

Exploring Sustainability and Digital Transformation in Smes: A Cluster Analysis Approach

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Abstract

The transition towards sustainability represents a major challenge for small and medium enterprises (SMEs), in the context of increasing digitalization and structural barriers. This study aims to explore the heterogeneity of SMEs in terms of sustainability practices, digitalization and perceived barriers, using a cluster analysis approach. The analysis is based on primary data collected through a questionnaire survey conducted in 2025 among 406 SMEs from Romania. A two-step clustering procedure was applied, combining hierarchical clustering Ward's method and K-means clustering. The results reveal three distinct clusters of SMEs, such as Sustainability Leaders, Transitional SMEs and Low Adoption SMEs. The findings indicate that sustainability and digitalization act as key drivers of SME differentiation, while perceived barriers play a secondary role. SMEs actively involved in sustainability practices report higher awareness of barriers, illustrating that experience increases sensitivity to institutional constraints. The results show that transition towards sustainability is gradual. The coexistence of different levels of sustainability engagement underlines the need for differentiated support mechanisms tailored to the specific needs of firms at various stages of development. The study contributes to the literature by highlighting the heterogeneous nature of SMEs' green transition and provides relevant policy implications for supporting firms at different stages of sustainability adoption.

Keywords

Sustainability; digitalization; barriers; SMEs; cluster analysis

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Introduction

In recent years, sustainability has become a central concept for businesses worldwide. Small and medium enterprises (SMEs) play an important role in achieving sustainability objectives. Their transition toward sustainable business remains uneven as it is influenced by multiple diverse elements (Costa Melo et al., 2023). Although existing literature explores sustainability and digital transformation in SMEs, as well as the challenges associated with their adoption, these streams are analyzed separately. There is a lack of integrative studies that examine sustainability practices, digitalization and perceived barriers simultaneously within SMEs. Most studies adopt a linear perspective, focusing either on drivers or barriers, rather than capturing the interaction between enabling factors and constraints in sustainability transitions. Many studies overlook the fact that SMEs may be at different stages of sustainability adoption. Especially, the role of perceived barriers is insufficiently explored in relation to different types of companies. Central and Eastern European countries remain underrepresented in the literature, with limited empirical evidence from Romania.

The present study aims to explore the patterns of sustainability practices, digitalization and perceived barriers among SMEs, with a particular focus on identifying distinct groups of SMEs. The study seeks to identify typologies that reflect different levels of engagement in the green transition, using cluster analysis approach. In order to address the research objective, the study is guided by the following research questions:

- RQ1: What distinct patterns of sustainability practices, digitalization and perceived barriers can be identified among SMEs?
- RQ2: How do SMEs differ in their levels of sustainability and digitalization adoption?
- RQ3: What role play the perceived barriers in differentiating SMEs?
- RQ4: Can SMEs be classified into distinct typologies based on these dimensions?

1. Literature review

A bibliometric analysis was performed based on Web of Science Database, in order to identify the main research trends related to sustainability, digitalization and SMEs. The search query resulted in 161 relevant publications for the period 2015–2026, with a cumulative number of 2,217 citations, an average of 13.77 citations per document and h-index of 25. Year 2025 was the peak for academic interest in sustainability and digitalization in SMEs. The largest share of studies is concentrated in Environmental Sciences area (42), followed closely by Green & Sustainable Science & Technology (41) and Environmental Studies (41). At the same time, a significant number of studies are classified within Management (37) and Business (39), reflecting the increasing interest in the organizational and strategic implications of sustainability and digital transformation. The presence of Engineering (15), Economics (12), and Computer Science (11) further highlights the technological and economic dimensions of the field, especially in relation to innovation, digital tools and process optimization. The countries with the highest research output in the field of sustainability and digitalization are India followed by Germany, England, Italy and Indonesia. The keyword co-occurrence network performed in VosViewer highlights two main research directions, respectively sustainability and digital transformation in SMEs together with barriers and challenges related to adoption, emphasizing the need for integrated approaches. The highest research intensity is concentrated around the keywords sustainability, SMEs and digital transformation, confirming their central role in the literature.

