

BARRIERS TO GREEN INNOVATION ADOPTION IN SMES AND LARGE COMPANIES: EVIDENCE FROM CENTRAL EUROPE

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Received 02 05 2026; Accepted 20 05 2026

Abstract

The transition towards a low-carbon and resource-efficient economy presents both opportunities and challenges for enterprises of different sizes. Green innovation can enhance environmental performance, improve resource efficiency, and strengthen long-term competitiveness; however, its adoption is often constrained by internal and external barriers. This paper examines barriers to green innovation adoption in manufacturing enterprises in Central Europe, with particular attention to differences among micro, small, medium-sized, and large enterprises. The study is based on a questionnaire survey conducted among 304 managers of manufacturing companies. The analysis covers fourteen perceived barriers related to finance, regulation, technology, human resources, market conditions, innovation priorities, access to knowledge, and cooperation with external partners. As the data were ordinal and did not meet the assumption of normality, the Kruskal–Wallis test was applied, followed by the Dwass–Steel–Critchlow–Fligner post-hoc test. The results reveal statistically significant differences among enterprise-size categories in three areas: lack of internal financial resources, the perception of material consumption reduction as a low innovation priority, and insufficient cooperation with research institutions and universities. The findings suggest that company size influences the perception of selected barriers to green innovation adoption. The paper highlights the need for differentiated support mechanisms, improved access to finance, stronger knowledge transfer, and closer collaboration between enterprises and research institutions.

Keywords: *Green Innovations, Small and Medium Enterprises, Large Companies, Barriers.*

JEL Codes: *O31, Q55, Q56, L25.*

Introduction

The transition towards a low-carbon and resource-efficient economy has become one of the key strategic challenges for enterprises in Europe. Environmental regulation, rising energy costs, pressure from supply chains, and increasing stakeholder expectations encourage firms to adopt greener production processes, reduce emissions, improve material efficiency, and introduce environmentally oriented innovations. Green innovation is therefore no longer perceived merely as a voluntary environmental activity, but increasingly as a factor of competitiveness, resilience, and long-term business sustainability.

This issue is particularly relevant for manufacturing enterprises, where production processes are closely connected with energy use, material inputs, waste generation, and technological modernization.

In Central Europe, firms are exposed to the combined effects of EU environmental objectives, national support schemes, increasing cost pressures, and changing expectations from customers and business partners. These conditions create incentives for green innovation, but they also make the barriers to its adoption more visible.

Understanding these barriers is therefore important not only for individual managers, but also for policymakers and business-support institutions that design instruments intended to accelerate the green transition.

Enterprises of different sizes do not face this transition under the same conditions. Small and medium-sized enterprises (SMEs) play an essential role in employment, regional development, and innovation; however, they

often operate with limited financial, human, and technological resources. Their ability to introduce green innovations may be constrained by high initial investment costs, insufficient access to external finance, shortages of skilled workers, limited access to information, and weaker cooperation with research institutions. At the same time, SMEs constitute a large share of the business population and contribute significantly to the environmental footprint of the enterprise sector, which makes their involvement in the green transition particularly important (OECD, 2021; European Commission, 2024).

Large companies usually have better access to capital, advanced technologies, internal expertise, and formalized innovation processes. They are also more likely to be integrated into international supply chains and subject to environmental reporting, ESG requirements, and stricter regulatory scrutiny. However, their green transformation may be complicated by organizational complexity, path dependency, high coordination costs, and the need to adapt established production systems. In this respect, large companies may not necessarily face fewer barriers, but rather different types of barriers than SMEs.

Existing research has examined barriers to green innovation primarily in the SME segment, where financial constraints, regulatory

uncertainty, and limited technological capabilities are repeatedly identified as major obstacles (Klewitz & Hansen, 2014; Pollák & Dorčák, 2016; Demirel & Kesidou, 2019; Passaro et al., 2023; Giudici et al., 2023). However, only a limited number of studies compare these barriers across different company-size categories. This creates a research gap, as company size may significantly influence how companies perceive and manage the transition towards greener production. A comparative analysis of SMEs and large companies can therefore provide a more nuanced understanding of the barriers that hinder green innovation adoption.

