environmental responsibility, enhancing brand reputation and stakeholder trust. Chau (2025) shows that Vietnamese firms developing transparent green initiatives benefit from reduced debt costs, as banks and international investors offer preferential green credit lines. This financial advantage directly improves economic performance by reducing the weighted average cost of capital (WACC). However, this transition is not uniform; recent scholarship emphasizes a J-curve effect, especially for SMEs in Vietnam, where profitability may slump immediately after adoption due to costs and disruption before rising above baseline levels once efficiency is achieved (Ahmadov et al., 2026).

1.2. Theoretical foundations:

The resource-based and dynamic capabilities views

To rigorously analyze how these innovation off-sets translate into competitive advantage during

the “twin transition”, this study uses a multi-theoretical approach by combining the resource-based view (RBV), specifically the natural resource-based view (NRBV), and the dynamic capabilities view (DCV). This synthesis is critical because while RBV describes what competitive advantage is (what resources a firm has), DCV describes how competitive advantage evolves (the process by which firms deploy these resources in volatile environments).

The theoretical foundation of this research is based on the resource-based view (RBV) of the firm, a dominant paradigm in strategic management positing that firms are heterogeneous bundles of resources and capabilities. Sustainable competitive advantage is not the result of external market positioning alone but stems essentially from internal resources having four specific attributes: valuable, rare, inimitable, and non-substitutable (the VRIN framework) (Barney, 1991). Building upon this classic logic, Hart (1995) expanded the RBV to include the constraints and challenges posed by the natural environment to develop the natural resource-based view (NRBV). The NRBV argues that as environmental degradation becomes a worldwide imperative, companies that lead the way in developing capabilities in pollution prevention, product stewardship, and sustainable development will enjoy a clear strategic advantage over competitors who are only playing catch-up with regulatory pressures (Kraus et al., 2020).

In the context of this study, green innovation (GI) is conceptualized as a strategic resource bundle that fits the NRBV perspective. As defined by Chen et al. (2006), green innovation is not a unilateral effort but a complex combination of hardware and software innovations related to green products or processes, ranging from energy-saving technologies to waste recycling, eco-design, or corporate environmental management systems (Albort-Morant et al., 2017).

When viewed through the lens of VRIN, green innovation becomes a strategic necessity in an emerging economy like Vietnam. First, in terms of value, green innovation enables firms to leverage opportunities and mitigate threats. By adopting green processes, firms become more efficient in their operations by minimizing energy consump-

tion and waste disposal costs, thus reducing the cost structure (Singh et al., 2020). Simultaneously, green product innovation delivers value by harnessing the growing demand from international buyers in the EU and the US for a sustainable supply chain. Second, in terms of rarity, even though basic environmental compliance requirements are becoming standardized, fine-tuned environmental innovation remains relatively rare in Vietnam (Nguyen et al., 2023). Due to financial limitations and technological gaps common in emerging markets, only a subset of firms possesses the advanced capabilities to adopt circular economy models or zero-waste manufacturing. This scarcity enables early adopters to distance themselves from laggards, commanding premium pricing and preferential access to green credit. Furthermore, the inimitability of green innovation arises from causal ambiguity and social complexity (Dhir et al., 2021). Successful green innovation is often not about purchasing machinery but involves complex cross-functional coordination, deep tacit knowledge of material sciences, and long-term relationships with eco-centric suppliers. These socially complex routines are path-dependent and difficult for competitors to replicate quickly. Additionally, regarding non-substitutability, as international rules like the carbon border adjustment mechanism become stricter, there are fewer strategic alternatives to genuine sustainability; greenwashing or paying fines are no longer viable substitutes for substantive green innovation (Al Shaar et al., 2022).

Nevertheless, despite the explanatory power of the RBV and NRBV, these frameworks have been criticized for being overly static (Priem & Butler, 2001). The RBV tends to view resources as stable stocks that automatically generate returns. However, in the hyper-competitive and volatile environment of an emerging economy, exacerbated by digital disruptions, possessing green resources is insufficient. A firm may control advanced green technology, but without the organizational agility to integrate it into real-time market operations and data ecosystems, the resource remains latent and underutilized.

This limitation necessitates the integration of the dynamic capabilities view (DCV), which explains how firms reconfigure resources to survive high-velocity change (Teece et al., 1997). Within this combined theoretical framework, digital transfor-

mation (DT) is conceptualized not merely as a set of IT tools, but as the paramount dynamic capability required to operationalize green resources. DT provides the essential micro-foundations of sensing, seizing, and transforming (Teece, 2007). For example, big data analytics provides the sensing capability to detect invisible supply chain vulnerabilities, while artificial intelligence provides the seizing capability to optimize real-time production schedules to minimize waste (Li et al., 2021; Mikalef & Gupta, 2021).

1.3. Digital transformation as the moderating capability

Within this dynamic framework, digital transformation (DT) is considered not just as a technological asset or set of IT tools, but as a profound capacity for dynamic renewal that orchestrates change. Vial (2019) defines digital transformation as a process seeking to enhance an entity by initiating significant changes to its properties using combinations of information, computing, communication, and connectivity technologies. Recent scholarship emphasizes the importance of DT in increasing firm agility for the effective utilization of green resources (Warner & Wager, 2019).

Following the micro-foundations proposed by Teece (2007), we posit that DT drives economic performance in the green context through three mechanisms: sensing, seizing, and transforming. First, digital technologies offer the sensing capability needed to detect opportunities and threats in the sustainability landscape. Traditional companies are often blind to their carbon footprints or emerging regulatory changes. However, technologies like big data analytics (BDA) and the Internet of Things (IoT) enable firms to sense granular energy consumption patterns, supply chain vulnerabilities, and shifting consumer preferences for eco-friendly products that were previously invisible (Li et al., 2021). For example, big data analytics capability acts as a critical antecedent for sustainable supply chain agility because it enables firms to scan the environment for weak signals of market change before rivals do (Dubey et al., 2019).

Second, once opportunities are sensed, firms must possess the seizing capability to mobilize resources to capture value. This includes making quick

decisions with data; artificial intelligence (AI) and automated decision-making systems help firms seize green opportunities by optimizing production schedules in real-time to reduce waste or by quickly prototyping green product designs using digital twins (Mikalef & Gupta, 2021). In manufacturing, smart seizing enables immediate adaptation of energy loads during peak pricing, turning green operational strategies into financial savings (Dieguez & Machado, 2025).

Finally, the transforming capability is the ability to endlessly reinvent the organization's business model. Technologies such as blockchain contribute to the transformation of entire supply chains by ensuring transparency, accompanying circular business models like product-as-a-service, and facilitating a high degree of collaboration within the value network (Carlos & de Mattos, 2025). By reducing transaction costs and ensuring claims of sustainability, digital platforms provide an opportunity for firms to transition from linear take-make-dispose models to circular ecosystems, guaranteeing sustainable competitive advantages in the long term (Elia et al., 2021).

