Small and Medium-Sized Enterprises as Providers of Regional Environmental Open Data: Connecting LCA Indicators with ESG Reporting and Sustainable Regional Development

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Abstract. Small and medium-sized enterprises (SMEs) generate considerable amounts of environmental data in their everyday operations, but much of this information remains unused outside the enterprise. These data could support regional policymaking, especially if they were collected and shared in a structured form. In practice, business-generated data often do not meet the standards required for integration into public databases. This paper examines how SMEs can contribute to regional environmental open data, with a focus on Life Cycle Assessment (LCA), ESG reporting, and sustainable regional development. The study combines preliminary empirical evidence from Slovak SMEs with a systematic review of relevant literature. It investigates whether SMEs monitor environmental indicators more frequently in the earlier stages of the product life cycle, particularly procurement and production, than in the later stages, such as consumption, use, and end-of-life treatment (H1). Five specific indicators are examined: product origin transparency (H2a), energy consumption in production (H2b), fuel consumption (H2c), average product lifespan (H2d), and the proportion of repaired products compared with discarded products (H2e). The findings show that SMEs tend to focus mainly on indicators linked to internal processes. Indicators from downstream life cycle phases are monitored less frequently. The paper contributes to the discussion on how SME-generated environmental data can be transformed into regional open data and used more effectively in sustainability-oriented policy and reporting.

Keywords: Life cycle assessment (LCA) · Small and medium-sized enterprises (SMEs) · Open data · ESG reporting · Regional development

1 Introduction

Over the past few years, data have taken on a much more significant role as a strategic resource for public institutions, businesses, and society. The rise of digital technologies has reshaped how data are gathered, analysed, and applied. In this context, open data

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are increasingly viewed as a valuable instrument for fostering innovation, enhancing governance, and generating public value. At the same time, enterprises are under growing pressure to incorporate sustainability into their everyday operations, driven largely by environmental challenges, stakeholder expectations, and regulatory requirements within the European Union. Reliable environmental assessment therefore requires evidence-based information that can support both business decisions and regional sustainability policies. In this context, environmental open data can help connect corporate activities with regional decision-making, particularly in relation to SMEs.

Following an analysis of various scholarly sources [5, 8, 9, 15, 16, 23] several frameworks focusing on open data, environmental reporting, ESG, and LCA were identified. However, existing studies provide only minor coverage of SMEs as active providers of environmental open data.

The strategic research gap addressed by this study lies in the absence of an integrated approach that systematically links the environmental data of SMEs with regional open data initiatives within the framework of LCA and ESG reporting. Specifically, there is a lack of identification of administratively manageable environmental data and a deeper understanding of the barriers preventing SMEs from engaging in the open sharing of environmental information.

2 Literature Review

Open data consist of information collected and provided by public entities that is made accessible for reuse without restrictions. It is characterized by its multi-dimensionality, reproducibility and real-time dynamics. Typical examples include governmental data, such as postal codes, meteorological data, and survey results [2] which are primarily available in Europe through portals such as data.europa.eu, Eurostat, or the EEA Datahub. Research highlights [11, 20, 22] the increasing significance of open data for the digitalization of the economy and corporate management, where data-driven insights support innovation and the generation of economic value, particularly within the SME environment.

Enterprises are producing increasing amounts of data. Some of these data are slowly entering open data systems, but many enterprises still face a strategic dilemma: whether to keep data for internal use or share selected information through open data channels. Participation in open data ecosystems may create additional value, but the practical conditions for doing so remain unclear, especially for SMEs [9].

This issue is also pointed out by the World Economic Forum [23]. They emphasize that SMEs often face difficulties not only in publishing open data, but also in effectively using their own data. Among the main obstacles are insufficiently developed data governance structures, unclear responsibilities, and ongoing concerns related to data security. Enders et al. [9] similarly identify privacy and security risks as important obstacles to data sharing. In addition, many SMEs have limited IT infrastructure and analytical capacity. This reduces their ability to extract value from the data they already collect. The relevance of open data becomes especially clear in the context of sustainability and environmental management. Enterprises are increasingly expected to reduce their environmental impact and provide more transparent information about their activities [3]. For

SMEs, however, the implementation of sustainability practices is often limited by financial and human resources, technical expertise, and awareness of environmental impacts [4, 18]. These limitations are reinforced by low perceived benefits of environmental data sharing, time and cost constraints, missing reporting standards, and restricted access to information from supply chain stakeholders [23].

