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Linking environmental sustainability, digital transformation, and innovation: Evidence from micro-enterprises and SMEs

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ABSTRACT

This study explores the impact of environmental sustainability on the performance of Peruvian micro-, small, and medium-sized enterprises (MSMEs) under mediation by digital transformation and innovation. The study is based on partial least squares structural equation modeling (PLS-SEM) with questionnaire data from a sample of 345 Peruvian MSMEs. Digital transformation directly improved performance and promoted innovation. Environmental sustainability acted as a technology pull factor, encouraging digital transformation and innovation. Innovation had the most significant direct effect on performance. Theoretically, the study extends capability alignment theory to a developing-country context. Empirically, it demonstrates that environmental sustainability primarily influences performance indirectly via digital transformation and innovation, a rarely explored pathway in the context of Latin America. The study also offers region-specific evidence on the magnitude of these mediated relationships. From a managerial perspective, the results highlight the importance of incorporating environmental sustainability objectives into digital transformation and innovation strategies. Policy implications include the need to design policies that combine support for environmental compliance with funding for digitalization and innovation training. The limitations of the study highlight the value of performing longitudinal, segmented, and multi-country replication studies across Latin America.

Introduction

Micro-, small, and medium-sized enterprises (MSMEs) drive economic growth, innovation, and social advancement in emerging economies (OECD, 2023). In Peru, MSMEs represent >98 % of registered businesses and provide over 60 % of formal employment. Hence, their resilience and performance are central to sustainable development (Ministerio de la Producción, 2024). MSMEs occupy a strategic position due to their high resource intensity, contribution to value-added production, and disproportionate environmental footprint (Matthess & Kunkel, 2020). Their operational processes and supply chains make them not only critical job creators but also central actors in environmental impact limitation and resource efficiency.

MSMEs are particularly relevant when analyzing environmental sustainability (ES) because these firms often face immense pressure from global supply chains to adopt greener practices and improvements through technological innovation (Broccardo et al., 2023). MSMEs are often forced to adapt production methods, invest in cleaner technologies, and respond to increasing demands for responsible sourcing and waste management (Gupta & Gupta, 2021). Thus, their capacity to align ES with digital transformation (DT) and innovation is pivotal for both industry competitiveness and national sustainability. However, reports indicate that only 26 % of Peruvian MSMEs have adopted formal ES policies, and fewer than 15 % report having systematic DT initiatives or digital process automation (Ministerio de la Producción, 2024). These figures reflect the urgency but also the opportunity for MSMEs to integrate ES and DT.

The intersection of ES and DT has garnered considerable interest from scholars and practitioners. Both ES and DT are considered strategic tools for improving operational efficiency, product innovation, and market responsiveness (Cricelli & Strazzullo, 2021; Díaz, 2021). Recent studies support the idea that DT drives transformational, sustainable

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growth (Broccardo et al., 2023) and can facilitate new, more sustainable business models (Acciarini et al., 2022). Despite this enthusiasm, current research often treats ES and DT as separate efforts. Few studies have examined their combined effects or have considered the challenges faced by MSMEs in Latin America, which notably include regulatory uncertainty and uneven adoption of sustainability (Jara Ortega et al., 2019; Matthess & Kunkel, 2020).

Persistent gaps remain in the academic literature regarding how ES practices shape performance in MSMEs in combination with other critical processes such as DT implementation. Meta-analyses have linked ES adoption to improved efficiency and competitiveness (D'Agostini et al., 2017; Lu & Taylor, 2016) and DT to process innovation and adaptive capacity (Broccardo et al., 2023). However, less is known about whether these capabilities interact or require alignment under mediation by innovation (Govindan et al., 2020; Gupta & Gupta, 2021). Consequently, MSME managers have little empirical guidance for integrating ES and DT strategies under resource constraints.

Despite their importance for national economic growth, Peruvian MSMEs face persistent barriers. Scarce resources, limited digital infrastructure, and escalating compliance costs all restrict their ability to implement ES and DT strategies. This situation raises two intertwined questions:

1. To what extent can environmental sustainability (ES) practices alone translate into improved business performance in MSMEs under resource constraints?
2. How and under what conditions do digital transformation (DT) and innovation mediate this relationship?

This study addresses these gaps by examining the individual and joint effects of ES, DT, and innovation on the performance of Peruvian MSMEs. Using a robust stratified sample and partial least squares structural equation modeling (PLE-SEM), the study clarifies whether ES directly improves performance or does so primarily through interaction with DT and innovation. By clarifying these mechanisms in Peruvian MSMEs, this study advances the academic debate on strategic alignment in resource-constrained settings, while providing actionable recommendations for managers and policymakers committed to sustainable and inclusive industrial growth.

This paper makes three key contributions. First, it offers region-specific evidence of the role of ES, DT, and innovation in the performance of a high-impact segment of the Peruvian economy, namely MSMEs. Second, it describes the interaction between ES, DT, and innovation in influencing performance in Latin America. Third, it provides actionable recommendations for managers and policymakers aiming to foster sustainable, digitally enabled, innovative MSME business models (Del Río Castro et al., 2021; Díaz, 2021).

The paper is structured as follows. "Literature review and hypotheses" reviews the literature and presents the hypothesis-based theoretical model used in the study. "Data" details the sample. "Methodology and results" presents the methodology and empirical results. "Discussion" discusses the findings and implications, linking them to the existing scholarship. "Conclusions" concludes by outlining the contributions, limitations, and suggestions for future research.

Literature review and hypotheses

Interest in how ES, DT, and innovation collectively shape the performance of MSMEs in emerging economies has surged. Understanding these relationships is especially important in high-impact sectors with high resource intensity and regulatory scrutiny (Matthess & Kunkel, 2020). Scholarly consensus is that MSMEs drive job creation, innovation, and economic growth. However, they often struggle to integrate ES and DT, hindered by limited resources, market volatility, and knowledge barriers (Broccardo et al., 2023; OECD, 2023).

Meta-analyses have shown a positive, though context-dependent, link between ES adoption and firm performance (Al Hawaj & Buallay, 2022), suggesting sector-based variability in the size of these effects. D'Agostini et al. (2017) reported that environmental practices such as resource conservation, supply chain management, and emission reductions yield performance benefits, including operational efficiency, cost savings, and enhanced market access. These benefits are particularly pronounced in MSMEs, which, proportional to their revenue, tend to have large environmental footprints and high regulatory exposure (Matthess & Kunkel, 2020; Willenbacher et al., 2021). Similarly, technological advances and clean production methods have become key mechanisms for MSMEs to reduce waste, energy, and water use, while strengthening stakeholder relationships (Díaz, 2021; Teng et al., 2022).