Consequently, while green innovation is a path to competitive advantage, the "twin transition" literature suggests its full economic potential depends on digital transformation. We argue that digital transformation mediates the relationship between GI and performance through information asymmetry reduction, operational optimization, and value co-creation.

One persistent obstacle to realizing the economic value of green innovation is information asymmetry. In markets for sustainable goods, buyers often lack information to verify green claims, leading to a "market for lemons" where true innovators cannot command premium prices (Akerlof, 1970). Digital transformation fills this gap. By deploying technologies such as blockchain and IoT, firms create unchangeable, transparent records of a product's journey, reducing transaction costs associated with verification and trust-building (Saberli et al., 2019). In Vietnam, this is a game-changer for digital validation in key export sectors like agriculture and textiles. For example, traceability via blockchain enables Vietnamese coffee and garment manu-

facturers to prove the origin of organic raw materials to European buyers, transforming an intangible green claim into a provable high-value attribute (Agrawal et al., 2021). Furthermore, digital platforms reduce signaling costs by enabling real-time communication of ESG data to stakeholders without costly auditing intermediaries. Recent research confirms that such digitally enabled transparency generates increased customer willingness to pay and investor confidence, improving financial returns on green innovation (Kouhizadeh et al., 2021).

Beyond market signaling, digital transformation is a strong force multiplier for green process innovation through its ability to shift from static compliance to dynamic optimization. In emerging economies where resource wastage is a key cost factor, combining IoT and AI enables firms to overcome manual monitoring limitations and unlock the full efficiency potential of green technologies. Granular data usage reduces resource use. Traditional green innovations often fail to yield predicted savings due to sub-optimal usage patterns based on historic averages. However, using digital twins, virtual replicas of physical production systems, firms can simulate and optimize energy and material flows in real-time (Psarommatidis et al., 2022). For example, IoT sensors track minor inefficiencies in textile dyeing processes and automatically adjust valves to minimize waste, a feat impossible to do manually. Bag et al. (2021) confirm that this real-time "sensing and seizing" capability is a critical source of variable cost reduction, turning environmental compliance into operational excellence.

Furthermore, AI-powered predictive maintenance is essential for maintaining the economics of green investments. Green technologies, such as solar arrays or filtration systems, require precision calibration and lose efficiency without maintenance. AI algorithms analyze vibration, thermal, and acoustic data to predict anomalies before failure (Zonta et al., 2020). This proactive approach prevents costly downtime and prolongs the life of green assets, improving return on assets (ROA) (Lee & Chung, 2022). By reducing operational expenditure (OPEX) for green infrastructure, digital capabilities make sustainability economically viable for resource-constrained firms in Vietnam.

Overall, we argue that DT moderates the relationship between GI and EP primarily through information asymmetry reduction and operational optimization. A persistent obstacle to monetizing sustainability in emerging markets is the “market for lemons” phenomenon, where international buyers cannot independently verify a supplier’s green claims (Akerlof, 1970). Digital technologies directly resolve this bottleneck. By deploying blockchain traceability, Vietnamese manufacturers can create immutable records of a product’s organic origins, transforming an intangible green claim into a provable, high-value attribute (Agrawal et al., 2021). Furthermore, IoT sensors paired with digital twins shift green process innovation from static compliance to dynamic optimization, adjusting energy and material flows in real-time to maximize variable cost reductions (Bag et al., 2021). Consequently, we hypothesize that the economic linkage of green investments is fundamentally conditional on a firm’s digital maturity.

1.4. Identifying research gaps in the literature

Despite growing academic interest in the “twin transition,” a critical analysis reveals substantive lacunae limiting the understanding of this phenomenon in emerging economies like Vietnam. The first gap is the heavy geographic slant in scholarship, with the bulk of empirical work focused on the European Union and shaped by the European Green Deal (Muench et al., 2022). These findings, premised on mature frameworks and subsidies, may not generalize to the Global South, where firms face institutional voids and unique regulatory pressures like Vietnam’s Resolution 55-NQ/TW (Nguyen & Hong, 2025). There is a paucity of systematic empirical research examining how Vietnamese firms, from state-owned enterprises to resource-constrained SMEs, navigate these dual pressures under local conditions (Khanna & Palepu, 2010).

Second, a silo problem persists in strategic management literature, where green innovation and digital transformation are often addressed as parallel, independent variables rather than interacting forces. While separate streams of literature exist, there is a dearth of conversation on the synergistic mechanism, how digital capabilities serve

as a moderator to unlock the economic value of green initiatives (Gregori & Holzmann, 2020). Most studies analyze direct effects but fail to empirically test the interaction effect (DT x GI) in a quantitative framework.

Third, a methodological gap exists regarding the measurement of innovation in emerging markets. Much literature uses secondary proxy data like patent counts, which underestimates the catch-up strategies and incremental improvements typical of developing economies (Zanello et al., 2016). There is a need for studies using primary survey data to capture the managerial reality of firms rather than administrative proxies (Cirera & Muzi, 2020). Finally, few studies differentiate between levels of digital maturity. The current discourse often treats digital transformation as dichotomous, ignoring the difference between basic digitization and advanced Industry 4.0 integration (Westerman et al., 2014).

1.5. Hypotheses and research framework

In summary, this review highlights that while green innovation offers potential resource value, its translation into economic performance in emerging markets is not automatic. The integration of the dynamic capabilities view suggests that digital transformation provides the necessary mechanisms to actualize this value. To address the identified geographic, theoretical, and methodological gaps, this study examines these parallel transitions as integrated, interacting forces.

Based on the theoretical framework and literature analysis, the purpose of this study is to determine the extent to which digital capabilities amplify the economic returns of green innovation in Vietnamese firms. To test the conceptual model (Figure 1) of these intersecting forces, the following hypotheses are proposed:

- H1: Green innovation is positively associated with the economic performance of firms in Vietnam.*
- H2: Digital transformation has a significant positive direct effect on the economic performance of firms in Vietnam.*

