




Multicriteria analysis of Sustainability, Entrepreneurship, and Innovation indicators in the Sertão Region of Alagoas

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RESEARCH ARTICLE

Socioeconomic Analytics
<https://periodicos.ufpe.br/revistas/SECAN/>
ISSN Online: 2965-4661

Submitted on: 28.01.2025.
Accepted on: 30.08.2025.
Published on: 03.09.2025.

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Abstract

The analysis of Sustainable Development Goal (SDG) indicators aligned with entrepreneurship and innovation in the Alagoas hinterland (*Sertão de Alagoas*) is essential to understanding local dynamics and promoting balanced growth, supporting regional strategies and policies. The integration of sustainability with innovation can boost the local economy while preserving resources and promoting social equity. This study presents an analysis of sustainable development indicators in the Alagoas hinterland, based on a municipal perspective. The multicriteria method PROMETHEE II and Business Intelligence (BI) were used for data processing and dashboard creation. The mapping of SDGs revealed the innovative potential and critical areas in the region's municipalities. Municipalities with higher investments in education, technology, and infrastructure show greater potential for innovation and creative growth, while areas with significant deficiencies in infrastructure and quality of life face substantial challenges. The multicriteria analysis identified regional patterns and priority areas for intervention, providing a solid foundation for public policy formulation. These results offer valuable insights to promote more balanced and sustainable development, enabling a strategic approach to overcome barriers and foster a more favorable environment for innovation in the Alagoas hinterland.

Keywords

Sustainable Development Goals. Innovation. Alagoas. Multicriteria Analysis. Business Intelligence.

1. Introduction

Regional development is a process that involves various factors within the social, political, economic, and environmental spectrums (Pedroso *et al.*, 2023; Šūmakaris, Kovaitė and Korsakienė, 2023). The associated analysis, therefore, depends on various indicators, so that it is possible to have a complete view of the level of development to support decision-making and the development of strategies and policies aimed at maintaining or improving the situation (dos Reis and de Almeida, 2021; Fischer *et al.*, 2021). Considering the perspective of commercial productivity and economic growth in emerging regions, it is necessary to observe which sets of indicators are most aligned (Steven White, Gunasekaran and Roy, 2014).

In this sense, there are the Sustainable Development Goals (SDGs) that involve groups of indicators specifically linked to the thematic axes of each goal. The SDGs represent global action lines to reduce inequalities, combat poverty, in addition to protecting the planet and ensuring that future generations have a quality of life, so that each of the seventeen goals has specific targets to be achieved by 2030 (Paletta and Bonoli, 2019).

Moreover, actions related to frugal innovation align with concepts of sustainable socioeconomic development and business strategy in favor of low-cost products endowed with regional characteristics (Moreira *et al.*, 2024), serving as a catalyst for progress towards various SDGs simultaneously. Thus, entrepreneurship and innovation not only drive economic growth but can also be strategic in achieving more equitable and sustainable development.

Focusing on the central elements of this contextualization, the main objective of this work is to apply an analysis of sustainable development indicators to generate a ranking of municipalities in the hinterland region (*Sertão* region) of the state of Alagoas, based on the SDGs aligned with the perspective of Entrepreneurship and Innovation. Associated with this objective are (i) the determination of the SDGs that have conceptual alignment with Entrepreneurship and Innovation; (ii) the generation of a multicriteria analytical model for the ranking of municipalities considering the sets of indicators; and (iii) the generation of analytical dashboards based on maps through a Business Intelligence tool. (BI).

Thus, the main research problem is to understand the current state of evolution of the municipalities in the Alagoas hinterland, based on the premises of the SDGs aligned with Entrepreneurship and Innovation, to enable public authorities and the private sector to make appropriate decisions for the development of joint strategies and policies to support local development.

The remainder of this article is divided as follows: Section 2 presents the theoretical framework on the topics involved; Section 3 contains the methodology applied in the study; Section 4 presents the results obtained with the appropriate discussion, especially demonstrating the theoretical, practical, and social implications of the study; and finally, Section 5 concludes the article by also presenting perspectives for future work.