However, how ES practices influence firm performance remains a black box for scholars (Gupta & Gupta, 2021). This statement is particularly true for MSMEs, where limited managerial and analytical capabilities can obscure the causal pathways linking environmental initiatives to operational or financial outcomes. Recent studies (Gupta & Gupta, 2021) have highlighted the need to break down these pathways by considering the roles of DT and innovation in clarifying the contribution of ES to measurable performance outcomes.

In the same vein, the literature cautions against viewing sustainability initiatives in isolation. One important factor that appears to interact with ES is DT, or the integration of digital technologies into business models and processes. DT has become a strategic imperative, enhancing information flows, resource allocation, and process automation (Broccardo et al., 2023; Matt et al., 2015; Škare et al., 2023). Empirical findings suggest that DT supports supply chain transparency, market responsiveness, and the capacity to personalize products, while reducing operational costs (Heavin & Power, 2018; Kindermann et al., 2021; Mourtzis & Doukas, 2014). DT also connects MSMEs with stakeholders, enables quicker adaptation to technological and regulatory changes, and improves competitive position (Chen et al., 2021; Nuryanto et al., 2024; Škare et al., 2024).

Yoo et al. (2021) explained that DT does not merely refer to a technological upgrade. Instead, it refers to a multidimensional change process, often calling upon leadership, process innovation, and capability-building, especially in MSMEs. The findings of Yoo et al. underline the importance of holistically integrating sustainability goals with digital strategy to maximize innovation-driven competitiveness.

The intersection of ES and DT is now considered fertile ground for generating synergistic effects on performance. Meta-analyses and sector-based studies imply that the strategic alignment of ES practices with DT capabilities can amplify gains in productivity, innovation, and competitiveness when encouraged by external pressures, organizational culture, and leadership commitment (Broccardo et al., 2023; Cricelli & Strazzullo, 2021; D'Agostini et al., 2017; Díaz, 2021; Jansson et al., 2017).

However, these synergistic effects from ES and DT alignment are not automatic. The importance of innovation for firm growth and competitiveness has been acknowledged since Acs and Audretsch (1988) empirically showed its role in both large and small firms. Studies have repeatedly underscored the mediating role of organizational innovation, translating ES and DT into tangible performance outcomes (Canhoto et al., 2021; Govindan et al., 2020; Gupta & Gupta, 2021; Rosenbusch et al., 2011). Innovation in MSMEs (e.g., product launches, process improvements, cleaner technology adoption, and organizational change) has been linked to improved efficiency, sales growth, market adaptation, and reputation (Al-Hanakta et al., 2023; Avermaete et al., 2004; García-Pérez-de-Lema et al., 2021; Van Auken et al., 2008). Research further suggests that digital capabilities can reinforce the role of innovation by, for instance, supporting new business models, training, and sustainable practices in daily operations (Bai et al., 2020; Burchardt & Maisch, 2019; Chatterjee et al., 2021; Matt et al., 2015).

In Latin America, regulatory uncertainty and uneven digital infrastructure pose additional barriers. However, empirical studies have shown the potential of leveraging ES and DT for strategic gains in

MSMEs when innovation is prioritized (Del Río Castro et al., 2021; Jara Ortega et al., 2019; Matthess & Kunkel, 2020). Policy initiatives such as Peru's Corporate Sustainability and Reporting for Competitive Business program have empowered MSMEs to implement sustainable strategies, access partnerships, and expand into new markets, signaling the practical value of capability alignment (Jara Ortega et al., 2019).

Drawing from this literature, is it hypothesized that ES and DT do not merely exert independent effects on performance. Instead, their alignment, particularly when mediated by innovation, drives the superior performance of MSMEs in Peru. This conceptual framework is grounded in capability alignment theory (Canhoto et al., 2021; Luftman et al., 2017; Saunila, 2020; Yeow et al., 2018), recent meta-analyses, and sector-specific studies, which provide support for each hypothesis. According to a recent meta-analysis, the average effect size of ES initiatives on SME performance is moderate (mean $\bar{r} = 0.25$). However, it varies considerably across contexts and often depends on the interaction with digital capabilities and innovation (D'Agostini et al., 2017). Accordingly, the following testable hypotheses are proposed:

H_1: Environmental practices (ENV PR) directly and positively affect business performance (PERFORM) in Peruvian MSMEs.
H_2: Environmental practices (ENV PR) promote digital transformation (DIGIT) in Peruvian MSMEs.
H_3: Environmental practices (ENV PR) foster innovation (INNOV) in Peruvian MSMEs.
H_4: Digital transformation (DIGIT) positively affects business performance (PERFORM) in Peruvian MSMEs.
H_5: Digital transformation (DIGIT) encourages innovation (INNOV) in Peruvian MSMEs.
H_6: Innovation (INNOV) positively affects business performance (PERFORM) in Peruvian MSMEs, mediating the effects of ENV PR and DIGIT.

These hypotheses are captured in the research model displayed in Fig. 1. They reflect accumulated evidence that environmental sustainability (in the form of environmental practices) and digital transformation (when integrated and aligned with innovation) yield significant performance advantages for MSMEs (Broccardo et al., 2023; Cricelli & Strazzullo, 2021; Del Río Castro et al., 2021; Díaz, 2021; Lu & Taylor, 2016). This study advances the literature by systematically quantifying both direct and indirect effects, accounting for sector-specific dynamics, resource constraints, and the mediating influence of innovation.

This framework and the research model displayed in Fig. 1 are built on robust theoretical and empirical foundations (Broccardo et al., 2023; Cricelli & Strazzullo, 2021; D'Agostini et al., 2017; Del Río Castro et al., 2021; Díaz, 2021; Lu & Taylor, 2016). Moreover, they are tailored to the realities of Peruvian MSMEs, considering sector dynamics, resource limitations, and the critical role of capability alignment for ES, DT, and innovation.

Data

Source

This study builds on the data obtained in the report on "MSMEs' digitalisation and sustainable development in Peru". Data were collected by telephone and via an online survey of MSME managers in Peru. Both data collection approaches were cost-effective, with a high response rate. A simple random sample that was representative of the population was used. The survey was conducted in February and March 2022. Managers of Peruvian MSMEs were chosen as respondents given their roles as the most critical decision-makers in their firms (García-Pérez-de-Lema et al., 2021). Respondents were instructed that there were no correct or incorrect answers. Anonymity and data confidentiality were guaranteed (Castillo-Vergara & García-Pérez-de-Lema, 2021; Yang et al., 2015). Data collection yielded 345 valid questionnaires, representing an overall sampling error of 5.3 % for a confidence