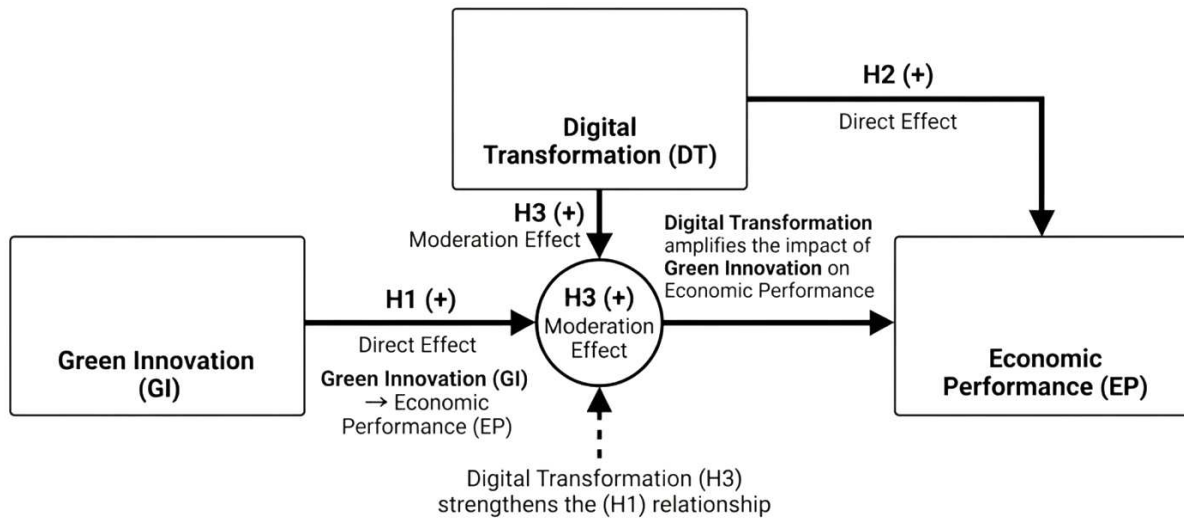


Figure 1. Conceptual framework

H3: Digital transformation positively moderates the relationship between green innovation and economic performance, such that the impact of green innovation on performance is stronger for firms with higher levels of digital transformation capabilities.

2. METHODS

This study adopts a positivist research philosophy and a deductive approach to empirically test the proposed structural relationships. To achieve methodological precision and address geographical gaps in current literature, the study utilizes a quantitative, cross-sectional survey design explicitly bounded to active enterprises within Vietnam’s manufacturing and service sectors. These specific sectors were selected because they represent the twin engines of national GDP and are concurrently the most exposed to environmental decarbon-

ization mandates and Industry 4.0 disruptions. To guarantee a representative snapshot of these vital industrial hubs, a stratified random sampling technique was applied. The sampling frame was derived from the Vietnam Enterprise White Book and the VNR500 list. Stratification was executed along two strict parameters: geographic location (ensuring proportional representation across the Northern, Central, and Southern Key Economic Zones to account for regional infrastructural variations) and industry sector (balancing high-tech/traditional manufacturing with modern/traditional services).

The comprehensive demographic data of the respondents are systematized in Table 1.

Strict ethical guidelines were followed during data collection. Participants were informed via a cover letter that their participation was voluntary, anonymous, and that data would be aggregated for ac-

Table 1. Respondent demographics

Category	Sub-category	Frequency	Percentage (%)
Gender	Male	246	64.06
	Female	138	35.94
Position	C-Level (CEO, CFO, CTO)	165	42.97
	Senior Manager	219	57.03
Industry	Manufacturing	204	53.12
	Services	180	46.88
Region	Northern Key Economic Zone	142	36.98
	Southern Key Economic Zone	184	47.92
	Central Key Economic Zone	58	15.10
Total		384	100

ademic purposes only. No personally identifiable information (PII) or sensitive corporate financial data were stored. Informed consent was obtained digitally prior to the start of the survey.

Given the strategic nature of the constructs, green innovation and digital transformation, the survey required respondents who have a holistic and high-level view of the activities within the organization. Consequently, our target was key informants, defined strictly as C-suite executives (CEOs, CFOs, CTOs) and senior managers (e.g., Sustainability Directors, R&D Managers). Consistent with established methods, these individuals are considered to be most knowledgeable about the firm's allocation of resources, the long-term strategic course of action in terms of green initiatives, and the degree of digital technology integration.

The data collection procedure was carried out over a period of 4 months, specifically between January and April 2025. This specific timeframe was chosen to capture the most recent firm behaviors following the acceleration of Vietnam's National Digital Transformation Programme and the post-COP26 regulatory environment. An administration strategy of multiple modes was used to maximize response rates. The survey was disseminated predominantly via email using a secure online interface (Qualtrics). To overcome potential non-response problems, we exploited a customized approach to design developed by Dillman (2007). Of a distribution of 600 questionnaires, 412 were returned. After verifying completeness, a final valid sample of 384 responses was maintained, resulting in a 64% response rate. To check for possible non-response bias, we compared early and late respondents with respect to key firm characteristics; results from *t*-tests did not indicate significant

differences ($p > 0.05$). Importantly, the survey results presented here are original and have not been used in previous publications.

To establish the reliability and validity of the measurement instrument, all constructs were operationalized using multi-item scales adapted from established previous studies. This formulation was chosen to ensure the questionnaire items were validated in prior literature, thereby enhancing content validity. A 7-point Likert scale, varying from 1 ("Strongly Disagree") to 7 ("Strongly Agree"), was used to ensure requisite variability in respondent perceptions. For the independent variable (Table 2), green innovation was conceptualized as the second-order construct with two dimensions (green product innovation and green process innovation), adapting scales from Chen et al. (2006) and Albort-Morant et al. (2016). Green product innovation focuses on the firm's output (e.g., less energy, easy recycling), while green process innovation concerns internal operations (e.g., reducing waste and emissions). For the moderating variable, digital transformation was measured as a whole-of-organization capability, capturing digital strategy, digital technology integration, and digital agility, based on Vial (2019) and Li et al. (2021). For the dependent variable, economic performance, we used subjective indicators (ROI, ROS, market share, profitability) relative to competitors, adopting the methodology of Wall et al. (2004) due to the difficulty of obtaining objective financial data in emerging markets. Prior studies support the validity of this approach. Control variables included firm size, firm age, industry type, and R&D intensity. The full questionnaire is included in Appendix A.

The English instrument underwent a rigorous back-translation procedure (Brislin, 1970) into

Table 2. Summary of construct operationalization

Construct	Dimensions	Measurement Items (Likert Scale 1-7) (See Appendix)	Key Literature
Green Innovation (IV)	Green Product Innovation	GI1: Our company uses materials that cause less pollution GI2: Our products consume less energy/resources	Chen et al. (2006), Albort-Morant et al. (2016)
	Green Process Innovation	GI3: Our manufacturing process effectively reduces hazardous waste GI4: We have reduced the consumption of water/electricity in production	
Digital Transformation (MV)	Digital Integration	DT1: We use Big Data analytics for decision-making. DT2: We use cloud computing for operations DT3: We use digital tools to interact with customers DT4: We use IoT (Internet of Things) sensors in our production lines	Vial (2019), Li et al. (2025), Zhang et al. (2023)
Economic Performance (DV)	Financial & Market	EP1: Return on Investment (ROI) compared to competitors EP2: Return on Sales (ROS) compared to competitors EP3: Growth in market share over the last 3 years	Fornell et al. (2006), Ta (2026)

Vietnamese. A subsequent pilot study with 30 senior managers led to the refinement of two process-innovation items to better reflect localized manufacturing contexts. Based on feedback, two items related to green process innovation were improved to be more specific to the manufacturing context in Vietnam. Finally, the quantitative analysis of data was conducted using Statistical Package for Social Sciences (SPSS) version 26.0. The process began with data screening for missing values and outliers, followed by normality tests (skewness and kurtosis). We then evaluated the measurement model for reliability and validity. For empirical testing, hierarchical linear regression was employed to explicitly observe the incremental change in explained variance (R^2) when interaction terms are included. Variables were mean-centered prior to generating the interaction term to reduce multicollinearity, consistent with Aiken and West (1991).