2. SDG, Entrepreneurship and Innovation

The connection between the SDGs, entrepreneurship, and innovation is direct, as there is one specific goal dedicated to “Industry, Innovation, and Infrastructure” (SDG 9). In summary, the 17 SDGs were defined by the United Nations in 2015 and constitute a global plan to eradicate

poverty, protect the environment, and ensure prosperity for all as part of a new sustainable development agenda (Hossain, Park and Shahid, 2023). Entrepreneurship and innovation emerge as drivers for achieving these goals, as they offer creative and efficient solutions to socio-economic-environmental challenges (Ricciardi, Rossignoli and Zardini, 2021).

In this context, sustainable entrepreneurship stands out for the creation of businesses considering ecologically correct practices to ensure the existence of social and economic equity as well as the well-being of people (Shahid *et al.*, 2023). On the other hand, taking into account that innovation is the process of transforming new ideas into products, services, or processes, there is an alignment with the search for ways to guarantee the quality of life of people and the health of the planet, adhering to the principles of sustainable development for the creation of clean and energy-efficient technologies, circular business models, and strategies that reduce waste and promote the efficient use of resources (Dam, Kaya and Bekun, 2024; Hossain, Park and Shahid, 2023).

In the context of emerging economies and markets, entrepreneurship and innovation emerge as vital engines for sustainable economic development (Borchardt *et al.*, 2021). Innovative entrepreneurs committed to the sustainable development of their business regions can create solutions to local challenges, generating jobs and income while contributing to the SDGs (Lubowiecki-Vikuk, Dąbrowska and Machnik, 2021). For example, a startup that develops clean technologies contributes to SDG 7 (Affordable and Clean Energy), while also contributing to SDG 8 (Decent Work and Economic Growth) by ensuring job creation, and to SDG 9 (Industry, Innovation, and Infrastructure) by enabling the establishment of a technology-based company in the area, stimulating the arrival of other organizations and the emergence of a technology park, thereby boosting the local economy.

2.1. Multicriteria Analysis and the PROMETHEE II Method

Multicriteria methods are very useful tools to assist in the analysis of complex options, where multiple criteria are considered. Among the most well-known methods are TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), AHP (Analytic Hierarchy Process), and the methods from the PROMETHEE family (Preference Ranking Organization Method for Enrichment of Evaluations) and the ELECTRE family (*Élimination et Choix Traduisant la Réalité*) (Moreira *et al.*, 2024). Each of them has different approaches and procedures, also being oriented towards different issues among selection, classification, and ordering, as defined by Bernard Roy (Roy, 1996). The choice of the most appropriate method depends on the characteristics of the problem situation being analyzed in the context of the decision, considering the types of available data and the preferences of the decision-makers (Roy and Słowiński, 2013).

In the study developed, the PROMETHEE II method was chosen, which has a very suitable approach due to its alignment with the ordering issue, desired for the creation of a ranking of the municipalities targeted in the analysis, in addition to ensuring the delivery of a very objective result, based solely on binary relations of Preference (P) and Indifference (I). The algorithm behind the PROMETHEE II method can be represented according to the following steps (Behzadian *et al.*, 2010; de Carvalho, Poletto and Seixas, 2018):

Stage 1: Determination of deviations based on pair-to-pair comparison:

$$d_j(a, b) = g_j(a) - g_j(b) \quad (1)$$

where $d_j(a,b)$ is the difference between alternatives a and b for each criterion.

Stage 2: Application of the Preference Function:

$$P_j(a, b) = F_j[d_j(a, b)] \quad j = 1, \dots, k \quad (2)$$

where $P_j(a,b)$ is the preference of alternative a over alternative b for each criterion as a function of $d_j(a,b)$.

Stage 3: Calculation of the Global Preference Index:

$$\forall a, b \in A \quad \pi(a, b) = \sum_{j=1}^k P_j(a, b)w_j \quad (3)$$

where $\pi(a,b)$ of a about b (from 0 to 1) is the weighted sum of $P_j(a,b)$ for each criterion, and w_j is the weight associated with the j -th criterion.