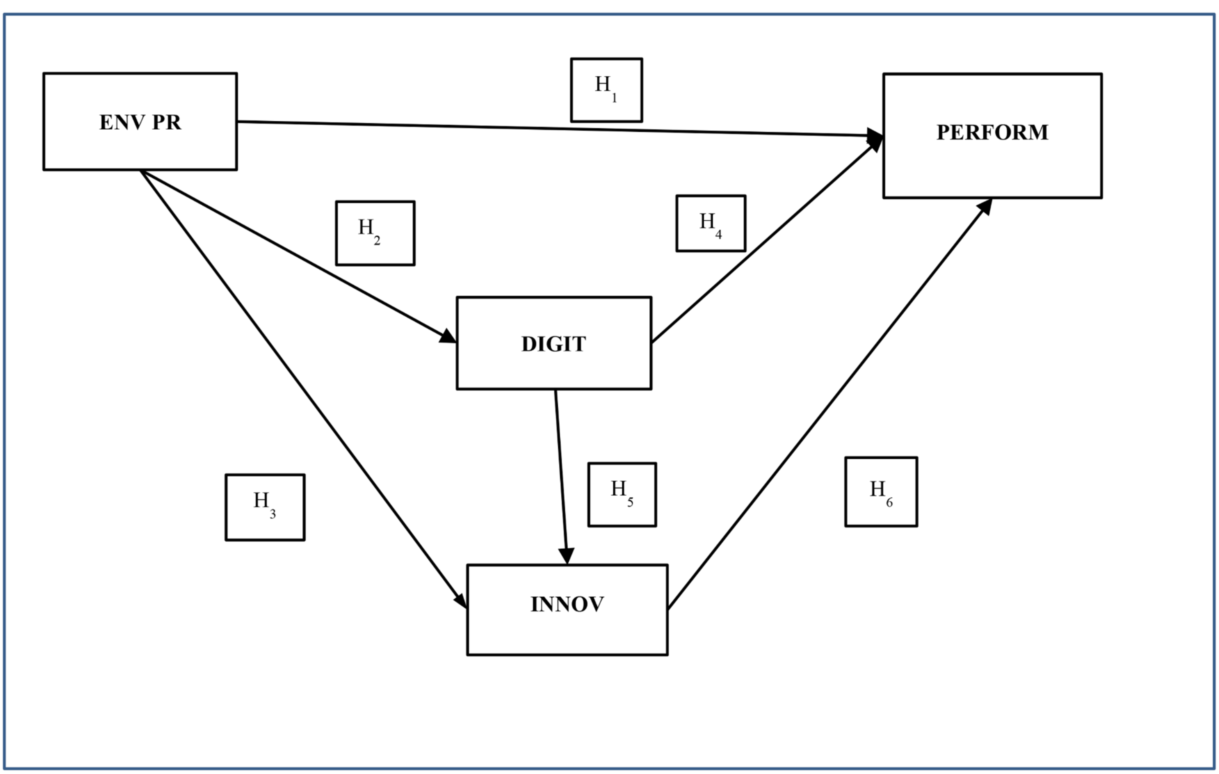

Fig. 1. Research model.
Notes. ENV PR = environmental performance; DIGIT = digital transformation; INNOV = innovation; PERFORM = business performance.

level of 95 %. Table 1 shows the sample distribution.

Tests were conducted to check for potential bias. First, Harman's one-factor approach (Podsakoff et al., 2003) was used to perform a principal component analysis of all variables in the model. There was no dominant factor. The main factor explained 21.631 % of the variance. This result confirmed the absence of common method bias. Second, early and late respondents were compared to check for potential non-response bias (Scott, 1955; Wiseman, 1972). There were no significant differences in age, size, or industry in the dependent or independent variables.

Variables

This section describes the variables in the model.

Business performance (PERFORM)

The dependent variable (PERFORM) was a construct built from responses to five-point Likert-type scale questions. These questions asked MSME managers about performance indicators compared with direct competitors. Managers compared their firm's performance with that of competitors in terms of product quality, production process efficiency, customer satisfaction, the speed of adapting to market changes, sales growth, profitability, and employee satisfaction. Responses were scored on a scale ranging from 1 (*much worse*) to 5 (*much better*). According to the literature (Duréndez et al., 2016; García-Pérez-de-Lema et al., 2016), the relative position of an MSME with respect to competitors can describe its relative success (AECA, 1988). The indicators used in this study were similar to those used in other studies (Chenhall & Langfield-Smith, 2007; Dehning et al., 2007; Gunday et al., 2011; López-Mielgo et al., 2009).

Business innovation (INNOV)

The innovation construct (INNOV) was created from responses to five-point Likert-type scale questions about the importance of different innovations by the sampled MSMEs. The items included improvements or changes in products or services, new products or services, improvements in production processes, acquisition of capital equipment, and improvements or changes in the organization or internal processes. These items were consistent with the literature on innovation in MSMEs (Al-Hanakta et al., 2021; Avermaete et al., 2004; García-Pérez-de-Lema et al., 2021; Rosenbusch et al., 2011; Van Auken et al., 2008). Respondents recorded their answers on a scale ranging from 1 (*not very important*) to 5 (*very important*).

Environmental practices (ENV PR)

This variable captured the importance of various environmental practices in supplier selection, management of plastic containers and derivatives, process design, energy management, water management, waste management, and environmental certifications. These environmental practices are in line with the Sustainable Development Goals (SDGs) defined as part of the 2030 Agenda (United Nations, 2016), as well as the literature on MSMEs and sustainable management (Cantele & Zardini, 2020; Jansson et al., 2017; Ndubisi et al., 2021). This variable captured the environmentally responsible practices and organizational transformations undertaken to achieve the SDGs. MSMEs play a critical role in the pursuit of the SDGs because they are the most common type of business. To attain the SDGs, the specific issues facing MSMEs must be considered given that these firms behave differently from large corporations (Cantele & Zardini, 2020). Respondents recorded their answers on a scale ranging from 1 (*not very important*) to 5 (*very important*).

Table 1
Sample distribution by sector and size.

Sector	Number of companies	%
Primary sector	27	7.83
Extractive sector	61	17.68
Building	30	8.70
Commerce	31	8.99
Services	152	44.06
Other	44	12.75
Size		
Micro (6–9 employees)	179	51.88
Small (10–49 employees)	108	31.30
Medium (50–249 employees)	58	16.81
Total sample	345	100.00

Digital transformation (DIGIT)

This variable assessed the level of DT in the sampled MSMEs. It captured the following aspects: awareness of the possibilities and benefits of digitalization, resource allocation to digitalization, evaluation and updating of the business model in terms of digitalization, training of employees and managers for digital development, the degree of process automation, the use of digitalization in organizational management, and the existence of regular DT training within the company. This construct was aligned with prior research. Continuous assessment of resource allocation and targeted training are essential in DT (Heavin & Power, 2018; Kindermann et al., 2021; Matt et al., 2015). Furthermore, aspects of DT such as automation demand new skills and organizational changes (Heavin & Power, 2018; Matt et al., 2015). In this regard, a technological and strategic organizational orientation that encompasses the entire organization to leverage digital resources and structural adjustments promotes effective DT (Kindermann et al., 2021). Nevertheless, educating managers on how digitalization can enhance the company is crucial (Bai et al., 2020; Burchardt & Maisch, 2019; Chatterjee et al., 2021). Respondents recorded their agreement with a series of statements about DT within their MSME using a scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

Control variables

Finally, the following control variables were selected in line with the literature on MSME performance: firm size (SIZE), measured by the number of employees, firm age (AGE), and sector dummies (Duréndez et al., 2016; García-Pérez-de-Lema et al., 2016; González-Cruz et al., 2021; Van Auken et al., 2008). Table 2 defines all the variables used in the model.

