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Diagnosis of the circular economy in municipalities of Misiones, Argentina

Diagnóstico de Economía circular en municipios de Misiones, Argentina

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Abstract
This article outlines the methodology and summarizes the main results of the 2023 circular economy assessment carried out in Misiones Province, Argentina. The research was held through a collaborative agreement between the academy and the government, aiming to provide inputs for the preparation of the first provincial report on circular economy. The stratified sampling method was used to obtain selection of a representative sample of 21 localities out of 78 municipalities. In addition to surveying these municipalities, information was collected from private companies involved in household waste recycling. The analysis made it possible to estimate the circularity index, identify circular practices, quantify recycled and composted fractions, assess the available infrastructure, and recognize challenges according to municipality size. The results indicate that only 15.36% of the generated waste returns to productive or biological cycles, with higher circularity levels in more populated municipalities. The findings suggest that waste management should be reinforced and circular strategies broadened through collaborative work, policymaking, and further research.

Keywords: circular economy, management, municipalities, household waste, surveys.

Resumen
Este artículo presenta la metodología y los principales resultados sobre el diagnóstico de economía circular en la provincia de Misiones, Argentina para el período 2023. La investigación se desarrolló mediante un convenio de colaboración entre la Academia y el Estado, con el objetivo principal de generar insumos para la elaboración del primer informe provincial sobre economía circular. Se aplicó el muestreo estratificado, el cual permitió seleccionar una muestra representativa de 21 localidades a partir de la población constituida por 78 municipios. Además de encuestar a dichos municipios, se recolectó información de las empresas privadas vinculadas al reciclaje de residuos domiciliarios. El análisis permitió estimar el índice de circularidad, identificar prácticas circulares, cuantificar las fracciones recicladas y compostadas, evaluar la infraestructura disponible y reconocer desafíos según el tamaño municipal. Los resultados indican que solo el 15,36 % de los residuos generados vuelve a ciclos productivos o biológicos, con mayores niveles de circularidad en municipios más poblados. Se concluye que es necesario fortalecer la gestión de residuos y ampliar las estrategias circulares, mediante el trabajo colaborativo, políticas públicas y futuras investigaciones.

Palabras clave: economía circular; gestión; municipios; residuos domiciliarios, encuestas.

1 Introduction

Globalization and urban growth have contributed to significantly increased solid waste production, challenging the capacity of municipalities to manage them in a proper way. In this context, Circular Economy (CE) arises as a new paradigm that redefines the concept of waste, allowing it to be a resource through strategies by reusing, recycling, repairing, and reducing consumption of unspoiled resources. According to the Ellen MacArthur Foundation [1], CE is a proposal for closing productive cycles, minimizing natural resources extraction by reducing the environmental impact of waste generated along consumption stages or industrial processes.

CE has also been catalogued as a transversal strategy that promotes sustainability and innovation in waste management. Geissdoerfer et al. [2] describe it as a convergence among environmental sustainability, economic efficiency, and social responsibility.

In Latin America and the Caribbean, recent studies reveal that the CE approach continues to emphasize recycling, whereas strategies like reuse and prevention remain underused because of institutional and governmental barriers, insufficient incentives, and inadequate municipal infrastructure, among other issues [3,4,5].

In Argentina, the adoption of the circular model at the municipality level is still incipient in most

localities. Some cities have developed circular strategies based on the Comprehensive Urban Solid Waste Management Plan (from Spanish, GIRSU Plan), while others still reveal structural deficits and limited coordination among public, private, and social actors, which constrain municipalities' ability to adequately address management needs.

In Misiones Province, municipalities have a higher-level entity for the province, the Undersecretary of Circular Economy, which has been promoting these initiatives since 2022. In this context, several municipalities in the province have begun exploring initiatives related to the circular economy through the installation of "eco-points" and "clean points" (recycling stalls or stands). These are community spaces for daily use where residents can separately dispose of recyclable and bulky waste. In addition, public programs were implemented, such as "My school recycles" and organic waste composting [8].

In 2024, the School of Engineering of the National University of Misiones, in Oberá, and the Ministry of Climate Change agreed to work collaboratively on fields related to Circular Economy (CE), producing the first provincial report on CE by 2023. In contrast to the previously prepared report, which primarily presented the results, this new document offers a more in-depth examination of the research methodology, incorporating a greater rigorous and critical analysis, as well as the discussion of the findings. In this regard, the objective of this study is to present a diagnostic assessment of the Circular Economy (CE) in the municipalities of Misiones, Argentina, supported by a detailed description of the methodology, including employed procedures and tools.

