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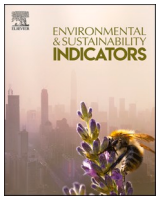

Exploring critical issues for local sustainability assessment through community participation

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ABSTRACT

Despite several initiatives in local sustainability assessment, there remains a lack of knowledge on how to balance an assessment that considers multiple aspects while also focusing on specific critical issues of local sustainability. The primary goal of this research is to explore how a subset of 'technical' and 'voluntary' indicators can be co-developed to assess critical local sustainability issues. To this end, a participatory approach was employed with the communities of three local case studies in Brazil where solid waste was a critical issue for local sustainability. The results indicate that the co-developed goals and indicators effectively address critical sustainability issues. They also show that voluntary indicators were able to capture in-depth, context-specific problems and were more user-friendly. Due to these characteristics, we argue that they may be more suitable for citizen monitoring. Overall, this study highlights that technical and voluntary indicators developed through community participation enhance their relevance and usability for local sustainability assessments.

1. Introduction

Sustainability assessment is a process designed to guide decision-making related to policies, plans, programs, projects, and activities (Bond and Morrison-Saunders, 2011; Ramos, 2019; Huang, 2023). Studies about it have exponentially increased in the last decades (Sharifi, 2021), as well as about using indicators in evaluation and monitoring processes (Pandey et al., 2021). Sustainable development necessitates a sophisticated information system that accounts for the complexity of reality in decision-making processes. Sustainability indicators can serve as essential tools in this context (Merino-et al., 2020; Spangenberg, 2002; Valentin and Spangenberg, 2000), providing crucial information for planning, monitoring, and evaluation (Francis and Thomas, 2023; Tekouabou et al., 2022; Wang et al., 2021).

Ideally, sustainability indicators (SI) aim at embodying, in a balanced way, each one of the sustainability aspects regarding a certain context or evaluation object (United Nations, 2007). However, achieving a balanced consideration of sustainability aspects can be challenging in practice due to a) a restricted number of indicators that can be integrated into the system, b) the diversity and complexity of natural and human systems to be assessed (Mengxue et al., 2022; Organisation for Economic Cooperation and Development, 2008), c) the need to develop balanced evaluation tools in thematic terms (Sharifi, 2020, 2021; United Nations, 2007), and d) the necessar y resources to develop and keep evaluation systems (Sharifi, 2020).

Thus, it becomes evident that sustainability indicator sets are necessarily constrained to a limited number of indicators per aspect or dimension to ensure feasibility. For example, many local sustainability assessment systems incorporate no more than three indicators to evaluate the solid waste aspect (Cetrulo et al., 2020). This number may not be enough to represent the critical issues for local sustainability and to support correlated decision-making. Some examples of critical issues for local sustainability are a) the risk of drought periods in Northern African regions (Ahmadalipoura et al., 2019); b) the risk of desertification in Central Asia (Jiang et al., 2019); c) floods in localities in Europe, Asia, Latin America and Africa (Douglas, 2017); and d) solid waste to several countries in Southern Asia, Persian Gulf Region, Africa, and Latin America (Bjerkli, 2015; Samson, 2017; Kaza et al., 2008). Accordingly,

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there is the need to detail procedures to represent the complexity of these issues critical for local sustainability, even in balanced and reduced systems from other sustainability aspects (see Section 2). The outcomes might be unbalanced sets of indicators that capture the relative importance of pivotal topics within a specific scope and context.

Although there is extensive literature on participatory processes for developing indicators in local sustainability assessments (for example, Sharif et al. (Sharifi, 2021), Bekier and Parisi (2023), and Reid and Rout (2020)), much less attention has been given to systems that address critical sustainability issues. Besides, because the focus on particularly critical sustainability topics is linked to knowledge of local realities, one can clearly understand that a participatory approach aimed at indicators' construction allows a better understanding of their specificities if one has in mind the political, institutional, geographic, and socio-economic-cultural contexts.[1] Thus, the main aim of the present study was to explore the co-development of a subset of indicators to assess critical issues of local sustainability. Furthermore, we analyzed the suitability of voluntary indicators for this context, including their potential use in future citizen-based monitoring initiatives (see Section 3).

2. Critical issues for sustainability assessment

Local sustainability assessments incorporate key sustainability aspects through indicators designed to represent them. This process frequently results in complex and dense tools. Moreover, the local sustainability perspective[2] is notably complex because each place is highly unique and conditions change rapidly, which requires flexible and context-specific approaches (Turcu). In the pursuit of a holistic view encompassing the multiple dimensions of sustainability, indicator sets often end up overlooking important aspects of sustainable development at the local level. In other words, the effort to cover a broad range of sustainability dimensions can lead to more superficial indicators. As a response to these limitations, sustainability assessment tools focused on critical issues have emerged. These tools emphasize the need for in-depth analysis of locality-specific concerns, as they are crucial to achieving meaningful progress in local sustainability.

Although scientific literature specifically dedicated to this approach is still limited, several studies have acknowledged its relevance. For instance, Diéz-Unquera et al. (Díez-Unquera et al., 2012) and Harbiankova and Scherbina (2021) identified 'critical aspects of sustainability' to analyze rural-development sustainability or Flores et al. (2018) that explored the 'key sustainability aspects' for the context of bioenergy generation from biomass sources. In these studies, critical issues were the starting points for the development of sustainability indicators in those studies. Similarly, Kwatra et al. (2021) propose a methodology to assess and prioritize key sustainability issues at a regional scale. Other works focus on a single critical issue, such as climate-change-induced flooding in Australia's Hunter Valley Region (Mortimer et al., 2023).

In the context of environmental impact assessment, Morrison-Saunders and Pope (2013) emphasize the importance of focusing on key sustainability-issue categories at the time to assess projects' environmental impacts. Morrison-Saunders et al. (2014) argue that emphasizing essential environmental/sustainability aspects, rather than attempting to address an overly broad set of topics, offers clear advantages, especially during project follow-up. A practical application of this model approach is found in the Canadian Mackenzie Gas Project, which performed detailed analyses of individual issues during the process to identify key sustainability categories (Gibson, 2011). In these types of assessments, the recommendation "to engage with stakeholders and identify the most critical sustainability issues to focus on assessment" is consistently emphasized (Borgert et al., 2019).

It is important to highlight that there is still ambiguity in the terminology adopted across studies. A sustainability aspect refers to a specific element that can interact with or impact sustainability. It is neutral by nature and is often treated as a component within a broader sustainability dimension (Fritz et al., 2016). The term sustainability issue, by contrast, generally refers to a problem or challenge that affects the ability to achieve sustainable development (Crosman et al., 2022), reflecting a more problem-oriented perspective. The latter term was adopted in this paper, as the proposed framework is designed to focus on the critical sustainability-related problems within a given locality, critical referring to those that most significantly hinder sustainable development.

The literature also refers to critical factors for sustainability, used in various contexts such as social sustainability (Chan and Lee, 2008) or for achieving peace and national development (Igbuzor, 2021). However, the tern 'critical factor' is predominantly associated with corporate sustainability strategies (see the review of this subject by Nilsson and Göransson (2021)). It's important to note that critical factors focus exclusively on causes, while critical issues encompass both causes and effects within a cause-and-effect framework.