SMEs are considered the backbone of many economies (Costa Melo et al., 2023), as they represent approximately 90% of global businesses and 50% of the workforce. Sustainability is defined as the adoption of business strategies that meet the current needs of the enterprise and its stakeholders while protecting and enhancing the human and natural resources needed in the future (Paliwal et al., 2024). Modern sustainability in SMEs focuses on balancing three pillars: economic, social and environmental (Machado et al., 2024). Sustainability Oriented Innovation (SOI) enables firms to create solutions that minimize negative environmental impacts while generating social benefits and profit (Zaki et al., 2025). Circular Economy (CE) has become an essential lever for sustainable supply chain management, emphasizing resource efficiency, waste reduction and life cycle management (Castillo et al., 2025).

Digitalization is no longer just an option, but a strategic necessity for SMEs seeking to become sustainable (Isensee et al., 2025). Technologies such as Artificial Intelligence, Internet of Things and Big Data enable SMEs to monitor and reduce energy consumption, carbon footprint and waste generation (Awad & Martín-Rojas, 2024). AI forecasting systems can reduce excess inventory by up to 20%, preventing waste (Castillo et al., 2025). AI and machine learning algorithms can optimize production processes, leading to a reduction in energy consumption of up to 30% and material waste of approximately 20% (Setyadi et al., 2025). Digital transformation improves product traceability and supply chain transparency, which are critical elements for implementing the principles of the circular economy (Kamšalić et al., 2020). The use of digital platforms enables SMEs to participate in collaborative innovation networks and co-create social and environmental value together with other partners (Awad & Martín-Rojas, 2024). The adoption of digital technologies improves decision making through access to real time data, leading to increased operational efficiency and longterm competitiveness (Farace & Tarabella, 2024).

Despite the clear benefits, SMEs face significant obstacles that slow down the adoption of sustainable practices and related digital technologies. The high costs of implementing green technologies and advanced digital systems are the main barrier, as SMEs often have limited financial resources (Radicic & Petković, 2023). A conservative organizational culture and resistance from employees or management to new ways of operating can hinder sustainability initiatives (Farace & Tarabella, 2024). Many SMEs suffer from a lack of technical knowledge and digital literacy among employees, which makes it difficult to manage new processes (Radicic & Petković, 2023). Some SMEs do not have a defined strategic vision for sustainable digital transformation, often acting reactively rather than proactively (Zaki et al., 2025). Lack of support from regulatory authorities, outdated legislation and uncertainty regarding longterm return on investment discourage the adoption of these practices (León-Gómez et al., 2025). SMEs overcome the lack of internal financial resources by participating in collaborative research and development (R&D) projects (Silvestri et al., 2023). By aligning digital transformation with business strategy, SMEs can adopt financial technology platforms. These play a key role in improving access to funding sources, loans and investors, providing the

capital needed to support innovation and digital adaptation (Kurniasari et al., 2023). Aligning environmental practices with corporate strategy facilitates access to external financial assistance, such as tax benefits, government grant or funding programs (León-Gómez et al., 2025).

Based on the literature and the exploratory nature of the study, the following hypotheses are proposed:

- H1: SMEs show heterogeneous patterns in terms of sustainability practices, digitalization and perceived barriers;
- H2: Sustainability practices and digitalization tend to occur within the same groups of SMEs;
- H3: SMEs with higher levels of sustainability adoption perceive barriers strongly;
- H4: Perceived barriers play a secondary role compared to sustainability and digitalization in differentiating SMEs.

