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What Makes Cities Sustainable? Empirical Evidence From a Brazilian Context

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About 70% of the world's population will live in urban areas by 2050, emphasizing the importance of assessment tools to guide decisions toward more sustainable cities. The "Mandala ODS" is an alternative tool promoted by the Brazilian government to quantify the sustainability of cities based on the UN SDGs. Although diagnoses are important steps for governance, the behavioral profile of decision makers also appears as a key aspect. This work aims to assess the potential association evidence among biophysical, socioeconomic and cultural variables with city sustainability as measured by the "Mandala ODS." A sample of 130 Brazilian cities is considered as a sample, and the Pearson's chi-square indicator is calculated for association analysis. Results show that Brazilian cities located in the South/Southeast/Midwest regions, with HDI higher than 0.75, incidence of poverty lower than 40%, territorial area lower than 3,000 km^2, and GDP/capita higher than 25,000 R$/person.yr, have significant statistical association that leads them to higher levels of sustainability than other cities without these characteristics. Population density, academic background of mayors, their political ideology and gender showed no association with city sustainability. These findings highlight the fundamental role of governance focused on local characteristics instead of standardized and larger scale based public policies that would hardly bring the same benefits for all cities with different socioeconomic and cultural characteristics. Although additional efforts are still needed to achieve a more comprehensive picture, this work contributes to the discussions about the reasons that lead some cities to achieve higher degrees of sustainability than others.

Keywords: Agenda 2030, governance, Mandala ODS, socioeconomic drivers, sustainable cities

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INTRODUCTION

According to the United Nations (UN, 2022), ∼70% of the world's population will live in urban areas by the year 2050, consuming 80% of the energy generated and emitting 75% of the carbon on the planet. This urbanization process will put pressure on the countries' infrastructure, economy, environment and social performance, generating inequalities, social exclusion, and environmental impacts. Focusing on the world's sustainable development, in 2015 the United Nations created the Agenda 2030, consisting of 17 interdependent goals defined as sustainable development goals (SDGs), whose document has been used worldwide as an important reference for management (UN, 2022). To implement this complex global plan for sustainability, focusing

on small territories such as cities appears to be important because they represent the administrative units closest to the problems and actions necessary for the SDGs achievements. The effectiveness of institutional actions and stakeholder demands occurs mainly at city scale, where policies can be critically evaluated.

To support city managers, there are tools and indicators that seek to quantify and rank those more sustainable and smarter cities. Among others, the CIMI (IESE, Spain), GFCI (Z/Yen, London), GPCI (IUS MMF, Japan), GLI (EIU, London), SCI (Arcadis, Netherlands), QLCR (Mercer, USA), GCI (At. Kearney, USA), the IMD (Switzerland), in addition to the Brazilian ones Urban System (Connect Brasil), and Sustainable Municipalities Institute (MCTI Brazil). Specifically for the Brazilian case, there is an important public tool called "Mandala ODS" (CNM, 2021) that aims to quantify the sustainability of municipalities. Proposed and managed by the National Confederation of Municipalities (CNM), the Mandala ODS seeks to assess the evolution of the cities' sustainability through indicators annually updated, chosen according to the goals and principles established by the Agenda 2030. The main goal of Mandala ODS is to support the city manager by providing information about which indicator should receive priority for improvements to efficiently increase the city's overall sustainability level.

According to Nevado Gil et al. (2020), sustainability-oriented governance may be related to some indicators outside from the technometric management model, such as geographic location, economic-financial management, social and moral values of society, population diversity, political ideology and professional training of managers. Studies on these relationships have been published, including: Dierwechter (2017) and Dierwechter et al. (2017) that discuss the regional cooperation among cities and its influence on urban performance for sustainability; Herrchel and Dierwechter (2015) and Hudalah et al. (2013) that shows the advantages of regional-scale planning, emphasizing the importance of collaboration, negotiation, and deliberation involving multiple actors for an effective management; Adams and Funk (2011) and Duflo (2012) that observes the differences in style and behavior of female city managers compared to male managers; and Steurer and Hametner (2010) which claims that certain political ideologies are more favorable to sustainability-oriented policies. Studying the influence of some of these factors on managing complex problems, Bruce et al. (2021) have found that Brazilian cities that effectively fought the Covid-19 pandemic were managed by women, achieving fewer deaths (44%) and fewer hospitalizations (30%) than cities managed by men.

