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Sustainable Innovation Maturity in the Cosmetics Industry: An Item Response Theory-Based Analysis

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Abstract

Environmental, Social, and Governance (ESG) activities can be understood as a commitment to the sustainability agenda, representing responsible business practices. In this context, the research seeks to address the following question: how are the levels of sustainable innovation maturity structured in the cosmetics industry, and what is the differentiating role of ESG practices in this process? Accordingly, this study aimed to analyze sustainable innovation maturity in cosmetics industry firms, identifying its latent structure, the distribution of maturity levels, and the differentiating role of the practices under analysis. To ensure clarity and systematization of the methodological procedure adopted, the study was structured into six sequential phases, encompassing the definition of the research design, data collection and treatment procedures, computational procedures, and the interpretation of results. The findings demonstrate that the advancement of sustainable innovation in the sector depends less on the isolated adoption of specific practices and more on the strategic integration of sustainability, technological innovation, and ESG governance. Practices related to ESG governance, the development of green technologies, and the adoption of recycled or renewable inputs exhibited greater discriminatory power, emerging as central elements in differentiating firms at more advanced levels of maturity.

Keywords: ESG; cosmetics industry; maturity; latent structure

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1. Introduction

Environmental, Social, and Governance (ESG) activities can be understood as a commitment to the sustainability agenda, representing responsible business practices. This characterization has contributed to the increasing adoption of such actions across firms, particularly as a means of strengthening innovation and socio-environmental responsibility (Tan & Zhu, 2022; Zou et al., 2023; Baratta et al., 2025).

According to the literature, ESG initiatives have been driven by growing demand from both consumers and investors for organizations to adopt and disclose information related to ESG activities, thereby increasing awareness of environmental and social issues (Sharma et al., 2022). Cho (2023) highlights that this trend has been further reinforced by more robust regulatory frameworks and initiatives, particularly in Europe, which have encouraged companies to integrate ESG into their strategic agendas.

ESG guidelines function as both normative and operational tools that guide the transition toward sustainable economic models. These policies provide practical directions to enable a fair and effective shift toward the so-called "green economy." In essence, ESG standards, by encouraging socially responsible corporate behavior and strategic vision, aim to mitigate systemic market risks, promote transparency, and enhance long-term value creation across all sectors (Christensen, Serafeim, & Sikochi, 2022; Chen, Xie, & He, 2024; Wang & Chu, 2024).

The cosmetics industry represents a sector with significant economic relevance and growth projections, alongside an increasing trend toward sustainable products and packaging (Celadon, 2014). This shift is driven by changing consumer preferences regarding the environmental role of companies and their broader impacts. As a result, brands are compelled to reconsider packaging decisions as a critical business strategy. In this context, the adoption of ESG principles (Environmental, Social, and Governance) becomes central to strategic development (Morel et al., 2024).

According to Costa et al. (2026) sustainable practices in the cosmetics sector can stimulate innovation, improve brand reputation, and create long-term value in addition to satisfying customer demands and legal obligations.. Companies that ensure sustainability in their processes are generally better positioned in the market and may establish stronger connections with their increasingly environmentally conscious customer base.

Despite the advancement of discussions on sustainable innovation and ESG, there are still limitations in understanding how these practices are organized across different levels of organizational maturity, especially in resource-intensive sectors such as the cosmetics industry. Most studies adopt aggregated approaches, without considering that practices emerge at different stages and exhibit varying capacities to differentiate firms.

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In this context, the research seeks to address the following question: how are the levels of sustainable innovation maturity structured in the cosmetics industry, and what is the differentiating role of ESG practices in this process? Accordingly, this study aimed to analyze sustainable innovation maturity in cosmetics industry firms, identifying its latent structure, the distribution of maturity levels, and the differentiating role of the practices under analysis.

2. Literature Review

2.1. Sustainable Innovation, ESG, and Organizational Maturity

Sustainable innovation extends beyond the mitigation of environmental harm by integrating economic, social, and environmental objectives into the firm's strategy. This shift moves sustainability from a reactive response toward a value-creation logic, requiring the reconfiguration of resources, capabilities, and business models (Afeltra et al., 2022). Rather than being limited to the development of green products, it encompasses processes, routines, and collaborative networks aimed at generating positive socio-environmental outcomes (Liu & Stephens, 2019; Santana et al., 2025). Sustainable innovation therefore reflects a composite organizational capability in which competitiveness, socio-environmental responsibility, and interorganizational learning operate in an integrated manner.

ESG criteria reinforce this dynamic by transforming environmental, social, and governance demands into parameters for evaluation, monitoring, and decision-making. ESG connects sustainability to risk management, transparency, corporate reputation, and investment decisions (Asif, Searcy, & Castka, 2023), while also incorporating environmental, social, and governance metrics into sustainable performance measurement systems (Barbosa et al., 2023). This formalization removes sustainability, at least partially, from the realm of declaratory discourse and brings it closer to verifiable managerial routines. In this sense, ESG functions as an evaluative environment that pressures firms to demonstrate consistency between stated commitments and effectively implemented practices.

