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Article

Assessing the relationship between sustainability and regional competitiveness in the Brazilian context

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Abstract


Sustainability has become a central priority in regional development agendas, yet its relationship with regional competitiveness remains insufficiently understood at the municipal level, particularly in emerging economies. This study examines how

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sustainability attributes are associated with regional competitiveness across Brazilian municipalities. Using indicators derived from the Sustainable Development Goals (SDGs), sustainability is operationalized through latent dimensions and analyzed alongside competitiveness dimensions – institutions, society, and economy – using multiple linear regression and canonical correlation analyses. The empirical results identify three sustainability dimensions: (i) economic and institutional factors, (ii) resources and ecosystems, and (iii) socio-environmental conditions. The findings indicate that sustainability attributes are systematically associated with regional competitiveness. In particular, the economic and institutional dimension and the resources and ecosystem dimension show the strongest positive associations with competitiveness indicators, suggesting that institutional capacity and sustainable resource governance are key drivers of regional performance. The socio-environmental dimension also contributes to competitiveness, although its influence appears more limited. Evidence regarding territorial covariates – such as location in wealthier regions and participation in regional agglomerations – remains mixed, highlighting that structural conditions alone do not fully explain competitiveness outcomes. These results underscore the importance of considering the interaction between agency – expressed through institutional capacity and policy choices – and structural territorial contexts. From a public policy perspective, the findings highlight the need for integrated strategies that strengthen institutions, promote sustainable resource management, and leverage local capabilities to enhance sustainable regional competitiveness.

Keywords: sustainable development, regional competitiveness, municipal competitiveness, municipal sustainability, SDGs.

Análise da relação entre sustentabilidade e competitividade regional no contexto brasileiro

Resumo

A sustentabilidade tornou-se uma prioridade central nas agendas de desenvolvimento regional; no entanto, sua relação com a competitividade regional ainda não é suficientemente compreendida no âmbito municipal, especialmente nas economias emergentes. Este estudo examina como os atributos de sustentabilidade estão associados à competitividade regional nos municípios brasileiros. Utilizando indicadores derivados dos Objetivos de Desenvolvimento Sustentável (ODS), a sustentabilidade é

operacionalizada por meio de dimensões latentes e analisada em conjunto com as dimensões da competitividade – instituições, sociedade e economia –, empregando regressão linear múltipla e análises de correlação canônica. Os resultados empíricos identificam três dimensões de sustentabilidade: (i) fatores econômicos e institucionais, (ii) recursos e ecossistemas, e (iii) condições socioambientais. As conclusões indicam que os atributos de sustentabilidade estão sistematicamente associados à competitividade regional. Em particular, a dimensão econômica e institucional e a dimensão de recursos e ecossistemas apresentam as associações positivas mais fortes com os indicadores de competitividade, sugerindo que a capacidade institucional e a governança sustentável dos recursos são fatores-chave para o desempenho regional. A dimensão socioambiental também contribui para a competitividade, embora sua influência pareça mais limitada. As evidências relativas às covariáveis territoriais – tais como a localização em regiões mais ricas e a participação em aglomerações regionais – permanecem contraditórias, destacando que as condições estruturais por si só não explicam totalmente os resultados de competitividade. Esses resultados ressaltam a importância de considerar a interação entre a agência - expressa por meio da capacidade institucional e das escolhas políticas - e os contextos territoriais estruturais. Do ponto de vista das políticas públicas, as conclusões destacam a necessidade de estratégias integradas que fortaleçam as instituições, promovam a gestão sustentável dos recursos e aproveitem as capacidades locais para aprimorar a competitividade regional sustentável.

Palavras-chave: desenvolvimento sustentável, competitividade regional, competitividade municipal, sustentabilidade municipal, ODS.

Análisis de la relación entre la sostenibilidad y la competitividad regional en el contexto brasileño

Resumen

La sostenibilidad se ha convertido en una prioridad fundamental en las agendas de desarrollo regional; sin embargo, su relación con la competitividad regional sigue sin entenderse lo suficiente a nivel municipal, especialmente en las economías emergentes. Este estudio examina cómo los atributos de sostenibilidad se relacionan con la competitividad regional en los municipios brasileños. Utilizando indicadores derivados de los Objetivos de Desarrollo Sostenible (ODS), la sostenibilidad se operacionaliza a través de dimensiones latentes y se analiza junto con las dimensiones de la competitividad

– instituciones, sociedad y economía – mediante análisis de regresión lineal múltiple y de correlación canónica. Los resultados empíricos identifican tres dimensiones de la sostenibilidad: (i) factores económicos e institucionales, (ii) recursos y ecosistemas, y (iii) condiciones socioambientales. Los resultados indican que los atributos de sostenibilidad están sistemáticamente asociados con la competitividad regional. En concreto, la dimensión económica e institucional y la dimensión de recursos y ecosistemas muestran las asociaciones positivas más sólidas con los indicadores de competitividad, lo que sugiere que la capacidad institucional y la gestión sostenible de los recursos son factores clave del rendimiento regional. La dimensión socioambiental también contribuye a la competitividad, aunque su influencia parece más limitada. Las pruebas relativas a las covariables territoriales – como la ubicación en regiones más prósperas y la participación en aglomeraciones regionales – siguen siendo contradictorias, lo que pone de relieve que las condiciones estructurales por sí solas no explican plenamente los resultados de competitividad. Estos resultados subrayan la importancia de tener en cuenta la interacción entre la agencia – expresada a través de la capacidad institucional y las decisiones políticas – y los contextos territoriales estructurales. Desde la perspectiva de las políticas públicas, los resultados ponen de relieve la necesidad de estrategias integradas que fortalezcan las instituciones, promuevan la gestión sostenible de los recursos y aprovechen las capacidades locales para mejorar la competitividad regional sostenible.

Palabras clave: desarrollo sostenible, competitividad regional, competitividad municipal, sostenibilidad municipal, ODS.

1. INTRODUCTION

The relationship between environmental issues and development occupies a prominent place in contemporary discussions. Raising awareness of how sustainability attributes relate to regional competitiveness remains a challenge. Despite the recognized importance of integrating sustainability and competitiveness, a notable gap persists in academic research concerning their interaction, particularly at the regional level (Capobianco-Uriarte et al., 2019). Only recently has scholarly interest increased in exploring the interplay and mutual dynamics between these two critical phenomena, with relatively few approaches focusing on the regional dimension.

Although an expanding body of literature has examined the connection between sustainability and competitiveness – primarily from a business perspective (Durst & Leyer, 2022; Hermundsdottir & Aspelund, 2021; Momtaz & Parra, 2024; Rabaya & Saleh, 2022) – studies addressing this relationship at the regional level remain comparatively limited (Martínez & Poveda, 2022; Pane, 2023; Ziaei & Roshani, 2024). This deficiency is particularly evident in the context of the Global South. Many of these studies rely on predefined composite indices, treating sustainability and competitiveness as aggregated constructs without examining their underlying structural dimensions. This approach restricts the capacity to understand how specific sustainability configurations relate to regional competitive performance.

In nations characterized by extensive geographic size and pronounced regional heterogeneity, the convergence of sustainability and competitiveness emerges as a critically important research area. Brazil, marked by its vast territorial expanse and diverse economic landscapes, offers a particularly apt setting for investigating these issues. At the municipal level – where public policies are implemented and development strategies materialize – understanding the relationship between sustainability attributes and competitiveness is especially important.

In light of these considerations, this study addresses the following research question: To what extent and through which structural dimensions is sustainability performance associated with regional competitiveness at the municipal level? To address this question, sustainability is operationalized through the Sustainable Development Goals (SDGs), enabling an empirical assessment of how different sustainability dimensions relate to patterns of competitiveness across Brazilian municipalities. These sustainability dimensions (attributes), as represented by the SDGs, are considered to reflect local sustainability practices that may be associated with regional competitiveness. The central premise of the analysis is that variations in municipal competitiveness could be related to differences in sustainability performance, without assuming a deterministic relationship.