The aim of this paper is to examine and compare barriers to green innovation adoption in SMEs and large companies in Central Europe. The research focuses on manufacturing enterprises, as this sector is closely associated with material and energy consumption, emissions, waste generation, and technological modernization. By identifying differences in the perceived severity of barriers according to company size, the paper contributes to the discussion on how policy instruments, financial support, and cooperation mechanisms should be differentiated for SMEs and large companies. Figure 1 summarizes the conceptual logic of the study.

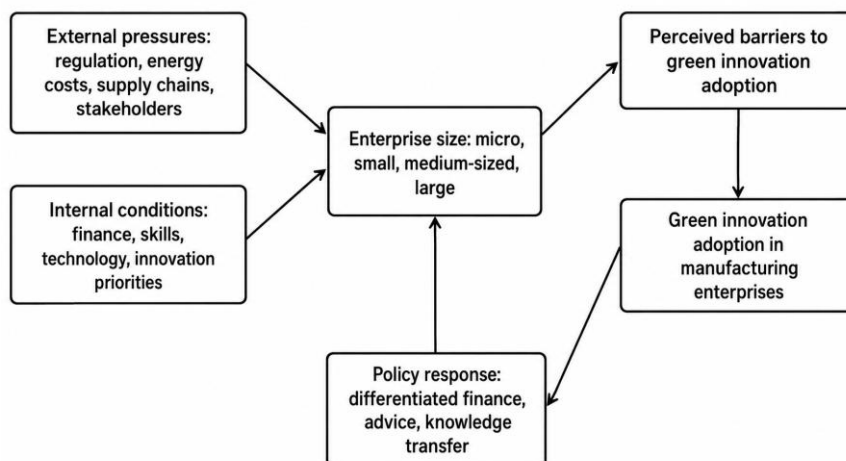


Figure 1. Conceptual framework of barriers to green innovation adoption by enterprise size

**Source: Authors.*

Literature review

Green innovation refers to the development and implementation of new or improved products, processes, technologies, organizational practices,

or business models that reduce negative environmental impacts while supporting economic performance. The concept is closely associated with eco-innovation, sustainable

innovation, circular economy principles, and corporate environmental responsibility. Green innovation may involve energy-efficient technologies, waste reduction, recycling, cleaner production, low-emission processes, renewable energy solutions, eco-design, and resource-saving business models (Klewitz & Hansen, 2014; Dorčák, Markovič, Pollák, 2017; Takalo & Tooranloo, 2021; Zastempowski, 2023). From a theoretical perspective, the adoption of green innovation can be explained through several complementary approaches. The resource-based view emphasizes the importance of internal capabilities, including knowledge, technology, skilled labour, managerial competencies, and financial resources. Companies that can develop and combine these capabilities may gain competitive advantages through improved efficiency, lower material and energy costs, and a stronger environmental reputation (Borsatto & Bazani, 2021). Institutional theory highlights the role of external pressures, such as environmental regulation, public policy, customer expectations, supply-chain requirements, and social norms. These pressures encourage companies to adopt green innovations; however, they may also create administrative and compliance burdens, particularly for companies with limited organizational capacities (Del Rio, Peñasco, & Romero-Jordán, 2017; Bamel et al., 2024). Evolutionary and dynamic capability perspectives further suggest that companies must continuously adapt to technological change, regulatory development, and changing market conditions to remain competitive during the green transition (Arici & Uysal, 2022; Afeltra et al., 2023).

The literature shows that SMEs and large companies differ substantially in their ability to respond to these pressures. SMEs are often more flexible and closer to local markets; nevertheless, their innovation capacity is constrained by limited financial reserves, weaker bargaining power, smaller management teams, and lower access to specialized knowledge. As a result, SMEs may perceive green innovation as risky, costly, or difficult to implement, particularly when the payback period is long and market demand remains uncertain (Demirel & Kesidou, 2019; Testa et al., 2022; Passaro et al., 2023). Recent European evidence further confirms that

SMEs continue to face difficulties when implementing resource-efficiency measures, particularly in relation to costs, administrative complexity, and access to support mechanisms (European Commission, 2024). Large companies usually possess more developed innovation systems, stronger financial capacities, and greater access to external expertise. They may also benefit from economies of scale when implementing energy-efficient technologies or circular production systems. However, they face different types of challenges. Green transformation in large enterprises often requires changes across complex organizational structures, multiple production sites, established supplier networks, and formalized decision-making processes. Large companies are also more exposed to ESG reporting obligations, stakeholder scrutiny, and reputational risks. Consequently, their barriers are frequently associated not only with resources, but also with coordination, compliance, organizational inertia, and the integration of sustainability into existing corporate systems (Aboelmaged & Hashem, 2019; Kluza et al., 2021; Boiral et al., 2023).