SMEs are central to the European economy. They represent more than 99% of all business entities in Europe and are responsible for a significant share of environmental pollution, estimated at 60–70% [19]. They also contribute to regional development and employment [1]. Although SMEs possess a wide range of potentially useful data, several barriers still prevent these data from being shared as open data [5, 15]. The academic literature has paid only limited attention to SMEs in the role of data publishers.

From an operational perspective, SMEs regularly generate environmental, ESG, and LCA-related information. This includes data on energy and water consumption, material inputs, emissions, waste, and logistics [5]. De la Puente et al. [8] also point out that routine environmental practices, such as recycling, energy saving, and waste reduction, produce information that could be used as environmental open data.

Other frameworks extend this view beyond internal operations. The OECD framework [21], for example, assesses SME environmental engagement through publicly available sources such as company websites. This approach includes elements of communication and transparency (environmental certifications, environmentally friendly processes, responsible sourcing, and emissions). Fortier et al. [12] also propose ESG indicators suitable for measuring SME environmental performance. These could be for example energy and water use, waste generation, recycling, carbon footprint, and product lifetime. These approaches suggest that SMEs already own relevant environmental data. What varies is the way these data are utilized. In some cases, they serve internal management purposes or support daily operations, while in others they have the potential to be applied in external communication, ESG reporting, or even integrated into standardized open data frameworks.

LCA is particularly relevant in this context. It enables environmental impacts to be assessed across the whole product life cycle. Its importance is reinforced by the CSRD Directive (EU) 2022/2464, which introduces sustainability reporting requirements for large enterprises and gradually affects SMEs through value chains [17]. Niemann et al. [16] show that SMEs are increasingly aware of the need for environmental reporting, but they often face numerous barriers.

At the regional level, environmental data remain relatively underdeveloped and are still concentrated mainly among large enterprises. If SMEs were able to collect and share selected LCA-related information, regions could gain a more complete picture of cumulative environmental impacts. Such a perspective cannot be achieved through large-enterprise reporting alone [6, 13]. Local and regional authorities could therefore play a more active role in supporting the collection, aggregation, and use of environmental indicators generated by SMEs.

Open data are an important part of this ecosystem. According to the European Union [10], making environmental data openly available helps to strengthen environmental protection by improving access for public institutions, businesses, and the research community. From this perspective, environmental data generated by SMEs have the potential

to go beyond transparency alone. They can also support innovation, more effective decision-making, and contribute to sustainable development at the regional level. Connecting open data practices with tools such as LCA and ESG reporting creates value not only for individual enterprises, but also for the development of public policies [7, 14].

3 Methodology and Hypotheses

The primary objective of this research is to determine whether SMEs measure indicators associated with becoming active providers of regional open data within the context of LCA and ESG reporting, and to identify which specific indicators are being measured. The paper applies a two-phase research approach. Primary research is based on a questionnaire survey and combined with qualitative research (a systematic literature review). Based on the findings, recommendations are formulated for SMEs, aimed at overcoming the obstacles that limit their participation as active providers of environmental open data.

Phase 1. The preliminary quantitative research, conducted between October 2025 and February 2026, focused on assessing the readiness of SMEs to implement the LCA method. The objectives were to determine whether they measure environmental indicators relevant to LCA and ESG reporting, identify which specific indicators are monitored, and explore the overall level of preparedness for engaging in corporate environmental data practices.