Both theoretical and empirical evidence suggest that high regional competitiveness is closely associated with a strong commitment to sustainability (Del-Aguila-Arcenales et al., 2022; Martínez & Poveda, 2022; Pane, 2023). Focusing on municipalities is justified because localities play a pivotal role in shaping regional competitiveness (Musterd & Kovács, 2013). Moreover, sustainability and development

issues tend to be less addressed at the municipal level, even though it is precisely where changes typically originate and take shape (Irina & Evgeny, 2024).

The data used in this study were collected from secondary sources that assess both competitiveness and SDG performance in Brazilian municipalities. The empirical strategy advances the literature in three main ways. First, an Exploratory Factor Analysis (EFA) is applied to SDG indicators to extract latent sustainability dimensions, allowing the identification of underlying structural patterns instead of relying solely on predefined composite scores. Second, linear regression models are used to estimate average associations between sustainability attributes and regional competitiveness. Third, Canonical Correlation Analysis (CCA) captures the simultaneous multivariate relationship between sustainability and competitiveness dimensions. Together, these techniques provide a more comprehensive analytical framework for investigating the sustainability–competitiveness nexus.

By adopting this multidimensional and structural approach, the study contributes theoretically to Public Administration and regional development. It advances the understanding of sustainability not merely as a normative policy objective, but as a structural determinant of territorial competitiveness, highlighting the strategic role of municipal governance in integrating sustainability and development agendas within decentralized systems. Furthermore, it provides empirical evidence of the sustainability–competitiveness relationship within a municipal context in the Global South, thereby addressing a notable gap in existing studies, which predominantly focus on business and industrial sectors in developed countries. In doing so, the study offers both analytical refinement and theoretical insight into the relationship between sustainability performance – understood as a structured and multidimensional phenomenon – and regional competitiveness at the local level.

2. SUSTAINABILITY AND REGIONAL COMPETITIVENESS

Sachs (1992) identifies five core dimensions of sustainability: social, economic, ecological, spatial, and cultural. Pravitasari et al. (2018) further refine this view, suggesting that sustainability involves functioning within the limits imposed by environmental, technological, and social requirements. This multidimensional framework underscores the fact that sustainability intersects numerous disciplines, prompting

extensive theoretical debates about the nature and practical application of sustainability indicators. Such debates are crucial for unpacking the complexities and nuances involved in defining and employing these indicators across various contexts (Kuhlman & Farrington, 2010; Pravitasari et al., 2018).

Although the concept of competitiveness has been the subject of wide-ranging scholarly debates and discussions across multiple dimensions, it has also shifted beyond national boundaries to encompass regional analyses (Judrupa, 2021). Competitiveness should be viewed as a relative capacity in which one entity – be it a nation, region, organization, or actor – demonstrates stronger performance than another (Gräbner-Radkowsch et al., 2023). Importantly, competitiveness is not confined to growth and economic performance; it also involves factors such as the environment, quality of life, and knowledge creation (Balkyte & Tvaronavičiene, 2010). Consequently, competitiveness encompasses elements reflecting a complex web of societal relationships. In this regard, numerous studies have expanded the discussion to account for the interplay between human agency and structural factors as a key driver of regional development, as illustrated by (Dinmore et al., 2024; Hassink et al., 2019; Sotarauta & Grillitsch, 2023).

Budd and Hirmis (2004) previously observed that regional competitiveness is not merely a straightforward aggregation of businesses within a given area nor a simple disaggregation of the national economy. Rather, it arises from a more complex interplay of multiple factors. In the present study, regional competitiveness is framed in a multifaceted manner linked directly to sustainability. This aligns with the notion that regions – whether countries, states, or municipalities – strive to bolster sustainability as a pathway to greater competitiveness, thereby framing sustainability as a competitive advantage (Gräbner-Radkowsch et al., 2023). In this process, both actors and institutional structures interact to shape sustainability outcomes and broader regional development dynamics. Sustainability attributes can be interpreted as observable expressions of these dual influences on regional development and competitiveness. Although sustainability and competitiveness may share common structural determinants, this study conceptualizes sustainability as a mediating structural condition through which regional capabilities are articulated.

Porter (1986) offers a foundational framework for understanding competitive advantage, which has been widely mobilized in later discussions connecting

competitiveness and sustainability. Within a broader industrial and economic context, Porter and Linde (1995) argued that environmental concerns and competitiveness are not inherently contradictory; rather, thoughtfully designed regulations can align environmental and economic objectives. As Gräbner-Radkowitz et al. (2023) note, sustainability and competitiveness have become central concepts in an era marked by escalating climate challenges and growing demands for improved social welfare, surpassing earlier emphases on growth and productivity. Similarly, Hermundsdottir and Aspelund (2021) highlight the multifaceted connections between sustainability and competitiveness, demonstrating that sustainability practices significantly influence elements of sustainable competitiveness.

Lengyel and Rechnitzer (2013), along with Scaccabarozzi et al., (2022) and Gräbner-Radkowitz et al. (2023), argue that a more comprehensive understanding of competitiveness necessarily incorporates sustainability-related considerations. From this perspective, achieving a high level of competitiveness hinges on strong sustainability performance. Accordingly, from a regional standpoint, performance in sustainability matters is directly linked to the extent of regional competitiveness – a connection corroborated by studies such as (Martínez & Poveda, 2022; Pane, 2023).

Furthermore, Lengyel and Rechnitzer (2013) emphasize that regional competitiveness is closely tied to territorial contexts and heavily influenced by endogenous development. This underscores that sustainability-related concerns often hinge on distinctive regional features (Pravitasari et al., 2018). Hence, research addressing sustainability and competitiveness indicators at subnational levels carries significant weight, as these spaces serve as strategic points where market mechanisms intersect with public policy interventions. Additionally, they function as the governance level most directly connected to citizens, rendering them crucial for interpreting and tackling local challenges and needs.

Despite this significance, Capobianco-Uriarte et al. (2019) highlight a notable gap in the literature regarding the interplay between sustainability and competitiveness from a territorial standpoint. Nevertheless, several studies offer evidence of this relationship. For instance, Martínez and Poveda (2022) identify environmental performance as a key factor driving regional competitiveness in Colombian regions, while Pane (2023) observes a similar trend in Italian provinces, demonstrating a positive correlation between robust sustainability practices and enhanced competitiveness. In an analysis of Chinese

cities, Du et al. (2014) also report a favorable link between sustainability and competitiveness, and Cucculelli and Goffi (2016) indicate that sustainability indicators positively affect competitiveness in the local tourism sector.

In Brazil, existing research also points to a connection between sustainability and regional competitiveness. Araripe-Silva et al. (2018) find that municipalities in Ceará with stronger sustainability indicators exhibit higher competitiveness, while Silva et al. (2021) observe a similar relationship in municipalities in Rio de Janeiro. In a sector-specific study, Goffi et al. (2019) investigate tourist regions in Salvador and Rio de Janeiro, concluding that sustainability attributes positively shape tourism competitiveness.

Collectively, these studies suggest that sustainability within a territorial context tends to exert a favorable influence on regional competitiveness. This linkage is particularly relevant given that competitiveness itself increasingly revolves around the pursuit of an improved economic environment alongside stronger sustainability, a dual priority highlighted in contemporary scholarly debates (Donald & Gray, 2019).

Although the relationship between sustainability and competitiveness has been widely discussed in the literature, its theoretical foundations remain heterogeneous. Rather than assuming a purely mechanical causal link, this study situates both dimensions within broader processes of territorial development shaped by the interaction between agency and structural conditions. In line with Giddens (1984), regional development can be understood as the outcome of recursive interactions between institutional structures and the strategic actions of local actors. Within this perspective, sustainability is interpreted as an observable manifestation of how agency and structural conditions are articulated at the territorial level, which in turn may shape regional competitiveness.