Organizational maturity helps explain why such incorporation does not occur uniformly across firms. Maturity models examine progressive stages in the development of capabilities, thereby avoiding the reduction of analysis to the mere presence or absence of practices (Hein-Pensel et al., 2023). In the field of sustainability, this perspective distinguishes isolated, reactive, or compliance-driven responses from more advanced configurations in which sustainability is integrated with strategy, governance, innovation, and performance indicators (Stachowiak & Pawłyszyn, 2021; Gerhardt et al., 2022; Michelin et al., 2022). Sustainable innovation maturity therefore represents the degree to which sustainable practices are internalized within the organization and transformed into structured capabilities.

2.2 Sustainable Innovation in the Cosmetics Industry

The cosmetics industry constitutes a critical context for analyzing sustainable innovation because its externalities extend across the entire product life cycle, from raw material selection to post-consumption disposal (Bom et al., 2019). Water dependency is particularly significant, as this resource is involved in product formulation, raw material cultivation, equipment cleaning, thermal processes, and packaging production (Aguiar et al., 2022). In addition, biodiversity, energy use, chemical inputs, and global supply chains make sustainability a requirement for legitimacy, operational continuity, and competitive differentiation (Suphasomboon & Vassanadumrongdee, 2023).

The dimensions of sustainable innovation in the sector vary in scope and complexity. In product formulation, they include green chemistry, the substitution of conventional ingredients, and the use of renewable raw materials or agro-industrial by-products (Bom et al., 2019; Mondello, Salomone, & Mondello, 2024). In water management, they involve solid, concentrated, or waterless cosmetics aimed at reducing the product's water footprint (Aguiar et al., 2022; Martins & Marto, 2023). In packaging and post-consumption practices, they encompass recyclable, reusable, refillable, and biodegradable solutions, as well as initiatives associated with reverse logistics (D'Adamo et al., 2024). Sustainable innovation in cosmetics therefore emerges from the articulation of formulation, manufacturing, ecodesign, packaging, supply chain management, and consumption practices.

The adoption of these practices is asymmetric and reflects differences in resources, capabilities, and strategic orientation. Leading firms tend to incorporate ecodesign, life cycle assessment, traceability, and circularity, whereas smaller firms often concentrate their efforts on regulatory compliance, waste reduction, and incremental adjustments (Kolling, Ribeiro, & Medeiros, 2022; Suphasomboon & Vassanadumrongdee, 2023). This heterogeneity prevents sustainability from being treated as a flat set of equivalent practices. In the cosmetics sector, sustainable innovation should therefore be interpreted as a maturity trajectory, defined by the degree of complexity, systematization, and integration of sustainable practices into the firm's decision-making and innovation processes.

2.3. Sustainable Innovation Maturity as a Latent Structure

Conventional approaches to measuring organizational sustainability still privilege aggregated scores, summed practices, averages, and composite indices. Although these instruments facilitate managerial communication and inter-firm comparison, they tend to level practices of differing complexity. In the case of ESG scores, this limitation stems from the difficulty of capturing temporality, impact, resource management, interconnectivity, materiality, and transparency (Clément, Robinot, & Trespeuch, 2022). The measurement of sustainable performance also depends on the alignment of indicators with the organizational context, strategic orientation, sectoral materiality, and data quality (Damtoft, Van Liempd, & Lueg, 2025). Without such distinctions, basic compliance practices may receive similar weight to advanced sustainable capabilities.

Sustainable innovation maturity may be understood as a latent trait: an organizational dimension that is not directly observable but inferred from the firm's pattern of responses to a set of practices. This perspective shifts the analysis from the isolated presence of actions to the capability structure underlying their adoption. Item Response Theory (IRT) is particularly suitable for this framework because it