2. Methodology

The empirical analysis is based on primary data collected through a questionnaire survey conducted in 2025 among SMEs entrepreneurs and managers in Romania. A total of 406 valid responses were obtained, providing a robust dataset for analysis. The questionnaire included Likert-scale items (1–5) measuring sustainability practices, digitalization and perceived barriers in the transition towards a green economy. The analysis is based on 15 variables, such as: sustainable packaging, waste reduction, environmentally friendly technology, resource consumption monitoring, implementation of waste reduction policies, prioritization of green technology investments, digital technology for green project innovation, digitalization of resource consumption, reducing resources, consumption and dematerialization, optimizing processes, bureaucratic procedures, high costs, lack of information, lack of financial resources, unclear regulations. The variables are grouped into three dimensions, sustainability, digitalization and barriers. This selection of variables allows for the simultaneous capture of enabling factors and constraints, providing an integrated perspective on how SMEs approach the transition to sustainability. The bibliometric review was performed using Web of Science Database and VOSViewer tool in order to identify the relevant studies for the literature body. Statistical analysis employed the following: descriptive statistics, hierarchical cluster analysis and ANOVA analysis performed in SPSS. All variables were standardized using z-scores before clustering to ensure comparability.

3. Results and discussion

Descriptive statistics indicate that overall SMEs report moderate to high levels of sustainability adoption, particularly in areas such as waste reduction, resource monitoring and the use of environmentally friendly technologies. Digitalization is also relatively well integrated, especially in process optimization and resource efficiency. Respondents highlight the persistence of barriers, including financial constraints and bureaucratic procedures, which continue to affect the green transition (Table no. 1).

Table no. 1. Descriptive statistics

Categories	Indicators	Mean	Standard deviation
sustainability	Sustainable packaging	4.50	0.807
	Waste reduction	3.99	0.770
	Environmentally friendly technology	4.01	0.868
	Resource consumption monitoring	4.25	0.819
	Implementation of waste reduction policies	4.06	0.844
	Prioritization of green technology investments	4.04	0.825
digitalization	Digital technology for green project innovation	4.06	0.864
	Digitalization of resource consumption	4.21	0.751
	Reducing Resource Consumption and Dematerialization	4.20	0.785
	Optimizing Processes	4.33	0.807
barriers	Bureaucratic Procedures	4.05	0.678

	High Costs	4.01	0.879
	Lack of Information	3.93	0.840
	Lack of Financial Resources	4.14	0.726
	Unclear Regulations	4.07	0.687

The hierarchical cluster analysis using Ward's method and squared Euclidean distance was employed to determine the optimal number of clusters. The examination of the agglomeration schedule revealed a substantial increase in the fusion coefficients at the final stage, supporting a three-cluster solution, refined through k-means clustering (Tabel no. 2).

Table no. 2. Final clusters centers

	Clusters		
	1	2	3
Zscore Unclear Regulations	0.28621	-1.15869	-0.15605
Zscore Lack of Financial Resources	0.16561	-0.86123	-0.05736
Zscore Lack of Information	0.11052	-0.90264	0.01832
Zscore High Costs	0.28006	-0.87137	-0.19800
Zscore Bureaucratic Procedures	0.20624	-1.23900	-0.04269
Zscore Optimizing Processes	0.54897	-1.60335	-0.40618
Zscore Reducing Resource Consumption and Dematerialization	0.44987	-1.79521	-0.24977
Zscore Digitalization of resource consumption	0.48882	-1.51456	-0.34668
Zscore Digital technology for green project innovation	0.46858	-2.10955	-0.21879
Zscore Prioritization of green technology investments	0.48024	-2.01328	-0.24992
Zscore Implementation of waste reduction policies	0.53653	-2.16015	-0.29459
Zscore Resource consumption monitoring	0.39468	-2.15444	-0.11911
Zscore Environmentally friendly technology	0.60351	-1.71721	-0.45437
Zscore Waste reduction	0.46035	-2.00311	-0.22692
Zscore Sustainable packaging	0.47735	-2.42154	-0.17584

Cluster 1 is characterized by above average values across all sustainability and digitalization indicators. SMEs in this group implement green practices actively, including sustainable packaging, waste reduction policies and environmentally friendly technologies. They also make extensive use of digital solutions to optimize processes and reduce resource consumption. Although these firms are aware of existing barriers, they are not significantly constrained by them. This cluster can be defined as Sustainability Leaders.