Methodology and results

Partial least squares data analysis

The study sought to determine the predictive quality of the proposed model. The hypotheses were tested by applying PLS in SmartPLS Version 4.1.0.0 (Ringle et al., 2022). PLS uses the total variance of the constructs to estimate the model (Hair, 2014). PLS has two advantages. It requires no assumptions about the distribution of the indicators, and independence of the observations is not required (Chin, 2010).

PLS was used to assess a multivariate model with observed items. Both the structural model (causal relationships between dependent and independent constructs) and the measurement model (loadings of observed items with their respective constructs) were assessed. One notable feature of PLS is that it is relatively robust to deviations from normality. The proposed PLS methodology has three steps: model description, measurement model evaluation, and structural model evaluation. Appendix A outlines the steps in this method.

First step: measurement model

First, the model is described graphically (Tompson et al., 1995). The structural model is specified in terms of causal relationships between variables. The measurement model is defined in terms of relationships between the indicators (items) and the constructs. The validity and reliability of the measures for all constructs must be tested (Tompson et al., 1995). Fig. 1 illustrates the model. The measurement model (inner

Table 2
Variable definitions.

Variable	Items	Refs.
Business performance (PERFOM)	Compared to your direct competitors, indicate where your company stands with the following performance indicators from 1 (*worse*) to 5 (*better*): Product quality Efficiency of production processes Customer satisfaction Speed of adaptation to changes in the market Rapid sales growth Profitability Employee satisfaction	Duréndez et al., 2016; García-Pérez-de-Lema et al., 2016; Chenhall & Langfield-Smith, 2007; Dehning et al., 2007; López-Mielgo et al., 2009; Gunday et al., 2011
Business innovation (INNOV)	If your company carried out any of the following innovations in 2021, indicate the degree of importance of each one from 1 (*not very important*) to 5 (*very important*): 1. Changes or improvements in existing products/services 2. Market launch of new products/services 3. Changes or improvements in production processes 4. Acquisition of new capital goods 5. Changes or improvements in organization and/or management 6. Changes or improvements in purchases and/or supplies 7. Changes or improvements in commercial and/or sales	Avermaete et al., 2003; Van Auken et al., 2008; Rosenbusch et al., 2011; Al-Hanakta et al., 2021; García-Pérez-de-Lema et al., 2021
Environmental practices (ENV PR)	If your company used any of the following environmental criteria in 2021, indicate the degree of importance of each one for your company from 1 (*not very important*) to 5 (*very important*): Environmental criteria in the selection of suppliers Environmental criteria in the management of plastic packaging and derivatives Environmental criteria in the design of processes Environmental criteria for energy management Environmental criteria for water management Environmental criteria for waste management Environmental certifications (e.g. ISO14001/ EMAS)	United Nations, 2016; Jansson et al., 2017; Cantele & Zardini, 2020; Ndubisi et al., 2021
Digital transformation (DIGIT)	Indicate your degree of agreement or disagreement with the following aspects related to digitalization strategy from 1 (*strongly disagree*) to 5 (*strongly agree*): 1. We are aware of the possibilities and advantages of digitization. 2. We allocate significant resources to digitize the business. 3. The business model is evaluated and updated in terms of digitization. 4. Our employees are prepared for the digital development of the company. 5. Our managers are well-trained in digitalization. 6. The degree of process automation is high in my company. 7. We use digitization in the organizational management of the company. 8. Our company regularly organizes training for digital transformation.	Matt et al., 2015; Heavin & Power, 2018; Kindermann et al., 2020; Burchardt & Maisch, 2019; Chatterjee et al., 2021
Size Age Sector dummies	Number of employees Firm age	Van Auken et al., 2008; Duréndez et al., 2016; García-Pérez-de-Lema et al., 2016; González-Cruz et al., 2021

model) describes the latent variables and their linkages with the corresponding observable indicators.

Analysis of loadings

According to Hair (2014), the loadings of exploratory reflective models should be between 0.60 and 0.70. At this level, the factor explains 50 % of the variance of the indicator. If the loading of an indicator is between 0.40 and 0.60, it is advisable to remove the indicator from the model to improve composite reliability. Carmines and Zeller (1979) explained that, in reflective constructs, the loading (λ), or simple correlations of each element (the indicators of the respective construct), must be greater than 0.707 to verify the reliability of the indicator.

Reliability of reflective models

To assess construct reliability, Cronbach's alpha and composite reliability were used as measures of internal consistency. According to Chin (1998)), a value of 0.6 is acceptable for exploratory models. According to Henseler et al. (2015), a value of 0.7 is a suitable benchmark for models. A value of 0.8 or higher is considered adequate for confirmatory research (Cho & Kim, 2015), whereas a value greater than 0.90 may indicate that the indicators are different. In conclusion, construct reliability is established using Cronbach's alpha, the composite reliability, and the Dijkstra-Henseler indicator (Rho_A), all of which must be greater than 0.7 (Hair, 2014).

Average variance extracted (AVE)

To identify the internal consistency of the model, convergent validity must be analyzed. The average variance extracted (AVE) is used for this purpose. According to Hair (2014), the AVE reflects the total amount of the variance of the indicators considered by the latent variable. The highest AVE values occur when the indicators represent the latent variable. AVE values should be greater than 0.50 to confirm convergent validity (Chin, 1998; Fornell & Larcker, 1981). Such a value means that the factors explain more than half of the variance of their respective indicators and are highly significant and correlated.

Discriminant validity

Discriminant validity is used to confirm that the observed indicators (items) do not correlate with other measures that are known to be independent of the variable to be measured. The Fornell and Larcker (1981) criterion can be used for this purpose. They recommend that the square root of the variance extracted (AVE) of each latent variable should be greater than the Pearson correlations with the rest of the constructs. Another criterion is that the heterotrait-monotrait ratio (HTMT) should be below 1 to confirm discriminant validity (Henseler et al., 2015).

Inner model

The loading (λ) of each element in the model (Table 3) must be greater than 0.707 to verify reliability. The model met this reliability requirement. The Dijkstra-Henseler Rho_A indicator, Cronbach's alpha coefficient, and composite reliability all exceeded 0.7 (Table 3). The AVE values (Table 3) were also above the threshold of 0.5, so convergent validity was confirmed. Finally, all variables had discriminant validity. The HTMT was satisfied, and the bootstrap-based confidence interval for the HTMT value (Table 3) reached the required threshold.