Phase 2. The second phase was based on a systematic literature review methodology to synthesize existing knowledge on SMEs as providers of environmental open data, with a particular focus on the connection of LCA, ESG reporting, and sustainable regional development. A structured search strategy was applied across selected academic databases. The databases systematically searched included Scopus (1996–2025), Web of Science Core Collection (1996–2025), and Google Scholar, which was used to identify supplementary sources. The search strategy employed Boolean operators with the following terms: (“open data” OR “environmental open data” OR “open data for sustainable region”) AND (“LCA” OR “ESG reporting”) AND (“SMEs”). Backward citation tracking was conducted on all included studies to identify additional relevant sources not captured in the initial database search. The study included publications meeting the following criteria: peer-reviewed journal articles and conference proceedings published in English, thematically focused on open data, LCA, and SMEs, covering theoretical frameworks or practical applications, published between 2017 and 2025, and available in full text. The final sample consists of 23 articles.

Artificial intelligence tools were used to assist in improving the clarity and formulation of the presented results.

Sample

The preliminary research focused on SMEs operating in Slovakia. The representativeness of the sample was verified using a chi-square test, considering a margin of error of 5% and a proportion of $p = 0.5$ for an unknown population parameter. The overall test of representativeness yielded a p-value of 0.778, exceeding the significance level of $\alpha = 0.05$. The minimum required sample size was set at 100 SMEs.

Data Analysis

To evaluate the hypotheses, IBM SPSS Statistics 29 was used. Methods of inductive and correlational statistics were applied. The Friedman test was used to identify statistically significant differences among the measured environmental indicators. The Wilcoxon signed-rank test was used to determine which indicators are most frequently measured by SMEs in Slovakia.

Hypotheses

Based on the literature review and empirical evidence, four hypotheses were formulated to be tested in the context of Slovak SMEs:

H1: It is assumed that SMEs measure environmental indicators related to the production and procurement phase more frequently than indicators associated with the consumption, use, and end-of-life disposal phase.

The types of environmental data routinely generated by SMEs are primarily linked to internal operations such as production processes, material inputs, and energy consumption, indicating a stronger measurement focus on upstream life cycle phases [5]. SMEs face limited access to data from customers and downstream processes, which limits their ability to measure environmental indicators related to the use and end-of-life phases [23]. The structure of ESG indicators in SMEs is largely concentrated toward production related metrics, while indicators associated with product use, lifespan, and end-of-life management are less frequently emphasized [12].

By formulating hypotheses H2a-H2e, the study aims to examine patterns in the measurement of environmental indicators across different phases of the product life cycle and to identify which indicators are most frequently monitored by SMEs.

H2a: It is assumed that, in the procurement phase, SMEs most frequently measure the indicator of product origin transparency.

Indicators related to procurement, such as material inputs and responsible sourcing practices, are commonly observed in SMEs, suggesting an increasing emphasis on supply chain transparency, including aspects related to product origin [5, 21].

H2b: It is assumed that, in the production phase, SMEs most frequently measure the indicator of energy consumption in production.

Among environmental indicators, energy consumption represents one of the most routinely collected metrics within SME production processes, as it is directly linked to internal activities and does not require complex data acquisition [5, 12].

H2c: It is assumed that, in the transport and distribution phase, SMEs most frequently measure the indicator of fuel consumption.

Although logistical processes are recognized as part of SME environmental data, specific indicators such as fuel consumption are not consistently emphasized, indicating a less systematic measurement approach in the transport and distribution phase [5, 12].

H2d: It is assumed that, in the consumption and use phase, SMEs most frequently measure the indicator of average product lifespan.

Indicators related to the use phase, such as product lifespan, reusability, and repairability, are identified in SME ESG frameworks, however, their measurement is

less directly embedded in routine operations compared to production related indicators [12].

H2e: It is assumed that, in the end-of-life phase, SMEs most frequently measure the indicator of the proportion of repaired products versus discarded products.

End-of-life indicators in SMEs are reflected through waste generation or recycling activities, however, more detailed metrics, such as the proportion of repaired versus discarded products, are not systematically captured [8, 12].

4 Results and Discussion

This section presents the main empirical findings and interprets them in relation to the literature. Hypothesis 1 was tested using the Wilcoxon signed-rank test, which compared the number of environmental indicators measured across selected life cycle phases. The results show that SMEs measure more indicators in the production and procurement phases than in the consumption, use, and end-of-life phases. The difference was statistically significant ($p < 0.001$). In the questionnaire, questions 28 and 29 focused on procurement and production. Questions 36 and 37 addressed transport and distribution, consumption, and use (Fig. 1).