3. RESULTS

The empirical analysis was undertaken with a thoroughly rigorous framework comprising two stages. First, we evaluated the measurement model in order to validate the psychometric properties of the survey instrument and ensure that the constructs were reliable and valid. Second, we conducted hierarchical linear regression analysis to examine the structural associations and, most importantly, the hypothesized effect of moderation. This multiple-step approach ensures that the path coefficients are drawn from a sound foundation of measurement, minimizing the risk of fallacious conclusions based on noisy data.

3.1. Measurement model assessment

To establish the robustness of the latent constructs, including green innovation (GI), digital transformation (DT), and economic performance (EP), we assessed the measurement model in terms of internal consistency reliability, convergent validity, and discriminant validity. Internal consistency was tested using two measures: Cronbach's Alpha and composite reliability (CR). As shown in Table 3, the Cronbach's Alpha values for the constructs varied from 0.86 to 0.89, which are much greater than the conventional threshold of 0.70 recommended by Hair et al. (2010). This indicates that the items within each scale have high correlations with one another and are reliable measures of the same construct. Furthermore, composite reliability (CR) values, which provide a more rigorous estimate by prioritizing items with higher factor loadings, varied from 0.90 to 0.92, confirming that the measurement model has good internal consistency.

Convergent validity, the degree to which the items have a high proportion of variance in common, was examined in terms of factor loadings and average variance extracted (AVE). All individual item factor loadings were statistically significant and above the benchmark of 0.70 (ranging from 0.75 to 0.85). Consequently, the AVE values of all three constructs were in the range of 0.61 to 0.68. Since these values exceed the 0.50 threshold (Fornell & Larcker, 1981), we can conclude that the constructs account for more than half the variance of their indicators, providing strong evidence for convergent validity.

To ensure that the constructs were empirically different, and thereby not merely measuring the

Table 3. Reliability and validity analysis

Construct	Items	Factor Loading	Cronbach's alpha	CR	AVE
Green Innovation (GI)	GI1	0.82	0.88	0.91	0.64
	GI2	0.79			
	GI3	0.85			
	GI4	0.76			
Digital Transformation (DT)	DT1	0.81	0.89	0.92	0.68
	DT2	0.84			
	DT3	0.83			
	DT4	0.80			
Economic Performance (EP)	EP1	0.78	0.86	0.90	0.61
	EP2	0.81			
	EP3	0.75			

same thing, we tested for discriminant validity with the heterotrait–monotrait ratio of correlations (HTMT), which is considered superior to the traditional Fornell–Larcker criterion. The outcomes of the analysis revealed that all the HTMT ratios were consistently below the conservative threshold of 0.85 (Henseler et al., 2015). This confirms that green innovation, digital transformation and economic performance are indeed separated concepts in the perceptions of the respondents hence validating the structural separation of the independent and moderating variables.

3.2. Structural model and hypothesis testing

Having established the validity of the measurement model, we used hierarchical regression analysis to examine the proposed hypotheses. This technique makes it possible to isolate the particular variance accounted for by the control variables, the main effects, and the interaction term. The variables were mean-centered before creating the interaction term (GI x DT) to reduce possible effects of multicollinearity, a frequent problem in moderation analysis (Aiken & West, 1991). The variance inflation factor (VIF) scores were all less than 3.0 thus confirming that multicollinearity was not biasing the regression estimates. The results are described in Table 4.

As shown in Table 4, Model 1 contained only the control variables to provide a baseline. The model accounted for a weak 9% of the variance in economic performance ($R^2 = 0.09$). Among the con-

trols, firm size ($= 0.12, p < 0.05$) and R&D intensity ($= 0.15, p < 0.01$) had significant positive associations with output, implying that large, research-intensive firms are inherently more efficient because of resource slack. Firm age was not significant, suggesting that there is no automatic advantage of incumbency in this context.

Accordingly, Model 2 incorporated the independent variable (green innovation) and moderator (digital transformation). The inclusion of these variables increased the model’s explanatory power significantly, with R^2 jumping to 0.38 ($R^2 = 0.29, p < 0.001$). Regarding Hypothesis 1 (H1), this analysis shows a positive and significant relationship between green innovation and economic performance ($= 0.24, p < 0.001$). This finding is consistent with H1 and the Porter Hypothesis, which predicts that in the Vietnamese context, the efficiency gains and market differentiation afforded by green practices outweigh the costs of compliance. With reference to Hypothesis 2 (H2), digital transformation had a strong positive effect on economic performance ($= 0.31, p < 0.001$). Interestingly, the magnitude of the DT coefficient is greater than that of GI, suggesting that digital capabilities have the potential to provide greater financial returns in the short term than green investments, possibly because of the accelerated efficiency gains and cost reductions. Thus, H2 is strongly supported.

Finally, Model 3 included the interaction term (GI x DT) to test the core “twin transition” hypothesis. The results are crucial empirical support for the moderation effect. The results provide crucial

Table 4. Hierarchical regression results (dependent variable: economic performance)

Variables	Model 1 (Controls)	Model 2 (Direct Effects)	Model 3 (Moderation)
Control Effect			
Firm Size	0.12*	0.09	0.08
Firm Age	0.04	0.03	0.02
R&D Intensity	0.15**	0.08	0.07
Main Effects			
Green Innovation (GI)		0.24*	0.21*
Digital Transformation (DT)		0.31*	0.28*
Interaction Effect			
GI x DT			0.19
R^2	0.09	0.38	0.42
ΔR^2		0.29***	0.04**
F-statistic	4.21**	28.56***	32.14***

Note: Standardized coefficients reported. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

empirical support for Hypothesis 3 (H3), as the interaction term was positive and statistically significant ($\beta = 0.19$, $p < 0.01$). Furthermore, the inclusion of the interaction term led to a significant increase in variance explained ($R^2 = 0.04$, $F^{\text{change}} = 32.14$, $p < 0.01$). While 4% might seem small on the surface, in social science research, interaction effects usually explain 1–3% of variance; therefore, a 4% increase represents a substantial substantive impact (Cohen, 1988). The positive sign of the interaction term ($= 0.19$) indicates a synergistic effect. The effect of green innovation on economic performance is amplified by increasing the level of digital transformation. Statistically, this means that if a firm has high digital capabilities, the slope of the regression line between GI and performance is greater. Conversely, for firms with low levels of digital maturity, the transformation of green efforts into economic profit is much flatter (less effective). This finding gives empirical validity to the theoretical argument that digital transformation is a catalyst (dynamic capability) that unleashes the full value of green resources.