Stage 4: Computing of Inflows and Outflows:

$$\Phi^+(a) = \frac{1}{n-1} \sum_{b \in A} \pi(a, b) \quad (4)$$

$$\Phi^-(a) = \frac{1}{n-1} \sum_{b \in A} \pi(b, a) \quad (5)$$

where $\Phi^+(a)$ is the positive flow (of entry) and $\Phi^-(a)$ is the negative flow (outflow) of each alternative.

Stage 5: Calculation of Net Flow:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \quad (6)$$

where $\Phi(a)$ is the net cash flow in each alternative.

It should also be noted that the usual criterion was used in *Stage 2* to generate the ranking of the alternatives in this study, which is defined by:

$$P(x) \begin{cases} 0 & \forall d_j(a, b) \leq 0 \\ 1 & \forall d_j(a, b) > 0 \end{cases} \quad (7)$$

The following are the sentences that define the Preference (P) and Indifference (I) relations of the PROMETHEE II method:

$$aPb \text{ se } \Phi(a) > \Phi(b) \quad (8)$$

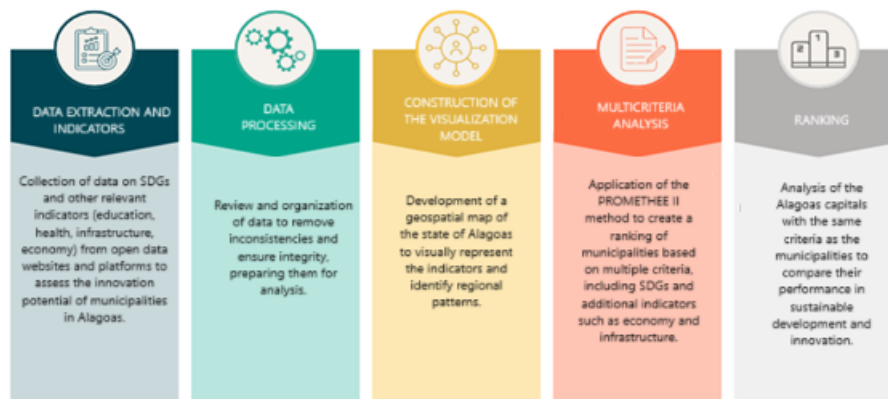
$$aIb \text{ se } \Phi(a) = \Phi(b) \quad (9)$$

The algorithm generates a complete pre-order from the net flow, thus defining the ranking of the alternatives.

3. Methodology

This study followed a structured methodological approach in several stages, starting with the extraction of essential data and indicators for the analysis of sustainable development. The data collection covered reliable sources and open data platforms, encompassing not only the SDG indicators but also additional information on critical areas such as education, health, infrastructure, economy, well-being, and security. Figure 1 summarizes the elements of the methodological process.

Figure 1: Methodological process.



3.1. Data extraction and indicators

The first stage of the methodology involved the extraction of data and indicators from Alagoas municipalities, aimed at identifying the innovation potential of the cities in the region. Open data websites and platforms were used to provide information about the SDGs in each municipality. The table 01 below lists the sources and indicators extracted:

Table 1: Information about the indicators used in the work.

INDICATOR	SOURCE
Public Administration Participation in the Economy	DataViva
Average Salary	IBGECidades
School with Library	IBGECidades
School with Computer Laboratory	IBGECidades
School with Science Laboratory	IBGECidades
Health and Well-Being (SDG)	IDSC

Quality Education (SDG)	IDSC
Drinking Water and Sanitation (SDG)	IDSC
Accessible and Clean Energy (SDG)	IDSC
Decent Work and Economic Growth (SDG)	IDSC
Industry, Innovation and Infrastructure (SDG)	IDSC
Reduction of Inequalities (SDGs)	IDSC
Cities of Sustainable Communities (SDGs)	IDSC
Responsible Consumption and Production (SDG)	IDSC
Partnerships and Means of Implementation (SDGs)	IDSC

In addition to the data related to the SDGs, detailed information was also collected on crucial areas such as: Education, health, infrastructure, well-being, and economy. This data provides a comprehensive view of the socioeconomic and structural conditions of the municipalities, allowing for a deeper analysis of the environment.