Research in regional development increasingly emphasizes the importance of this agency-structure interplay in explaining uneven regional trajectories, as suggested by (Dinmore et al., 2024; Sotarauta & Grillitsch, 2023). This perspective suggests that regional development outcomes are not solely determined by structural constraints but emerge from the recursive interaction between institutional structures and the strategic actions of local actors. Structural conditions shape opportunities for development while simultaneously constraining local action, whereas collective agency may gradually reshape these structural conditions over time (Hassink et al., 2019).

Building on this perspective, sustainability outcomes can be interpreted as expressions of how local actors organize and institutionalize environmental management, social inclusion, and economic coordination within a given structural context (Dinmore et al., 2024; Pravitarsari et al., 2018). When these practices become embedded in territorial institutions, they may contribute to improving the quality of the local development environment by reducing systemic vulnerabilities, strengthening coordination, and fostering more stable development trajectories (Gräbner-Radkowitz et al., 2023). The literature on environmental regulation and competitiveness further suggests that sustainability-oriented policies and institutional arrangements may stimulate innovation and productivity improvements (Porter & Linde, 1995).

From this perspective, the association between sustainability and competitiveness may reflect identifiable institutional and economic mechanisms. Sustainability-oriented governance may improve the quality of the regional development environment by strengthening institutional coordination, reducing environmental and social vulnerabilities, and fostering innovation dynamics. These mechanisms may influence productivity conditions, knowledge generation, and the attractiveness of territories for investment and economic activity. In this sense, sustainability can be interpreted as a structural dimension shaping the institutional environment in which firms operate, thereby affecting competitive performance (Hermundsdottir & Aspelund, 2021; Porter, 1986; Porter & Linde, 1995). While competitiveness may also reinforce sustainability outcomes over time, the analytical strategy adopted in this study focuses on how sustainability-related institutional conditions may be associated with regional competitiveness, particularly in territorial contexts where governance arrangements and collective action influence development trajectories.

In this sense, sustainability should not be understood merely as a normative or environmental objective, but as a multidimensional set of social, environmental, and institutional conditions that support productive activity, knowledge creation, and investment attraction (Hermundsdottir & Aspelund, 2021; Kuhlman & Farrington, 2010). Regions exhibiting stronger sustainability attributes may therefore provide more favorable environments for economic activity and innovation (Gräbner-Radkowitz et al., 2023; Hermundsdottir & Aspelund, 2021). Although sustainability and competitiveness share several structural dimensions – such as economic, social, environmental, and institutional conditions – their analytical roles differ in the present

framework. The sustainability indicators primarily capture the quality of territorial conditions, including environmental resources, socio-environmental dynamics, and institutional-economic arrangements that shape the context in which development occurs. By contrast, competitiveness indicators emphasize the capacity of territories to transform these conditions into economic performance, productive dynamism, and societal outcomes. Treating sustainability as an explanatory dimension therefore allows the analysis to focus on how underlying territorial conditions may influence the competitive performance of municipalities.

From this perspective, sustainability is interpreted as reflecting the structural conditions of territorial development, while competitiveness represents the observable outcomes associated with how effectively these conditions are mobilized. Such conditions reinforce the argument that lasting competitive advantages derive not only from costs or productive specialization but also from the quality of the institutional and social environment (Porter, 1986; Porter & Linde, 1995). Within this analytical framework, sustainability is treated as an explanatory dimension reflecting how agency interacts with structural conditions in ways that may condition the institutional environment relevant to competitive outcomes. The direction adopted in this study therefore represents an analytical strategy consistent with theoretical arguments in regional development, positioning sustainability as a structural dimension through which the interaction between agency and institutional contexts may influence regional competitiveness.

3. METHODOLOGY

3.1 Research design and data collection

This study focuses on a subset of Brazilian municipalities encompassing all of the country's geographic regions and states. The sample is restricted to municipalities with populations exceeding 80,000 residents, totaling 404 municipalities, which collectively represent approximately 60% of Brazil's population. Given that over three-quarters of Brazil's 5,570 municipalities have fewer than 20,000 residents, the choice to concentrate on larger municipalities is driven by both the availability of relevant sustainability and

competitiveness data and the substantial pressures these municipalities face in addressing related challenges.

Data collection encompasses two key constructs: sustainability and competitiveness. For sustainability, this study uses the SDGs as a proxy. Municipal SDG performance is captured by the Sustainable Development Index of Cities, published by the Sustainable Cities Institute – Instituto de Desenvolvimento Sustentável das Cidades (IDSC), in Portuguese, a Brazilian civil society organization – covering indicators linked to all 17 SDGs (IDCS, 2024). Competitiveness is measured by the overall Competitiveness Index and its three dimensions – Institutions, Society, and Economy – compiled by the Public Leadership Center (Centro de Liderança Pública, CLP), in Portuguese, in its Competitiveness Ranking of Brazilian Municipalities (CLP, 2024). Both the sustainability and competitiveness measures are composite indicators, as detailed in each organization’s publication (see Supplementary Information – Index Descriptions for details and Supplementary Information – Available Data for dataset access). Given the multidimensional nature of sustainability and competitiveness (Canuto & Cherobim, 2018; Pane, 2023; Santos & Brandi, 2014; Scaccabarozzi et al., 2022), using composite indices is particularly appropriate because single metrics would be insufficient to capture these complex phenomena.

In Brazil, the Instituto Brasileiro de Geografia e Estatística (IBGE) is a leading government agency providing statistics across diverse fields. Over time, civil society organizations have also begun producing relevant data and information for researchers, society, and government. Among these organizations, CLP and IDCS stand out for publishing the indices mentioned above. Other organizations from various sectors of Brazilian civil society play important roles as well, see (Federação das Indústrias do Estado do Ceará [FIEC], 2025; Federação das Indústrias do Estado do Rio de Janeiro [FIRJAN], 2025; Transparência Internacional Brasil [TI-BR], 2024). Data from these organizations support robust statistical analyses and highlight the growing contributions of Brazilian civil society to public data repositories. Moreover, using indices developed by such organizations is a common academic practice (Del-Aguila-Arcenales et al., 2022; Ziaei & Roshani, 2024).

Although the indices used are plausible for empirical study, it is important to acknowledge their methodological limitations. Composite indicators inevitably reflect normative and methodological choices regarding the selection, aggregation, and

weighting of their underlying variables. As a result, such indices may embed implicit assumptions about development priorities and institutional performance. Additionally, because sustainability and competitiveness both relate to broad regional development processes, some overlap in their underlying determinants – such as institutional quality, human capital, socio-environmental issues, and governance capacity – may occur. To mitigate the risk of conceptual redundancy and spurious correlation, this study does not directly employ the aggregated indices as explanatory variables. Instead, an EFA is conducted to identify empirically distinct latent dimensions underlying the sustainability indicators, allowing the analysis to capture structural territorial conditions while reducing potential overlap with competitiveness outcomes.

Beyond sustainability and competitiveness data, this study includes two additional variables: region, indicating whether a municipality is located in Brazil’s wealthier regions (South or Southeast), and territorial agglomeration, identifying whether it is part of a metropolitan area or an integrated development region. Common variables such as Gross Domestic Product (GDP) per capita and population are already embedded within the Competitiveness and SDG indices and thus are not separately modeled. Table 1 summarizes the variables used in the statistical analyses.