Regardless of the adopted application and based on several case studies, Latawiec and Agol [40, p. 244] concluded: "that indicators addressing issues critical to sustainability (in a specific context), in a more comprehensive manner, can help better understanding and measuring development progress than 'traditional' indicators". Responding to this gap, Cetrulo (2020) proposed a local sustainability assessment framework that incorporates a critical issues subset, advocating the coexistence of a broader indicator set alongside one or more focused subsets dedicated to the most pressing sustainability challenges at a given time in the local context. The present article aims to contribute to the proposition by Cetrulo (2020) by deepening the understanding of how stakeholders' participation can support the selection, development, and evaluation, of indicators to compose this type of subset, dedicated to a critical issue of local sustainability.

3. Stakeholder participation in sustainability assessment

Historically, the challenge of assessing sustainable development has led to the creation of numerous indicators, often referred to as part of an "indicator industry" (Rinne et al., 2012Rydin et al., 2003; Rinne et al., 2012). This expression reflects the tendency to produce many sustainability indicator sets without ensuring their relevance or applicability, such as to local contexts (Rinne et al., 2012; Rydin et al., 2003). It is not uncommon to find cases in which such proposals are ultimately disregarded at the end of the project and never implemented (McKenna and Hanrahan, 2024; Mickwitz and Melanen, 2009). According to Rydin et al. (2003), among other reasons, this outcome can be attributed to a lack of understanding of local realities.

The involvement of social actors in defining sustainability objectives (Fraudatario et al., 2023), as well as in the selection, development, and evaluation of SI, is considered fundamental by several authors for the consolidation of sustainability assessment tools (Reid and Rout, 2020; Bell and Morse, 2001; Reed et al., 2006; Ramos and Caeiro, 2010). According to them, interested parties' involvement reinforces tools' legitimacy and relevance (see Reid and Rout (2020)), besides improving the quality of decision-making, because it provides broader information (Reed, 2008). The literature provides several examples of stakeholder involvement in developing indicators applicable to local sustainability assessment, such as the case of Ireland (Reed et al., 2006; Ramos and Caeiro, 2010), United Kingdom (Turcu; Turcu, 2012), Australia (Graymore, 2014; Cox et al., 2016), Portugal (Coelho et al., 2010; Mascarenhas et al., 2010; Moreno-Pires et al., 2014; Mascarenhas et al., 2015), and Ireland (McKenna and Hanrahan, 2024).

[1] "This approach, with its focus on the sustainability issues relevant to a particular location and community, requires a collaborative approach to delivering the contribution to sustainability" (Excerpt taken from Morrison-Saunders et al., p. 41 (Turcu)).

[2] Local sustainability refers to communities, cities, or municipalities.

To further enhance the local sustainability assessment process, another modality of social actor involvement can be considered: citizen/community-based monitoring, which "refers to a range of activities through which concerned citizens gather and record systematic observations about environmental or social conditions" (A et al., 2005). In this modality, the community is involved in initiatives for collecting data or in technology-based initiatives (Domingues et al., 2018). Several studies in this field advocate the idea that data collected by volunteers can complement those gathered by formal or professional monitoring processes (Ramos, 2019; Mascarenhas et al., 2015; Ramos et al., 2014). In other words, stakeholder-driven initiatives can operate in parallel with, yet interactively support, formal sustainability monitoring processes (Domingues et al., 2018).

In the last decades, some countries involved communities in data collection processes aimed at environmental monitoring (Domingues et al., 2018; Bio Innovation Service, 2018). Examples of these processes comprise a) direct observation by the population to monitor biodiversity (the entire European continent, mainly birds and butterfly populations); b) reports by local groups providing information on litter collected during clean-up operations (the entire European continent, mainly plastic waste); c) individuals reporting the incidence of illegal waste disposal (Scotland); d) monitoring air pollution through data collected by simple sensors used in people's homes (Netherlands); or by bad smell (10 countries in Europe); e) tracking nonpoint water pollution (EUA). It is important to highlight that all these schemes are used for monitoring, reporting, or informing policymaking in various locations (Domingues et al., 2018; Bio Innovation Service, 2018).

Several initiatives incorporate data collected by local communities into scientific research. Trained citizen scientists collected macroinvertebrate and hydromorphological data accurate enough to quantify stream ecological stressors, such as exposure to pesticides (Gönner et al., 2023). Similarly, the community conducts regular monitoring of aquatic macroinvertebrates to assess urban stream quality (Krabbenhoft and Kashian, 2020). Two forest conservation-monitoring systems in Liberia were compared and results have shown that Citizen-based monitoring led to stronger commitment by participating families to the creation and application of forest-use rules (Christensen et al., 2021). Voluntary teams of residents collected data in China to measure water quality by using inexpensive field kits. They recorded observations about water clarity and smell and conducted chemical tests (Buntaine et al., 2021). The accuracy of five water quality parameters was assessed to collect water quality data; three of them recorded satisfactory results (Quinlivan et al., 2020a). Community-based monitoring presents availability, skills, and incentives for local participants as its advantages. They can complete traditional monitoring schemes given the long-term, spatially broad, and repeated nature of their sampling (Krabbenhoft and Kashian, 2020). Citizen monitoring developed by several initiatives has provided data on a scale or frequency that would not be available otherwise. The community can also help reveal issues that are not properly covered by existing monitoring networks, such as those observed in air pollution and illegal open dump initiatives (Rijck et al., 2020). Additionally, citizen-led data collection offers a means to pressure the government, as seen in Beijing, where residents utilized Twitter to disseminate air pollution data obtained from home-based monitoring devices (Lu et al., 2015). Furthermore, stakeholder-based monitoring can ensure that local managers are answerable to higher authorities, as demonstrated in the management of water sources in China (Buntaine et al., 2021).

However, certain public agencies and academic researchers present skepticism regarding the accuracy of data produced by volunteers (Krabbenhoft and Kashian, 2020). A literature review carried out by Quinlivan et al. (2020b) about data voluntarily collected to measure SDG 2.3.2 also pointed out the status of "non-quality data" associated with 'amateur' assessments. On the other hand, a study developed by Danielsen et al. (2013) assessed 12 international environmental agreements and showed that 117 of the 186 indicators can involve community members in monitoring at the data collection stage.

Domingues et al. (2018) argue that conventional and voluntary processes can use the same set of indicators to assess or monitor the same issues, but in different ways. Using common language facilitates communication between experts and non-experts, however we argue that such initiatives should include user-friendly indicators that are accessible to a broad range of stakeholders, as this enables more inclusive and active participation in monitoring processes. In this regard, this research aims to explore how a subset of 'technical' and 'voluntary' indicators can be defined and used to assess critical local sustainability issues.

4. Method

A methodological approach based on multiple-case studies was carried out, following the recommendations of Saunders et al. (2019). Multiple cases enable the observation of a phenomenon on multiple occasions, making them preferable to a single case when the necessity arises to generalize from these findings. The Brazilian municipalities of Nobres, Sapezal, and São José do Rio Claro were selected to explore the construction of an indicator set tailored to local critical issues.