Indicators related to the SDGs, such as the quality of education (SDG 4), access to health services (SDG 3), sustainable infrastructure (SDG 9), and inclusive economic growth (SDG 8), are essential for understanding the conditions that promote or restrict sustainable development in municipalities. These data allow for mapping both the opportunities and challenges faced by municipalities in Alagoas, providing a solid foundation for planning initiatives that integrate innovation and sustainability.

3.2. Cleaning and structuring of data and indicators

After extracting the data and indicators from the municipalities of Alagoas, an essential step of cleaning and structuring the information was carried out. Initially, the raw data was carefully reviewed to eliminate inconsistencies, such as duplications and missing values, ensuring the accuracy of the collected information.

Next, the data was organized into a structured and coherent format, facilitating further analysis. This process included the standardization of metrics related to the SDGs, as well as the categorization of additional indicators in areas such as education, health, infrastructure, and economy. The structuring of the data was carried out in a way that ensured that all indicators were aligned with the study's objectives, allowing for an integrated analysis that considered both the potential for innovation and sustainable development in the municipalities of Alagoas.

3.3. Construction of the visualization model

After cleaning and structuring the data, a geospatial visualization was developed to represent the analyzed indicators, using a map of the state of Alagoas. This visualization aimed to provide a clear and intuitive representation of the studied variables, facilitating the interpretation of regional patterns and trends.

The map highlighted the variations in sustainable development indicators, such as education quality, access to healthcare services, infrastructure, and economic performance, among the municipalities of the hinterland region in Alagoas. The construction of the visualization model involved integrating structured data into a format that allowed for efficient spatial analysis, showcasing areas with potential for innovation and those facing significant challenges. This visual approach aims not only to facilitate the identification of regional discrepancies but also to provide a basis for formulating targeted strategies focused on promoting sustainable development and innovation.

3.4. Application of the Multicriteria Analysis Method

To conduct a detailed and comparative assessment of the municipalities of Alagoas, the multicriteria analysis method PROMETHEE II was used. As previously mentioned, this method was chosen for its ability to handle multiple criteria and provide a balanced evaluation of the alternatives, in addition to its direct alignment with the target issue of ordering, resulting in an outcome where the interpretation is quite objective, producing a ranking of the evaluated alternatives.

The application of the PROMETHEE II method involved the use of a wide range of structured data to calculate a ranking of the municipalities. In addition to indicators related to the SDGs, additional data was incorporated that covers crucial areas such as economy, infrastructure, health, well-being, and security. These complementary indicators were essential for a more holistic analysis, allowing for a comprehensive assessment of the conditions that influence sustainable development and the potential for innovation in municipalities.

4. Results and discussions

The results of this study provide a comprehensive and detailed analysis of the mapping of sustainable development indicators and the construction of a ranking aimed at identifying the potential for innovation and creativity in the municipalities of the hinterland region of Alagoas. This analytical effort is crucial to understanding regional dynamics and to creating strategies that promote balanced and sustainable growth in the region.

The construction of the municipality ranking was carried out based on a combination of indicators related to sustainable development, integrated with additional data on the economy, infrastructure, and quality of life. This approach enabled an evaluation of the performance of the municipalities across various essential dimensions for development and innovation. The following points are highlighted:

Identification of Regional Patterns: The analysis of the ranking enabled the identification of distinct regional patterns, revealing clusters of municipalities with similar characteristics in terms of sustainable development and innovation capacity. This identification of patterns is fundamental to understanding regional particularities and to directing specific interventions