Financial barriers remain among the most frequently discussed obstacles to green innovation adoption. In SMEs, the primary challenges often include insufficient internal financial resources, limited access to loans, and uncertainty regarding the return on investment. Green technologies may require substantial upfront expenditures, while benefits are often realized only gradually through energy savings, efficiency gains, or enhanced market positioning. Although large companies generally have better access to capital, their investment decisions may be constrained by the scale of required transformation, shareholder expectations, and the need to coordinate investments across multiple units and production processes (Ghisetti & Pontoni, 2015; Giudici et al., 2023; Agrawal et al., 2024).

Technological and knowledge-related barriers also vary according to firm size. SMEs often lack internal research and development capacities, technical specialists, and information about suitable green technologies. As a result, they may depend heavily on external consultants, suppliers, public support schemes, or cooperation with universities and research institutions (Belas

& Rahman, 2023). In contrast, large companies may possess internal R&D departments and access to advanced technologies but still face difficulties integrating new green solutions into existing production systems, legacy technologies, and complex operational processes (Cainelli, De Marchi, & Grandinetti, 2015; Kougias et al., 2021).

Regulatory and administrative barriers represent another important dimension of green innovation adoption. Environmental standards, carbon-reduction policies, energy-efficiency requirements, and sustainability reporting obligations can stimulate green innovation by creating incentives and pressure for change. However, when regulations are overly complex, unstable, or administratively demanding, they may discourage companies from investing in green solutions. SMEs are particularly sensitive to administrative burdens because they typically possess fewer legal and compliance capacities. Large companies, in contrast, are generally better equipped to manage formal compliance, but face higher public visibility and stronger pressure from investors, customers, and regulators (European Commission, 2023; Cifuentes-Faura, 2022; Horbach, Rennings, & Rexhäuser, 2022).

Cooperation with external partners is widely recognized as an important enabler of green innovation. Collaboration with suppliers, customers, universities, research institutions, public agencies, and larger enterprises can improve access to knowledge, technology, funding, and practical experience. For SMEs, such cooperation may compensate for limited internal resources and reduce the risks associated with green innovation adoption. For large companies, cooperation may support open innovation, supply-chain decarbonization, and systemic sustainability transformation. Nevertheless, insufficient trust, lack of suitable partners, weak information flows, and limited institutional support may reduce the effectiveness of cooperation mechanisms (Filipović et al., 2022; Lagioia et al., 2023; Figura & Vevere, 2025).

Overall, the literature suggests that company size shapes both the intensity and the nature of green innovation barriers. SMEs are more likely to struggle with financing, skills, technological capacity, and access to external

knowledge, whereas large companies are more likely to face organizational complexity, transformation costs, compliance pressure, and coordination challenges. This distinction is highly relevant for policy design, as uniform support instruments may not adequately address the specific needs of different company-size groups (Feng et al., 2024). More effective green innovation policies should therefore combine financial support, regulatory simplification, advisory services, knowledge transfer, and cooperation platforms tailored to the specific conditions of SMEs and large companies.

Methodology

The study examines and compares barriers that limit the adoption of green innovations in manufacturing enterprises in Central Europe, with particular attention to differences among micro, small, medium-sized, and large companies. The research focuses on whether enterprise size influences the perceived severity of selected financial, regulatory, technological, human-resource, market-related, and cooperation-related barriers.

The empirical part of the study is based on a quantitative research design. Primary data were collected through a structured questionnaire administered to managers of manufacturing enterprises. The final research sample consisted of 304 respondents, representing small and medium-sized enterprises and large companies operating in the manufacturing sector. Respondents were selected from enterprises active in Central Europe, where the transition towards environmentally sustainable production is strongly shaped by regulatory pressure, technological modernization, and access to financial resources.

Data collection was conducted using the Computer-Assisted Telephone Interviewing method. This approach enabled standardized data collection and ensured that all respondents received identical instructions and questionnaire structure. The questionnaire consisted of eleven substantive questions and three classification questions. The substantive section focused on the adoption of green innovations and the perceived importance of selected barriers, while the classification section captured basic enterprise characteristics, including company size.