Table 1

Description of variables for statistical modeling

Variables	Definition	Value	Source
Dependent			
Competitiveness ^a	Competitiveness Index	Continuous	CLP (2024)
Independent			
SDG ^b	SDG Index	Continuous	IDCS (2024)
Region	Indicates whether the municipalities are located in the wealthiest regions (South and Southeast)	Dummy: 1 = Yes; 0 = No	IBGE (2024)
Territorial agglomeration	Indicates whether the municipality is part of territorial agglomeration (metropolitan or integrated development region)	Dummy: 1 = Yes; 0 = No	CLP (2024)

Notes: ^aBoth the overall index and the indices for the dimensions – Institutions, Society, and Economy – were considered. ^bThe SDG indices, along with those for the 17 individual SDGs, were used in factor analysis, and the extracted latent factors were subsequently employed in regression and canonical correlation analyses.

Source: Elaborated by the authors.

It is important to note that both indices – the SDG Index and the Competitiveness Index – are constructed using datasets that refer to different years, that is, they rely on the most recent data available. This procedure is common in the construction of composite indices, see (Institute for Management Development [IMD], 2025; World Intellectual Property Organization [WIPO], 2025). Both the Competitiveness and SDG indices analyzed in this study were published in 2024, with most indicators referring to the year 2023, although some indicators correspond to earlier years (see Supplementary Information – Index Descriptions for details).

Figure 1 presents the sample of municipalities distributed across performance quartiles in the Competitiveness and SDG Indices. Above-median performance is more prevalent in the South and Southeast regions, while below-median performance dominates in the North, Northeast, and Central-West regions.

Figure 1
Distribution of municipalities across performance quartiles in the Competitiveness and SDG indices

	Quartile 1	Quartile 2	Quartile 3	Quartile 4	
North, Northeast, and Central-West	52%	34%	11%	3%	Competitiveness Index
	52%	30%	17%	1%	SDG Index
Southeast and South	8%	19%	34%	39%	Competitiveness Index
	8%	22%	30%	40%	SDG Index

Source: Elaborated by the authors based on data from CLP (2024) and IDCS (2024).

3.2 Statistical analysis

An EFA is performed to reduce the full set of SDGs to a smaller set of latent factors or dimensions. Each retained factor is a linear combination of the original variables, with the total number of factors being fewer than the number of variables (Hair et al., 2019). Mathematically, the empirical model can be expressed as:

$$F_k = s_{k,1} \cdot SDG_1 + s_{k,2} \cdot SDG_2 + \dots + s_{k,17} \cdot SDG_{17} \quad (1)$$

Where F represents each retained factor (with $k < 17$), and s denotes the factor score corresponding to each variable within each retained factor. The SDGs represent the modeled variables. The dimensions derived from the SDGs serve as independent variables in both the linear regression and canonical correlation analyses.

The study employs several multivariate analyses. Specifically, multiple linear regression analyses are used to investigate the average effects that sustainability indicators have on municipal competitiveness indicators. The ordinary least squares (OLS) estimation method is applied (Hair et al., 2019).

To explore the robustness of patterns linking sustainability and competitiveness, multiple regression specifications were estimated. First, models used the overall SDG index as the primary explanatory variable for overall competitiveness. Second, alternative specifications replaced the aggregated SDG index with its latent dimensions derived from the EFA, allowing evaluation of whether specific sustainability dimensions are more strongly associated with competitiveness outcomes. Third, additional models considered each dimension of the competitiveness index as dependent variables, enabling assessment of whether observed associations are consistent across different components of territorial performance. Taken together, this modeling strategy provides complementary robustness checks that help reduce concerns regarding spurious correlations between composite indicators. The models also include covariates: region (*Reg*), and territorial agglomeration (*Taggl*). It is worth noting that the natural logarithm was applied to the dependent variables, while the latent variables derived from the EFA were standardized using z-scores. This general empirical relationship is expressed in Equation 2:

$$Comp_d = \beta_0 + \beta_1 SDG_{ld} + \beta_3 Reg + \beta_4 TAggl + \varepsilon \quad (2)$$

Comp indicates competitiveness, where *d* represents the overall index and its three dimensions. The parameter β denotes the coefficients, while ε accounts for the errors. Note that *ld* represents the respective latent factors of the SDGs.

Diagnostic procedures were conducted to assess the validity of the regression assumptions. Multicollinearity among explanatory variables was evaluated using Variance Inflation Factors (VIF). The presence of influential observations was examined through leverage statistics, and the distribution of residuals was inspected to assess the normality assumption. The inspection of residual plots indicated the presence of heteroskedasticity, suggesting non-constant variance in the residuals. To address this issue and ensure robust statistical inference, bootstrap procedures were applied to all regression models.

Given that the empirical analysis relies on cross-sectional data, the estimated relationships should be interpreted as statistical associations rather than causal effects. The empirical strategy therefore seeks to identify whether variations in sustainability attributes are systematically associated with variations in municipal competitiveness.

Since the focus of the study is on two sets of variables (sustainability and competitiveness), a CCA is employed, as in Santos and Brandi (2014). As noted by Rencher and Christensen (2012), CCA represents an extension of multiple regression, establishing relationships between multiple dependent and independent variables, and serving as a valuable complement to regression analysis. CCA is performed to assess the joint multivariate effects of the SDG latent dimensions on the competitiveness dimensions. The theoretical model can be represented as $Y_1, Y_2, \dots, Y_p = f(X_1, X_2, \dots, X_q)$, where Y_i represents the multiple dependent variables ($i = 1, 2, \dots, p$) and X_j represents the multiple independent variables ($j = 1, 2, \dots, q$). From this, canonical variables are generated, which can be empirically expressed as shown in Equation 3 and Equation 4:

$$u_m = \sum_{i=1}^p (\alpha_i \cdot Comp_i) \quad (3)$$

$$v_m = \sum_{j=1}^q (\beta_j \cdot SDG_j) \quad (4)$$

Where u and v are canonical variables representing linear combinations of the dependent and independent variables, respectively. Already m represents the minimum value between p and q , indicating the number of canonical functions generated. In turn, p and q represent the number of dependent and independent variables, respectively (i.e., the three dimensions of competitiveness and the extracted factors from the SDGs). The parameters α and β are the coefficients. In this analysis, the correlation between u and v , known as canonical correlation, is maximized, while the correlation between two u variables is zero, and the same applies to the correlation between two v variables (Rencher & Christensen, 2012).

All statistical analyses – EFA, multiple linear regressions, and CCA – are conducted using SPSS software, enabling a detailed and robust examination of the data.

4. RESULTS

Table 2 displays descriptive statistics for all variables used in this study, except for those SDGs that were ultimately excluded from the final factor analysis (Subsection 4.1 details the exclusion process). The subsequent multivariate analyses offer a comprehensive view of how sustainability and competitiveness are interrelated in the context of Brazilian municipalities. Overall, the results consistently reinforce the association between sustainability attributes and regional competitiveness levels.

Table 2
Descriptive statistics

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Comp	404	50.23	5.92	26.62	65.26
Comp Institutions	404	54.42	8.65	10.78	77.81
Comp Society	404	62.10	7.51	37.67	78.63
Comp Economy	404	34.89	5.95	17.65	60.49
SDG	404	48.83	6.23	31.48	64.03

SDG 3	404	65.33	5.50	49.31	78.12
SDG 4	404	50.98	7.90	28.63	68.67
SDG 6	404	73.25	14.96	21.56	96.89
SDG 7	404	83.09	14.22	0.00	99.84
SDG 8	404	47.01	11.05	19.89	75.04
SDG 11	404	56.52	17.56	18.62	88.71
SDG 12	404	44.23	15.87	3.03	83.10
SDG 13	404	70.66	14.63	17.11	96.26
SDG 14	334	50.41	32.29	0.39	100.00
SDG 15	403	31.46	10.06	0.16	66.67
SDG 16	403	42.78	8.02	19.44	76.47
SDG 17	404	24.86	11.43	1.08	100.00
Region	404	0.61	0.49	0.00	1.00
Territorial agglomeration	404	0.59	0.49	0.00	1.00

Source: Elaborated by the authors.