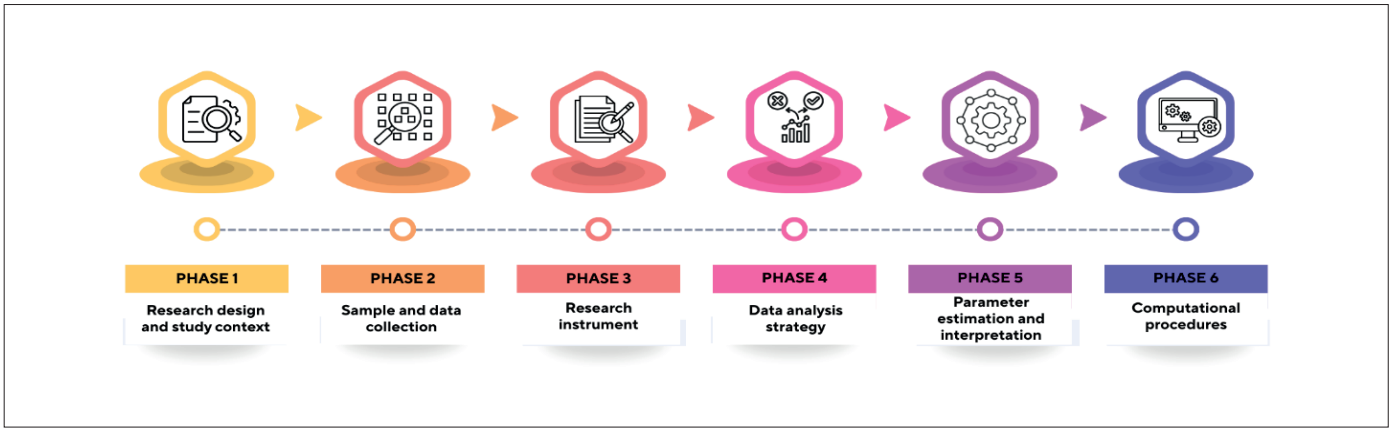
models the relationship between observable variables and the latent trait, estimating item parameters such as difficulty and discrimination (Foster, Min, & Zickar, 2017; Gyamfi & Acquaye, 2023). In sustainability and ESG instruments, this approach makes it possible to identify which items effectively differentiate levels of the construct and which merely reproduce low-informational adherence patterns (Barbosa et al., 2024).

This logic is especially relevant to the cosmetics industry, where sustainable practices are distributed across formulation, production, packaging, supply chain management, and post-consumption activities. Sectoral literature highlights a repertoire of practices ranging from waste reduction and input substitution to circularity, traceability, ecodesign, life cycle assessment, and sustainability governance (Bom et al., 2019; Martins & Marto, 2023; Mondello, Salomone, & Mondello, 2024). IRT enables the testing of whether these practices are organized into progressive levels of maturity, identifying which require greater organizational capability and which better discriminate firms at different stages (Barbosa et al., 2024; Gyamfi & Acquaye, 2023). The research gap lies in the absence of latent measurement approaches capable of indicating which practices structure, differentiate, and hierarchize sustainable innovation maturity in the cosmetics sector.

3. Methodology

To ensure clarity and systematization of the methodological procedure adopted, the study was structured into six sequential phases, encompassing the definition of the research design, data collection and treatment procedures, computational procedures, and the interpretation of results. This organization ensured coherence between the study context, data handling processes, and the application of Item Response Theory to analyze sustainable innovation maturity in the cosmetics industry. Figure 1 provides a visual synthesis of the methodological stages developed throughout the research.

Figure 1. Methodological framework of the study



Source: Authors (2026)

Phase 1: Research Design and Study Context: This research is characterized as a quantitative study of a descriptive and explanatory nature, conducted through a cross-sectional survey. The study was developed within the context of the Brazilian cosmetics industry, a sector marked by high regulatory pressure, intensive use of natural raw materials, strong reputational exposure, and increasing demands for sustainability and innovation practices. The unit of analysis corresponds to the firm, with responses provided by professionals knowledgeable about organizational practices related to sustainability, innovation, and strategic management.

Phase 2: Sample and Data Collection: The study sample consists of 89 companies operating in the Brazilian cosmetics industry that fully completed the questionnaire. The firms exhibit heterogeneity in terms of size, years of operation, and geographic location, encompassing different organizational contexts. Data collection was conducted through an electronic questionnaire, ensuring anonymity and confidentiality of information, as well as emphasizing the absence of right or wrong answers in order to reduce potential social desirability and common method biases.

Phase 3: Research Instrument: The data collection instrument consisted of 11 items designed to capture practices associated with sustainable innovation maturity, encompassing dimensions related to circular economy, social practices, ESG governance, technological innovation, and the strategic integration of sustainability. The items were measured using a five-point ordinal Likert scale ranging from Nonexistent (1) to Consolidated (5), reflecting different stages in the adoption and institutionalization of the analyzed practices. The use of an ordinal scale justifies the adoption of statistical methods appropriate for this type of measurement.

The definition of the maturity levels adopted in this study was based on the organizational progression logic of sustainable innovation, operationalized through a five-level ordinal scale: Nonexistent, Initial, Partial, Advanced, and Consolidated. These levels represent different stages of adoption, integration, and institutionalization of sustainable innovation practices within organizations. Subsequently, maturity was modeled as a continuous latent trait (θ) using Item Response Theory (IRT), allowing the estimation of the relative positioning of companies along the organizational maturity continuum.