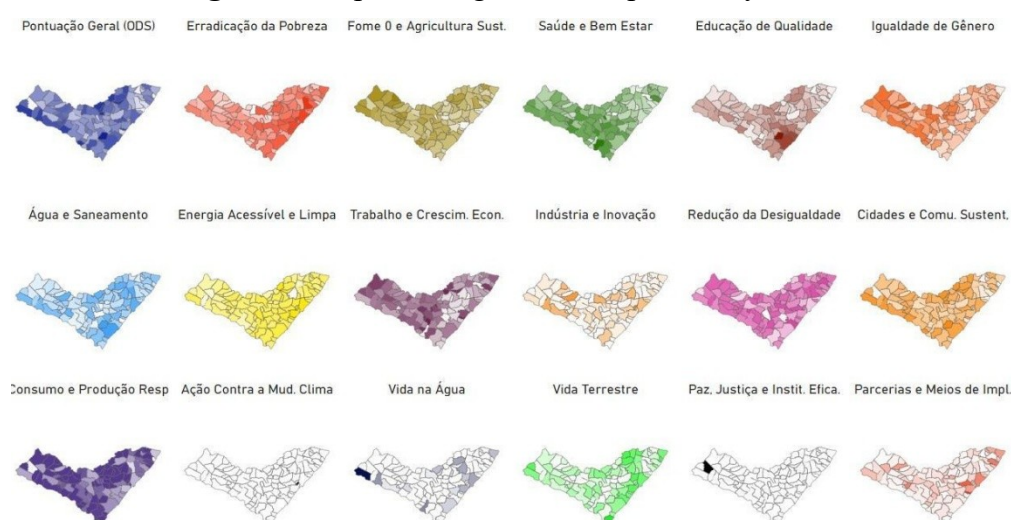
that meet local needs. The analysis of these patterns also allows identifying which areas are more prepared to adopt innovative practices and which face substantial challenges that need to be addressed to improve their performance and innovation potential.

Critical Areas and Development Opportunities: The ranking also highlighted critical areas where sustainable development and innovation potential can be significantly improved. Municipalities that showed low scores on key indicators were identified as priority areas for intervention and investment. These areas present valuable opportunities to implement targeted policies and strategies aimed at improving local conditions and creating a more favorable environment for the development of new initiatives and innovative solutions. Identifying these critical areas is essential to direct resources and efforts more effectively, ensuring that interventions are aligned with the specific needs and potentials of each municipality.

Ranking and Innovation Potential: The construction of the multicriteria analysis ranking based on the PROMETHEE II method made it possible to identify which of the surveyed municipalities have significant potential for innovation. Municipalities with higher investments in educational infrastructure, access to modern technologies, and support for innovative initiatives have a solid foundation for implementing and sustaining creative projects. These municipalities are well-positioned to become innovation hubs, with a more favorable environment for the emergence and growth of new ideas and ventures.

Critical Areas: The detailed analysis revealed critical areas that require attention to enhance their development conditions and innovation potential. These areas are characterized by significant deficiencies in key indicators, which directly impacts their ability to foster sustainable growth and innovation. The identification of these critical zones is essential to guide strategic interventions and investments aimed at overcoming existing barriers and creating a more conducive environment for development. These critical areas require specific approaches and solutions tailored to their realities, with the goal of improving local conditions and stimulating a more favorable environment for the emergence and implementation of innovative initiatives. Prioritizing these zones will allow for the formulation of effective policies and strategies, promoting a more balanced and sustainable development in the region.