Respondents evaluated fourteen barriers to green innovation adoption identified in the literature, including uncertain market demand, uncertain return on investment, insufficient internal financial resources, limited access to subsidies and tax incentives, weak regulatory incentives, lack of external financing, low priority of energy consumption reduction, technical and technological barriers, lack of skilled workers and technological capacity, dominance of established manufacturers, low priority of material consumption reduction, limited access to external knowledge and technical support, lack of suitable business partners, and insufficient cooperation with research institutions and universities.

The barriers were measured using an ordinal scale reflecting their perceived severity: very severe barrier (4), severe barrier (3), minor barrier (2), not a barrier (1), and not applicable (0). Since the variables were ordinal and the assumption of normality was not satisfied, non-parametric statistical procedures were applied.

The data were processed using the statistical software STATA. The hypotheses were tested at the significance level of $\alpha = 0.05$. First, descriptive statistics were used to summarize the structure of the research sample and the distribution of responses. Subsequently, the Kruskal-Wallis test was applied to identify statistically significant differences among several independent company-size groups. When statistically significant differences were detected, the Dwass-Steel-Critchlow-Fligner post-hoc test was used to examine pairwise differences between individual groups. This procedure was selected as it is suitable for ordinal data and helps control the risk of Type I error in multiple comparisons.

The methodological approach therefore enables the identification of differences in perceived green innovation barriers across SMEs and large companies and provides a basis for formulating size-specific policy and managerial recommendations.

Respondents evaluated 14 specific barriers, each presented separately: Uncertain market demand (Q03_A), Uncertain return on investment or excessively long payback period for green innovation adoption (Q03_B), Lack of financial resources within the company (Q03_C),

Insufficient access to existing subsidies and tax incentives (Q03_D), Existing regulations and structures not providing incentives for green innovation adoption (Q03_E), Lack of external financing (Q03_F), Energy consumption reduction not being considered an innovation priority (Q03_G), Technical and technological barriers (e.g., outdated technical infrastructure) (Q03_H), Lack of skilled workers and technological capacity within the company (Q03_I), Market dominance by established manufacturers (Q03_J), Material consumption reduction not being considered an innovation priority (Q03_K), Limited access to external information and knowledge, including underdeveloped technical support services (Q03_L), Lack of suitable business partners (Q03_M), and Lack of cooperation with research institutions and universities (Q03_N).

Results and discussion

Fernando et al. (2021) emphasized that competitiveness can be strengthened through recycled product development, particularly in sectors such as the automotive and construction industries. This underlines the broader importance of green innovation as a means of improving both environmental performance and business competitiveness. In line with this perspective, the present study examines whether enterprises of different size categories perceive barriers to green innovation adoption differently. The analysis addresses the following research question: Do statistically significant differences exist in the perceived severity of green innovation adoption barriers among micro, small, medium-sized, and large enterprises?

The following hypotheses were tested:

- **H₀ (Employment Size):** There are no statistically significant differences in the perceived severity of green innovation adoption barriers among enterprises of different size categories.

- **H₁ (Employment Size):** The perceived severity of green innovation adoption barriers differs significantly among enterprises of different size categories.

Table 1 presents the results of the Kruskal–Wallis test for all fourteen examined barriers. Statistically significant differences at the

5% significance level were identified for three barriers: lack of financial resources within the company (Q3_C; $p = 0.019$), material consumption reduction not being considered an innovation priority (Q3_K; $p = 0.008$), and lack of cooperation with research institutions and universities (Q3_N; $p = 0.009$). These results indicate that enterprise size significantly influences the perception of these barriers.

The lowest p-values was observed for Q3_K and Q3_N, suggesting that innovation priorities related to material consumption and cooperation with research institutions vary across

enterprise size categories. The result for Q3_C further confirms that internal financial capacity remains an important factor differentiating enterprises in their ability to adopt green innovations. Although other variables, such as energy consumption reduction not being considered an innovation priority (Q3_G; $p = 0.061$), lack of skilled workers and technological capacity (Q3_I; $p = 0.056$), and technical and technological barriers (Q3_H; $p = 0.099$), did not reach the conventional 5% significance level, their values suggest potential relevance and warrant further investigation in future research.