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
o36_37 - o28_29	Negative Ranks	44[a]	26,07	1147,00
	Positive Ranks	5[b]	15,60	78,00
	Ties	51[c]		
	Total	100		

a. o36_37 < o28_29
b. o36_37 > o28_29
c. o36_37 = o28_29

Test Statistics[a,c]

			o36_37 - o28_29
Z			-5,376[b]
Asymp. Sig. (2-tailed)			0,000
Monte Carlo Sig. (2-tailed)	Sig.		0,000
	99% Confidence Interval	Lower Bound	0,000
		Upper Bound	0,000
Monte Carlo Sig. (1-tailed)	Sig.		0,000
	99% Confidence Interval	Lower Bound	0,000
		Upper Bound	0,000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on 10000 sampled tables with starting seed 2000000.

Fig. 1. Wilcoxon Signed Ranks Test for H1

Since the p-value is below the 0.05 significance threshold, the null hypothesis is rejected, and Hypothesis 1 is confirmed. The results indicate that SMEs monitor environmental indicators mainly in the earlier stages of the product life cycle. Indicators linked to product use and end-of-life disposal receive less attention.

This pattern can be understood in terms of how data are available, who has control over them, and the limits SMEs face in terms of resources. In practice, most environmental data is generated and handled in internal processes. In areas such as production and procurement, collecting data is already part of routine operations [5]. These activities are directly linked to energy use, material consumption, and relationships with suppliers. This makes it easier to track and monitor. In contrast, downstream phases such as consumption, use, and end-of-life are less visible to SMEs. They often depend on customers, users, or post-sale processes. This makes systematic measurement beyond the production more difficult [23].

Our findings are consistent with the theoretical frameworks of LCA [5, 12, 17, 23], which emphasize the importance of assessing environmental impacts across all phases of the life cycle. However, empirical evidence suggests that SMEs only partially apply this perspective. Their attention is mainly paid to indicators in upstream phases, while end-of-life indicators remain less developed. This suggests a gap between the theoretical framework and its practical implementation in SMEs.

Hypothesis H2a was tested using the Friedman test to compare the frequency of measurement among procurement-related environmental indicators (Fig. 2).

Friedman Test

Ranks

	Mean Rank
o28a	2,94
o28b	2,96
o28c	3,15
o28d	2,94
o28e	3,02

Test Statistics[a]

N	100
Chi-Square	3,644
df	4
Asymp. Sig.	0,456

a. Friedman Test

28a Share of certified suppliers among all suppliers
28b Share of purchases of environmentally certified products
28c Share of materials from recyclable sources among all raw materials
28d Transparency of product origin
28e Share of local suppliers among all suppliers

Fig. 2. Friedman Test for H2a

The analysis did not identify statistically significant differences between the indicators ($p = 0.456$). The mean ranks were very similar, indicating that SMEs measure procurement indicators with approximately the same intensity. Product origin transparency did not stand out as a clearly dominant indicator. Since the p-value is above

0.05, Hypothesis H2a is not supported. The results suggest that SMEs do not prioritize one procurement indicator, but rather apply a balanced measurement approach.

The procurement phase plays a key role. It represents the stage where SMEs engage directly with suppliers and obtain inputs. Existing research [12, 21] highlights that responsible sourcing and transparency regarding product origin are becoming increasingly important in the context of ESG reporting. In reality SMEs often struggle to obtain reliable data from their suppliers [23]. This barrier is further worsened by the absence of standardized frameworks and defined data governance, resulting in fragmented approaches to measuring environmental performance.

Hypothesis H2b was assessed using the Friedman test, which examined differences in measurement frequency among production-related indicators. The test showed statistically significant differences between the analysed indicators ($p < 0.001$), meaning that SMEs do not monitor all production indicators with the same intensity.