Second step: structural model

The second step was to verify the internal validity of the latent variables with formative indicators to rule out multicollinearity problems. The variance inflation factor (VIF) was used for this purpose. It was calculated using regression analysis. A VIF value greater than 10 indicates a potential multicollinearity problem (Myers, 1990). The results showed that there were no multicollinearity problems.

Bootstrapping

Bootstrap-based fit tests were performed for the estimated model to examine the stability of the estimates provided by the PLS analysis (Chin, 1998). According to Chin (1998)), the two-tailed Student's *t*-distribution with $(n - 1)$ degrees of freedom should be used, where n is the number of subsamples. The significance levels of $p < 0.05$, $p < 0.01$, and $p < 0.001$ were applied. The values resulting from the bootstrapping should be compared with the t value. The next step was to confirm whether there were causal relationships between two latent variables in the model.

Structural model assessment

Structural model assessment is defined by the relationships between the dependent and independent latent variables, which should reflect the theory and hypotheses in the model (inner structural relationships). For the PLS-SEM technique to be considered acceptable, the standardized root mean square residual (SRMR) of the fitted model must be below 0.08 (Hair, 2014).

Hypothesis testing

The hypotheses were tested by examining the path coefficients (ß) to determine whether the predictors contributed to the explained variance of the endogenous variable. The ß values represent the standardized regression weights. They must exceed 0.20 to be considered significant. However, a ß value greater than or equal to 0.30 is preferable (Chin, 1998).

External model

Hayes and Scharkow (2013) showed that the bootstrap-estimated confidence interval can be used to detect path coefficients. The path coefficients were found to be compatible in all cases. Table 4 shows the bootstraps with a 95 % confidence interval. Fig. 2 shows the structural model and the results. The model explains 31.5 % of the variation in business performance (PERFOM).

Based on Table 4, most of the hypotheses are supported (H2, H3, H4, H5, and H6, with coefficients of 0.306, 0.290, 0.244, 0.297, and 0.383, respectively). However, H1 is not supported (coefficient = 0.071, p value = 0.230).

The mediating role of the digital transformation (DIGIT) variable was analyzed to determine the type of mediation and its indirect effect. Results are shown in Table 5. For the analysis of effect size, cases with missing values were eliminated to rule out problems with the standard errors (Cohen, 1988, 1990). The indirect effects were statistically significant, as were the total effects. Interestingly, the total effect of environmental practices (EVN PR) on business performance (PERFORM) became significant under mediation by digital transformation (DIGIT). The other direct effects were larger under mediation.

Third step: predictive analysis

Coefficient of determination (R^2)

Predictive analysis was performed by measuring the magnitude and statistical significance of the path coefficients. The R^2 measure indicates the amount of variation in the endogenous variable explained by the constructs that predict it. This explained variance value is used to assess

Table 4
Construct effects on endogenous variables (including confidence interval with lower and upper bounds of 2.5 % and 97.5 %).

Hypothesis		Path coeff.	t ratios for path coeff.	Confidence intervals			
				2.5 %	97.5 %	*p* value	
H_1	**Env Pr → Perform**	0.071	1.273	−0.037	0.183	0.230	
H_2	**Env Pr → Digit**	0.306	5.430	0.194	0.415	0.000	***
H_3	**Env Pr → Innov**	0.290	4.292	0.156	0.422	0.000	***
H_4	**Digit → Perform**	0.244	4.433	0.134	0.349	0.000	***
H_5	**Digit → Innov**	0.297	4.811	0.176	0.417	0.000	***
H_6	**Innov → Perform**	0.383	6.517	0.269	0.497	0.000	***

Notes. For one-tailed test 1.645 and for two-tailed test 1.960. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 3
Reliability, convergent validity, and discriminant values of outer model.

Construct	Cronbach's alpha	Dijkstra-Henseler (Rho_A)	Composite reliability	AVE	Heterotrait–monotrait (HTMT) matrix			
					DIGIT	ENV PR	INNOV	PERFORM
DIGIT	0.923	0.907	0.937	0.651				
ENV PR	0.938	0.943	0.950	0.732	0.325			
INNOV	0.936	0.938	0.948	0.723	0.412	0.399		
PERFOM	0.910	0.918	0.928	0.649	0.447	0.315	0.535	

Notes. AVE = average variance extracted; DIGIT = digital transformation; ENV PR = environmental practices; INNOV = business innovation; PERFORM = business performance.