2 Materials and methods

This study follows a quantitative approach, relying on data collected through structured instruments; more specifically, a questionnaire, which enables the statistical analysis of observed patterns and relationships, along with surveys administered to the relevant stakeholders. Furthermore, this is applied research [9], as it is directly aimed at collecting information through orienting strategies for a concrete issue: diagnosing and generating empirical insights for designing useful public policies for household waste, regarding the circular economy in Misiones Province.

The study was developed through three primary stages: first, a round of exploratory surveys was conducted in randomly selected municipalities in Misiones Province. During the second stage, a formal survey was elaborated, and the representative sample of municipalities was determined by stratum.

In the third stage, surveys were administered to sample municipalities, private recycling companies, and some other relevant companies that could be accessed, with the aim of gathering this information. Ultimately, data analysis and conclusion discussions were carried out. Below, a brief description of the previously mentioned stages can be found:

2.1 Stage 1: Elaboration of the exploratory survey

The first phase consisted of a round of exploratory surveys designed through a Google Forms questionnaire to identify key topics and adjust the questions for the formal survey targeted to municipality stakeholders. These preliminary surveys were conducted with a small group of participants randomly selected from different municipalities. The results of this preliminary stage helped to refine the questionnaire and ensure the relevance and clarity of the questions, in order to obtain more useful answers and reduce errors as well as uncertainty among respondents.

2.2 Stage 2: Elaboration of the formal survey and determination of the sample

To define the formal questionnaire, questions from the sample version were redesigned. The items and questions that made up the final questionnaire [10] included:

-Municipality denomination.

-Individuals in charge of the Waste Management Area.

-WhatsApp contact.

-The following questions: 1. How many tonnes of bulky and Urban Solid Waste (USW) did the municipality generate in 2023?; 2. How many tonnes of this waste collected in 2023 were sent to the AESA transfer station?; 3. How many tonnes of waste were recovered to recycle and compost in 2023?; 4. Does the municipality have a final disposal site for bulky waste (such as pruning, wood, scrap materials, among others)?; 5 Name of the municipality government area that manages USW; 6. Does the municipality have a waste sorting facility?; 7. Does it have a composting program?; 8. If the previous question was answered affirmatively, how many tonnes of compost are produced every year?; 9. Does the municipality have "eco-points"? How many "eco-points" does the municipality have?; 10. What is the total number of municipality workers dedicated to waste management?; 11. Does the municipality articulate material recovery for recycling with urban waste recuperators?; 12. Are there any urban waste recuperators in the municipality? "Urban waste recuperators" are individuals who collect, select, recover, transform, trade, and reuse solid waste, previously known as "cartoneros" (in Argentina, similar to scrap dealers) or recyclers.; 13. If the previous question was answered affirmatively, please indicate the

estimated number of urban recuperators in the municipality.; 14. Does the municipality have any of the following programs? Please, only mark the programs that the municipality HAS: recovery of Used Cooking Oil (UCO), end-of-life tires, electrical and electronic devices, none, others; 14. Does it have a global figure representing the total amount of waste recovered by private actors or parties in the municipality? That is to say, it is asked to estimate the approximate kilograms that companies or organizations recycle in the municipality every month.; 15. Does the municipality have entrepreneurs or salespeople who reuse materials? Please, comment briefly. (For instance, 5 entrepreneurs using plastic bottles for decorations, 2 entrepreneurs using glass for local fairs or markets.)

Before distributing the formal survey, a sample of municipalities was selected from the entire population in Misiones to identify those that would receive the questionnaire. In order to do this, 78 municipalities were enlisted and selected as a representative list of Misiones Province population by following the steps described below.

2.2.1 Sample selection

The sample for this study has been selected employing the stratified sampling method to ensure that all relevant subgroups (municipalities categorized by zone and population size) were adequately represented, according to Sampieri *et al.* [9]. In which, for every stratum h:

- N_h: total population (inhabitants) of the stratum
- n_h: number of sample municipalities in the stratum
- w_i: weight for population-based weighting, applied by zone (z) and by population category (c):

$$wi = w(z) * w(c) \quad (1)$$

$$w(z) = \frac{Zone\ population}{Province\ population} \quad (2)$$

$$w(c) = \frac{Category\ population}{Total\ population\ of\ the\ zone} \quad (3)$$

Stratification was carried out by zone (z) and by category according to population size (c). Based on the total population of municipalities and weighting (1) by the province zone in which each municipality is located (South, Centre, or North) and (2) by population category (Low, Medium, or High), a certain number of municipalities were selected, constituting the sample after applying the corresponding formulas.