Participatory workshops served as the main method to involve selected local actors in the process of defining critical issues, respective goals, and indicators. Public participation relevance for local sustainability indicators construction has been broadly discussed in the literature (see Mickwitz et al. (Mickwitz and Melanen, 2009), Reed et al. (2006), Fraser et al. (2006), and Rosenström and Kyllönen (2007)). The adoption of participatory workshops as a method to involve stakeholders can be observed in various studies (for example, Marques et al. (2013), Droege et al. (2021), and Ramos et al. (2021)).

4.1. Case study description

The three selected municipalities are Nobres, Sapezal, and São José do Rio Claro, located in Mato Grosso state, Midwestern Brazil (Fig. 1). Nobres is situated near Chapada dos Guimarães National Park, an important Protected Area of the Cerrado biome. In contrast, Sapezal and São José do Rio Claro are in a transition zone between the Cerrado and the Amazon biomes.

These municipalities are relatively small, each with a population of less than 20,000 residents with a Human Development Index (HDI) lower than the national average of 0.755. Interestingly, their per capita GDP is slightly above the national average of approximately USD 8917.67, except for Sapezal, which boasts a per capita GDP of about 3.5 times higher than the national average. Table 1 offers a more detailed overview of these municipalities.

The three municipalities exhibit fundamental challenges in basic sanitation and public cleanliness. Less than half of households in these municipalities have adequate sewage systems[3] (in São José do Rio Claro, only 3.7 % of households have adequate sewage systems). Less than 20 % of residences are located on streets with adequate urbanization standards[4] (in Sapezal, this number reaches 3.3 %).

These municipalities were chosen due to their shared challenge of addressing a critical sustainability issue: solid waste management. Notably, the waste from these municipalities is often disposed of in unregulated dumpsites lacking environmental permits. At these sites, individuals can still be seen collecting recyclable materials, and animals are commonly present" (Government of Brazil, 2019; Government of Brazil, 2017). Moreover, a roster of municipalities was submitted to officials from the Environmental Secretariat of the State of Mato Grosso, wherein solid waste was identified as a critical sustainability concern in

[3] Sewage systems, including those connected to the general network or those of the septic tank type.

[4] Presence of manholes, sidewalks, paving, and curbs.

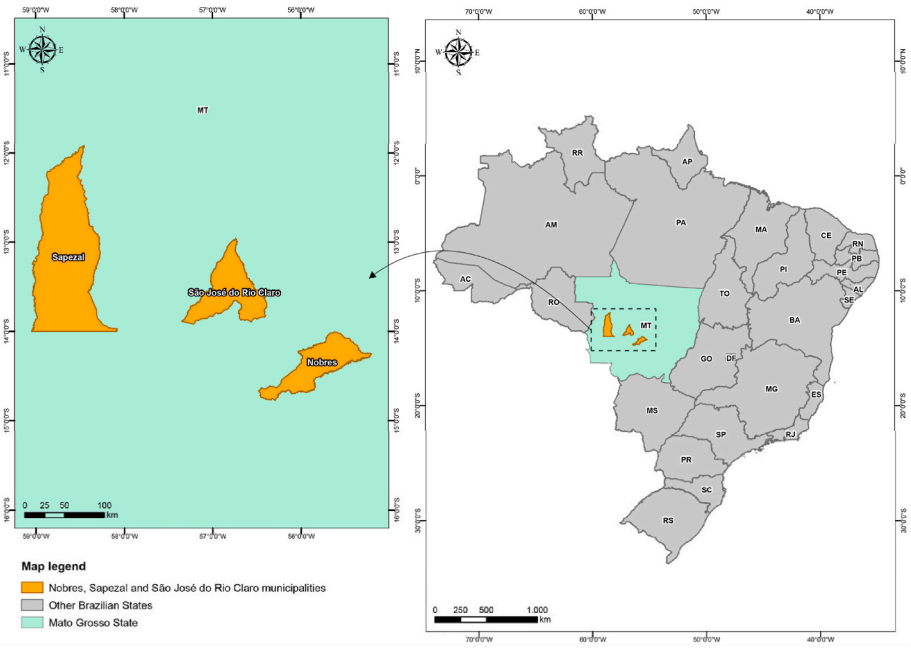

Fig. 1. Location of the three Brazilian municipalities.

Table 1
Sociodemographic features of the three Brazilian municipalities involved in the study.

	Nobres	São José do Rio Claro	Sapezal
Territory (km^2)	3912	4533	13,642
Population	15,334	21,011	26,688
Main economic activity	Cement and limestone industry	Plant-based resource harvesting	Agribusiness (soybean)
GDP *per capita*	USD 13,761.94	USD 12,990.96	USD 48.052.71
HDI	0.699	0.682	0.732

Source: Government of Brazil (Government of Brazil, 2019).

the three municipalities.

4.2. *Indicators' set development*

The development, selection, and evaluation of indicators took place based on goals to plan, manage, and monitor a critical issue for local sustainability, in this case: 'solid waste management'. The option was made to not use goals resulting from institutionalized planning instruments (e.g., National Policies). Aiming to strengthen the recognition of what is important regarding the theme for the location, the objectives were defined by the participants themselves in the first workshop. To achieve this, an adapted version of the Ketso® Workshop Planner (Ketso and Ketso, 2024) was used, which allows for more productive participation of individuals in the activity (Tippett, 2013; Tippett et al., 2021).

In the second workshop, participants had access to a preliminary list of solid waste management indicators identified in the literature on local sustainability assessment. This list could be supplemented by participants to better represent the goals they defined. Structured questionnaires were used to rank the indicators (Saunders et al., 2019) and were completed in person during the participatory workshops. A detailed step-by-step description of the methodology is provided below.

Step 1: Identifying key actors in the three municipalities

Representatives from several sectors of society were invited to participate in the workshop to contribute to a broader view of local peculiarities and to represent the diversity of society's perception of the same issue. Representatives from various sectors of society were invited to participate in the workshop, contributing to a broader understanding of local specificities and reflecting the diversity of societal perspectives on the issue. In all three municipalities, initial contact was made with the Public Prosecutor's Office. Subsequently, we requested the City Hall's support in facilitating and reinforcing invitations to municipal secretariats and councils for their participation in the workshops. Additionally, the City Hall provided logistical support, particularly regarding the venue and necessary equipment. By engaging with municipal councils (e.g., health, tourism, and housing councils), we established connections and secured support for inviting civil society organizations, local media, among other stakeholders. No selection process was implemented, and participation was open to all interested individuals. In Table 2 the participants' profiles are summarized.

Although several other actors from different sectors of the society were invited to the workshops, most participants represented local administration. Only Nobres counted on the participation of civil society's representatives. No municipality counted on the participation of judges, media, NGOs, or scholars. The hard time having members from scavengers' cooperatives was also clear, be it because of lack of access to communication means (e-mail or text message) or of their difficulty in stopping working to join the workshops.

Step 2: Introducing the research scope and its basic concepts

According to the approach proposed by Mascarenhas et al. (2015, 2016), 2016, it is important to explain, using non-technical language, the meaning of indicators as well as their use for sustainability assessment purposes. Besides, the aims of the workshops were defined, as well as the tasks to be accomplished by the participants. The aims of this presentation were to promote a common baseline about the subjects to be discussed and to potentiate participants' involvement in the subsequent steps.

Step 3: Defining goals for critical issues

In each city, participants were organized into groups of 4–6 individuals, with an emphasis on including representatives from diverse

Table 2
Number of participants per group of stakeholders and municipality.