Phase 4: Data Analysis Strategy: Data analysis was conducted using Item Response Theory (IRT), specifically the Graded Response Model, which is appropriate for ordinal items with multiple ordered categories. IRT enables sustainable innovation maturity to be modeled as a continuous latent trait (θ), not directly observable but inferred from the response patterns to the questionnaire items. The choice of a unidimensional model is grounded in the theoretical coherence among the items and was empirically supported by the high proportion of variance explained by a single latent factor, as well as by the predominance of high factor loadings, indicating that the analyzed practices reflect a common underlying process of organizational maturation in sustainable innovation. By combining several evaluation criteria and offering stronger analytical evidence, quantitative decision-support techniques are being used more frequently to handle complicated organizational issues (Ferreira et al., 2026). Because it makes it possible to characterize sustainable innovation maturity as a latent concept deduced from firms' response patterns, item response theory (IRT) was used in this study.

Phase 5: Parameter Estimation and Interpretation: In the Graded Response Model, the discrimination parameter (a) and the difficulty parameters (b1, b2, b3, and b4) are estimated. The parameter a indicates each item's ability to differentiate firms positioned at different levels of the latent trait, with higher values associated with greater discriminatory power. The b parameters represent the points along the latent trait continuum at which the probability of transition between adjacent response categories becomes higher, thereby identifying the stage of maturity at which each practice tends to emerge. Latent trait scores (θ) were estimated using the Expected a Posteriori (EAP) method, widely adopted in IRT applications due to its greater stability and lower sensitivity to extreme values. Higher θ values indicate more advanced levels of sustainable innovation maturity. For analytical and descriptive purposes, θ scores were subsequently examined according to their empirical distribution, allowing the identification of firms concentrated at low, intermediate, and high levels of maturity.

Phase 6: Computational Procedures: The analyses were conducted using the R software environment with the mirt package, which is widely employed in Item Response Theory applications. This procedure ensures both the reproducibility of results and the statistical robustness of the estimated parameters.

4. Results

First, the sample was characterized, comprising Brazilian companies from the cosmetics industry with different sizes, years of operation, and regional distribution, as shown in Table 1:

Table 1. Characterization of the Companies in the Sample

Characteristic	Category	n
Firm Size	Micro	38
	Small	12
	Medium	21
	Large	18
Years of Operation (Firm Age)	**Less than 5 years**	**24**
	5 to 10 years	19
	11 to 20 years	10
	More than 20 years	36
Region	**North**	**1**
	Northeast	0
	Central-West	3
	Southeast	71
	South	14

Source: Authors (2026)

The analysis of Table 1 highlights the heterogeneity of the sector, indicating that the sample encompasses different organizational contexts, which is appropriate for the objective of measuring sustainable innovation maturity in the cosmetics industry.

4.1 Latent Structure of Sustainable Innovation Maturity in the Cosmetics Industry

Subsequently, Item Response Theory (IRT) was applied using the Graded Response Model, which indicated that sustainable innovation maturity can be represented by a unidimensional latent structure, explaining 63.2% of the total variance of the analyzed items (SS loadings = 6.957). This result evidences a high level of internal consistency of the construct and suggests that the environmental, social, and governance practices under analysis share a common conceptual foundation, reflecting a single underlying process of organizational maturation.

In the context of the Brazilian cosmetics industry, this finding suggests that sustainable innovation does not manifest as isolated initiatives—whether purely environmental or social—but rather as an integrated process in which strategic decisions, operational practices, and governance mechanisms evolve jointly. This evidence is particularly relevant for a sector characterized by intense regulatory pressure, high use of packaging and raw materials, and growing demand for socio-environmental transparency across the value chain.

Table 2. Factor Loadings and Communalities of the Unidimensional Model

Item	Fator 1	h^2
Reuse and Remanufacturing	0.741	0.549
Recycled/Renewable Inputs	0.883	0.779
Circularity Indicators	0.765	0.585
Human Rights and Labor Practices	0.448	0.201
Diversity and Inclusion	0.762	0.581
Supplier Audits	0.786	0.618
ESG in Strategy	0.845	0.714
ESG in Corporate Decision-Making	0.818	0.669
ESG Governance	0.880	0.775
Green Technology Partnerships	0.884	0.781
Sustainability Policies	0.840	0.706

Source: Authors (2026)

Factor loadings (F1) and communalities (h^2) further reinforce the consistency of the estimated latent structure. Factor loadings indicate the degree of association between each practice and the sustainable innovation maturity construct, while communalities represent the proportion of each item's variance explained by this underlying factor. In this regard, practices associated with ESG governance, partnerships for green technologies, and the use of recycled or renewable inputs exhibited high F1 and h^2 values, indicating strong alignment with sustainable innovation maturity in the cosmetics sector.

In contrast, the item related to human rights and working conditions presented lower factor loading and communality values, suggesting that, although it is a fundamental practice, it operates more as a basic compliance requirement than as a differentiating element across levels of sustainable innovation maturity.