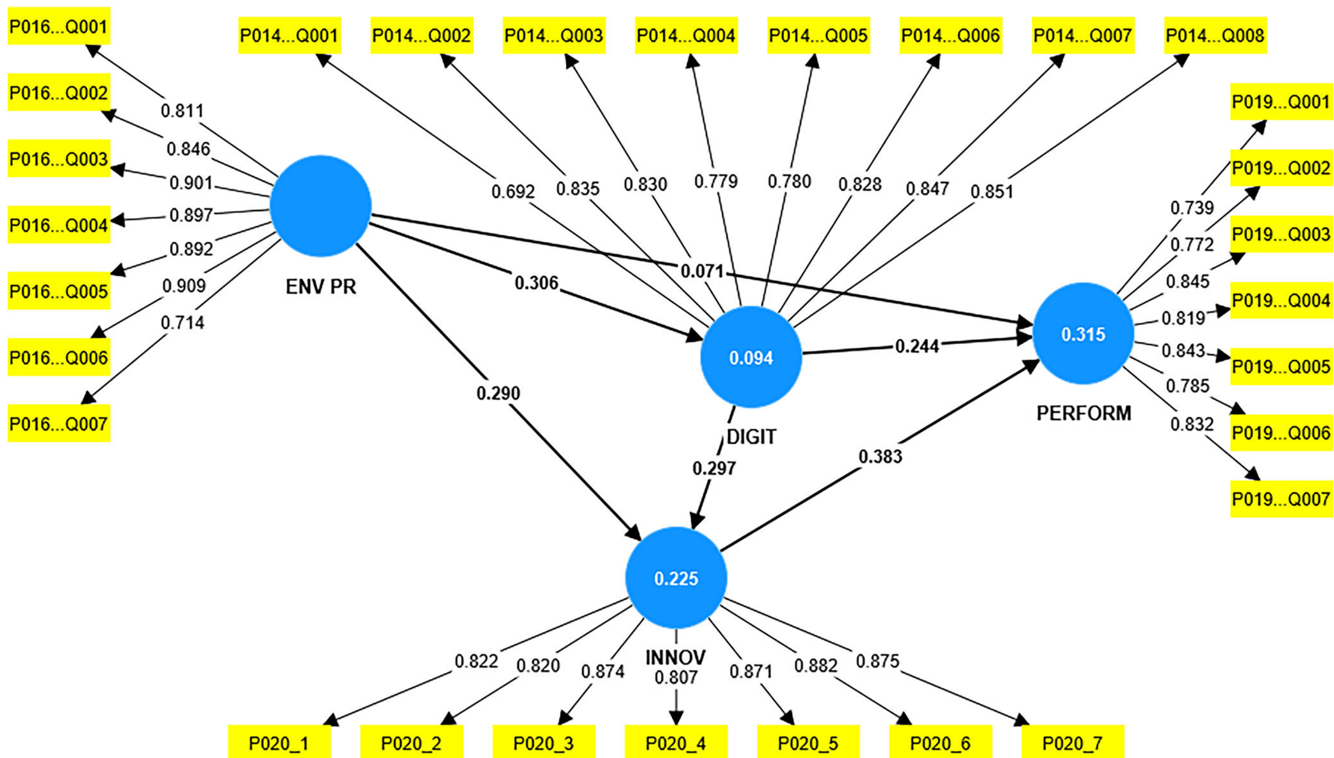

Fig. 2. Structural model and results.
Notes. ENV PR = environmental performance; DIGIT = digital transformation; INNOV = innovation; PERFORM = business performance.

Table 5
Direct and indirect effects analysis based on effect size.

Direct effects	Coeff.	Effect	2.5 %	97.5 %	*p* value	Sig.	Effect size
H_1 (ENV PR→ PERFOM)	0.071		−0.037	0.183	0.230		0.006
H_2 (ENV PR→ DIGIT)	0.306		0.134	0.349	0.000	***	0.104
H_3 (ENV PR→ INNOV)	0.290		0.156	0.422	0.000	***	0.098
H_4 (DIGIT→ PERFORM)	0.244		0.176	0.417	0.000	***	0.071
H_5 (DIGIT→ INNOV)	0.297		0.194	0.415	0.000	***	0.103
H_6 (INNOV→ PERFORM)	0.383		0.269	0.497	0.000	***	0.166
Total indirect effects							
Path ($H_{DIGIT*PERFORM}$)		0.114	0.058	0.184	0.000	***	0.318
Path ($H_{ENV\ PR*\ PERFORM}$)		0.221	0.157	0.294	0.000	**	0.757
Path ($H_{ENV\ PR*INNOV}$)		0.091	0.048	0.144	0.000	***	0.239
Indirect effects							
H (ENV PR→ DIGIT→ PERFORM)		0.075	0.037	0.119	0.000	***	0.113
H (ENV PR→ DIGIT→ INNOV→PERFORM)		0.035	0.016	0.062	0.004	***	0.035
H (ENV PR→ DIGIT→ INNOV)		0.091	0.048	0.144	0.000	***	0.151
H (DIGIT→ INNOV→ PERFORM)		0.114	0.058	0.184	0.000	***	0.168
H (ENV PRO→ INNOV→ PERFORM)		0.111	0.059	0.171	0.000	***	0.145
Total effects							
H (ENV PR→ PERFORM)		0.292	0.173	0.412	0.000	***	
H (ENV PR→ DIGIT)		0.306	0.194	0.415	0.000	***	
H (ENV PR→ INNOV)		0.381	0.259	0.502	0.000	***	
H (DIGIT→ PERFORM)		0.358	0.251	0.456	0.000	***	
H DIGIT→ INNOV)		0.297	0.176	0.417	0.000	***	
H (INNOV→ PERFORM9)		0.383	0.269	0.497	0.000	***	

Notes. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. DIGIT = digital transformation; ENV PR = environmental practices; INNOV = business innovation; PERFORM = business performance.

the coefficient of determination, represented by the symbol R^2 (Henseler et al., 2015). Falk and Miller (1992) explained that R^2 values should be greater than 0.10 for the model to have minimum explanatory power.

Goodness of fit (GoF)

This index is the result of multiplying the square root of the average AVE by the square root of the average R^2. To check the reliability and fit of the model, the GoF must be greater than or equal to 0.5.

Effect size

Effect size indicates how generalizable an effect of one construct on another is to the population from which the sample was drawn. It is not enough to identify the occurrence of a certain effect. In addition, its magnitude or size must also be determined (Cohen, 1990).

Cohen (1988) and Kock (2014) explain how to measure effect size using Cohen’s d. It is calculated as the difference between the means of two groups divided by the pooled standard deviation: d(M1,M2)/SD. Values <0.02 indicate a small effect; 0.15 indicates a medium effect; 0.35 indicates a large effect.

Regarding the assessment of the structural model, for the endogenous variables PERFORM, INNOV, and DIGIT, their R^2 values were 0.315, 0.225, and 0.094, respectively. The GoF value was 0.395 (small >= 0.1, medium >= 0.25, large >= 0.36). This value exceeded the required threshold.

Standardized root mean square residual (SRMR)

The SRMR value of the saturated model was 0.055. Given that this value is below the threshold of 0.08 suggested by Hu and Bentler (1999),