4.1 Reducing SDGs to latent factors

An EFA was carried out to condense the 17 SDGs into fewer latent factors, thereby capturing the fundamental dimensions of sustainability. Initially, despite an overall good model fit, the analysis extracted six latent factors, three of which each contained only a single SDG. Inspection of the anti-image correlation matrix revealed that SDG 2 and SDG 10 had measure of sampling adequacy (MSA) values below 0.5, indicating their unsuitability for factor analysis. A revised model excluding these SDGs yielded four retained factors; however, one factor contained only SDG 5, which was deemed conceptually weak. Consequently, SDG 5 was also removed. Additional evaluation showed that SDG 1 and SDG 9 had communalities below 0.4, prompting their exclusion as well.

Ultimately, five SDGs – SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender Equality), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 10 (Reduced Inequalities) – were excluded. Although the final solution is more parsimonious, this outcome reflects the difficulty of harmonizing all SDGs with the

specificities of this dataset. Therefore, the results, while valuable, should be interpreted with caution.

The Kaiser-Meyer-Olkin (KMO) statistic registered a strong value of 0.815, indicating the adequacy of the sample for factor analysis (Hair et al., 2019). Additionally, Bartlett's test of sphericity was significant, with chi-square (degrees of freedom) = 1,286.905 (66) and p-value < 0.001. This significance suggests that the variables are significantly correlated and that the estimated correlation matrix is statistically different from the identity matrix, thereby justifying the use of factor analysis, as recommended by (Hair et al., 2019). Most commonalities exhibit adequate values above 0.5, although the values for SDG 13, SDG 15, and SDG 16 are slightly below this threshold. Meanwhile, the MSA consistently remains above 0.6. The cumulative explained variance exceeds 50% for all variables, which is considered acceptable in social science research. The detailed results are presented in Table 3.

Table 3
Results of the EFA with SDGs

SDGs/Latent dimensions	Economic and Institutional	Resources and Ecosystem	Socio- Environmen tal
SDG 8 (Decent work and economic growth)	0.853		
SDG 4 (Quality education)	0.798		
SDG 12 (Responsible consumption and production)	0.736		
SDG 16 (Peace, justice, and strong institutions)	0.657		
SDG 17 (Partnerships for the goals)	0.594		
SDG 6 (Clean water and sanitation)		0.736	
SDG 7 (Affordable and clean energy)		0.712	
SDG 14 (Life below water)		0.686	
SDG 13 (Climate action)		0.679	
SDG 11 (Sustainable cities and communities)			0.753
SDG 15 (Life on land)			0.647
SDG 3 (Good health and well-being)			0.485
Eigenvalue	4.231	1.532	1.258

Explained variance	35.25%	12.76%	10.48%
Cumulative variance	35.25%	48.02%	58.50%

Note: Extraction by principal component and varimax rotation.

Source: Elaborated by the authors.

The three extracted factors represent broad aspects and share certain points of similarity. However, the first factor groups the goals of the 2030 Agenda most closely associated with economic aspects and institutional relations. The second factor groups goals involving the supply and demand of resources (water and energy) as well as environmental issues, while the third factor reflects a more socio-environmental dimension. These factors served as variables in the subsequent statistical analyses.

4.2 SDG and competitiveness through the lens of linear regression

The study examines the statistical association between SDG attributes and competitiveness, focusing on whether overall SDG performance and the factors associated with its latent dimensions are related to variations in municipal competitiveness. Overall, the regression models demonstrated an adequate fit to the data, satisfying the assumption of normality in the distribution of residuals. This was evidenced by Leverage values remaining below 0.2 across all models, indicating the absence of significant multivariate outliers. The assumption of independent residuals was not formally evaluated, given the cross-sectional nature of the data. The models also exhibited no signs of multicollinearity, as indicated by VIF values remaining below 5.0 for all explanatory variables. The presence of heteroskedasticity was assessed through the visual inspection of residual plots (standardized residuals versus predicted values), which suggested heteroskedasticity in the distribution of residuals. To mitigate its potential effects on statistical inference, bootstrap estimation with 5,000 resamples was performed to obtain robust standard errors and bias-corrected and accelerated 95% confidence intervals for the regression coefficients (Hair et al., 2019). It is important to note that, given the cross-sectional design of the analysis, the regression results should be interpreted as indicating statistical associations rather than causal relationships. The detailed results of these regression analyses are presented in Table 4, Table 5, Table 6, and Table 7.

Table 4
Bootstrap linear regression analysis for the Competitiveness Index

Variable	Model 1			Model 2		
	B	SE	CI	B	SE	CI
SDG	0.088***	0.006	[0.078; 0.099]			
SDG Economic and Institutional				0.081***	0.004	[0.073; 0.090]
SDG Resources and Ecosystem				0.041***	0.003	[0.034; 0.048]
SDG Socio-Environmental Region				-0.006*	0.003	[-0.013; 0.000]
Territorial agglomeration	0.040***	0.009	[0.021; 0.059]	0.008	0.009	[-0.012; 0.026]
Constant	0.015*	0.007	[0.002; 0.029]	0.008	0.006	[-0.004; 0.019]
	3.876***	0.007	[3.862; 3.890]	3.921***	0.008	[3.905; 3.937]
Adjusted R ²	0.690			0.761		
Z Statistic	299.444***			212.776***		
N	404			333		

Note: Bootstrap with 5,000 resamples; B = unstandardized regression coefficient; SE = bootstrap standard error; CI = bootstrap 95% confidence interval; Significance level: ***0.001; **0.01; *0.05.

Source: Elaborated by the authors.

Table 5
Bootstrap linear regression analysis for the Competitiveness Index – Institutions

Variable	Model 1			Model 2		
	B	SE	CI	B	SE	CI
SDG	0.069***	0.017	[0.039; 0.102]			

SDG Economic and Institutional				0.068***	0.010	[0.047; 0.088]
SDG Resources and Ecosystem				0.012	0.008	[-0.004; 0.028]
SDG Socio-Environmental				-0.041***	0.007	[-0.055; -0.027]
Region	0.031	0.021	[-0.012; 0.073]	0.005	0.022	[-0.037; 0.049]
Territorial agglomeration	0.038*	0.018	[0.004; 0.072]	0.005	0.016	[-0.027; 0.041]
Constant	3.940***	0.018	[3.902; 3.977]	3.996***	0.022	[3.952; 4.037]
Adjusted R ²	0.187			0.288		
Z Statistic	31.949***			27.831***		
N	404			333		

Note: Bootstrap with 5,000 resamples; B = unstandardized regression coefficient; SE = bootstrap standard error; CI = bootstrap 95% confidence interval; Significance level: ***0.001; **0.01; *0.05.

Source: Elaborated by the authors.

Table 6
Bootstrap linear regression analysis for the Competitiveness Index – Society

Variable	Model 1			Model 2		
	B	SE	CI	B	SE	CI
SDG	0.089***	0.005	[0.079; 0.099]			
SDG Economic and Institutional				0.066***	0.005	[0.057; 0.075]
SDG Resources and Ecosystem				0.054***	0.003	[0.047; 0.061]
SDG Socio-Environmental				0.017***	0.003	[0.011; 0.024]
Region	0.052***	0.010	[0.032; 0.072]	0.037***	0.010	[0.016; 0.057]

Territorial agglomeration	0.013*	0.007	[0.000; 0.027]	0.022**	0.006	[0.010; 0.035]
Constant	4.081***	0.008	[4,065; 4.096]	4.105***	0.009	[4.089; 4.121]
Adjusted R ²	0.722			0.761		
Z Statistic	349.218***			212.461***		
N	404			333		

Note: Bootstrap with 5,000 resamples; B = unstandardized regression coefficient; SE = bootstrap standard error; CI = bootstrap 95% confidence interval; Significance level: ***0.001; **0.01; *0.05.