Participants' profile		Nobres	São José do Rio Claro	Sapezal
Public Prosecutor's Office	Local Prosecutor's Office	1	0	1
Local Administration	City Hall	1	0	0
	Management Secretary	1	0	1
	Environment Secretary	2	1	0
	Education Secretary	1	0	7
	Tourism Secretary	1	0	0
	Construction Project Secretary	1	1	0
	Treasury Secretary	1	0	1
	Health Secretary	1	4	1
	Social Work Secretary	0	1	3
Association of scavengers	Association of scavengers	1	0	0
Councils and humanitarian organizations	Municipal Health Council	4	0	0
	Municipal Tourism Council	1	0	0
	Rotary Club	0	3	0
Legislative Power	City Council	0	2	0
Total		16	12	14

sectors to encourage discussions enriched by multiple perspectives. The primary objective of this initial workshop session was to define solid waste management goals specific to each municipality. For this purpose, an adapted version of the Ketso® method was employed. This method is more effective than having some people simply talking in a meeting, because all participants can work on their ideas in parallel, and avoid issues such as intimidation, and imposition of ideas, among others.

The Ketso approach uses the metaphor of a tree to organize the thoughts of a group. Participants must distribute "leaves" that reflect their experience on thematic branches over a smooth surface. The leaves are split into different colors representing different meanings (goals, challenges, solutions, future possibilities). These concepts can be adapted to other contexts. This approach has already been employed in various types of participatory workshops, consistently yielding very positive outcomes, such as: a) in tourism planning in places like Kurdistan and New Zealand (Sarky et al., 2016; Wengel et al., 2019), b) in sharing knowledge about drinking-water practices in Peru (Furlong and Tippett, 2013), c) to discuss poverty in Russia (Ivashinenko et al., 2019), d) to shine light on Saudi teachers' opinion (Alabbasi and Stelma, 2018), e) in sustainable impact assessment (Žemaitis et al., 2021), among others.

During the workshop, participants identified thematic branches representing critical issues of solid waste management. The adaptation applied to the workshop (Figure A.1, Appendix) involved assigning specific meanings to the colors of the leaves.

- Brown leaves (symbolizing earth): represented actions already undertaken in the municipality regarding each thematic branch (e.g., final waste disposal).
- Green leaf (symbolizing new growth): Denoted future possibilities or needs for each thematic branch.
- Grey leaf (symbolizing clouds): Means challenges associated with realizing each future possibility or need.
- Yellow leaves (symbolizing sunlight): Marked the most critical points to be prioritized ("illuminated").

After completing this exercise, participants presented their yellow leaves and shared the key ideas emphasized during the plenary session. These consolidated ideas were then refined and formalized into solid waste management goals for each municipality.

Step 4: Indicator assessment and selection process

The process began with a preliminary selection of indicators aligned with the solid waste management objectives identified by each municipality in the preceding step. This generated an initial list of indicators (Table A.1, Appendix) comprising both technical (formal/conventional) indicators and voluntary (informal) indicators. Participants were instructed to propose new indicators for each of the objectives established in the first workshop (as carried out by Coelho et al. (2010) and Ferreira et al. (2018)).

Subsequently, the participants were asked to evaluate all the indicators on the Relevance criterion (see Ramos et al. (2004)). Relevance, in this context, refers to the importance and suitability of each indicator for monitoring a specific objective. Participants rated the indicators on a scale from 1 (very low relevance) to 5 (very high relevance), with additional options of 0 (not applicable) and NS (not sure) available for selection.

To rank the indicators, a scoring system was implemented based on the frequency of responses.[5] Each indicator was assigned a Score (S) ranging from 0 to 1, calculated by normalizing the aggregated individual evaluations. This score provided a general measure of the indicator's relevance: the closer the score was to 1, the greater the number of participants who rated the indicator as highly relevant.

The final set of indicators was determined by arranging the list in decreasing order of Score (S). Indicators with the highest scores were identified as the most relevant for monitoring local sustainability goals. While most studies establish a cut-off at $n = 10$ indicators (e.g., Stone et al. (2016), Hashemi et al. (2021), and Carra et al. (2022)), this study adopted $n = 20$ to ensure a broader selection of indicators for each goal. Examples of studies that similarly used $n = 20$ include Castillo and Pitfield (2010) and Okey (2018).

5. Results

5.1. Co-developed goals to address the critical issue in the three municipalities

The workshops promoted in-depth discussions on the situation of solid waste in the municipalities and enabled key actors to define goals for solid waste management systems in each of the assessed localities. Table 3 presents the goals co-developed by participants during the participatory workshops held in the three municipalities. Despite similarities in certain thematic areas, such as environmental education (Goal 3), which was proposed in all three locations, the goals reveal distinct local priorities and contextual needs. For example, while Nobres and São José do Rio Claro proposed actions focused on directing waste to landfills (Goal 1), Sapezal emphasized the need to construct a landfill, indicating that such infrastructure was not yet available in the municipality. Regarding selective collection (Goal 2), all municipalities addressed the theme, although at different stages of implementation — ranging from setting up a program to broadening an existing one. Composting also appeared in the three cases (Goal 4), with variations in scale and focus. Some goals were unique to each municipality and reflected specific local challenges, such as creating an association of scavengers (Nobres), establishing an environment fund (São José do Rio Claro), and expanding the 3 W workshops (Sapezal). The final goals (Goal 6) also varied significantly, covering construction debris management, improvements in recyclable material separation, and the

[5] Score (S) was calculated based on the normalization (0–1) of the equations' result:$S = \frac{1}{n}\sum_{j=1}^{n} R_j$, wherein R_j is the relevance of indicators with regards to each respondent $j(j = 1, .., n)$

Table 3
Co-developed goals during the participatory workshops conducted in each municipality.

	Nobres	São José do Rio Claro	Sapezal
Goal 1	Sending the waste to landfills	Sending the waste to landfills	Building a landfill in the municipality
Goal 2	Setting a selective collection program	Implementing a selective collection project	Broadening the selective collection program
Goal 3	Implementing an environmental education program	Implementing an environmental education program	Implementing an environmental education program
Goal 4	Creating a composting station	Creating a sorting and composting unit	Creating a composting project
Goal 5	Creating an association of scavengers	Creating the environment fund	Broadening the 3w workshops in the municipality
Goal 6	Giving proper destination to construction debris	Making collection cans available for the separation of recycling materials	Applying fees

application of service fees. These differences highlight the capacity of participatory processes to generate context-specific objectives that reflect the realities, needs, and governance maturity of each locality.

Considering that the development of goals was carried out jointly with the participants, the list of indicators[6] drawn from the literature did not fully encompass all the goals co-developed in the first workshop, since it would be impossible to predict in advance all the aspects related to such a complex theme. For instance, composting and environmental education were common goals across the three municipalities; however, no indicators related to these themes were pre-selected in the literature to be part of the initial list. Despite this gap, during the phase in which participants were directed to offer supplementary indicators beyond the initial list to more accurately represent the objectives they had established, none of the stakeholders recommended the development of new indicators.