Recognizing the importance of Mandala ODS as a tool to assist management for sustainability of Brazilian cities, while at the same time recognizing the evidence that sustainability-oriented governance may be related to socioeconomic, cultural, gender and political ideology variables, the following question arises: Can these identified variables lead to a higher or lower degree of sustainability for the Brazilian cities? The existence of a potential association between some variables could help to better understand the reasons as to why some cities achieve higher sustainability levels than others.

Abbreviations: CNM, Brazilian National Confederation of Municipalities; GDP, Gross Domestic Product; GINI, A measure of the distribution of income across a population; HDI, Human Development Index; Mandala ODS, Brazilian public tool used to quantify cities sustainability; R$, Brazilian currency "Real;" SDGs, Sustainable Development Goals; TCI, Technocentric Model; UN, United Nations.

THEORETICAL BACKGROUND

The Mandala ODS: an Approach to Measure Cities Sustainability

The Mandala ODS (details in CNM, 2021) is an online, freely available platform developed by the National Confederation of Municipalities in Brazil with the main objective being to quantify the sustainability level of cities and serve as reference to support city's monitoring and management for the Agenda 2030 objectives. It includes 28 indicators divided into economic, social, environmental and institutional dimensions, all represented by the SDGs; the social dimension is more prominent, being represented by 46% of indicators.

As the Mandala ODS presents an individual comparative analysis among its 28 indicators, the results are subject to possibly misleading interpretations, which could be avoided by future efforts in proposing a single and overall indicator. Anyway, the Mandala ODS is an important framework toward more sustainable cities, as it helps managers to diagnose, develop, practice and monitor their actions. This present study does not discuss the advantages and disadvantages of the Mandala ODS—this is a topic for another work –, but it discusses the potential relationships of association between some socioeconomic, biophysical, and cultural variables with higher or lower levels of a city's sustainability as measured by the Mandala ODS. Instead of exhausting the theme, insights are proposed for further analysis and developments.

Indications of Variables That Would Lead to More Sustainable Cities

In search of sustainable development, city managers have been opting for specific actions such as the use of new planning, communication and security technologies, implementation of waste recycling stations, investments in mobility and urban transport, while at the same time encouraging environmental and sociocultural aspects (Schaffers et al., 2011; Bibri and Krogstie, 2017), political sharing, and social governance (Kearns and Forrest, 2000). However, according to Huang et al. (2009), there are obvious limitations in using exclusively biophysical indicators of sustainability to monitor the evolution of actions, as they hardly reflect the systemic social interactions that take place and the aspirations of a population. As an alternative approach, a Technocentric Model (TCI) has been implemented by urban administrations to transform cities into a reference for intelligence and sustainability. The TCI is a top-down management option capable of collecting and managing data in real time and meeting citizens' needs faster and more efficiently in a continuous process (Han et al., 2017). This model has evolved into a broader concept of sustainability, incorporating the human factor into its priorities rather than the technology

by itself (Giffinger et al., 2007; Breuer et al., 2014). The inclusion of citizens in the cities governance makes them participatory and responsible for quality of life priorities (Chourabi et al., 2012).

The scientific literature has shown that some factors disregarded by the TCI can be essential for cities development, and those factors need to be considered in governance plans to contribute to the strengthening of sociocultural aspects and allow the formation of more solid political-institutional structures (Bibri and Krogstie, 2017). As an example, Nam and Pardo (2011) highlight that factors such as technology, people (creativity, diversity and education) and institutions (governance and politics) are equally important for a city to achieve greater levels of smartness and sustainability.