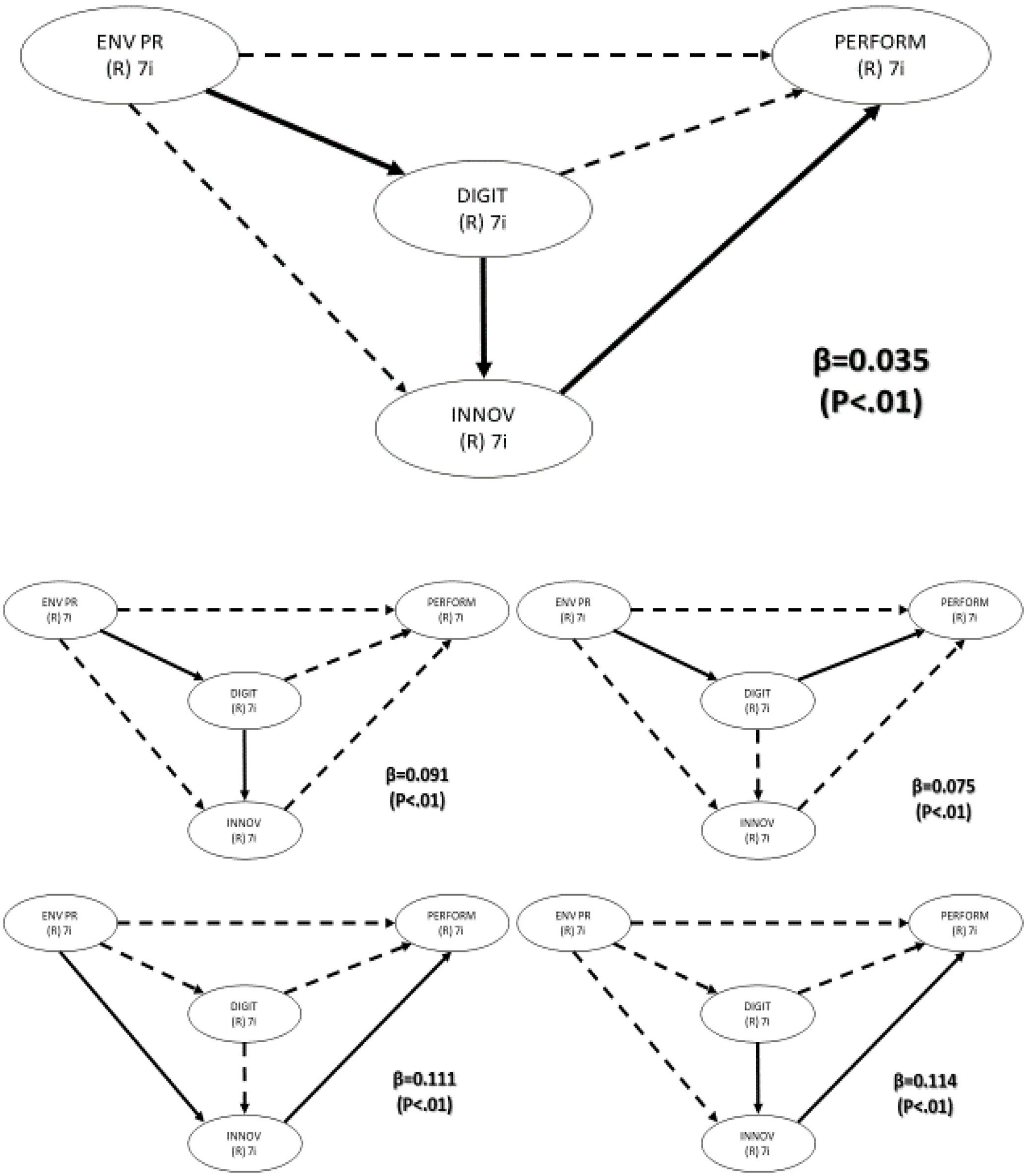

Fig. 3. Alternative pathways of interaction among variables.
Notes. ENV PR = environmental performance; DIGIT = digital transformation; INNOV = innovation; PERFORM = business performance.

it provides empirical evidence for the fit of the constructs used to operationalize the underlying concepts.

Discussion

Summary and interpretation of key findings

This study investigates the relationships between ES, DT, and innovation in Peruvian MSMEs. The results suggest that ES does not have a statistically significant direct impact on performance (H1: $\beta = 0.071$, $p = 0.230$). This finding differs from evidence from meta-analyses, which consistently indicate positive links between ES and performance (Albertini, 2013; Ambec & Lanoie, 2008). Several contextual factors may explain this difference. For instance, many Peruvian MSMEs adopt ES mainly for regulatory compliance rather than for market differentiation strategies (Durrani et al., 2024; Menguc & Ozanne, 2005). In addition, it is often only partially implemented because of resource limitations, which may hinder financial and market benefits (Delmas & Burbano, 2011; Kirchoff & Falasca, 2022; OECD, 2018; UN Trade & Development, 2025). This finding supports the view expressed by Gupta and Gupta (2021) that the effects of ES remain a black box until mediated by complementary capabilities such as DT and innovation. It also aligns with the observations of Matthess and Kunkel (2020), who found that, in Latin America, ES alone rarely produces immediate performance gains without technological and organizational reinforcement.

From the perspective of capability alignment theory, this study confirms that ES positively influences DT (H2) and innovation (H3). This finding suggests that environmental sustainability goals can act as a technology pull factor (Cricelli & Strazzullo, 2021; Jansson et al., 2017), encouraging MSMEs to digitize operations and propose innovative offerings. The results suggest that DT exerts a direct positive effect on performance (H4) and fosters innovation (H5). This finding supports the views of Yoo et al. (2021) and Kindermann et al. (2021), who argued that DT is a multidimensional technical, organizational, and strategic transformation that enhances both efficiency and responsiveness.

From a Schumpeterian perspective, entrepreneurship and dynamic innovation are considered central to economic development (Backhaus & Schumpeter, 2003). The current results suggest that this view remains highly relevant to MSME research. According to the results, innovation not only exerts the largest direct effect on performance but also plays a mediating role by amplifying the effects of ES and DT (H6). This finding is in line with those of Rosenbusch et al. (2011) and Van Auken et al. (2008) and reaffirms the central role of innovation in MSME competitiveness. Furthermore, the results suggest that the INNOV → PERFORM path ($\beta = 0.383$) is strong, as reported Popović-Pantić et al. (2020) for Serbian SMEs. This finding indicates particularly high marginal returns to innovation in less digitized, resource-constrained settings. Overall, the findings demonstrate that ES primarily influences performance indirectly through its effect on DT and innovation. It thus generates synergistic effects that are greater than the sum of the individual effects. Fig. 3 shows the alternative pathways of interaction among variables.

Theoretical implications

These findings extend capability alignment theory (Luftman et al., 2017; Yeow et al., 2018) by showing that ES is a strategic resource that supports performance rather than directly boosting it in resource-constrained settings. Based on the resource-based view (RBV), the results of the current study indicate that ES practices in Peruvian MSMEs function as enabling resources that must be combined with complementary capabilities (in this case DT and innovation) to create sustainable competitive advantage (Ofori-Baafi & Opoku, 2025; Teece, 2018). This conclusion broadens the traditional RBV framework by showing that, in developing economy contexts, environmental practices alone may not satisfy the valuable, rare, inimitable, non-substitutable (VRIN) resource criteria needed for direct performance improvement.

The study advances dynamic capability theory by empirically confirming the role of ES as a sensing capability that leads to organizational reconfiguration through DT and innovation. The findings are aligned with the literature on dynamic capabilities, illustrating that firms must continually adjust their resource configurations to sustain their competitive advantage (Pisano & Teece, 2007; Teece, 2007). The significant pathways from ES to DT ($\beta = 0.306$) and ES to innovation ($\beta = 0.290$) show that ES acts as a catalyst for capability building, supporting the idea that sustainability pressures can encourage organizational learning and adaptive capacity development.

In line with recent research (Pelletier et al., 2025; Peretz-Andersson et al., 2024), this study enhances the general understanding of capability orchestration in MSMEs by demonstrating that the alignment of ES, DT, and innovation produces synergistic effects that surpass their individual contributions. This finding builds on the work of scholars who emphasize the importance of capability integration in small firms (Canhoto et al., 2021; Saunila, 2020). The mediating role of innovation ($\beta = 0.383$) particularly underscores how MSMEs can overcome resource constraints through strategic capability combination, providing empirical evidence of the value of innovative sustainability, a concept that combines innovation capacity with sustainability goals.

The results also contribute to the environmental strategy literature by shedding light on the validity of the Porter hypothesis. This hypothesis, which posits that environmental regulations can spark innovation that often offsets compliance costs (Ambec et al., 2010), may function differently in developing economy MSMEs. Instead of direct cost offsets, the findings indicate that ES practices generate value through indirect pathways that enhance technological and innovation capacities, ultimately leading to performance outcomes. In line with Petroni et al. (2018), this nuanced understanding challenges simple interpretations of the ES–performance link. It highlights the importance of considering mediating mechanisms and contextual factors in environmental strategy research.