4.2 Item Parameters and Differentiation of Maturity Levels

Once the latent structure of sustainable innovation maturity has been established, the analysis advances toward understanding how different practices contribute to distinguishing firms positioned at different levels of this construct. To this end, item parameters estimated by the Graded Response Model were examined, with particular emphasis on the discrimination parameter, which indicates each practice's ability to differentiate firms with lower and higher levels of sustainable innovation maturity. Table 3 presents these parameters, enabling the identification of which practices act as key elements in the transition toward more advanced stages of maturity within the cosmetics industry context.

Table 3. Parameters for Identifying Key Practices Across Maturity Stages in the Cosmetics Industry

Item	a	b1	b2	b3	b4
Reuse and Remanufacturing	1.878	-2.150	-1.673	-0.977	0.552
Recycled/Renewable Inputs	3.197	-0.944	-0.492	0.472	1.277
Circularity Indicators	2.019	-1.055	-0.425	0.552	1.227
Human Rights and Labor Practices	0.853	-3.909	-3.106	-0.569	1.708
Diversity and Inclusion	2.003	-1.231	-0.654	0.854	1.775
Supplier Audits	2.167	-1.888	-0.807	0.377	1.506
ESG in Strategy	2.686	-0.906	0.113	0.602	1.168
ESG in Corporate Decision-Making	2.419	-1.386	-0.750	-0.098	1.710
ESG Governance	3.159	-0.879	-0.234	0.679	1.561
Green Technology Partnerships	3.210	-1.314	-0.555	0.549	1.123
Sustainability Policies	2.636	-1.418	-0.666	0.444	1.207

Source: Authors (2026)

The joint analysis of the parameters estimated by the Graded Response Model makes it possible to understand, in an integrated manner, how sustainable innovation maturity is structured and evolves over time within the cosmetics industry. The discrimination parameter (a) highlights the ability of each practice to differentiate firms positioned at distinct levels of maturity, revealing which elements function as true markers of organizational advancement. Practices with high a values exhibit a strong capacity to distinguish less mature firms from those positioned at more advanced levels, whereas lower values indicate practices that are widely disseminated throughout the sector and therefore possess limited differentiating potential.

Additionally, the difficulty parameters (b) make it possible to identify the stage of the maturation process at which each practice tends to be adopted, thereby organizing them along a maturity trajectory. Practices associated with lower b values emerge at early stages, reflecting basic requirements of institutional compliance, whereas practices associated with higher values—especially at thresholds b3 and b4, corresponding to the advanced and consolidated levels of the scale—require higher levels of organizational maturity for their full implementation.

In this context, practices related to human rights and working conditions exhibit low discriminatory power and low levels of difficulty, indicating their consolidation as a minimum expected standard within the cosmetics industry. In contrast, practices associated with ESG governance, the development of green technologies, and the adoption of recycled or renewable inputs combine high discriminatory power with high levels of difficulty, emerging predominantly at advanced stages of maturity.

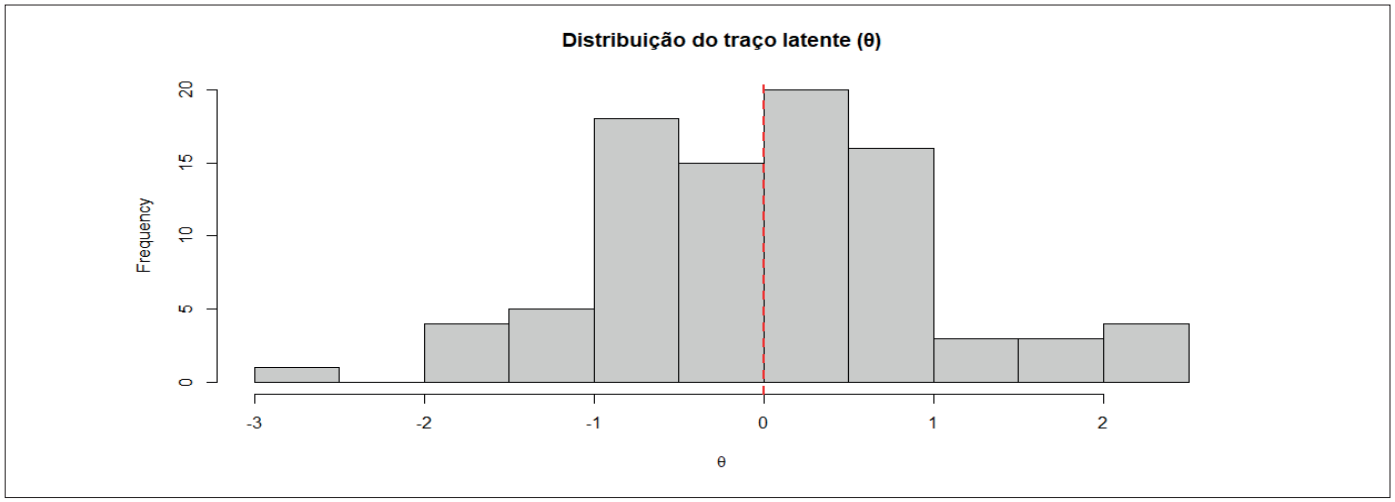
These findings indicate that sustainable innovation in the sector is not characterized by the mere adoption of isolated practices, but rather by the strategic integration of sustainability, technological innovation, and governance. This configuration reflects a progressive and qualitative maturation process in which only firms with greater organizational capabilities are able to achieve and sustain high levels of maturity.