There is an increasing recognition of the importance in stakeholders for the practical advancement of sustainability-oriented policies in cities with different scales (Jepson, 2004; Hanna, 2005; Conroy, 2006), in addition to specific socioeconomic and institutional characteristics (Howell-Moroney, 2004; Jepson, 2004; Conroy and Iqbal, 2009; Portney and Berry, 2010) such as population income level, educational structure, community growth level, and cooperation. This latest one is supported by Herrchel and Dierwechter (2015) and Hudalah et al. (2013) who state that governance implies the collaboration of multiple actors to obtain the benefit of all involved. All these aspects emphasizes the importance for a multi and participative approach when dealing with decisions toward more sustainable cities.

From this more holistic perspective, Nevado Gil et al. (2020) indicated that regional location, gender of mayor, and political ideology might be important drivers in the implementation of policies aimed at "smarter cities" for sustainable development in European cities; although authors have found associative relationship only for regional location and gender of mayor. Literature on the gender of managers topic suggests differences between the styles adopted by women and men (Duflo, 2012). According to Fox and Schuhmann (1999) and Beck (2001), male and female councilors agree that women are more responsive to their contributors, as they encourage citizen participation, communication, and contribution. Other works highlight that the increase in the number of women in formal political roles, as representation members of councils or as mayors in cities, has influenced the generation of a powerful structure that improved cities functioning in Spain (Araujo and Tejedo-Romero, 2017).

The political ideology factor can also interfere in the prioritization of governance objectives, since political competition contributes to achieve higher sustainability levels for cities (Prado-Lorenzo et al., 2012). In the same line of thought, Smith and Fridkin (2008) argue that cross-party competition plays a fundamental role in the decision of politicians to give back the institutional power to the citizens, paying more attention to the demands of taxpayers. As an example for the Brazilian case, the implementation of the so-called Participative Councils with the participation of stakeholders in the cities of Porto Alegre, Belo Horizonte, and São Paulo resulted in an efficient definition of priorities and solution of local problems (Avritzer, 2008).

Although the intention of this present work is not to exhaust the subject, the scientific literature indicates that socioeconomic (income per capita; GINI index; HDI), cultural (ethical behavior), gender (male/female), and political ideology of mayors (left-right wing) are variables being related to the higher or lower levels of cities' sustainability; regional location (climatic conditions) and happiness index can be also considered. Once governance is related to these variables, identifying them is important to effectively implement public policies toward sustainable cities.

METHODOLOGICAL APPROACH

Figure 1 presents the methodological steps developed in this study. Five cities from each Brazilian state were randomly chosen, totaling 130 cities as a sample from a population of 5,568 cities. A larger sample would be more representative, and it can be considered as the main limitation of this work, but future efforts can be made to increase the sample size and the procedures applied can be revisited to assess whether the conclusions would be similar.

Data on individual city's performance for each of the 28 indicators of the Mandala ODS is obtained *ipsis litteris* from the Mandala ODS website (CNM, 2021); it includes five indicators in the institutional dimension, seven in the economic, 12 in the social and four in the environmental dimension. These values are considered in the clustering step (c), then the association analysis [step (d)] between clusters and association variables is performed.

Cluster analysis [step (c) in **Figure 1**] was performed using the R® statistical software, considering the Euclidean distance clustering method. The grouping variables considered were the cities' 28 indicators from Mandala ODS. Results show different clusters of cities. Statistical verification of clusters quality was performed through analysis of variance (ANOVA), performed using Excel® software. Significant differences between the three clusters were evidenced for 95% of significance level (p-value of 1.30E-15 $<$ 0.05), in other words, the cities' sustainability performance is different among the three obtained clusters: sustainability of cluster 2 $>$ cluster 3 $>$ cluster 1. Important to highlight that 95% of significance level is the usual value for such statistical analysis, however, one could argue that when dealing with socio-economic analysis, lower levels of significance would be acceptable. Anyhow, we decided to keep with the 95% as standard value.