Friedman Test

Ranks

	Mean Rank
o29a	6,52
o29b	6,03
o29c	5,92
o29d	5,16
o29e	5,27
o29f	5,01
o29g	5,37
o29h	5,14
o29i	5,02
o29j	5,58

Test Statistics[a]

N	100
Chi-Square	60,552
df	9
Asymp. Sig.	0,000

a. Friedman Test

29a Energy consumption in production
29b Water consumption in production
29c Heat consumption in production
29d Volume of polluted wastewater discharged into the environment
29e Energy consumption in warehouse facilities
29f Heat consumption in warehouse facilities
29g Rate of use of recycled or recyclable packaging
29h Amount of packaging material per unit of product
29i Share of environmentally labeled products
29j Amount of waste generated from production

Fig. 3. Friedman Test for H2b

Energy consumption in production reached the highest mean rank in Fig. 3 and was therefore the most frequently measured indicator in this phase. The Wilcoxon signed-rank test further confirmed that energy consumption was statistically more significant than the other production-related indicators.

A second group of indicators included water consumption in production, heat consumption in production, and the volume of wastewater discharged into the environment. These indicators are also monitored, but not as consistently as energy consumption.

Hypothesis H2b is confirmed. SMEs appear to focus primarily on energy consumption in production, most likely because it is directly linked to operating costs, regulatory expectations, and environmental impact.

Production is the most data-intensive stage of the product life cycle for many SMEs. The indicators measured in this phase are usually connected with internal processes, where data collection is already embedded in daily operations [5].

Energy consumption is especially important because it relates to production efficiency, cost management, and environmental performance. Fortier et al. [12] note that SMEs tend to focus on indicators that are easy to measure and economically relevant. Energy consumption meets both conditions and is also central to ESG reporting and LCA assessment.

From an ESG reporting perspective, SMEs tend to prefer metrics that are easy for them to measure and directly relate to their economic performance. These indicators are often also necessary for ESG reporting, which is consistent with our theoretical frameworks.

Friedman Test

Ranks

	Mean Rank
o35a	4,38
o35b	4,47
o35c	5,38
o35d	4,53
o35e	4,30
o35f	3,95
o35g	4,30
o35h	4,71

Test Statistics[a]

N	100
Chi-Square	44,703
df	7
Asymp. Sig.	0,000

a. Friedman Test

35a Share of deliveries carried out by environmentally certified transport providers
35b Share of consolidated shipments
35c Fuel consumption in vehicles
35d Average vehicle capacity utilization
35e Share of low-emission vehicles in the fleet
35f Number of driver trainings on eco-driving
35g Share of empty runs
35h Vehicle maintenance rate

Fig. 4. Friedman Test for H2c

Hypothesis H2c was tested using the Friedman test for transport and distribution indicators (Fig. 4). The results showed statistically significant differences between the analysed indicators ($p < 0.001$). This confirms that SMEs do not measure all transport-related indicators equally.

Fuel consumption achieved the highest mean rank. Meaning that it is the most frequently measured indicator in this phase. This result was also supported by the Wilcoxon signed-rank test, which showed that fuel consumption was statistically more significant than the other transport-related indicators.

Other indicators, such as the share of consolidated shipments, average vehicle capacity utilization, and the share of low-emission vehicles in the fleet, formed a second tier. They are monitored, but less frequently than fuel consumption.

Since the p-value is below 0.05, Hypothesis H2c is confirmed. SMEs mainly monitor fuel consumption in transport and distribution because it is closely related to logistics costs, operational efficiency, and environmental impact.

Transport and distribution are important life cycle phases because they influence energy use, emissions, and logistics performance. SMEs generate operational data in this area, especially on fuel consumption, which is directly connected with transport activity and cost structures [5]. Fuel consumption is also one of the most quantifiable transport indicators.

Its relevance is strengthened by its connection to greenhouse gas emissions and environmental performance, both of which are important elements of ESG reporting [12]. Under growing sustainability and regulatory pressure, SMEs are more likely to monitor indicators that provide information about both economic performance and environmental footprint. Fuel consumption fulfils this role well.