5. Discussion

5.1. Distribution of Sustainable Innovation Maturity

Subsequently, a descriptive analysis of the latent trait (θ) associated with sustainable innovation maturity was conducted in order to understand how the firms in the sample are distributed across the different levels of this construct. The latent trait θ represents the relative position of organizations along a maturity continuum, in which lower values indicate initial stages of sustainable innovation, whereas higher values reflect more advanced levels of integration between innovation, ESG practices, and organizational governance. Figure 2 presents the distribution of the latent trait (θ) through a histogram.

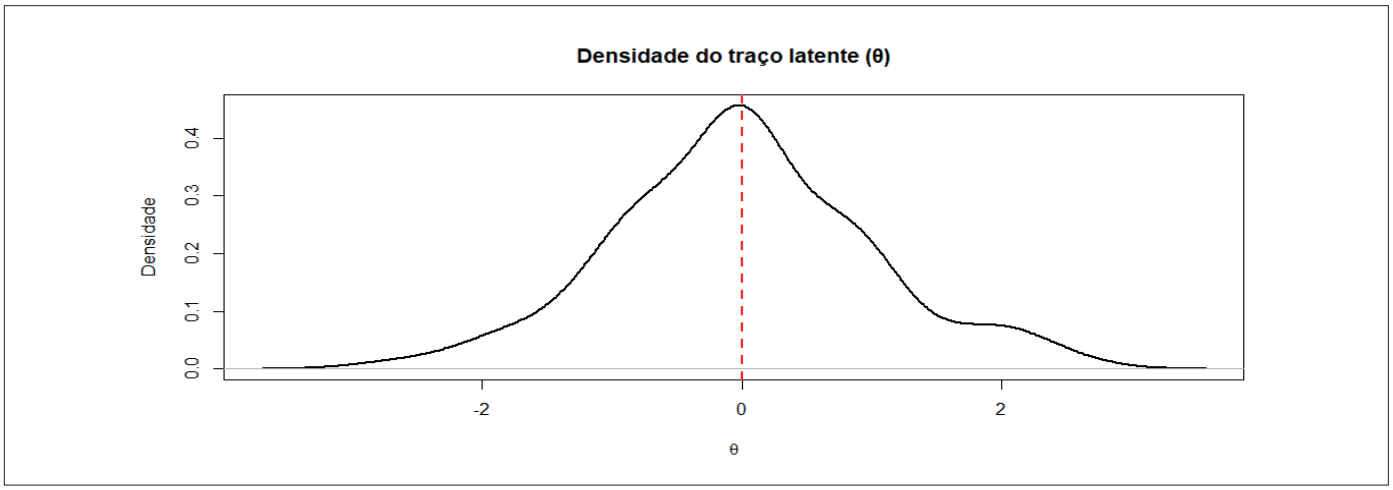
Figure 2. Distribution of the Latent Trait (θ) of Sustainable Innovation Maturity



Source: Authors (2026)

It can be observed that the distribution is centered around θ = 0 (mean = −0.001), with values ranging from −2.619 to 2.498 and a standard deviation of 0.973. This result indicates that most firms in the sample exhibit intermediate levels of sustainable innovation maturity, while also highlighting the heterogeneity of the sector. Accordingly, Figure 3 illustrates the density curve of the latent trait (θ).