Pearson's chi-square test focuses on the analysis of independence, in which the independence of unpaired observations on two variables are assessed. The null hypothesis (H0) means that variables are not associated, that is, they are independent. The alternative hypothesis (H1) means that variables are associated, that is, they are dependent. Pearson's chi-square test is performed in Excel® software, applied to the original and expected frequency tables using data obtained from the clusters and from the 11 variables analyzed: population density, GDP/inhabitant, city's HDI, academic background of mayors, regional locations, incidence of poverty, gender of mayors, GINI index, political ideology of mayors, city size area, and religion of inhabitants. The test is applied separately for each variable and interpreted as follows: if the "p-value" is higher than

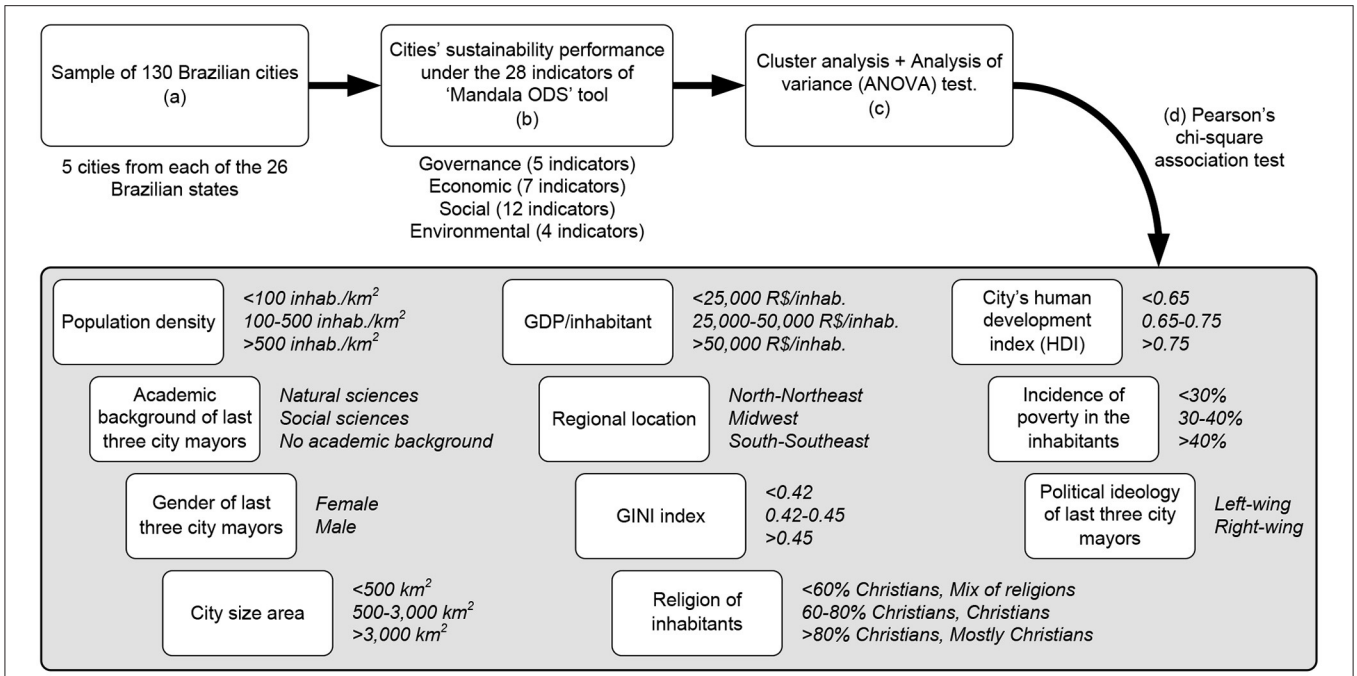

FIGURE 1 | Schematic representation of the methodological steps applied in this study: (a) sample choice, (b) gathering data from the "Mandala ODS" for the sample chosen, (c) cluster analysis and verification of its quality from ANOVA test, and (d) association test among variables (within the larger gray rectangle) and clusters. Due to reduced page numbers allowed for this perspective letter, raw data is exclusively available through direct correspondence with first author.

0.05, the hypothesis H0 is accepted, while if the "*p*-value" is lower than 0.05, the alternative hypothesis H1 is accepted.