Source: Elaborated by the authors.

Table 7
Bootstrap linear regression analysis for the Competitiveness Index – Economy

Variable	Model 1			Model 2		
	B	SE	CI	B	SE	CI
SDG	0.108***	0.008	[0.092; 0.125]			
SDG Economic and Institutional				0.120***	0.007	[0.106; 0.135]
SDG Resources and Ecosystem				0.040***	0.006	[0.027; 0.053]
SDG Socio-Environmental				-0.023***	0.007	[-0.036; -0.010]
Region	0.022	0.015	[-0.008; 0.052]	-0.041**	0.016	[-0.073; -0.010]
Territorial agglomeration	0.003	0.013	[-0.023; 0.029]	-0.019	0.012	[-0.042; 0.005]
Constant	3.523***	0.012	[3.500; 3.546]	3.600***	0.014	[3.574; 3.627]
Adjusted R ²	0.441			0.535		
Z Statistic	107.088***			77.455***		
N	404			333		

Note: Bootstrap with 5,000 resamples; B = unstandardized regression coefficient; SE = bootstrap standard error; CI = bootstrap 95% confidence interval; Significance level: ***0.001; **0.01; *0.05.

Source: Elaborated by the authors.

The analysis revealed that both the overall SDG performance and its latent dimensions are statistically associated with the competitiveness of the sampled municipalities. Coefficients are considered statistically significant when the bootstrap 95% confidence interval does not include zero (Hair et al., 2019). Notably, the SDG Economic and Institutional and the SDG Resources and Ecosystem exhibit a consistently positive average effect on competitiveness, both overall and within its dimensions. In contrast, the SDG Socio-Environmental dimension presents a more ambiguous pattern of results, being positively associated only with the Society dimension of competitiveness, while showing negative associations with other dimensions and with the overall Competitiveness Index. These results provide relevant empirical evidence on the relationship between sustainability-related indicators and competitiveness within the context of the study.

The covariates yield mixed results. Regional location and participation in territorial agglomerations demonstrate a more conclusive positive significance for the Society dimension of competitiveness. In the regression model for the overall Competitiveness Index, these covariates are also positively associated with competitiveness when considered alongside the overall SDG Index.

4.3 SDG and competitiveness through the lens of canonical correlation

CCA was employed to simultaneously assess the relationships between multiple dependent and independent variables. The VIF statistic values were above 1.0 and below 3.0, enabling further analysis. Specific multivariate tests indicated joint statistical significance for all equations, i.e., for the complete model that includes all simultaneous functions. This result indicates that the two sets of variables – sustainability and competitiveness – are significantly correlated. Table 8 presents the results for the overall model.

Table 8
Multivariate tests of significance

Tests	Statistics	Approx. F	Hypoth. Df
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Pillai	1.054	59.358***	9.00
Hotelling	4.416	159.781***	9.00
Wilk	0.148	105.563***	9.00
Roy	0.804		

Note: *** Significance of F at the level $p < 0.001$.

Source: Elaborated by the authors.

Additionally, the CCA results indicate that only the first two canonical functions were statistically significant, effectively capturing the relationship between sustainability and competitiveness. However, the first canonical function alone demonstrated high explanatory power, as reflected in the extremely high values of the squared canonical correlation (analogous to R^2 in linear regression) and the explained variance. These findings underscore the substantial impact of sustainability on competitiveness, as derived from the modeled specification. Table 9 presents the results of the CCA.

Table 9
Canonical correlation analysis results

Canonical function	Engenivalue	Rc^a	Rc^2	F-test	Hypoth. Df	Variance	Cumm. variance
1 (u1, v1)	4.090	0.896	0.804	105.562***	9.00	92.62%	92.62%
2 (u2, v2)	0.316	0.490	0.240	25.079***	4.00	7.16%	99.78%
3 (u3, v3)	0.010	0.099	0.010	3.235	1.00	0.22%	100.00%

Note: ^a Rc = Canonical correlation. *** Significance of F at the level $p < 0.001$.

Source: Elaborated by the authors.

Table 10 presents the canonical functional structure, based on the standardized coefficients. These coefficients more effectively illustrate the relative effect of the variables in the presence of each other, which is a key aspect of multivariate analysis (Rencher & Christensen, 2012).

Table 10
Canonical functional structure

Variables	Standardized coefficients		
Dependents	u1	u2	u3

Comp Institutions	-0.072	0.735	0.903
Comp Society	-0.762	-0.812	0.425
Comp Economy	-0.313	0.540	-1.131
Independents	v1	v2	v3
SDG Economic and Institutional	-0.854	0.342	-0.393
SDG Resources and Ecosystem	-0.520	-0.528	0.671
SDG Socio-Environmental	-0.022	-0.777	-0.629

Source: Elaborated by the authors.

The standardized coefficients in the first canonical correlation (u_1 , v_1) share the same sign, indicating that the pairs of canonical variables (sustainability and competitiveness) consistently contribute to the canonical relationship in the same direction. Conversely, opposite signs would indicate an inverse relationship between the pairs of canonical variables. Among the variables, Comp Society, SDG Economic and Institutional, and SDG Resources and Ecosystem exert the greatest joint average effect on the first canonical correlation, indicating they contribute the most to the sustainability-competitiveness relationship.

5. DISCUSSION

The complexity of the SDGs, developed to capture the multifaceted nature of sustainability, makes it challenging to distill them into a few core dimensions. Presently, the SDGs serve as a fundamental framework for various entities – companies, non-governmental organizations, nation-states, and municipalities – guiding them in aligning operations and strategies with sustainability targets. This is the case despite well-documented criticisms, such as potential overlaps and contradictions between indicators (Greenland et al., 2023) or the disproportionate emphasis on certain goals at the expense of others (Del-Aguila-Arcentales et al., 2022). The SDG-based data approach in this study is pertinent but subject to criticism due to the uneven distribution of indicators (see Supplementary Information – Index Descriptions).

Notwithstanding these issues, data on larger Brazilian municipalities reveal three extracted dimensions that are broader and more integrated than the traditional economic, social, and environmental axes. The findings indicate that sustainability may encompass (i) economic and institutional features, (ii) resources and ecosystems, and (iii) socio-environmental issues. This configuration suggests that sustainability dynamics at the municipal level cannot be fully captured by conventional tripartite frameworks, as the SDGs tend to combine governance, economic development, and environmental management in more complex ways. In particular, the socio-environmental dimension appears to capture broader social conditions that interact with environmental outcomes and whose effects on competitiveness may depend more strongly on contextual and institutional conditions. This observation aligns with the premise that rigid models often fail to accurately capture specific contextual realities. Other scholars corroborate the difficulties in simplifying sustainability – particularly through the SDGs – when faced with real-world contexts (Eustachio et al., 2019; Greenland et al., 2023).

The results of this study, which demonstrate systematic associations between sustainability attributes and municipal competitiveness, align with prior research at the regional or territorial level (Del-Aguila-Arcetales et al., 2022; Du et al., 2014; Martínez & Poveda, 2022; Pane, 2023). In particular, the consistently positive associations observed for the economic and institutional dimensions, as well as those relating to resources and ecosystems, strengthen confidence in these findings. These patterns suggest that local institutional capacity and economic structures may enable municipalities to translate sustainability-related assets into improved competitive performance. In contrast, socio-environmental dynamics may exert more indirect or context-dependent effects, reflecting the complexity of social inclusion and environmental governance processes at the local level.