Cluster 2 shows significantly below average values across all variables, indicating a very low level of engagement in both sustainability practices and digitalization. SMEs in this group appear to stay behind in the transition towards green economy. They report lower perceptions of barriers, which may reflect limited involvement rather than favorable external conditions. This cluster is defined as Low Adoption SMEs.

Cluster 3 represents firms with moderate levels of sustainability and digitalization. These firms are in a transition phase, gradually adopting green practices and integrating digital solutions. Their perception of barriers is relatively neutral, indicating a balanced position between opportunities and constraints. This group is defined as Transitional SMEs.

Figure no. 1 illustrates the distribution of SMEs across the three identified clusters. The results show that the majority of SMEs (51.5%) belong to Cluster 1, characterized by a high level of sustainability practices and digitalization. Cluster 3 includes 41.4% of the sample and represents SMEs in transition, with moderate levels of adoption. Cluster 2 includes only 7.1% of SMEs, reflecting a group of firms facing significant barriers and demonstrating low levels of engagement in sustainability and digital transformation.

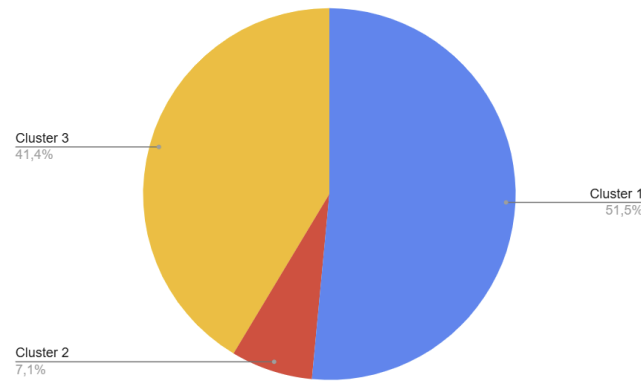


Figure no. 1. Distribution of SMEs across clusters

The ANOVA analysis results confirm significant differences across clusters for all variables (Table no. 3).

Table no. 3. ANOVA results for cluster differentiation

	F	Sig.
Zscore Unclear Regulations	35.144	0.000
Zscore Lack of Financial Resources	14.848	0.000
Zscore Lack of Information	13.958	0.000
Zscore High Costs	25.187	0.000
Zscore Bureaucratic Procedures	30.811	0.000
Zscore Optimizing Processes	138.893	0.000
Zscore Reducing Resource Consumption and De-materialization	113.879	0.000
Zscore Digitalization of resource consumption	102.612	0.000
Zscore Digital technology for green project innovation	166.082	0.000
Zscore Prioritization of green technology investments	155.240	0.000
Zscore Implementation of waste reduction policies	217.140	0.000
Zscore Resource consumption monitoring	145.097	0.000
Zscore Environmentally friendly technology	189.571	0.000
Zscore Waste reduction	144.742	0.000
Zscore Sustainable packaging	246.573	0.000

The highest F-values are associated with sustainability indicators, such as sustainable packaging and waste reduction policies, highlighting their central role in differentiating SMEs. Digitalization variables also show a strong presence, especially process optimization and the use of digital technologies in green projects. Perceived barriers show lower F-values, suggesting that they are not the primary drivers of cluster formation. The distances between final cluster centers further validate the robustness of the clustering solution. The largest distance is observed between Sustainability Leaders and Low Adoption SMEs clusters, indicating strong heterogeneity. Transitional SMEs are positioned closer to Sustainability Leaders cluster, supporting the interpretation of a gradual transition toward higher levels of sustainability and digitalization.

The results suggest that sustainability and digitalization act as primary drivers of SMEs differentiation, while perceived barriers play a secondary role. SMEs that are more actively engaged in sustainability practices tend to report higher awareness of barriers, indicating that experience increases sensitivity to institutional and financial constraints.