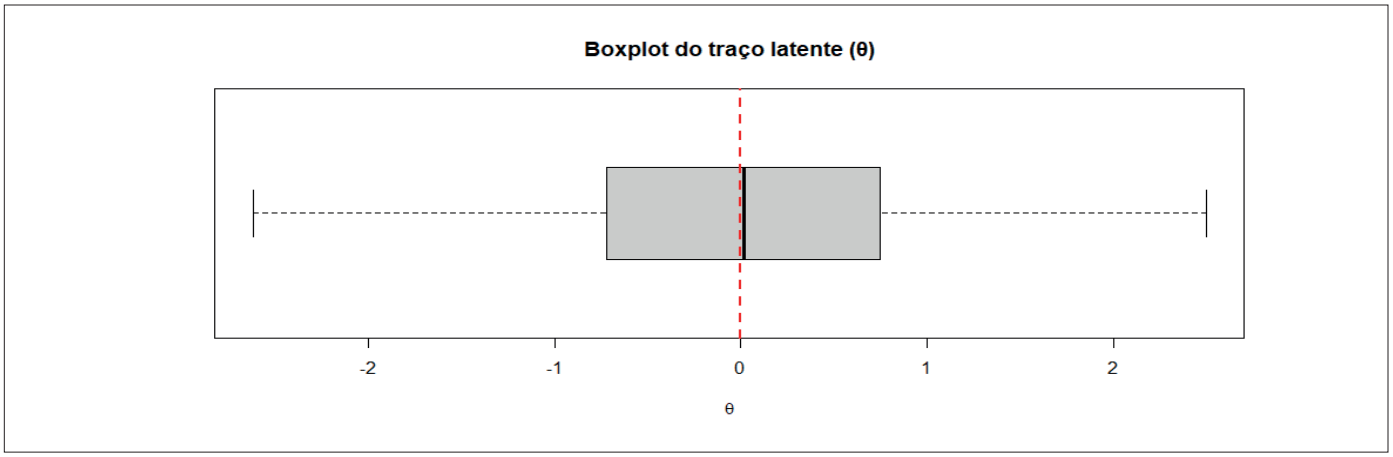
Figure 3. Density of the Latent Trait (θ)



Source: Authors (2026)

The figure corroborates this interpretation by revealing a predominant concentration of firms at intermediate levels of the latent trait, with no evidence of polarization between initial and advanced stages of maturity. This behavior indicates that sustainable innovation practices, although present within the sector, are incorporated progressively and at different paces among firms in the cosmetics industry. Complementarily, Figure 4, corresponding to the boxplot of the latent trait (θ), is presented below:

Figure 4. Boxplot of the Latent Trait (θ)



Source: Authors (2026)

It is possible to visualize the dispersion of the observed maturity levels. The median of the latent trait is located close to θ = 0, with quartiles distributed between Q1 = −0.719 and Q3 = 0.749, indicating that approximately half of the firms are concentrated within this interval. The range of values reinforces the existence of asymmetries in the sustainable innovation maturation process within the sector. The classification of firms according to maturity levels, presented in Table 4, corroborates the patterns observed in Figures 2, 3, and 4.

Table 4. Descriptive statistics of the latent trait (θ)

Statistic	**Value**	
Mean	≈ 0.00	
Standard Deviation	≈ 0.97	
Minimum	-2.62	
Maximum	2.50	
Maturity-Level Classification		
Maturity Level	**n**	**%**
Low	10	11.2
Intermediate	69	77.5
High	10	11.2
Total	**89**	**100.0**

Source: Authors (2026)

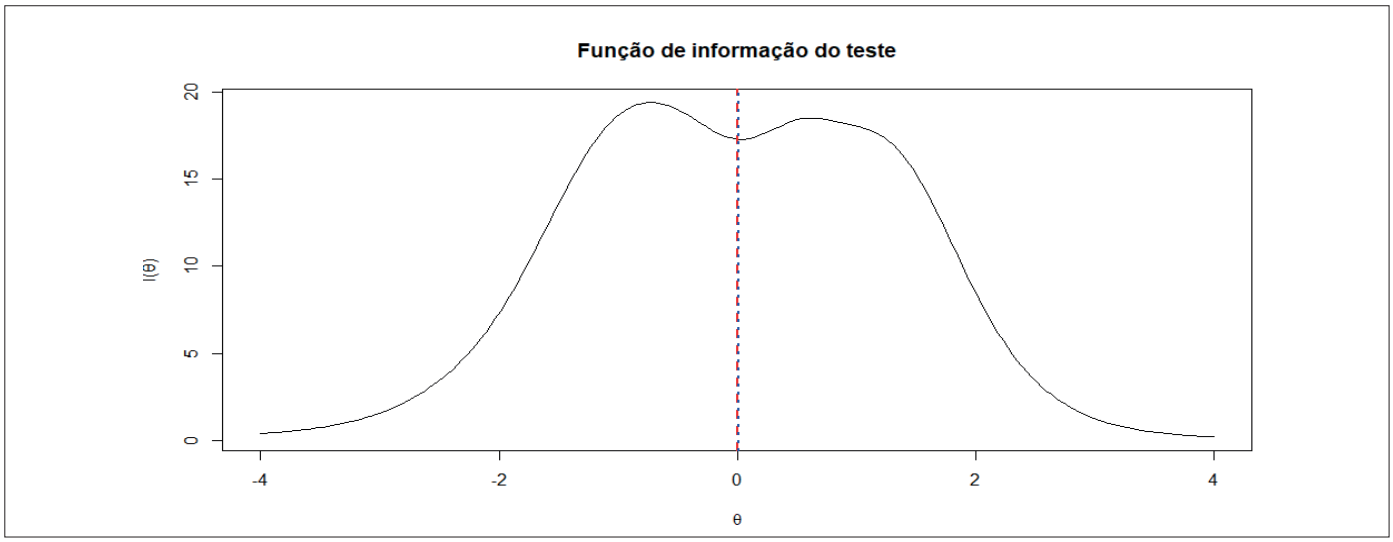
It can be observed that 77.5% of the firms are positioned at an intermediate level of sustainable innovation maturity, whereas 11.2% are situated at low levels and 11.2% at high levels. These results suggest that the cosmetics industry is currently in a transitional stage, in which sustainable innovation is already recognized as strategic but has not yet been fully consolidated in a homogeneous manner across organizations.