5.2. Developed indicators' set for addressing the critical issue

Fig. 2 shows the score of each sustainability indicator for the cities studied. The scores reflect the importance and suitability of the indicator for monitoring the objectives proposed, based on the evaluations provided by all respondents. To illustrate the interpretation, a score of 1 indicates that all participants in the workshop for a given city deemed the indicator to be highly relevant. Conversely, a score of 0 suggests that all participants considered the indicator to be of very low relevance. A score of 0.5 indicates either that all participants viewed the indicator as moderately relevant, or that it was evenly split, with half considering it highly relevant and the other half deeming it of very low relevance. The bar lengths are proportional to the score range (from 0 to 1), with each bar divided into thirds by color coding: red, yellow, and green (similar to a traffic light). This visual representation provides an intuitive understanding of each indicator's relevance to the proposed objectives.

Although workshops' results presented a general convergence in the goals' definition in municipalities, the same did not happen with indicators' selection for monitoring them. See in Fig. 2 that among the indicators chosen by the three municipalities (TOP 20, as presented in Section 4.2), only four were duplicated: 'Presence of vultures/birds close to open dumps' (VI4), 'Presence of rodents/insects close to open dumps' (VI5), 'Waste deposits in vacant lots' (VI9), and 'Waste generation' (TI41). As seen, three of these are "Voluntary Indicators (VI)", as well as most of the indicators make up the top 20 in the three municipalities (see Figs. 3–5). To confirm that the "Voluntary Indicators" (Median (*Mdn*) = 0.57; *range* = 0.1–0.84) had better scores than "Technical Indicators" (*Mdn* = 0.50; *range* = 0.0–1.0), a Mann-Whitney test was performed. The Mann-Whitney test successfully rejected the null hypothesis that the scores of the two types of indicators are equal at the 95 % significance level ($W = 7250.50$ and $p = 0.02$). The evidence was sufficient to conclude that the voluntary indicators performed better overall when compared to the technical indicators (see Figure A.3in the Appendix for additional visual support).

It is noteworthy that in Nobres City, 17 out of the 20 selected indicators are voluntary (see Fig. 4). Of the 20 indicators, seven are for monitoring waste disposal (e.g., batteries and tires in landfills), four are related to service quality (e.g., satisfaction with collection frequency and service cleanliness), four are for monitoring societal impacts (e.g., odors from open dumps and presence of animals at these sites), and three are for monitoring environmental impacts (e.g., waste transported by rainwater/runoff).

In Sapezal, 13 out of the 20 selected indicators are focused on monitoring final waste disposal (Fig. 4). These indicators include monitoring the disposal of batteries, tires, and electronic waste in the landfill, as well as assessing landfill quality. Additionally, four indicators are designated for societal impacts, such as the presence of scavengers in the open dump and garbage on the streets. It's worth noting that a majority of the indicators, 14 out of 20, are voluntary.

In São José do Rio Claro, final disposal was the most relevant among the selected indicators for monitoring the selected goals, with a total of 6 indicators. This municipality was unique in that it had indicators to monitor the quantity of waste (this includes, for example, five indicators for monitoring per capita solid waste generation and disposal, as well as the per capita amount of construction and demolition waste). Additionally, 5 indicators were selected to monitor the quality of solid waste management services provided in the municipality, and 2 to monitor potential impacts of inadequate waste management on society. São José do Rio Claro had a balance between selected technical and voluntary indicators (Fig. 5), reflecting its value for waste quantity indicators, which are predominantly quantitative (technical indicators).

Through the dialogues between the research team and the participants, a preference for voluntary indicators was observed: a) the language of this indicator type is closer to people and easier to understand; b) people identify themselves with this indicator type because it translates important aspects of their communities' daily life. Furthermore, no associations were found between the preference for voluntary indicators and the stakeholder composition of the workshop. Even in Sapezal City (almost all participants were government representatives), 75 % of TOP-20 indicators were voluntary. However, it is important to highlight that 85 % of indicators in Nobres City (higher participation of civil society) were voluntary.

6. Discussion

6.1. Local definition of goals

For the critical issue analyzed in the case studies, one possibility would be to leverage the objectives of institutionalized planning instruments, such as the National Solid Waste Policy and the State Solid Waste Plan. However, as seen in the literature, pre-established objectives have their shortcomings (as seen in Section 3 and in Fraudatario et al. (2023)). For instance, they can be overly vague, unclear, unrealistic, or may not be achievable by the locality (Ferreira et al., 2018). Especially for assessing critical sustainability issues, using objectives not tailored to the local context poses two risks: a) considering goals that do not matter for a specific locality; b) neglecting goals that are only specific to a given locality or that are mostly important to it.

As for the herein assessed cases, the participatory goals' definition allowed local society's concerns to be met. To exemplify, it can be noted

[6] In the process of collecting existing indicators, no specific indicators for citizen monitoring were discovered (as observed by Domingues et al. (2018)). As a result, the team created a preliminary list of voluntary indicators by drawing from other community monitoring initiatives.

Cod.	Indicator's name	S (Nobres)	S (Sapezal)	S (São José do Rio Claro)
VI1	Bad smell from open dumps	0.55	0.59	0.44
VI2	Waste deposited in the external area of open dumps	0.58	0.63	0.48
VI3	Waste transported by rainwater/runoff	0.58	0.69	0.40
VI4	Presence of vultures/birds close to open dumps	0.61	0.77	0.60
VI5	Presence of rodents/ insects close to open dumps	0.70	0.73	0.64
VI6	Presence of dogs, horses, and cattle in open dumps	0.45	0.54	0.30
VI7	Presence of scavengers in open dumps	0.25	0.66	0.50
VI8	Unauthorized waste disposal in open dumps	0.47	0.63	0.67
VI9	Waste deposits in vacant lots	0.69	0.70	0.55
VI10	Improper disposal of garbage	0.65	0.68	0.52
VI11	Use of inadequate vehicle for waste collection	0.29	0.47	0.13
VI12	Lack of protection equipment for waste collectors	0.34	0.45	0.42
VI13	Burning garbage	0.67	0.63	0.54
VI14	Disposal of infectious waste in open dumps	0.25	0.84	0.25
VI15	Disposal of construction and demolition waste in open dumps	0.55	0.60	0.56
VI16	Disposal of construction and demolition waste in vacant lots	0.60	0.66	0.52
VI17	Disposal of agricultural and forestry waste in open dumps	0.17	0.46	0.20
VI18	Disposal of agricultural and forestry waste in vacant lots	0.29	0.46	0.19
VI19	Disposal of electronic waste in open dumps	0.68	0.68	0.52
VI20	Disposal of electronic waste in vacant lots	0.56	0.71	0.21
VI21	Disposal of tires in open dumps	0.47	0.75	0.18
VI22	Deposits of tires in vacant lots	0.60	0.75	0.10
VI23	Disposal of batteries in open dumps	0.78	0.83	0.43
VI24	Disposal of batteries in vacant lots	0.66	0.73	0.18
VI25	Satisfaction with the quality/cleaning of the collection service	0.62	0.55	0.54
VI26	Satisfaction with the frequency of the collection service	0.67	0.59	0.61
VI27	Satisfaction with the frequency of the selective collection	0.71	0.55	0.79
VI28	Satisfaction with the quality/cleaning of the selective collection	0.50	0.64	0.75
TI29	Disposal of solid waste	0.29	0.65	0.43
TI30	Disposal per capita of solid waste	0.42	0.50	0.55
TI31	Problems with domestic waste disposal	0.81	0.57	0.65
TI32	Disposal of solid waste in improperly managed landfills	0.25	0.56	0.36
TI33	Existence of properly managed landfills	0.13	0.66	0.75
TI34	Disposal of solid waste in properly managed landfills	0.60	0.64	0.35
TI35	Ratio of solid waste processed by landfills	0.00	0.58	0.63
TI36	Priority for landfill disposal	0.00	0.73	0.50
TI37	Level of compliance of local landfills with regulations/standards	0.25	0.89	1.00
TI38	Quality of the landfill	0.13	0.81	0.25
TI39	Waste recovery and disposal proportions	0.31	0.58	0.30
TI40	Waste reuse and disposal proportions	0.10	0.55	0.21
TI41	Waste generation	0.84	0.82	0.58
TI42	Amount of urban solid waste by type	0.25	0.38	0.50
TI43	Amount of collected solid waste	0.42	0.43	0.58
TI44	Amount of construction and demolition waste	0.17	0.54	0.63
TI45	Amount of pruning waste	0.42	0.46	0.60
TI46	Urban solid waste composition	0.50	0.58	0.58
TI47	Management type	0.38	0.59	0.50
TI48	Presentation of the recycling program report	0.00	0.50	0.50
TI49	Solid waste political and management availability	0.44	0.68	0.50
TI50	Time involved in the recycling programs	0.25	0.65	0.50
TI51	Landfill area for solid waste	0.25	0.47	0.43
TI52	Existence of community recycling projects	0.25	0.60	0.38