More complex logistics indicators are more difficult to measure. SMEs may lack integrated information systems or the analytical capacity needed to track indirect indicators such as logistics optimization metrics [23]. Enders et al. [9] also show that enterprises tend to prioritize data that are readily available and strategically useful.

For regional open data systems, transport-related environmental data could provide valuable information on environmental impacts [6, 13]. Its measurability and practical relevance make it a suitable indicator for both enterprise monitoring and regional sustainability analysis.

Hypothesis H2d was evaluated using the Friedman test for indicators in the consumption and use phase (Fig. 5). The test showed statistically significant differences between the analysed indicators ($p = 0.023$), suggesting that SMEs do not measure all use-phase indicators with the same intensity.

Average product lifespan reached the highest mean rank in the sample. However, the Wilcoxon signed-rank test did not confirm statistically significant differences between individual indicators.

This means that, although differences were observed at the group level, no single indicator can be identified as statistically dominant across all SMEs.

Hypothesis H2d is therefore neither confirmed nor rejected. The results point to a possible tendency to prioritize product lifespan. Larger sample would be needed to verify whether this pattern also applies to the broader SME population.

Friedman Test

Ranks

	Mean Rank
o36a	3,25
o36b	2,83
o36c	2,96
o36d	3,02
o36e	2,95

Test Statistics[a]

N	100
Chi-Square	11,357
df	4
Asymp. Sig.	0,023

a. Friedman Test

36a Average product lifespan

36b Share of environmentally labeled products

36c Approximate water consumption during the use of your main product

36d Approximate electricity consumption during the use of your main product

36e Approximate heat consumption during the use of your main product

Fig. 5. Friedman Test for H2d

The consumption and use phase is important because long-term environmental impacts depend on product durability, efficiency, and user behaviour. Average product lifespan is especially relevant, as it reflects both resource efficiency and the sustainability of product design [12].

The LCA perspective stresses that environmental impacts should be assessed across the whole life cycle, including product use. Extending product lifespan can reduce environmental burdens by lowering the need for new inputs and reducing waste generation [6].

At the same time, SMEs often have limited control over how products are used after sale. They may also lack access to user-related data, which makes the measurement of these indicators difficult [23]. This explains why such indicators are less embedded in everyday monitoring than production-related indicators [9].

Despite these limitations, ESG reporting and regulatory developments are gradually broadening environmental monitoring toward downstream phases [16, 17]. In this context, product lifespan is a useful indicator because it links environmental, economic, and functional aspects of sustainability.

Hypothesis H2e was also tested in a similar way, using the Friedman test to compare end-of-life indicators. The results showed statistically significant differences between the analysed indicators ($p = 0.045$). Suggesting that SMEs do not measure all end-of-life indicators equally (Fig. 6).

The proportion of repaired products compared with discarded products achieved the highest mean rank. This suggests that the indicator may be relatively important for the analysed SMEs. However, the Wilcoxon signed-rank test did not confirm statistically

Friedman Test

Ranks

	Mean Rank
o37a	2,43
o37b	2,49
o37c	2,44
o37d	2,65

Test Statistics[a]

N	100
Chi-Square	8,067
df	3
Asymp. Sig.	0,045

a. Friedman Test

37a Share of products involved in take-back schemes

37b Amount of waste sent to landfill

37c Share of products designed for disassembly or recycling

37d Share of repaired products versus discarded products

Fig. 6. Friedman Test for H2e

significant differences between individual indicators. As a result, it is not possible to identify a clearly dominant end-of-life indicator for the broader SME population.

Hypothesis H2e is therefore neither confirmed nor rejected. The findings suggest a tendency to monitor the proportion of repaired versus discarded products, but further research with a larger sample is needed to confirm this relationship.

The end-of-life phase is increasingly important for sustainable product management. The ratio of repaired to discarded products can show how effectively enterprises extend product life cycles and reduce waste [12]. Previous research [13] emphasizes that environmental impacts continue after production, especially through decisions related to repair, reuse, recovery, and disposal. A higher share of repaired products can reduce raw material demand and environmental pressure, while also supporting regional sustainability goals.