In summary, the descriptive analysis of the latent trait indicates that sustainable innovation maturity is configured as a continuous process of organizational maturation, characterized by gradual and asymmetric advances among firms in the cosmetics industry. By identifying the practices that best distinguish firms based on their maturity level, the suggested maturity model aids in organizational assessment and highlights the value of quantitative analytical techniques for assisting managerial decision-making (Santos et al., 2026). These findings provide support for the analysis of measurement precision presented in the following section, in which the instrument's ability to discriminate firms across different levels of maturity is evaluated.

5.2. Measurement Precision

Subsequently, the precision of the sustainable innovation maturity measure was assessed through the analysis of the test information function, as presented in Figure 5. The test information function indicates the degree of precision with which the instrument measures the latent trait (θ) across different levels of maturity, with higher information values being associated with lower estimation error. As shown in Figure 5:

Figure 5. Test information function and distribution of the latent trait (θ)



Source: Authors (2026)

The analysis of Figure 5 shows that the instrument presents the highest level of information around the intermediate values of the latent trait, particularly near θ = 0. It is also observed that the information curve maintains high levels across a relatively broad interval of the continuum, approximately between θ = −2 and θ = +2, indicating a strong ability of the instrument to discriminate firms positioned at low and intermediate levels of sustainable innovation maturity.

On the other hand, a gradual reduction in information can be observed at the extremes of the latent trait, suggesting lower measurement precision for firms positioned at very low or very high levels of maturity. This behavior is expected in instruments of this type, since most of the evaluated practices tend to differentiate organizations located at intermediate stages of the organizational maturation process.

These results indicate that the developed instrument is particularly suitable for capturing relevant variations in sustainable innovation maturity within the cosmetics industry, especially in the range where most of the sample is concentrated. Therefore, the test information function reinforces the robustness of the proposed measure, highlighting its discriminatory capacity and its adequacy for measuring sustainable innovation maturity as a continuous latent construct.

6. Conclusions

This study analyzed sustainable innovation maturity in the cosmetics industry through the application of Item Response Theory (IRT), modeling sustainable innovation as a continuous latent trait. The results indicate that sustainable innovation maturity is structured as a unidimensional process in which environmental, social, and governance practices evolve in an integrated manner, reflecting a single trajectory of organizational maturation.

The findings demonstrate that the advancement of sustainable innovation in the sector depends less on the isolated adoption of specific practices and more on the strategic integration of sustainability, technological innovation, and ESG governance. Practices related to ESG governance, the development of green technologies, and the adoption of recycled or renewable inputs exhibited greater discriminatory power, emerging as central elements in differentiating firms at more advanced levels of maturity. In contrast, practices associated with human rights and working conditions appeared relatively homogeneous across firms, representing a basic level of institutional compliance with lower capacity to distinguish between maturity levels.

From a methodological perspective, the study contributes by demonstrating the applicability of IRT in an organizational context, offering a robust approach for capturing stages of sustainable innovation maturity. By identifying which practices effectively differentiate maturity levels, the results provide relevant insights for both researchers and managers interested in guiding more sustainable innovation strategies within the cosmetics sector.

It is important to recognize the limitations of this study. First, even though the sample of 89 businesses is sufficient to estimate the suggested Item Response Theory model, it is still somewhat small and might restrict how broadly the results can be applied. Second, the sample is geographically concentrated, with the majority of companies situated in Brazil's Southeast, which may lessen the representativeness of other regional settings while reflecting the structure of the country's cosmetics business. Lastly, the study used eleven items to gauge the maturity of sustainable innovation. Future research should broaden the instrument by adding more practices and confirming the model using bigger and more geographically diversified samples, even though these questions captured the primary ESG and innovation features found in the literature.

Future research may deepen the analysis of sustainable innovation maturity through longitudinal approaches, enabling the examination of firm evolution over time and transitions across different maturity

levels. Furthermore, applying the proposed model to other industrial sectors or conducting intersectoral comparative studies may contribute to assessing the generalizability of the findings. Additional studies may also explore the moderating role of organizational characteristics such as firm size, years of operation, and regional location, as well as integrate IRT with structural models or mixed-method approaches, thereby expanding the understanding of the factors that drive sustainable innovation across different organizational contexts.

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