Fig. 2. Scores (S) for all indicators in the three municipalities. The scores (0–1) are represented by proportional bars and colors corresponding to terciles (red for lower, green for higher).

that a significant portion of the participants' concern was linked to compliance with legislation, more specifically the National Solid Waste Policy (PNRS), and this greatly influenced the co-construction of the goals. In the group discussions, the topics of final disposal and the need to increase recycling emerged, and these concerns of the participants were reflected in the goals. Participants from the three cities discussed the feasibility of setting up a consortium between municipalities to comply with the PNRS (which set deadline of August 2014 for municipalities to cease the disposal of urban solid waste in open dumps). Similarly, they discussed the need to implement selective collection programs to ensure access to federal funding (as directed by the PNRS).

6.2. *Technical and voluntary indicators for the critical sustainability issue*

Evaluation systems of local sustainability are traditionally composed of indicators; they are organized into dimensions, topics, or thematic areas. Each one of these thematic areas includes a limited number of indicators designed to represent the main aspects of the evaluation process, in a balanced manner. This structure implied the need to choose only a few indicators representing the whole complexity of each topic. This becomes particularly problematic when addressing critical local sustainability issues. For example, a review of local sustainability assessment systems (Cetrulo, 2020) has shown that 80 % of SI sets only count on 1 to 3 indicators to represent the solid waste topic. This same review evidenced that the most used indicators are '*solid waste generation*', '*waste collection coverage*', and '*recycling rate*'. However, an analysis of the case studies reveals important limitations in these indicators. For instance, the *recycling rate* does not capture elements of social vulnerability associated with recycling activities, such as the presence of scavengers searching for recyclable materials in open dumps. We argue that

Rank	Cod.	Indicator's name	S (Nobres)
1	TI41	Waste generation	0.84
2	TI31	Problems with domestic waste disposal	0.81
3	VI23	Disposal of batteries in open dumps	0.78
4	VI27	Satisfaction with the frequency of the selective collection	0.71
5	VI5	Presence of rodents/ insects close to open dumps	0.70
6	VI9	Waste deposits in vacant lots	0.69
7	VI19	Disposal of electronic waste in open dumps	0.68
8	VI13	Burning garbage	0.67
9	VI26	Satisfaction with the frequency of the collection service	0.67
10	VI24	Disposal of batteries in vacant lots	0.66
11	VI10	Improper disposal of garbage	0.65
12	VI25	Satisfaction with the quality/cleaning of the collection service	0.62
13	VI4	Presence of vultures/birds close to open dumps	0.61
14	VI16	Disposal of construction and demolition waste in vacant lots	0.60
15	VI22	Deposits of tires in vacant lots	0.60
16	TI34	Disposal of solid waste in properly managed landfills	0.60
17	VI2	Waste deposited in the external area of open dumps	0.58
18	VI3	Waste transported by rainwater/runoff	0.58
19	VI20	Disposal of electronic waste in vacant lots	0.56
20	VI1	Bad smell from open dumps	0.55

Fig. 3. Ranking and Score (S) for the 20 best-performing indicators in the municipality of Nobres.

Rank	Cod.	Indicator's name	S (Sapezal)
1	TI37	Level of compliance of local landfills with regulations/standards	0.89
2	VI14	Disposal of infectious waste in open dumps	0.84
3	VI23	Disposal of batteries in open dumps	0.83
4	TI41	Waste generation	0.82
5	TI38	Quality of the landfill	0.81
6	VI4	Presence of vultures/birds close to open dumps	0.77
7	VI21	Disposal of tires in open dumps	0.75
8	VI22	Deposits of tires in vacant lots	0.75
9	VI5	Presence of rodents/ insects close to open dumps	0.73
10	VI24	Disposal of batteries in vacant lots	0.73
11	TI36	Priority for landfill disposal	0.73
12	VI20	Disposal of electronic waste in vacant lots	0.71
13	VI9	Waste deposits in vacant lots	0.70
14	VI3	Waste transported by rainwater/runoff	0.69
15	VI10	Improper disposal of garbage	0.68
16	VI19	Disposal of electronic waste in open dumps	0.68
17	TI49	Solid waste political and management availability	0.68
18	VI7	Presence of scavengers in open dumps	0.66
19	VI16	Disposal of construction and demolition waste in vacant lots	0.66
20	TI33	Existence of properly managed landfills	0.66

Fig. 4. Ranking and Score (S) for the 20 best-performing indicators in the municipality of Sapezal.

this overlooked element of social vulnerability is far more crucial for the sustainability of the locality than the recycling rate itself. Similarly, other context-specific conditions observed in the case studies are also absent from the most used technical indicators, despite their significant implications for environmental health and local quality of life. These include open-burning waste practices and the presence of rodents and vultures near open dumps. A further relevant observation is that among the initial list of indicators identified in the literature, only the voluntary indicators were able to capture this type of in-depth and context-specific problem.

A second important finding that strengthens this argument is the significant variation in the indicator rankings established by the three municipalities assessed in this study. This variation supports the argument that the local complexity of critical issues to sustainability cannot be assessed by a standardized set of technical indicators (see Moreno-Pires et al. (Moreno-Pires et al., 2014)). Although all municipalities are located in the same region, each presents a unique reality in terms of environmental conditions, socioeconomic context, governance, and political and cultural characteristics. Certainly, in localities with even more diverse realities, the set of selected indicators would be even more heterogeneous, as local priorities would naturally differ.