Table 1. Non-parametric test – Kruskal-Wallis

	χ^2	df	p	ϵ^2
Q3_A	3.69	3	0.297	0.01234
Q3_B	6.41	3	0.093	0.02144
Q3_C	9.94	3	0.019	0.03324
Q3_D	3.60	3	0.308	0.01204
Q3_E	2.96	3	0.398	0.00989
Q3_F	4.18	3	0.243	0.01397
Q3_G	7.37	3	0.061	0.02464
Q3_H	6.26	3	0.099	0.02095
Q3_I	7.58	3	0.056	0.02535
Q3_J	3.27	3	0.352	0.01092
Q3_K	11.72	3	0.008	0.03919
Q3_L	5.20	3	0.157	0.01740
Q3_M	3.48	3	0.323	0.01164
Q3_N	11.65	3	0.009	0.03895

*Source: Authors.

Following the identification of statistically significant differences in the Kruskal-Wallis test, the Dwass-Steel-Critchlow-Fligner (DSCF) test (a non-parametric post-hoc test) was applied to further examine pairwise differences between associated variables (Table 2-4).

Table 2 presents the results of the Dwass-Steel-Critchlow-Fligner post-hoc test for the barrier related to the lack of financial resources within the company (Q3_C). A statistically significant pairwise difference was found only between large enterprises and micro enterprises ($p = 0.016$), indicating differences in the

perception of internal financial constraints between the smallest and the largest companies in the sample.

The finding is consistent with the assumption that enterprise size influences the availability of internal financial resources for green innovation adoption. Micro enterprises typically operate with more limited capital reserves and lower investment capacity, which may make the initial costs of green technologies more difficult to absorb. Large enterprises, in contrast, are generally better positioned to allocate internal funds to environmental

innovation projects, although they may still face substantial transformation costs due to the scale and complexity of their operations. The absence of statistically significant differences among the remaining pairs of enterprise-size groups

suggests that financial barriers do not increase linearly with company size but are particularly pronounced when comparing micro and large firms.

Table 2. Pairwise comparisons between groups – Q3_C

		W	p
Large	Medium	-3.06	0.133
Large	Micro	-4.20	0.016
Large	Small	-2.28	0.372
Medium	Micro	-1.35	0.775
Medium	Small	1.04	0.882
Micro	Small	2.35	0.344

**Source: Authors.*

Table 3 presents pairwise comparisons for the barrier indicating that material consumption reduction is not perceived as an innovation priority (Q3_K). Statistically significant differences were identified between large and medium-sized enterprises ($p = 0.038$), medium-sized and micro enterprises ($p = 0.020$), and medium-sized and small enterprises ($p = 0.043$). These results show that medium-sized enterprises differ significantly from several other size categories in their perception of this barrier. The findings suggest that the perception of material-efficiency-related innovation priorities may vary across enterprise size categories, depending on the stage of organizational development and production structure. Medium-

sized enterprises may be associated with a higher recognition of material consumption as an important cost and sustainability issue, while at the same time they may not yet possess the same level of formalized innovation systems, environmental management tools, or investment capacity as large companies. In contrast, micro and small enterprises may be more strongly influenced by short-term operational constraints and financial pressures, which can reduce the strategic priority assigned to material consumption reduction. This result highlights the importance of targeted support for resource-efficiency measures, especially for firms that are in transition between small-scale operations and more complex production systems.

Table 3. Pairwise comparisons between groups – Q3_K

		W	p
Large	Medium	-3.780	0.038
Large	Micro	0.441	0.990
Large	Small	-0.843	0.933
Medium	Micro	4.080	0.020
Medium	Small	3.719	0.043
Micro	Small	-1.399	0.756

**Source: Authors.*

Table 4 shows the post-hoc results for the barrier related to the lack of cooperation with research institutions and universities (Q3_N). A statistically significant difference was found between medium-sized and micro enterprises (p

$= 0.008$). The comparison between medium-sized and small enterprises approaches statistical significance ($p = 0.068$), suggesting a potential pattern that could be further examined in future research.