Overall, the empirical analysis was conducted in two stages to ensure rigorous validation of the findings. First, the measurement model was assessed to verify the reliability and validity of the constructs: green innovation, digital transformation, and economic performance. Internal consistency was confirmed with Cronbach's Alpha values ranging from 0.86 to 0.89 and composite reliability values between 0.90 and 0.92, both exceeding recommended thresholds. Convergent validity was established as all factor loadings were significant and average variance extracted (AVE) values ranged from 0.61 to 0.68, surpassing the 0.50 benchmark. Additionally, discriminant validity was confirmed using the heterotrait–monotrait ratio (HTMT), with all ratios falling below the conservative threshold of 0.85.

Following the measurement validation, hierarchical linear regression was used to test the structural relationships and moderation hypotheses. The baseline model with control variables explained only 9% of the variance in economic performance, though firm size and R&D intensity showed significant positive associations. When the main effects were introduced in the second model, the explanatory power increased significantly to 38%. The re-

sults supported the first two hypotheses, showing that green innovation ($\beta = 0.24$) and digital transformation ($\beta = 0.31$) both have significant positive direct effects on economic performance. Notably, the stronger effect of digital transformation suggests it may offer more immediate financial returns than green investments.

The final model introduced the interaction term to test the “twin transition” hypothesis, confirming that digital transformation significantly moderates the relationship between green innovation and economic performance. The interaction term was positive and significant ($\beta = 0.19$), increasing the total variance explained by an additional 4%. This finding indicates a synergistic effect where the economic impact of green innovation is amplified in firms with higher digital capabilities, while the relationship remains flatter for those with low digital maturity. This empirically validates the theoretical argument that digital transformation acts as a dynamic capability essential for unleashing the full value of green resources.

4. DISCUSSION

This study set out to empirically quantify the economic viability of the “twin transition” by analyzing the interaction between environmental sustainability and digitalization. By strictly analyzing the operational realities within Vietnam's manufacturing and service hubs, the results provide profound, quantitative evidence that disrupts the siloed approaches traditionally found in corporate strategy.

First, the empirical analysis confirms a positive and significant relationship between green innovation and economic performance ($\beta = 0.24$). This finding directly engages with the longstanding academic debate between the costly regulation perspective and the Porter Hypothesis. Our results explicitly contradict the neoclassical “crowding-out” hypothesis postulated by Palmer et al. (1995) and Wang et al. (2021), which argues that environmental compliance diverts capital from productive investments and depresses profitability. Furthermore, our findings diverge from recent evidence in other developing economies, such as Zhang and Ma (2021), who observed a J-curve ef-

fect where green investments initially negatively impact financial performance due to implementation lags and market inefficiencies. Instead, the data from Vietnam strongly corroborated the Porter Hypothesis (Porter & van der Linde, 1995). This suggests that Vietnamese manufacturing and service firms have matured beyond the early implementation dip and are successfully leveraging innovation offsets, such as energy efficiency and access to premium international markets, to outweigh compliance costs.

Second, the study establishes digital transformation as a potent, independent driver of economic performance ($\beta = 0.31$). While this aligns with the broad consensus in information systems literature regarding the value of digital agility (Vial, 2019), a critical comparison of the standardized coefficients reveals a novel insight: the impact of digital transformation significantly exceeds that of green innovation. This finding suggests that in the specific context of an emerging economy, digital capabilities, such as automation and data analytics, yield more immediate financial returns than green legitimacy. This is likely due to the rapid reduction in transaction costs and operational friction. By interpreting this through the lens of Warner and Wäger (2019), we extend their theoretical work on dynamic capabilities by quantifying that digital transformation acts not merely as a technical upgrade, but as the foundational sensing and seizing mechanism required to navigate volatile market conditions.

Most significantly, this paper offers critical empirical validation for the interaction effect between green innovation and digital transforma-

tion ($\beta = 0.19$), confirming the core “twin transition” hypothesis. Previous scholarship has largely suffered from a “silo problem,” where sustainability and digitalization were analyzed as parallel, independent tracks (Demirel et al., 2019). Our findings refute this isolationist approach and empirically substantiate the theoretical propositions of Muench et al. (2022) within the Global South. The significant positive interaction demonstrates that digital capabilities act as a force multiplier for green resources; firms that combine high levels of green innovation with high digital maturity achieve performance levels superior to the sum of their individual parts. This effectively resolves the productivity paradox often observed when firms digitize without strategic direction. In this context, green innovation provides the strategic purpose (sustainability), while digital transformation provides the operational process (efficiency), creating a synergistic value creation mechanism.

Finally, these findings contribute to the broader “twin transition” narrative by distinguishing the mechanism in emerging markets from the European baseline. While EU-centric studies often attribute the transition to mature regulatory pressure and subsidies (Barbero et al., 2025), our results suggest a distinct leapfrogging mechanism in Vietnam. Vietnamese firms appear to be utilizing digital tools not just for compliance, but to overcome deep-seated institutional voids, such as information asymmetry and supply chain opacity, that typically stymie green markets. This indicates that for emerging economies, the twin transition is less about optimizing legacy systems and more about establishing new, digitally verifiable infrastructures for trust and value capture.

CONCLUSION

The primary objective of this investigation was to empirically examine the economic viability of the “twin transition” in the manufacturing and service sectors within Vietnam’s Northern, Central, and Southern Key Economic Zones. The empirical analysis reveals that both green innovation ($\beta = 0.24$) and digital transformation ($\beta = 0.31$) act as significant, independent drivers of economic performance. Most critically, the results validate a significant positive moderation effect ($\beta = 0.19$), confirming that the financial returns of green innovation are substantially amplified when coupled with high digital maturity.

Theoretically, this study concludes that the traditional costly regulation hypothesis is invalid within these targeted, highly industrialized regional hubs. Instead, the Porter Hypothesis prevails,

as firms successfully leverage innovation offsets to outweigh environmental compliance costs. Furthermore, while environmental initiatives provide a baseline for competitive legitimacy, digital tools serve as the paramount dynamic capability. Digitalization provides the critical sensing, seizing, and transforming mechanisms required to fully actualize and capture the economic value of sustainable resources.