An additional advantage of voluntary indicators, as demonstrated in

Rank	Cod.	Indicator's name	S (São José do Rio Claro)
1	TI37	Level of compliance of local landfills with regulations/standards	1.00
2	VI27	Satisfaction with the frequency of the selective collection	0.79
3	TI28	Satisfaction with the quality/cleaning of the selective collection	0.75
4	TI33	Existence of properly managed landfills	0.75
5	VI8	Unauthorized waste disposal in open dumps	0.67
6	TI31	Problems with domestic waste disposal	0.65
7	VI5	Presence of rodents/ insects close to open dumps	0.64
8	TI35	Ratio of solid waste processed by landfills	0.63
9	TI44	Amount of construction and demolition waste	0.63
10	VI26	Satisfaction with the frequency of the collection service	0.61
11	VI4	Presence of vultures/birds close to open dumps	0.60
12	TI45	Amount of pruning waste	0.60
13	TI41	Waste generation	0.58
14	TI43	Amount of collected solid waste	0.58
15	TI46	Urban solid waste composition	0.58
16	VI15	Disposal of construction and demolition waste in open dumps	0.56
17	VI9	Waste deposits in vacant lots	0.55
18	TI30	Disposal per capita of solid waste	0.55
19	VI13	Burning garbage	0.54
20	VI25	Satisfaction with the quality/cleaning of the collection service	0.54

Fig. 5. Ranking and Score (S) for the 20 best-performing indicators in the municipality of São José do Rio Claro.

our results, is that their language is more accessible and easier for people to understand. Moreover, people tend to identify with these indicators because they reflect important aspects of their communities' daily lives. This is particularly important in the context of post-monitoring by the community, as such indicators are perceived as both relevant and understandable by local residents.

6.3. *Consideration of the participatory process*

The main advantages of involving key actors in the construction of indicator sets include the incorporation of locally relevant issues and an enhanced capacity for community action. These benefits are a direct reflection of people's daily immersion in local issues (McKenna and Hanrahan, 2024). Regarding the incorporation of relevant issues, this advantage is even more prominent in indicator sets specifically designed for critical issues, as they provide a more profound understanding of how specific problems impact the lives of people in these localities. In other words, the way a problem affects people varies significantly from one locality to another due to differences in territorial characteristics, the degree of social vulnerability, and socioeconomic conditions. Therefore, developing more in-depth indicators in collaboration with those directly affected is essential to effectively capture these nuances.

For example, in the case study of Nobres, two indicators were used to represent the issue of construction waste. The first indicator, 'Disposal of construction and demolition waste in open dumps' (VI15), was considered low relevance by residents. In contrast, the second indicator, 'Disposal of construction and demolition waste in vacant lots' (VI16), was viewed as moderately relevant, receiving a score of 0.6. This indicates that residents saw the accumulation of construction and demolition waste in vacant lots as a more significant issue than its disposal in open dumps, despite both indicators addressing similar concerns. The community's perception is crucial, as it can be influenced by personal feelings about the issue. For instance, in the example mentioned, when construction and demolition waste is discharged in open dumps, residents may not visually perceive the problem.

Additionally, perceptions may also be linked to a pre-assessment of the problem in the locality. In the specific example, participants may perceive that the disposal of construction waste on vacant lots is a common practice and needs to be monitored more carefully. Individual perceptions of the problem are influenced by cultural factors, professional background, and understanding of local sustainability. It's important to note that residents in areas without proper waste collection, such as slums and villages, may have different perceptions of irregular waste disposal (Doe et al., 2020).

Accordingly, it is important to highlight the need to have balanced participation among social actors to avoid homogeneity of thoughts (see Ferreira et al. (2018)). Just as introduced in the previous section, most participants in workshops, in the three municipalities, were local-government representatives, and it may have contributed to the choices made for goals in compliance with legislation. It is worth pinpointing that the prosecutors' office attended the three workshops, and it may have even put more pressure on goals' choices for adjusting municipalities to PNRS. These results point towards the need for in-depth investigations about balance in key actors' participation; moreover, they corroborate Ramos et al. (2014), who have added other important elements to be taken into consideration in stakeholders' participation process, such as conflict of interest and engagement level.

Another caveat regarding participation concerns the difficulty in accessing certain stakeholders, as pointed out by Ballesteros and Dickey-Collas (2023). The assessed cases have shown that including less favored or socially excluded classes remains a barrier to be overcome. Despite attempts to include these actors, which in these cases involved contacting waste pickers by phone and physically visiting the open dumps to speak with them (Figure A.2, Appendix), it was challenging to engage them in the process. It means that, although the process is participatory, scavengers' representativeness, based on observations, was not the same as other participants.

An important aspect to highlight is that, although both workshops were participatory, the first one employed a methodology better suited to capturing and considering the worldviews of all participants. In this first workshop, the adapted version of Ketso® contributed positively to participant engagement. Its playful approach and easy-to-understand tasks facilitated active involvement, as noted in various studies utilizing this tool (e.g., Wengel et al. (2019) and Podar et al. (Podar, 2024)). This method also promoted the inclusion of individuals with varying levels of education and from different hierarchical positions. As a result, it fostered more equitable discussions, minimized information asymmetry, and incorporated diverse perspectives.

In contrast, the second workshop faced challenges. Although the facilitators made efforts to support participants[7] in developing the proposed activities, assessing all the indicators from the initial list remained a complex task. This underscores the need to rethink strategies that ensure the voices of those directly affected are valued (Ramos et al., 2014), from the initial discussions of the problem to the final selection of indicators.

Another limitation is exemplified by the case of Nobre. The Ketso® method effectively captured a waste picker's perception of the challenges of self-employment at the landfill. This perspective was considered significant enough to justify the definition of a specific objective. However, in the second workshop, no corresponding indicator was selected to track this goal, as most participants assigned it a low score.

7. Conclusions

This study aimed to investigate the joint development of a set of indicators capable of assessing critical sustainability issues within local contexts. Our results demonstrated that participatory workshops are effective in identifying locally relevant goals and indicators for assessing such issues. Although the goals developed across the three municipalities showed convergence in several thematic areas, the selection of indicators revealed notable differences, reflecting the unique socio-environmental and governance contexts of each locality. Importantly, voluntary indicators were selected more frequently than technical ones and received higher scores, as they were perceived as more accessible and relevant by the participants.

Perhaps the most important finding of this study was the evidence that standardized indicator sets often fail to capture the concerns of local communities, even when these concerns are highly relevant to local sustainability. This reinforces the value of participatory processes, not only for tailoring indicators to specific contexts but also for revealing elements of sustainability that might otherwise be overlooked. The participatory process, while central to this approach, presented both strengths and limitations. On the one hand, it enabled the inclusion of diverse perspectives and fostered local engagement. On the other hand, it also revealed challenges in ensuring balanced stakeholder representation and highlighted the potential influence of formal actors in shaping outcomes. Overall, the results underscore the potential of participatory approaches to produce indicators that are context-sensitive, socially legitimate, and suitable for citizen monitoring.

This study has certain limitations that should be acknowledged. Although well-established participatory methods were applied, some stakeholder groups, particularly waste pickers and other socially excluded populations, were underrepresented during certain phases of the process. Additionally, participants did not propose new indicators beyond those presented by the research team, which may reflect factors such as limited technical familiarity with indicator development or the contextual dynamics of the workshop environment. These observations highlight opportunities for further methodological innovation aimed at broadening engagement. Future studies could explore strategies to strengthen the involvement of marginalized groups, particularly in the indicator evaluation and scoring phases, where their perspectives are often underrepresented. In addition, research could test the applicability of the proposed framework in diverse local and thematic contexts and investigate the long-term impacts of co-developed indicators in community monitoring initiatives.