Such outcomes imply that local economic structures and institutional capacities – encompassing education, employment, sustainable economic growth, and the establishment of supportive institutional partnerships – may play a particularly important role in shaping regional performance. At the same time, environmental endowments alone do not appear sufficient to enhance competitiveness unless they are supported by institutional frameworks capable of managing resources effectively. These findings highlight the need to integrate these economic and institutional dimensions with environmental concerns in a complementary manner (Deng et al., 2024; Yang et al.,

2024). Moreover, merging core resources (e.g., water, energy) with ecosystem priorities (e.g., marine environments, climate) shows a positive association with competitiveness, suggesting that the interaction between local agency and structural conditions is central to the relationship between sustainability and regional development. This view is supported by (Dinmore et al., 2024; Hassink et al., 2019; Rabaya & Saleh, 2022).

Consequently, effective governance in planning and management processes for sustainability emerges as pivotal in fostering regional competitiveness. The present findings underscore the alignment between sustainability and competitiveness, particularly when economic, institutional, and environmental strategies are pursued in an integrated manner. Nevertheless, socio-environmental concerns appear to require further reinforcement in order to converge more effectively with the other dimensions – economy/institutions and resources/ecosystems – thereby boosting overall competitiveness. From a policy perspective, this highlights the need for systemic approaches to local development that combine economic policies, environmental management, and social inclusion strategies.

Additional, though less conclusive, evidence suggests that membership in wealthier, more integrated regions may be associated with stronger regional competitiveness, resonating with the findings of (Del-Aguila-Arcentales et al., 2022; Musterd & Kovács, 2013; Pane, 2023). This may reflect how regional contexts – through development and integration, both political and economic – act as key drivers of regional competitiveness. However, these relationships should be interpreted cautiously, as local institutional conditions and governance capacity may mediate or even override the advantages associated with geographic location. Regional contexts – through political and economic integration – can create opportunities for development, but their effects appear to depend strongly on the capacity of municipalities to leverage these structural conditions.

Structural factors such as regional location and territorial integration may be less decisive for competitiveness than governance and institutional efficacy. This conclusion aligns with Hassink et al. (2019), Dinmore et al. (2024), and Sotarauta and Grillitsch (2023), who maintain that regional development arises from a blend of local and non-local factors. Egedy et al. (2017) similarly argue that agglomeration and territorial location may fail to enhance competitiveness if public policies and market forces move in opposing directions. As Budd and Hirmis (2004) note, this underscores the critical role

of institutional and governance quality in shaping the locational advantages that bolster regional competitiveness.

These results carry significant policy implications. Regional competitiveness – a key factor in regional development – depends not only on intentional measures aimed at steering a region’s trajectory (particularly via economic and institutional frameworks) but also on structural factors such as resource availability and ecosystem health. In essence, agency drives action, while structure conditions shape the opportunities through which sustainability may contribute to competitiveness.

For policymakers, these findings highlight the importance of investing in education, institutional capacity, and inclusive economic development, while simultaneously strengthening environmental governance and resource/ecosystem management. Initiatives aimed at building partnerships, promoting multi-stakeholder governance arrangements, and ensuring the sustainable provision of key resources such as water and energy appear particularly relevant in this context.

Both sustainability and competitiveness are inherently complex phenomena, encompassing elements that cannot be fully captured through quantitative indices or indicators. Scholars such as Pane (2023), Santos and Brandi (2014), and Scaccabarozzi et al. (2022) point out the challenges in relying on quantitative metrics to capture these nuanced phenomena. Nonetheless, the evidence presented here reinforces the view that sustainability attributes are meaningfully associated with regional competitiveness. Although indicators cannot fully capture the complexity involved, they provide valuable insights into how sustainability dynamics may relate to regional competitiveness outcomes. The findings therefore highlight the importance of adopting a broad and balanced perspective that considers multiple dimensions of sustainability alongside diverse governance arrangements in the analysis of regional competitiveness.

6. CONCLUSION

This study set out to provide empirical evidence on the relationship between sustainability attributes and the competitiveness of Brazilian municipalities. By applying multivariate analytical methods, this research reduced the SDGs to a set of latent dimensions, estimated their average associations with competitiveness, and examined the joint multivariate relationships between the sustainability and competitiveness dimensions.

Collectively, these techniques offer a more comprehensive analytical framework for examining the sustainability-competitiveness nexus.

Additionally, this study contributes by framing sustainability as a structural factor associated with regional competitiveness rather than merely a normative policy goal. It emphasizes the strategic role of municipal governance in integrating sustainability and development agendas within decentralized systems. Empirically, it documents associations between sustainability and competitiveness at the municipal level in the Global South, addressing a gap in literature that largely focuses on firms and industrial sectors in developed countries. Overall, the study provides theoretical insight and analytical refinement on these interrelationships.

The analysis of the three latent SDG dimensions revealed distinct patterns of association with municipal competitiveness. The Economic and Institutional and Resources and Ecosystem dimensions consistently exhibit positive relationships across overall and dimensional competitiveness indicators. In contrast, the Socio-Environmental dimension shows a more mixed pattern, being positively associated only with the Society dimension while displaying negative or negligible associations with other dimensions. The canonical correlation analysis further shows that the Society dimension of competitiveness, together with the SDG Economic and Institutional and Resources and Ecosystem dimensions, exerts the strongest contribution to the joint sustainability-competitiveness association. Covariates such as regional location and participation in territorial agglomerations demonstrate positive associations with specific competitiveness dimensions. Overall, these results provide robust empirical evidence of systematic associations between sustainability attributes and municipal competitiveness, highlighting the multidimensional nature of these relationships and the relevance of economic, institutional, and resource-based factors in shaping regional competitive performance.

Despite these contributions and relevant findings, several limitations should be acknowledged. First, the study relies on cross-sectional data, which prevents the establishment of causal relationships between sustainability attributes and competitiveness outcomes. The findings should therefore be interpreted as associations rather than causal effects. Second, although the empirical models include some contextual controls, other potentially relevant variables were not incorporated. Third, the sample is restricted to municipalities with more than 80,000 inhabitants, which limits the

generalizability of the findings to smaller municipalities that may exhibit different institutional and socioeconomic dynamics.

Future research may address these limitations by incorporating longitudinal data, expanding the range of control variables, and including municipalities of different population sizes. It may also benefit from alternative approaches, such as confirmatory factor analysis and structural equation modeling. Comparative analyses across regions within Brazil or across countries may further contribute to a deeper understanding of how sustainability and competitiveness are associated in different territorial contexts.

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Manuela Fátima Paula de Medeiros: Conceptualization (Equal); Methodology (Equal); Writing – original draft (Equal); Writing – review & editing (Equal).

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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The entire dataset supporting the results of this study was published in the article itself.

AI USAGE STATEMENT

The ChatGPT artificial intelligence tool was used to assist with the technical and grammatical review of the text.

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APENDIX

SUPPLEMENTARY INFORMATION – INDEX DESCRIPTIONS

Table S1
SDG Index 2024 - indicator system

SDGs	Indicators	Year
SDG 1	Families registered in the Single Registry for Social Programs (%)	2023
	Percentage of people registered in the Single Registry receiving Bolsa Família	2023
	Percentage of people below the poverty line in the Single Registry after Bolsa Família	2023
	People with an income of up to 1/4 of the minimum wage (%)	2010
SDG 2	Childhood obesity (%)	2023
	Low birth weight (%)	2022
	Child malnutrition (%)	2023
	Family farmers supported by PRONAF (%)	2017
	Establishments practicing organic farming (%)	2017
SDG 3	Vaccination coverage (%)	2022
	Suicide mortality rate (per 100,000 inhabitants)	2022
	Infant mortality rate (children under 1 year old) (per 1,000 live births)	2022
	Maternal mortality rate (per 1,000 live births)	2022
	Childhood mortality rate (deaths of children aged 0 to 4 per 1,000 live births)	2022
	Neonatal mortality rate (children aged 0 to 27 days) (per 1,000 live births)	2022
	AIDS mortality rate (per 100,000 inhabitants)	2022
	Dengue incidence (per 100,000 inhabitants)	2023
	Premature mortality due to non-communicable chronic diseases (per 100,000 inhabitants aged 30 to 69)	2021-2022
	Municipal health budget (in BRL per capita)	2021-2022
	Population covered by family health teams (%)	2023
	Hepatitis detection rate (per 100,000 inhabitants)	2022
	Insufficient prenatal care (%)	2022
	Basic Health Units (per 1,000 inhabitants)	2023
	Average age at death	2022
	Teenage pregnancy rate (%)	2022
Tuberculosis incidence (per 100,000 inhabitants)	2021-2022	
SDG 4	Internet access in public elementary and high schools (%)	2023