In practice, however, SMEs face difficulties in collecting reliable end-of-life data. These difficulties are mainly related to limited contact with consumers and insufficient data infrastructure [23]. Still, current policy developments and sustainability frameworks increasingly support circular practices, including repair and reuse, as part of ESG and LCA integration [3, 17]. Waste handling and product recovery are also reflected in broader measures of environmental engagement [21].

For this reason, the proportion of repaired versus discarded products can be considered a meaningful end-of-life indicator. It captures both environmental performance and the degree to which SMEs move toward circular economy practices.

From an open data perspective, this imbalance in data availability at different LCA phases has important implications. It suggests that SMEs' contribution to regional open data using environmental indicators is currently limited to internally generated data.

These findings also confirm our theoretical assumptions [13, 21, 23] that SMEs find it difficult to collect and evaluate indicators in the consumption and disposal phases, as they often need information from customers or other stakeholders that is not available to them.

5 Conclusion

The research findings confirm that environmental data practices in SMEs are unevenly distributed across the product life cycle, with clear differences in the intensity of indicator measurement between individual phases. The production and procurement phases appeared as the most intensively monitored stages. In contrast, downstream phases, such as consumption, use, and end-of-life, were found to be significantly less systematically measured.

At the level of specific indicators, energy consumption in production and fuel consumption in transport and distribution were identified as the most frequently measured indicators, confirming their key role in SME environmental monitoring. No dominant indicator was identified in the procurement phase. For the consumption and end-of-life phases, although differences in measurement intensity were observed, the results did not provide sufficient statistical support to establish a clear hierarchy of indicators. This indicates that these phases remain underdeveloped in terms of systematic environmental data collection.

The results further demonstrate that SMEs already generate a large volume of environmental data which could be utilized at the regional level. This potential is not fully utilized due to organizational, technological, and knowledge-related barriers. The findings suggest that the key limitation is not the absence of data, but rather the lack of structured approaches to its standardization, integration, and sharing within regional open data.

Our findings provide a basis for the design of a governance-oriented framework for open data generated by SMEs. The findings suggest that initially regions should start creating open data systems primarily based on indicators that are routinely monitored in SMEs. These are, for example, energy or fuel consumption. We also identified barriers and limitations to tracking end-of-life data. This requires the need for supportive policies for SMEs, which would gradually expand data collection across all phases of LCA (the support is especially needed in the end-of-life indicators). To bridge this gap, a governance-oriented framework should be developed that enables the systematic collection, standardization, and aggregation of SME generated environmental data at the regional level. This framework could be based on the definition of a “minimum regional dataset”. It would be composed of key indicators such as energy and fuel consumption, waste generation, and material use, which are already routinely measured by SMEs. Regional authorities should play an active facilitating role by providing methodological guidelines, unified data templates, and digital platforms. This approach would enable simpler and more secure data submission. At the same time, cooperation among stakeholders can help reduce the barriers of data availability.

SMEs should prioritize the systematic monitoring of environmental indicators that are already incorporated in their operations, while gradually expanding measurement

practices toward downstream life cycle phases. Strengthening internal data governance, including clear responsibilities and standardized data collection procedures is essential. At the same time, enterprises should begin to perceive environmental data not only as a reporting obligation but as a strategic resource that can enhance their position within the market.

While this preliminary analysis focused on Slovak SMEs, the findings can be extended to other European countries. This applies for countries with a similar composition of SMES, comparable regulatory frameworks, and a similar level of digital development. Research from other EU member states points to many of the same challenges, particularly in areas such as data management, limited resources, and restricted access to downstream data. That said, these conclusions do not necessarily hold in settings with a different institutional context. For instance, in non-EU countries or in economies where sustainability reporting is subject to less regulatory pressure.

The limitations of the preliminary research are primarily related to the sample size and its focus on Slovak SMEs. This affected the generalizability of some findings, particularly in downstream phases where results were inconclusive. While the quantitative analysis provides valuable statistical insights, future research should incorporate qualitative methods to better understand the underlying reasons behind SME data practices and barriers. Further studies should also focus on testing the proposed framework in real regional contexts and on the development of tools that enable the automated transfer of SME data into open data platforms.

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