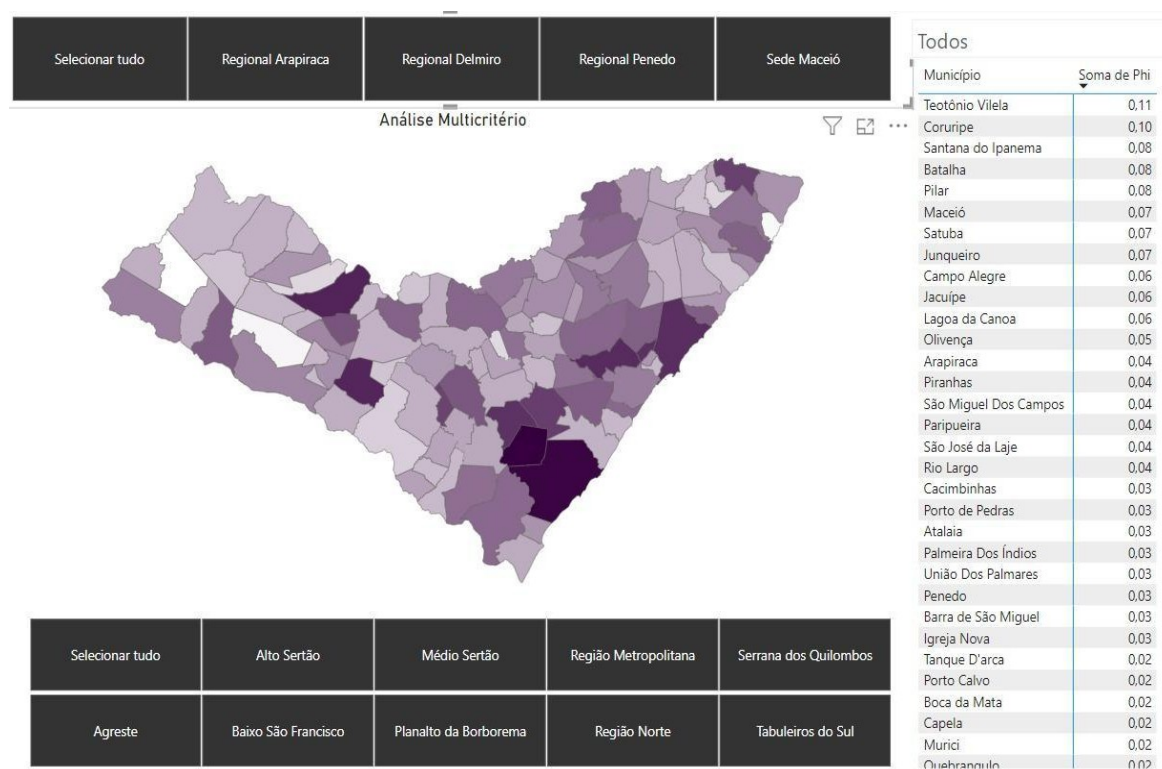
Figure 2: Maps of Alagoas municipalities by SDGs.



The mapping of indicators and the construction of the ranking provide a robust and informed basis for the formulation of policies and strategies that promote a more inclusive and conducive environment for creative and innovative development in the hinterland region of Alagoas. These results not only offer a detailed view of the current conditions but also provide a solid foundation for defining effective strategies aimed at achieving balanced and sustainable growth. Understanding regional patterns and critical areas allows for the development of policies tailored to local realities, promoting a more cohesive and sustainable regional development.

The application of the PROMETHEE II method, along with a visualization panel, allowed for the comparison of alternatives and the construction of a ranking of the municipalities in the hinterland of Alagoas based on multiple criteria. The analysis highlighted the most promising areas in potential for innovation and the regions with the greatest challenges, providing a comprehensive view of the conditions and capabilities of each municipality. The use of the panel enabled the monitoring of municipalities according to their innovation and development capacity, and also facilitated the identification of regional patterns and trends.

Figure 3: Ranking of Alagoas municipalities according to their innovation potential through multicriteria analysis.



5. Conclusion

This study provided a comprehensive analysis of sustainable development indicators and the potential for innovation in the municipalities of Alagoas hinterland, using a robust and integrated methodological approach. The construction of the ranking of municipalities, based on a strategic combination of data on economy, infrastructure, health, and quality of life,

allowed for a detailed assessment of the capacities and challenges faced by each locality. The application of multicriteria analysis, through the PROMETHEE II method, was essential to identify the most promising areas and the regions that require priority attention.

A crucial aspect of this study was the mapping of the SDGs for each municipality. This mapping provided a detailed view of local conditions regarding key sustainability indicators, allowing for a more comprehensive assessment of the municipalities' performance in essential areas such as education, health, infrastructure, and economy. The analysis of the SDGs facilitated the identification of regional patterns and highlighted the relationship between progress in sustainability indicators and the potential for innovation.

The identification of regional patterns and critical areas provides valuable insights for the formulation of targeted public policies aimed at overcoming specific challenges and promoting more balanced and sustainable growth. The analysis revealed that, while there are areas with substantial potential for innovation, there are also regions that face significant deficiencies that need to be addressed to create a more favorable environment for development.

A deep understanding of the indicators and the mapping of the SDGs provides a solid foundation for decision-making and the formulation of regional development strategies. The recommendations derived from this study can contribute to the implementation of more effective policies and to the strengthening of local capacities, promoting more inclusive and sustainable development in the hinterland of Alagoas. This work not only highlights the importance of an integrated approach to assessing innovation potential but also offers a detailed view of the areas that require intervention to achieve harmonious and dynamic regional growth.

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