The feasibility of implementing a traditional set of indicators, including more in-depth subsets for critical sustainability issues, is constrained by several challenges. These include the fact that, in many cases, there is not enough local capacity to monitor a large number of indicators, due to a lack of financial resources, proper equipment, and/or trained staff. In this context, community-based monitoring programs supported by citizen volunteers offer a promising strategy to address these limitations. Citizen engagement can significantly enhance data collection capacity and complement formal monitoring efforts. Building on this perspective, for subsystems focused on critical sustainability issues, the case studies highlight the importance of developing tailored sets of voluntary indicators that are both meaningful and easily understood by the local population.

In conclusion, despite the drawbacks of purpose-specific sustainability indicator sets, such as the lack of comparability, they are uniquely relevant to the priorities of local residents, especially when combined with mechanisms to address any detected negative effects. We believe that participation in the development of an indicator set for a critical sustainability issue can foster greater engagement from community members in subsequent voluntary monitoring programs. This approach can empower local stakeholders to identify overlooked or inadequately addressed elements in existing monitoring networks, enabling them to provide evidence for higher-level authorities and advocate for more effective, context-sensitive solutions.

CRediT authorship contribution statement

Natália Molina Cetrulo: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tiago Balieiro Cetrulo:** Writing – review & editing, Investigation. **Tomás Barros Ramos:** Writing – review & editing, Validation, Supervision, Methodology, Investigation. **Sylmara Lopes Francelino Gonçalves-Dias:** Writing – review & editing, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[7] Other studies (Marques et al., 2013; Droege et al., 2021; Ramos et al., 2021; Matschoss et al., 2020) that have employed the workshop approach likewise emphasize the importance of providing this type of support.

Appendix

Table A.1
Initial list of indicators used for the participatory workshops.

Cod.	Indicator's name
VI1	Bad smell from open dumps
VI2	Waste deposited in the external area of open dumps (access road)
VI3	Waste transported by rainwater/runoff
VI4	Presence of vultures/birds close to open dumps
VI5	Presence of rodents/insects close to open dumps
VI6	Presence of dogs, horses, and cattle in open dumps
VI7	Presence of scavengers in open dumps
VI8	Unauthorized waste disposal in open dumps
VI9	Waste deposits in vacant lots (urban or rural areas)
VI10	Improper disposal of garbage (outside the bin, on the street, on the sidewalk)
VI11	Use of inadequate vehicles for waste collection
VI12	Lack of protection equipment for waste collectors
VI13	Burning garbage
VI14	Disposal of infectious waste in open dumps (veterinary clinics, pharmacies, and hospital waste, among others)
VI15	Disposal of construction and demolition waste in open dumps
VI16	Disposal of construction and demolition waste in vacant lots (urban or rural areas)
VI17	Disposal of agricultural and forestry waste in open dumps
VI18	Disposal of agricultural and forestry waste in vacant lots (urban or rural areas)
VI19	Disposal of electronic waste in open dumps
VI20	Disposal of electronic waste in vacant lots (urban or rural areas)
VI21	Disposal of tires in open dumps
VI22	Deposits of tires in vacant lots (urban or rural areas)
VI23	Disposal of batteries in open dumps
VI24	Disposal of batteries in vacant lots (urban or rural areas)
VI25	Satisfaction with the quality/cleaning of the collection service
VI26	Satisfaction with the frequency of the collection service
VI27	Satisfaction with the frequency of the selective collection
VI28	Satisfaction with the quality/cleaning of the selective collection
TI29	Disposal of solid waste
TI30	Disposal per capita of solid waste
TI31	Problems with domestic waste disposal
TI32	Disposal of solid waste in improperly managed landfills
TI33	Existence of properly managed landfills (in compliance with regulations/standards)
TI34	Disposal of solid waste in properly managed landfills
TI35	Ratio of solid waste processed by landfills
TI36	Priority for landfill disposal
TI37	Level of compliance of local landfills with regulations/standards
TI38	Quality of the landfill
TI39	Waste recovery and disposal proportions
TI40	Waste reuse and disposal proportions
TI41	Waste generation
TI42	Amount of urban solid waste by type
TI43	Amount of collected solid waste (inhabitant/year)
TI44	Amount of construction and demolition waste (inhabitant/day)
TI45	Amount of pruning waste (inhabitant/day)
TI46	Urban solid waste composition
TI47	Management type
TI48	Presentation of the recycling program report
TI49	Solid waste political and management availability
TI50	Time involved in the recycling programs
TI51	Landfill area for solid waste
TI52	Existence of community recycling projects

Note: VI = Voluntary Indicators; TI = Technical Indicators.

Fig. A.1. The Use of Ketso in the Workshops

Fig. A.2. Waste Pickers at Open Dumps

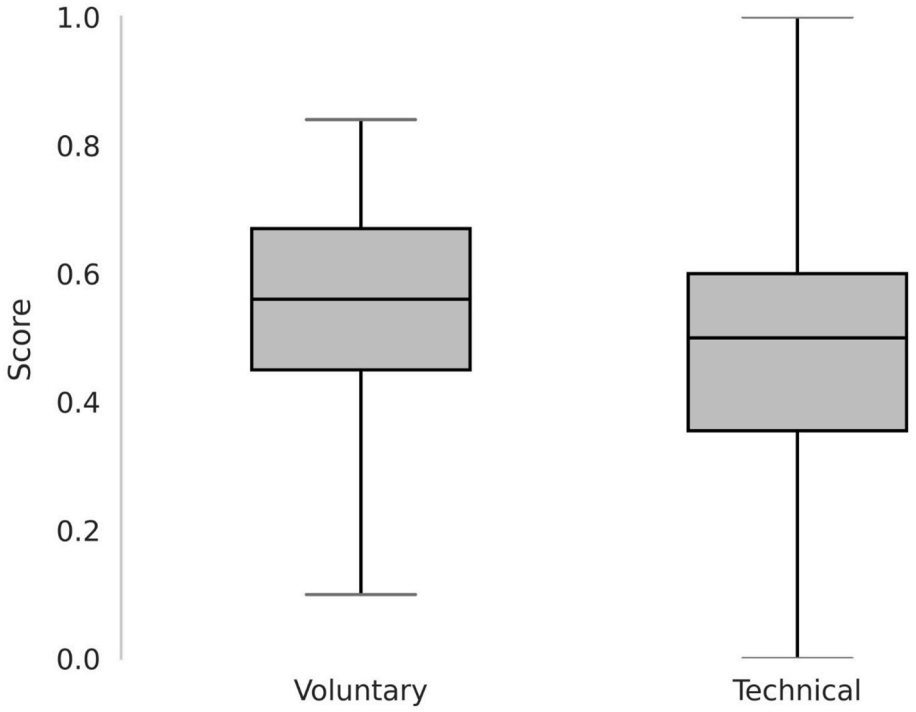

Fig. A.3. Distribution of indicators' scores by type: "Voluntary" and "Technical"

Data availability

No data was used for the research described in the article.

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