Practically, these results lead to the conclusion that treating sustainability and digitalization as isolated, parallel departmental functions is a highly sub-optimal strategy that results in underutilized assets and missed financial opportunities. Therefore, enterprise managers must actively dismantle traditional strategic silos and prioritize deeply integrated operational initiatives. By embedding digital technologies, such as artificial intelligence-driven resource optimization or blockchain-enabled supply chain transparency, directly into their environmental strategies, managers can utilize digital agility as a fundamental force multiplier for green goals.

From a macroeconomic policy perspective, it is concluded that the current bifurcation of government support mechanisms into separate “green growth” and “digital transformation” streams is inefficient for resource-constrained emerging economies. To effectively facilitate a leapfrog over carbon-intensive developmental stages, policymakers must design cohesive, integrated frameworks that deliberately target financial subsidies toward smart-green manufacturing and operational technologies, explicitly shifting focus toward immediate process efficiencies rather than relying on broader, currently stagnating sectors such as renewable energy generation.

Finally, to ensure the rigorous application of these findings, the initial conditions and limitations of this study must be explicitly defined. The sample size of 384 enterprises, while statistically robust for the hierarchical regression models utilized, is deliberately too small to support broad generalizations across the entirety of Vietnam’s diverse national economy. Consequently, this study’s conclusions are strictly bound to the operational realities of medium-to-large enterprises operating within the aforementioned Key Economic Zones. Future scholarship must build upon these quantitative insights by expanding the sampling frame geographically and sectorally to test the limits of this synergy. Subsequent research should employ longitudinal designs to better isolate the temporal lag effects of these combined investments, alongside targeted research that deconstructs the digital transformation variable to determine which specific technologies exert the strongest moderating influence on sustainable economic performance.

AUTHOR CONTRIBUTIONS

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REFERENCES

1. Agrawal, T. K., Kumar, V., Pal, R., Wang, L., & Chen, Y. (2021). Blockchain-based framework for supply chain traceability: A case example of textile and clothing industry. *Computers & Industrial Engineering*, 154, Article 107130. <https://doi.org/10.1016/j.cie.2021.107130>
2. Ahmadov, T., Nguyen, Q. M., Leitão, J. C. C., Chen, Q., Nhan, D. T. T., Burman, V. L., & Zhu, B. (2026). What drives open innovation in Vietnamese manufacturing firms? Adaptive capacity at the nexus of strategy and orientation. *Journal of Open Innovation: Technology, Market, and Complexity*, 12(1), Article 100733. <https://doi.org/10.1016/j.joitmc.2026.100733>
3. Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions*. Sage Publications.
4. Akerlof, G. A. (1970). The market for “lemons”: Quality uncertainty and the market mechanism. *The Quarterly Journal of Economics*, 84(3), 488-500. <https://doi.org/10.2307/1879431>
5. Al Shaar, I. M., Khatib, S., Alkaied, R., & Al-Abbadi, L. (2022). Supply chain integration and green innovation, the role of environmental uncertainty: Evidence from Jordan. *Uncertain Supply Chain Management*, 10(3), 657-666. <https://doi.org/10.5267/j.uscm.2022.5.009>
6. Alasoini, T. (2023). *Twin transition as a transformer of work and an opportunity for development*. Finnish Institute of Occupational Health. Retrieved from <https://workplaceinnovation.eu/wp-content/uploads/2025/02/Twin-Transition-as-a-Transformer-of-Work-and-an-Opportunity-for-Development-Tuomo-Alasoini.pdf>
7. Albort-Morant, G., Henseler, J., Leal-Millán, A., & Cepeda-Carrión, G. (2017). Mapping the field: A bibliometric analysis of green innovation. *Sustainability*, 9(6), Article 1011. <https://doi.org/10.3390/su9061011>
8. Albort-Morant, G., Leal-Millán, A., & Cepeda-Carrión, G. (2016). The antecedents of green innovation performance: A model of learning and capabilities. *Journal of Business Research*, 69(11), 4912-4917. <https://doi.org/10.1016/j.jbusres.2016.04.052>
9. Bag, S., Gupta, S., Kumar, A., & Sivarajah, U. (2021). An integrated artificial intelligence framework for knowledge creation and B2B marketing rational decision making for improving firm performance. *Industrial Marketing Management*, 92, 178-189. <https://doi.org/10.1016/j.indmarman.2020.12.001>
10. Barbero, J., Collado, L.A., Rodríguez-Crespo, E., & Santos, A. M. (2025). The twin transition in the European Union: Assessing regional patterns of EU-funded investments. *European Planning Studies*, 33(10), 1801-1821. <https://doi.org/10.1080/09654313.2025.2528882>
11. Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99-120. <https://doi.org/10.1177/014920639101700108>
12. Bianchini, S., Damioli, G., & Ghisetti, C. (2023). The environmental effects of the “twin” green and digital transition in European regions. *Environmental & Resource Economics*, 84(4), 877-918. <https://doi.org/10.1007/s10640-022-00741-7>
13. Brislin, R. W. (1970). Back-translation for cross-cultural research. *Journal of Cross-Cultural Psychology*, 1(3), 185-216. <https://doi.org/10.1177/135910457000100301>
14. Carlos, R. L., & de Mattos, C. A. (2025). Blockchain-enabled integration of circular economy practices in supply chains: A conceptual framework. *Business Strategy & Development*, 8(3), Article e70222. <https://doi.org/10.1002/bsd2.70222>
15. Chau, V. T. (2025). Green finance and firm performance in Vietnamese enterprises: A review with a sustainable orientation. *Global Academic Journal of Economics and Business*, 7(3). <https://doi.org/10.36348/gajeb.2025.v07i03.002>
16. Chen, Y.-S., Lai, S.-B., & Wen, C.-T. (2006). The influence of green innovation performance on corporate advantage in Taiwan. *Journal of Business Ethics*, 67(4), 331-339. <https://doi.org/10.1007/s10551-006-9025-5>
17. Cirera, X., & Muzi, S. (2020). Measuring innovation using firm-level surveys: Evidence from developing countries. *Research Policy*, 49(3), 103912. <https://doi.org/10.1016/j.respol.2019.103912>
18. Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.
19. Demirel, P., Li, Q., Rentocchini, F., & Tamvada, J. P. (2019). Born to be green: New insights into the economics of eco-innovation. *Small Business Economics*, 53, 759-771. <https://doi.org/10.1007/s11187-017-9933-z>
20. Dhir, A., Sadiq, M., Talwar, S., & Sakashita, M. (2021). Why do retail consumers buy green apparel? A knowledge-attitude-behaviour-context perspective. *Journal of Retailing and Consumer Services*, 59, Article 102398. <https://doi.org/10.1016/j.jretconser.2020.102398>
21. Dieguez, T., & Machado, J. (2025). Reviewing manufacturing execution system in Industry 4.0: A global approach. *EAI Endorsed Transactions on Digital Transformation of Industrial Processes*, 1(3). <https://doi.org/10.4108/dtip.9768>
22. Dillman, D. A. (2007). *Mail and internet surveys: The tailored design method* (2nd ed.). John Wiley & Sons.
23. Doan, B. T. (2025). Green exports and sustainability trends in Vietnam's international trade: Empirical evidence. *International Journal of Humanities and Social Science*, 1(1). Retrieved from <https://pin-naclepubs.com/index.php/IJHSS/article/view/254/261>