Practical implications

Managerial implications

From a managerial perspective, ES investments alone are unlikely to generate significant gains unless supported by DT and innovation. Aligning ES with DT through process automation, environmental monitoring technologies, analytics, or similar methods increases the likelihood of turning ES into measurable performance improvements. These findings align with those of Del Río Castro et al. (2021) and Díaz (2021), who advocate for integrated management strategies in resource-constrained environments.

Managers should therefore integrate ES goals into broader DT and innovation strategies. They should allocate resources not only to environmental projects but also to complementary technological and innovative endeavors. This integrated approach requires developing what Chen et al. (2024) and Kumar et al. (2021) term *ambidextrous capabilities*, which simultaneously pursue sustainability and digitalization. Specifically, MSME managers should take the following actions:

- Develop integrated capability roadmaps that align environmental monitoring systems with digital infrastructure investments, creating synergies between sustainability reporting and operational efficiency improvements.
- Implement phased technology adoption strategies that prioritize digital solutions with dual environmental and operational benefits, such as IoT-enabled energy management systems and automated waste-tracking platforms.
- Foster cross-functional collaboration between sustainability, information technology (IT), and innovation teams to ensure that environmental objectives drive rather than constrain DT initiatives.

Policy and industry support implications

For policymakers, the current evidence supports the value of designing integrated programs that combine environmental compliance support with funding for digitalization and innovation training. Industry associations can play a decisive role by providing targeted workshops that combine lean manufacturing, Industry 4.0 tools, and circular production techniques. Such combined interventions can create reinforcing feedback loops between sustainability and digitalization, fostering an innovation culture and generating high returns on both environmental and technological investment.

The European experience with twin transition policies demonstrates the effectiveness of integrated approaches (OECD, 2021; Rzepecka et al., 2024). Policymakers should therefore consider the following strategies:

- Creating twin transition hubs that provide SMEs with coordinated access to environmental compliance consulting, digital technology training, and innovation funding within single institutional frameworks.
- Designing sector-specific support packages that address the unique sustainability and digitalization challenges faced by different industries, recognizing that manufacturing SMEs have different needs from service firms.
- Establishing performance metrics that capture the synergistic effects of combined ES and DT investment, moving beyond traditional compliance measures to assess innovation outcomes and competitive improvements.

Finally, professional associations should offer certificates that validate SMEs' integrated ES and DT capabilities. Such certificates could offer market recognition for firms that successfully align these strategic priorities and foster peer learning networks for capability development.

Comparison with prior studies

The confirmation of H2, H3, H4, H5, and H6 and the rejection of H1 invite direct comparison with earlier studies. The absence of a significant direct ES → PERFORM effect echoes the results of Willenbacher et al. (2021), who found that environmental standards rarely lead to performance gains without innovation-driven integration. This finding contrasts with those of Cassaro et al. (2024), who observed that micro- and small enterprises struggle to derive value from DT because of their weak innovation cultures. The current results indicate that targeted innovation programs can bridge this gap in Peru.

The DT → PERFORM effect ($\beta = 0.244$) closely resembles the results of Del Río Castro et al. (2021), reinforcing DT's role as an independent driver of performance. The observation of the mediating role of innovation, amplifying the effect of ES and DT on performance, is aligned with the findings of Rosenbusch et al. (2011) and Popović-Pantić et al. (2020). However, the higher coefficients in the current study imply that these synergistic effects may be more pronounced in under-digitized, resource-constrained environments.

Conclusions

Study contributions

This research makes three key contributions to the literature. First, it provides region-specific evidence for MSMEs that can influence both economic and environmental outcomes in Peru. It thus expands theoretical understandings in developing country contexts. Second, it illustrates the interactions between ES and other capabilities such as DT and innovation in Latin America. It thus demonstrates that ES mainly influences performance through indirect pathways. Third, it offers practical recommendations for managers and policymakers aiming to promote sustainable, digitally enabled, and innovative business models in MSMEs.

Limitations

Several limitations are relevant when interpreting these findings. First, the sample was limited to 345 Peruvian MSMEs. This limitation constrains the applicability of the findings to other Latin American countries or developed economies. Second, performance measures relied on manager-reported data. This feature may have introduced potential common method bias and perceptual inaccuracies. Third, the cross-sectional design prevents causal inference. It may hide time-lagged effects between ES, DT, innovation, and performance.

Moreover, unique cultural and institutional features such as levels of informality, enforcement of regulations, and managerial attitudes toward sustainability may influence the observed relationships in ways that differ across contexts. Another limitation is the lack of segmentation analysis based on firm size (micro-, small, and medium-sized), despite evidence that size could moderate the ES–performance link. Finally, the multi-industry sample, while representative, introduces sector heterogeneity that was not fully addressed through cluster analysis because of sample size limitations.

Future research directions

Future studies should seek to address these limitations. For instance, longitudinal designs would capture the evolving, potentially delayed effects of ES and DT on innovation and performance. Likewise, objective operational and financial data could improve measurement accuracy and lessen reliance on perception-based measures.

Another promising area for future research is segmentation based on firm size, age, export orientation, or market scope. Such analyses could reveal diverse effects and identify strategic profiles for which ES and DT integration is most advantageous. Comparative studies across Latin American countries and different industries could also assess the external validity of the proposed capability alignment model and facilitate cross-national learning.

Researchers should also evaluate the effectiveness of combined policy interventions that merge sustainability regulations with funding and training for DT and innovation to speed up performance improvements in resource-constrained MSME settings. Finally, industry-specific analyses could offer more detailed insights into how sector characteristics influence the relationships between ES, DT, and innovation.

CRediT authorship contribution statement

González-Cruz Tomás: Writing – review & editing, Writing – original draft, Conceptualization. **Clemente-Almendros José-Antonio:** Investigation, Validation, Data curation, Formal analysis. **Castillo-Martínez Julennys-Carolina:** Writing – original draft, Writing – review & editing. **Díaz-Peláez Alejandro:** Formal analysis, Data curation.

Appendix A. Methodological flow

- **First step: Measurement model**
  - Load analysis
  - Reliability: Cronbach's alpha > 0.7; composite reliability > 0.70; Rho_A > 0.70
  - AVE > 0.50
  - HTMT < 0.90
  - Inner model
- **Second step: Structural model**
  - Bootstrapping
  - Structural model assessment
  - Hypothesis testing
  - External model
- **Third step: Predictive analysis**
  - Coefficient of determination (R2)
  - Goodness of fit > 0.5

- Effect size: ⟨ 0.02 small effect, ⟩ 0.15 medium effect, $>$ 0.35 large effect
- SRMR $<$ 0.08

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