It is important to highlight that variables considered for the association tests were chosen according to literature review (Fox and Schuhmann, 1999; Beck, 2001; Jepson, 2004; Hanna, 2005; Conroy, 2006; Nam and Pardo, 2011; Duflo, 2012; Araujo and Tejedo-Romero, 2017; Bibri and Krogstie, 2017; Nevado Gil et al., 2020) and to scientific meetings held with the research group in Cleaner Production at Paulista University, São Paulo, Brazil.

RESULTS FOR ASSOCIATION ANALYSIS

Table 1 shows that from the 11 variables assessed, five are associated with higher or lower levels of cities' sustainability as quantified by the Mandala ODS, while the other six variables are not associated. Similarly to Nevado Gil et al. (2020), the "regional location" variable is associated with cities' sustainability level, precisely, the cities located in the South, Southeast and Midwest regions of Brazil present higher sustainability levels (clusters 2 and 3) than cities located in the North and Northeast regions (cluster 1).

Cities with "HDI" higher than 0.75 indicate higher sustainability level. The obtained association evidence for the sample of Brazilian cities reflects the socioeconomic status of Brazil, a country considered still under development, with many institutional, social, economic, and environmental issues to be solved. This also applies in states and cities, especially those without effective governance structure and restricted access to economic resources available for administration and investments. Note that the "GDP/capita" variable is also associated with clusters (as identified by

TABLE 1 | *P*-value results of Pearson's chi-square association tests.

Variable	*p*-value	Interpretation of the association tests between variables and city clusters[a]
Regional location	4.75E-10	Associated
City's human development index (HDI)	1.09E-04	Associated
Incidence of poverty in the inhabitants	4.16E-05	Associated
City size area	1.75E-05	Associated
GDP/inhabitant	1.89E-08	Associated
Population density	0.17	Non-associated
GINI index	0.09	Non-associated
Religion of inhabitants	0.36	Non-associated
Gender of the last three city mayors	0.61	Non-associated
Academic background of the last three mayors	0.80	Non-associated
Political ideology of the last three city mayors	0.95	Non-associated

[a] *There is statistical association evidence between the variable and city clusters when the p-value is lower than 0.05 (significance level of 95%).*

Narayanan et al., 2021), which was expected because this variable is included in the HDI calculation framework. In general, cities with HDI higher than 0.75 and GDP/capita higher than 25,000 R$/person.yr have higher levels of sustainability.

Similar to other studies, **Table 1** shows an association between the variable "incidence of poverty" with cities' sustainability: the higher the incidence of poverty, the lower the level of sustainability. Although Duraiappah (1998) emphasizes that the relationship between poverty and sustainability is too simplistic because it ignores the complex matrix of factors that exist between them, the World Bank (Worldbank, 2021) attests that sustainable cities are competitive, inclusive, generate jobs, and are resilient to social, economic and natural shocks, indicating that these characteristics reduce poverty.

The city size area was shown to be associated with cities' sustainability level, which is in line with the ideas of Shumacher (1973) who argues that "small is beautiful" where the lower consumption, shorter production processes and chains, reduced transport needs, low storages, low population number, etc., will result in higher levels of sustainability under a biophysical perspective. Results show that the smaller the city size area, the higher levels of sustainability it will achieve. Differently, it is interesting to note that the population density variable was not associated to cities' sustainability level. This relationship of "smaller equals more sustainable" happens, perhaps, because governance is facilitated when compared to larger cities, and investments can be precisely allocated to solve problems identified by the stakeholders.

At first, it is understood that people with higher education are better prepared to face any cities administration-related issues, because they have more scientific resources and theoretical knowledge to carry out public administration focused on innovation and sustainability. Unexpectedly, the variables "GINI index" and "academic background of mayors" showed not to be associated with cities' sustainability level. Important to emphasize that "GINI index" obtained an *p*-value of 0.09, a much lower value than the "academic background of mayor" (0.80), and closest to the benchmark established of 0.05 to be considered associated; maybe, if considering a level of significance lower than 95%, a different result would be obtained. A possible explanation for non-association obtained by both variables is that the actions of city managers are integrated into the policies established by National or State Government that know little about the specificities of each city. Likewise, the non-association of the GINI index indicates that income concentration does not interfere with the implementation of sustainability-oriented policies, that is, municipalities with high and/or low GINI can achieve high and/or low sustainability levels.