	Percentage of children aged 0 to 3 enrolled in daycare	2023
	Schools with facilities adapted for people with disabilities (%)	2023
	Schools with resources for Specialized Educational Assistance (rate)	2023
	Basic Education Development Index (IDEB) – final years	2015-2021
	Basic Education Development Index (IDEB) – early years	2017-2021
	Youth completing high school by age 19 (%)	2010
	Teachers with higher education – Early Childhood Education – public sector (%)	2023
	Teachers with higher education – Elementary Education – public sector (%)	2023
	Ratio of enrollments to teachers in preschool (rate)	2023
	Ratio of enrollments to teachers in elementary school (rate)	2023
	Age-grade distortion rate in elementary school – public sector	2023
	Illiteracy rate among people aged 15 and older (%)	2022
	Cultural centers, houses, and cultural spaces (per 100,000 inhabitants)	2021
	Children and youth aged 4 to 17 attending school (%)	2023
SDG 5	Young women aged 15 to 24 who neither study nor work (%)	2010
	Presence of female council members in the Municipal Chamber (%)	2020
	Gender pay gap (women’s salary compared to men’s salary)	2022
	Percentage difference between young women and men who neither study nor work	2010
	Femicide rate (per 100,000 women)	2022
SDG 6	Diseases related to inadequate environmental sanitation (per 100,000 inhabitants)	2022-2023
	Treated water loss in distribution	2020-2022
	Population served by sewage systems (%)	2021-2022
	Sewage treatment index (%)	2021-2022
	Total population served with water supply (%)	2021-2022
SDG 7	Households with access to electricity (%)	2010
	Energy vulnerability	2019
SDG 8	Employed population aged 10 to 17 (%)	2010
	GDP per capita (BRL per capita)	2021
	Unemployment rate (%)	2010
	Youth unemployment rate (%)	2010

	Young people aged 15 to 24 who neither study nor work (%)	2010
	Formal employment rate for people aged 16 and older (%)	2022
SDG 9	Public investment in urban infrastructure per inhabitant (BRL per capita)	2019-2022
	Share of formal jobs in knowledge- and technology-intensive activities (%)	2022
SDG 10	Municipal income appropriated by the poorest 20% (%)	2010
	Gini coeficiente	2010
	Difference in infant mortality rates between children of PPI and White mothers	2022
	Difference in teenage pregnancy rates between PPI and White mothers	2022
	Difference in age-grade distortion rates in early elementary school between PPI and White students	2023
	Difference in age-grade distortion rates in final elementary school years between PPI and White students	2023
	Difference in homicide rates between PPI and White individuals	2022
	Difference in femicide rates between PPI and White women	2022
	Difference in male youth homicide rates between PPI and White youth	2022
	Ratio of average real income between PPI and White individuals	2010
	Access to basic healthcare facilities	2019
	Violence against LGBTQIA+ population (per 100,000 inhabitants)	2015-2023
	Percentage of PPI council members in Municipal Chambers (%)	2016-2020
SDG 11	Percentage of low-income population with a commute to work longer than one hour (%)	2010
	Traffic-related deaths (per 100,000 inhabitants)	2022
	Population living in subnormal settlements (%)	2010
	Households in favelas (%)	2019
	Municipal sports facilities (per 100,000 inhabitants)	2021
	Percentage of Black population in subnormal settlements (%)	2010
SDG 12	Household solid waste collected per capita (kg/day/person)	2020-2022
	Recovery of selectively collected urban solid waste	2020-2022
	Population served by selective waste collection (%)	2020-2021
SDG 13	CO ₂ e emissions per capita	2022
	Concentration of fire hotspots	2023
	Strategies for risk management and prevention of environmental disasters	2020

	Proportion of households in risk areas	2018
	Percentage of the municipality deforested (%)	2022
SDG 14	Sewage treated before reaching the sea, rivers, and streams (%)	2013
SDG 15	Hectares of forested and natural areas per inhabitant	2022
	Conservation units for full protection and sustainable use (%)	2024
	Maturity level of environmental protection financing instruments	2020
SDG 16	Male youth homicide rate (per 100,000 inhabitants)	2022
	Homicide rate (per 100,000 inhabitants)	2022
	Deaths by firearms (per 100,000 inhabitants)	2022
	Maturity level of internal control and anti-corruption policies	2019
	Maturity level of participation and human rights promotion policies	2019
	Maturity level of transparency policies	2019
SDG 17	Public investment (BRL per capita)	2021-2022
	Total municipal revenue collected (%)	2021-2023

Note: PRONAF = National Program for Strengthening Family Agriculture. BRL = Brazilian Real. PPI = Indigenous and Black people.

Source: ICS (2024).

Table S2
Competitiveness Index 2024 - indicator system

Dimensions	Pillars	Indicators	Year
Institutions	Fiscal sustainability	Fiscal dependency	2023
		Investment rate	2023
		Personnel expenses	2023
		Indebtedness	2023
	Public administration functionality	Cost of administrative functions	2023
		Cost of legislative functions	2023
		Quality of accounting and fiscal information	2022
		Time required to start a business	2023
		Civil servant qualification	2022
		Municipal transparency	2020
Society	Access to health services	Basic care coverage	2023
		Supplemental health coverage	2023
		Vaccination coverage	2023
		Prenatal care	2022
	Quality of health services	Maternal mortality	2022
		Childhood malnutrition	2023
		Childhood obesity	2023
		Infant mortality	2022

		Mortality from preventable causes	2022
Access to education		Attendance rate – early childhood education	2023
		Net enrollment rate – elementary education	2023
		Net enrollment rate – high school	
		Full-time students – early childhood education	2023
		Full-time students – elementary education	2023
		Full-time students – high school	2023
	Quality of education		IDEB – elementary school (early years)
		IDEB – elementary school (final years)	2021
		IDEB – high school	2021
		ENEM	2023
Safety		Intentional violent deaths	2022
		Deaths from undetermined causes	2022
		Youth mortality due to safety issues	2022
		Mortality in transportation	2022
		Morbidity in transportation	2023
	Sanitation		Water supply coverage
		Water distribution losses	2022
		Revenue losses in water distribution	2022
		Sewage collection coverage	2022
		Sewage treatment coverage	2022
		Domestic waste collection coverage	2022
		Waste disposal	2022
Environment			Greenhouse gas emissions
		Natural forest coverage	2022
		Illegal deforestation	2023
		Speed of illegal deforestation	2023
		Recovered areas	2022
Economy	Economic inclusion	Vulnerable population	2023
		Formality in the labor market	2022
		Growth in formal employment	2022
Innovation and economic dynamism		Resources for scientific research and development	2023
		Employment in the creative sector	2022
		Credit per capita	2023
		GDP per capita	2021
		Growth of GDP per capita	2021

	Economic complexity	2022
	Average income from formal employment	2022
	Growth of average income from formal employment	2022
Human capital	Gross enrollment rate – technical and vocational education	2023
	Gross enrollment rate – higher education	2022
	Qualification of workers in formal employment	2022
Telecommunications	Mobile phone access	2023
	Mobile phone access – 4G	2023
	Broadband access	2023
	Broadband access – fiber optic	2023
	Broadband access – high speed	2023

Note: IDEB = Basic Education Development Index. ENEM = National High School Examination.
Source: CLP (2024).

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