Cluster analysis results provide clear answers to the research questions and support the proposed hypotheses. In relation to RQ1 and RQ4, the findings confirm the existence of distinct patterns among SMEs, as the analysis identified three well defined clusters. This supports H1, demonstrating the heterogeneous nature of SMEs in terms of sustainability practices, digitalization and perceived barriers. Regarding RQ2, the results show substantial differences in the levels of sustainability and digitalization across clusters. These findings confirm H2, highlighting the co-occurrence of sustainability practices and digitalization within the same groups of firms. In relation to RQ3, the analysis reveals that perceived barriers do not represent the primary factor differentiating SMEs. This is further supported by the ANOVA results, where sustainability and digitalization variables exhibit higher F-values compared to barriers. Consequently, H4 is supported,

indicating that barriers play a secondary role in shaping firm typologies. The results provide support for H3, as firms in the Sustainability Leaders cluster report higher awareness of barriers compared to less engaged firms. This suggests that increased involvement in sustainability practices enhances sensitivity to institutional and financial constraints. Overall, the findings highlight a gradual transition pattern among SMEs, confirming the exploratory assumptions of the study and hypotheses H1, H2, H3, H4.

Conclusions

This study provides empirical evidence on the heterogeneity of SMEs in Romania regarding sustainability practices, digitalization and perceived barriers. The findings highlight the existence of three distinct clusters, such as Sustainability Leaders cluster, Low Adoption SMEs cluster and Transitional SMEs cluster, reflecting different stages of engagement in the green transition. The results demonstrate that sustainability and digitalization are closely interconnected and represent key drivers of organizational transformation. Firms that actively integrate digital technologies are more likely to adopt advanced sustainability practices, confirming the role of digitalization as an enabler of green transition. Although barriers such as financial constraints and bureaucratic procedures are present, they are not the primary factor structuring the behavior of SMEs. Instead, their impact becomes more visible among firms that are already engaged in sustainability initiatives, suggesting that awareness of constraints increases with experience.

The findings highlight the need for differentiated policy approaches tailored to the heterogeneity of SMEs in their sustainability and digitalization journeys. Given the existence of distinct clusters, a one-size-fits-all policy approach will not be effective. For SMEs identified as Sustainability Leaders, policies should focus on scaling and innovation. These firms would benefit from advanced funding schemes, incentives for green innovation and support for internationalization. Encouraging their role as mentors within business ecosystems could further accelerate the diffusion of sustainable practices. Transitional SMEs require targeted support to advance toward higher levels of sustainability. Policies should emphasize capacity building, including training programs, digital skills development and access to technical consultancy. Facilitating partnerships with universities, research institutions and innovation hubs may accelerate their transition. For Low Adoption SMEs, the priority lies in raising awareness and reducing entry barriers. Simplifying bureaucratic procedures, improving access to funding and providing clear guidelines for green practices are essential. Basic support instruments, such as introductory training and financial incentives, may help these firms initiate their sustainability journey. From a managerial perspective, the results suggest that firms should adopt a strategic and integrated approach to sustainability and digitalization. Managers are encouraged to view digital transformation as a key enabler of sustainable business models.

This study is based on cross-sectional data, which limits the ability to capture dynamic changes over time. Future research could adopt longitudinal approaches to better understand the evolution of sustainability practices among SMEs. The study focuses on SMEs in Romania, which may limit the generalization of the findings. Institutional, economic and cultural factors may differ across countries, suggesting the need for comparative studies at the European or international level. Future research could explore the causal relationships between digitalization and sustainability adoption, as well as the role of institutional factors in shaping firm behavior. Additionally, integrating qualitative approaches may provide deeper insights into the decision-making processes of SMEs. The results reveal that the transition towards sustainability among SMEs is gradual. The coexistence of different levels of engagement highlights the need for differentiated support mechanisms tailored to the specific needs of the SMEs at various stages of development.

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Generative Artificial Intelligence (GenAI) usage statement:

No GenAI tool was used in the development of this paper.

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