24. Dubey, R., Gunasekaran, A., Childe, S. J., Papadopoulos, T., Luo, Z., Wamba, S. F., & Roubaud, D. (2019). Can big data and predictive analytics improve the performance of sustainable supply chain? *Technological Forecasting and Social Change*, 144, 534-545. <https://doi.org/10.1016/j.techfore.2017.06.020>
25. Elia, V., Gnoni, M. G., & Tornese, F. (2021). Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production*, 142, 2741-2751. <https://doi.org/10.1016/j.jclepro.2016.10.196>
26. Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18(1), 39-50. <https://doi.org/10.2307/3151312>
27. Fornell, C., Mithas, S., Morgeson, F. V., & Krishnan, M. S. (2006). Customer satisfaction and stock prices: High returns, low risk. *Journal of Marketing*, 70(1), 3-14. <https://doi.org/10.1509/jmkg.2006.70.1.3>
28. Government of Vietnam. (2021). *Quyết định số 1658/QĐ-TTg của Thủ tướng Chính phủ: Phê duyệt Chiến lược quốc gia về tăng trưởng xanh giai đoạn 2021 - 2030, tầm nhìn 2050 [Decision No. 1658/QĐ-TTg on approving the national strategy on green growth for the 2021-2030 period, with a vision to 2050]*. (In Vietnamese). Retrieved from <https://vanban.chinhphu.vn/?docid=204226&pageid=27160>
29. Gregori, P., & Holzmann, P. (2020). Digital sustainable entrepreneurship: A business model perspective on embedding digital technologies for social and environmental value creation. *Journal of Cleaner Production*, 272, Article 122817. <https://doi.org/10.1016/j.jclepro.2020.122817>
30. Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis* (7th ed.). Pearson. Retrieved from <https://www.drnishikantjha.com/papersCollection/Multivariate%20Data%20Analysis.pdf>
31. Hart, S. L. (1995). A natural-resource-based view of the firm. *Academy of Management Review*, 20(4), 986-1014. <https://doi.org/10.5465/amr.1995.9512280033>
32. Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, 43, 115-135. <https://doi.org/10.1007/s11747-014-0403-8>
33. Hoang, V. H., Dong, V.-C., & Tran, T. M. T. (2026). Determinants of transforming to a circular economy: Evidence from a developing country. *Sustainable Futures*, 11, Article 101665. <https://doi.org/10.1016/j.sftr.2026.101665>
34. Khanna, T., & Palepu, K. G. (2010). *Winning in emerging markets: A road map for strategy and execution*. Harvard Business Review Press. <https://doi.org/10.1177/0974173920100316>
35. Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics*, 231, Article 107831. <https://doi.org/10.1016/j.ijpe.2020.107831>
36. Kraus, S., Rehman, S. U., & García, F. J. S. (2020). Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation. *Technological Forecasting and Social Change*, 160, Article 120262. <https://doi.org/10.1016/j.techfore.2020.120262>
37. Lee, C. K. M., & Chung, S. Y. (2022). From Industry 4.0 to Supply Chain 4.0: A systematic review. *Smart Manufacturing*, 1(1), Article 2230002. <https://doi.org/10.1142/S2737549822300024>
38. Li, H., Wu, Y., Cao, D., & Wang, Y. (2021). Organizational mindfulness towards digital transformation as a prerequisite of information processing capability to achieve market agility. *Journal of Business Research*, 122, 700-712. <https://doi.org/10.1016/j.jbusres.2019.10.036>
39. Mikalef, P., & Gupta, M. (2021). Artificial intelligence capability: Conceptualization, measurement calibration, and empirical study on its impact on organizational creativity and firm performance. *Information & Management*, 58(3), Article 103434. <https://doi.org/10.1016/j.im.2021.103434>
40. Muench, S., Stoermer, E., Jensen, K., Asikainen, T., Salvi, M., & Scapolo, F. (2022). *Towards a green and digital future: Key requirements for successful twin transitions in the European Union*. Publications Office of the European Union. <https://doi.org/10.2760/977331>
41. Ngo, T. Q., Doan, P. N., Vo, L. T., Tran, H. T. T., & Nguyen, D. N. (2021). The influence of green finance on economic growth: COVID-19 pandemic effects on Vietnam economy. *Cogent Business & Management*, 8(1), Article 2003008. <https://doi.org/10.1080/23311975.2021.2003008>
42. Nguyen, H. M., Nguyen, P. A., & Phung, N. B. H. (2022). Technological factors affecting green innovation: Evidence from the manufacturing sector in Vietnam. *Ho Chi Minh City Open University Journal of Science – Economics and Business Administration*, 12(1). <https://doi.org/10.46223/HCMCOUJS.econ.en.12.1.2099.2022>
43. Nguyen, H., & Hong, Y. (2025). National policy analysis of digital transformation in Vietnamese higher education: Conceptualising a three-layer model for implementation. *Policy Futures in Education*, 24(1), 35-58. <https://doi.org/10.1177/14782103251348089>
44. Nguyen, N. P., & Adomako, S. (2022). Stakeholder pressure for eco-friendly practices, international orientation, and eco-innovation: A study of small and medium-sized enterprises in Vietnam. *Corporate Social Responsibility and Environmental Management*, 29(1), 79-88. <https://doi.org/10.1002/csr.2185>
45. Nguyen, T. A., Le, P. H., Nguyen, H. D., Luong, T. C. T., & Ngo, M. T. (2023). The effect of environmental accounting information