The "religion of inhabitants" is not associated with the implementation of public policies for sustainability. According to Hope and Jones (2014), the inexistence of religious beliefs on environmental issues is justified by the fact that many religions do not accept that others should restrict anthropological needs, such as preserving natural capital. This is because, according to them, that man is the center of the universe and more important than everything else, and because to their faith into life after death doctrine. The same authors found that U.S. citizens who downplayed climate change were more likely to be evangelical Christians. This group was opposed to international treaties that deal with climate change, supporting only low-cost environmental policies. Probably, the central issue is the misleading understanding that man is disassociated from nature, being seen as two separate aspects in which man has greater importance. However, the existing biophysical restrictions on the Planet (biocapacity) is what sustains the existence of man on the Earth.

The raw data indicates that a practically insignificant percentage of Brazilian elected-mayors are women compared to men (17% of 130 cities were managed at least by a women considering the last three city's mayors), which may have influenced the result of non-association between the mayor's gender and cities' sustainability level. Differently, Nevado Gil et al. (2020) highlight that female participation in municipal governance in Europe is more significant (women managed 29% of 73 cities), a fact that may have influenced the association identified between gender and the European smart cities. Further studies will be carried to assess about the reasons of why the gender of mayors showed non-association with Brazilian cities clusters. On the other hand, similarly to the results obtained by Nevado Gil et al. (2020), **Table 1** shows that the "political ideology" variable is not associated with cities' sustainability level. It is important to mention that there are studies in the literature that obtained different results, such as those of Prado-Lorenzo et al. (2012), and Anderson and Mizak (2006), who identified evidence about the importance of mayors' political ideology on cities' sustainability levels.

The Mandala ODS has been considered an important tool supporting decision makers in search of higher levels of sustainability in the Brazilian cities, as it quantitatively shows the current cities' sustainability performance by identifying indicators that should be prioritized for improvements. Although recognized as important, the results of Mandala ODS allow limited actions to one or other specific indicators, but external drivers influencing these indicators can become factors that interfere in the successful implementation of strategic development plans. The sustainable development of cities will hardly be achieved exclusively considering the Mandala ODS performance indicators, since this management approach lacks a systemic view to understand the inherent complexities involved that requires the inclusion of stakeholders for the efficacy of public policies implementation. That is the reason of this perception letter: to call attention to external drivers that may boost higher levels of cities' sustainability.

FINAL REMARKS

The association analysis between variables and clusters showed that cities' sustainability level as quantified by the Mandala ODS are associated with the variables; regional location, HDI, incidence of poverty, city size area and GDP per capita. All

others variables showed no association with clusters. Trying to answer the central research question of this study, the Brazilian cities located in the South/Southeast/Midwest regions, with HDI higher than 0.75, incidence of poverty lower than 40%, territorial size area lower than 3,000 km2, and with GDP/capita higher than 25,000 R$/person.yr, have significant statistical association that leads them to higher levels of sustainability than other cities without these characteristics. These results raise doubts about the efficacy of larger scale national public policies for sustainability that are standardized and usually ignore local city characteristics. At this point, local governance appears to be of paramount importance.

Not all other assessed variables that in principle would be important to achieve higher levels of sustainability for cities showed statistical evidences of association. On the other hand, the scientific literature has been emphasizing the importance of such variables on cities' sustainability level, which from a systemic perspective would lead to an effective governance of such important systems for human development. In principle, assessing social, political, religious, gender diversity, professional training, and macroeconomic elements could lead to a better understanding of the reasons why some cities achieve higher levels of sustainability than others. Future efforts will include other variables for analysis and a larger sample of cities, also focusing on the potential cause-effect relationship among the assessed variables with city sustainability.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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