Table 4. Pairwise comparisons between groups – Q3_N

		W	p
Large	Medium	-2.11	0.441
Large	Micro	2.52	0.281
Large	Small	1.18	0.837
Medium	Micro	4.52	0.008
Medium	Small	3.47	0.068
Micro	Small	-1.57	0.684

**Source: Authors.*

This result indicates that cooperation with research institutions is not perceived equally across enterprise size categories. Differences in perceived cooperation may reflect variation in firms' access to external knowledge networks, , and managerial capacity to establish systematic cooperation with universities or research organizations. Micro enterprises may face constraints related to awareness of available research partnerships, innovation vouchers, technology-transfer schemes, or public support mechanisms. Medium-sized enterprises, by contrast, tend to exhibit more developed organizational structures and greater motivation to seek external knowledge, but still may not achieve the same level of institutionalized research cooperation as large companies. The finding therefore supports the need to strengthen knowledge-transfer mechanisms and make cooperation with universities more accessible, especially for smaller firms.

Conclusion

This study examined barriers to green innovation adoption in manufacturing enterprises in Central Europe, with particular attention to differences across enterprise size categories. The results confirm that company size influences the perception of selected barriers, particularly those related to internal financial resources, material consumption reduction, and cooperation with research institutions and universities. These

findings support the argument that green innovation policy should not rely on uniform instruments, but rather reflect the different capacities, needs, and constraints of micro, small, medium-sized, and large enterprises.

The results indicate that the lack of internal financial resources remains a significant barrier, particularly when comparing micro and large enterprises. This confirms that smaller firms face stronger constraints in financing the initial costs of green technologies, process modernization, and resource-efficiency measures. At the same time, the findings suggest that medium-sized enterprises differ significantly from other categories in the perception of material consumption reduction as an innovation priority, indicating a need for targeted support aimed at integrating resource efficiency into their innovation strategies and production processes (Dvorsky, 2025). The study also highlights the importance of external knowledge and cooperation. Significant differences in the perception of insufficient cooperation with research institutions and universities suggest that smaller enterprises, especially micro enterprises, may face greater challenges in accessing scientific knowledge, technical support, and innovation partnerships. Strengthening cooperation between enterprises, universities, research institutions, public agencies, and industry associations can therefore play an important role in accelerating green innovation

adoption. From a policy perspective, the findings point to the need for differentiated support mechanisms. Micro and small enterprises would benefit from simplified access to grants, low-interest loans, advisory services, innovation vouchers, and technical assistance. Medium-sized enterprises may require support focused on scaling up resource-efficiency solutions, improving material management, and integrating green innovation into broader business strategies. Large enterprises, although generally better equipped with financial and technological resources, may still need support in managing complex transformation processes, regulatory compliance, and supply-chain sustainability.

Overall, the study contributes to a better understanding of how barriers to green innovation adoption differ by enterprise size. By identifying the barriers most relevant to different enterprise size categories, the research provides useful evidence for policymakers, business support organizations, and managers seeking to accelerate the transition towards a low-carbon and resource-efficient economy. Future research should broaden the sectoral and geographical scope of the analysis and examine how financial support, regulatory simplification, and knowledge-transfer mechanisms influence the actual implementation of green innovations over time.

Limitations of the study

This study has several limitations that should be considered when interpreting the results. First, the research focuses on manufacturing enterprises operating in the Central European context. The findings are therefore influenced by the specific institutional, regulatory, technological, and economic conditions of this region. As a result, the

conclusions may not be fully generalizable to enterprises operating in other European regions or in countries with different innovation systems, environmental policies, or levels of public support for green transformation. Second, the research examines barriers at a single point in time. Green innovation adoption is a dynamic process that may change in response to new regulations, technological development, energy prices, market pressure, ESG requirements, and the availability of public funding. A longitudinal research design would allow for a more detailed assessment of how the perceived severity of barriers evolves over time and whether policy measures effectively reduce them. Third, although the study compares enterprises by size category, it does not fully capture other firm-level characteristics that may influence green innovation adoption, such as ownership structure, export orientation, technological intensity, financial performance, previous innovation experience, environmental certification, or participation in international supply chains. Future research could incorporate these variables to provide a more comprehensive explanation of differences between enterprises. Finally, the statistical analysis identifies significant differences between selected enterprise-size groups, but the observed effect sizes in the Kruskal–Wallis test are relatively small. This suggests that company size is an important but not exclusive factor in explaining differences in perceived barriers. Further research should therefore complement quantitative analysis with qualitative interviews to better understand the mechanisms behind these differences and the practical challenges faced by enterprises in implementing green innovations.

Acknowledgement

This research paper is a partial result of the multiyear research project VEGA no. 1/0110/24 and was funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I01-03-V04-00082.

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