- disclosure on financial performance of Vietnamese listed industrial firms: The moderating role of leverage and Big4. *Can Tho University Journal of Economics*, 15(2), 126-138. Retrieved from <https://ctujs.ctu.edu.vn/index.php/ctujs/article/view/605>
46. Palmer, K., Oates, W. E., & Portney, P. R. (1995). Tightening environmental standards: The benefit-cost or the no-cost paradigm? *Journal of Economic Perspectives*, 9(4), 119-132. <https://doi.org/10.1257/jep.9.4.119>
 47. Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 9(4), 97-118. <https://doi.org/10.1257/jep.9.4.97>
 48. Priem, R. L., & Butler, J. E. (2001). Is the resource-based “view” a useful perspective for strategic management research? *Academy of Management Review*, 26(1), 22-40. <https://doi.org/10.5465/amr.2001.4011928>
 49. Psarommatis, F., May, G., Dreyfus, P.-A., & Kiritsis, D. (2022). Zero defect manufacturing: State-of-the-art review, shortcomings and future directions in research. *International Journal of Production Research*, 58(1), 1-17. <https://doi.org/10.1080/00207543.2019.1605228>
 50. Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7), 2117-2135. <https://doi.org/10.1080/00207543.2018.1533261>
 51. Singh, S. K., Del Giudice, M., Chierici, R., & Graziano, D. (2020). Green innovation and environmental performance: The role of green transformational leadership and green human resource management. *Technological Forecasting and Social Change*, 150, Article 119762. <https://doi.org/10.1016/j.techfore.2019.119762>
 52. Ta, T. H. V. (2026, January 8). *Macroeconomic determinants of circular economy growth: A comparative analysis of Germany and China*. *Tạp chí Công Thương*. Retrieved from <https://tapchicongthuong.vn/macroeconomic-determinants-of-circular-economy-growth--a-comparative-analysis-of-germany-and-china-390292.htm>
 53. Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, 28(13), 1319-1350. <https://doi.org/10.1002/smj.640>
 54. Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7), 509-533. [https://doi.org/10.1002/\(SICI\)1097-0266\(199708\)18:7%3C509::AID-SMJ882%3E3.0.CO;2-Z](https://doi.org/10.1002/(SICI)1097-0266(199708)18:7%3C509::AID-SMJ882%3E3.0.CO;2-Z)
 55. Tran, T. K. N., & Le, P. C. L. (2024). The impact of traceability and information sharing on the digital transformation of logistics: A study with Vietnamese textile and garment industry. In *Twin transition: Digital transformation and green transition in businesses for sustainability* (pp. 165-187). VNU University of Economics & Business. Retrieved from <https://elib.vku.udn.vn/handle/123456789/5809>
 56. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems*, 28(2), 118-144. <https://doi.org/10.1016/j.jsis.2019.01.003>
 57. Wall, T. D., Michie, J., Paterson, M., Wood, S. J., Sheehan, M., Clegg, C. W., & West, M. (2004). On the validity of subjective measures of company performance. *Personnel Psychology*, 57(1), 95-118. <https://doi.org/10.1111/j.1744-6570.2004.tb02485.x>
 58. Wang, K.-H., Umar, M., Akram, R., & Caglar, E. (2021). Is technological innovation making world “greener”? An evidence from changing growth story of China. *Technological Forecasting and Social Change*, 165, Article 120516. <https://doi.org/10.1016/j.techfore.2020.120516>
 59. Warner, K. S. R., & Wäger, M. (2019). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. *Long Range Planning*, 52(3), 326-349. <https://doi.org/10.1016/j.lrp.2018.12.001>
 60. Westerman, G., Bonnet, D., & McAfee, A. (2014). *Leading digital: Turning technology into business transformation*. Harvard Business Review Press.
 61. Zanello, G., Fu, X., Mohnen, P., & Ventresca, M. (2016). The creation and diffusion of innovation in developing countries: A systematic literature review. *Journal of Economic Surveys*, 30(5), 884-912. <https://doi.org/10.1111/joes.12126>
 62. Zhang, G., Gao, Y., & Li, G. (2023). Research on digital transformation and green technology innovation – Evidence from China’s listed manufacturing enterprises. *Sustainability*, 15(8), Article 6425. <https://doi.org/10.3390/su15086425>
 63. Zhang, Q., & Ma, Y. (2021). The impact of environmental management on firm economic performance: The mediating effect of green innovation and the moderating effect of environmental leadership. *Journal of Cleaner Production*, 292(4), Article 126057. <https://doi.org/10.1016/j.jclepro.2021.126057>
 64. Zonta, T., da Costa, C. A., da Rosa Righi, R., de Lima, M. J., da Trindade, E. S., & Li, G. P. (2020). Predictive maintenance in the Industry 4.0: A systematic literature review. *Computers & Industrial Engineering*, 150, Article 106889. <https://doi.org/10.1016/j.cie.2020.106889>

APPENDIX A

Table A1. Questionnaire

Part 1: Introduction and Consent								
This survey is part of an academic research study examining the “Twin Transition” in Vietnam. The purpose is to understand how digital transformation impacts the relationship between green innovation and economic performance in manufacturing and service enterprises.								
This survey is intended for C-suite executives (CEOs, CFOs, CTOs) and Senior Managers (e.g., R&D Managers, Sustainability Directors) who possess a holistic view of their firm’s strategic activities.								
Ethical Statement and Consent								
Voluntary Participation:	Your participation in this study is completely voluntary. You may withdraw at any time without penalty.							
Anonymity:	The survey is anonymous. No personally identifiable information (PII) or sensitive corporate financial data will be stored.							
Data Usage:	All data collected will be aggregated and used strictly for academic analysis purposes.							
Consent:	By proceeding with this survey, you acknowledge that you have read the above information and agree to participate.							
Part 2: Demographics (General Information)								
<i>Please select the option that best describes you and your firm.</i>								
1. Gender:	<input type="checkbox"/> Male <input type="checkbox"/> Female							
2. Current Position:	<input type="checkbox"/> C-Level Executive (CEO, CFO, CTO) <input type="checkbox"/> Senior Manager							
3. Industry Sector:	<input type="checkbox"/> Manufacturing <input type="checkbox"/> Services							
4. Region (Key Economic Zone):	<input type="checkbox"/> Northern Key Economic Zone (e.g., Hanoi) <input type="checkbox"/> Southern Key Economic Zone (e.g., Ho Chi Minh City, Binh Duong) <input type="checkbox"/> Central Key Economic Zone (e.g., Da Nang)							
Part 3: Measurement Items								
<i>Instructions: Please rate the extent to which you agree with the following statements regarding your company’s activities. Use the scale: 1 = Strongly Disagree to 7 = Strongly Agree.</i>								
Section A: Green Innovation (GI)								
<i>This section measures your firm’s adoption of green products and processes.</i>								
Code	Statements	1	2	3	4	5	6	7
GI1	Our company uses materials that cause less pollution							
GI2	Our products consume less energy/resources							
GI3	Our manufacturing process effectively reduces hazardous waste							
GI4	We have reduced the consumption of water/electricity in production							
Section B: Digital Transformation (DT)								
<i>This section measures your firm’s digital strategy and technology integration.</i>								
Code	Statements	1	2	3	4	5	6	7
DT1	We use Big Data analytics for decision-making							
DT2	We use cloud computing for operations							
DT3	We use digital tools to interact with customers							
DT4	We use IoT (Internet of Things) sensors in our production lines							
Section C: Economic Performance (EP)								
<i>This section measures your firm’s performance relative to competitors over the last 3 years.</i>								
Code	Statements	1	2	3	4	5	6	7
EP1	Return on Investment (ROI) compared to competitors							
EP2	Return on Sales (ROS) compared to competitors							
EP3	Growth in market share over the last 3 years							

Thank you for your support!