2.2.2 Data collection procedure

Providing the formal survey in Google Forms, officials who work on waste management for the sample municipalities were contacted one by one. Employed methods to obtain answers can be found below:

- Telephonic verbal communication: calls were made to contact officials who work on waste management for the sample municipalities (or those who are in charge of waste management in the localities). On the other hand, municipality agents or staff members who preferred this type of communication for any reason were also contacted by phone.

In different cases, detailed answers in this type of communication were transcribed directly into the questionnaire.

- Mobile phone communication: WhatsApp messages were sent to distribute the questionnaire and facilitate communication with participants, taking advantage of the popularity of the platform.
- E-mail: surveys were also sent through email. These means of communication allowed participants the ability to answer an online form, providing more thoughtful answers described in the questionnaire.

2.3 Stage 3: Analysis of the obtained answers

Once the information from the municipalities was collected, an analysis was carried out in order to identify patterns and trends in the answers. Microsoft Excel v.2022 and IBM SPSS Statistics v.29.0.2.0 software were used for this purpose, as it is a useful software to analyse data and elaborate graphics since information can be downloaded from Google Form and imported directly into this software.

The application of the previously described stages ensured the selection of a representative sample and the collection of relevant data, offering a comprehensive view of the population's perspectives and circular economy practices across the municipalities of Misiones Province.

3 Results and discussion section

The municipalities of Misiones Province have been the subjects of this study.

In addition, the initial exploratory survey was only targeted at 10 municipalities randomly selected. This pilot exercise made it possible to identify key topics, areas of interest, and potential difficulties in understanding certain questions.

The school research team worked on the creation of a formal questionnaire based on the exploratory survey findings for more than one week. The development of the formal questionnaire was carried out in collaboration between the School of Engineering, in Oberá, and the Undersecretary of Circular Economy of Misiones. The final version included both open and closed questions to gather information on the municipalities' perspectives and practices regarding the circular economy, as well as activities related to "eco-points", "clean points", composting, and engagement with urban recuperators or local cooperatives.

To ensure that the municipalities selected in the sample were representative, the following steps were taken:

Step 1: Municipality separation by strata
The municipalities of Misiones Province were classified by strata according to their geographic location (South, Centre, or North) and by category (Table 1), considering the population characteristics reflected in the last National Population and Dwelling Census carried out by the National Statistics Institute (INDEC) in 2022 [11].

Table 1: Sample stratification.

Stratum by zone (h)	Nh (Number of municipalities by zone)	Sample stratification	Stratum by population category: c (number of municipalities by category)
North	24	5 municipalities	High (1)-Medium (2)-Low (2)
Centre	38	12 municipalities	High (1)-Medium (6)-Low (5)
South	15	4 municipalities	High (1)-Medium (2)-Low (2)

Source: Prepared following Sampieri *et al*. [9]

The study population consisted of 78 municipalities (N).
The sampling error (E) is calculated by combining the errors by stratum (Eh) according to (4):

$$E = Z * Etotal \quad (4)$$

With a 95% confidence level (Z = 1.96), where p = 0.5 (maximum variance)
For $n_{h=north}$=5, $n_{h=centre}$=12, $n_{h=south}$=4
Therefore, for each zone (h):

$$Eh = \sqrt{\frac{p*(1-p)}{nh}} * \sqrt{\frac{Nh-nh)}{Nh-1}} \quad (5)$$

$$Wh = \frac{Nh}{N} \quad (6)$$

$$Etotal = \sqrt{\sum_h (Wh^2 * Eh^2)} \quad (7)$$

By substituting the values and performing the corresponding calculations, the sampling error is 18.8%, which is consistent with the methodological criteria proposed by Sampieri *et al*. [9] (the error must be lower than 25%). Therefore, the sample ensures an acceptable level of representativeness.

Step 2: Selection of sample municipalities
Within each stratum (Table 1), the cities with the largest populations were selected (60,000 inhabitants or more), as well as towns with medium populations (higher than 10,000 and less than 60,000 inhabitants) and low populations (peripheral municipalities[1] with less than 10,000 inhabitants), resulting in a total of 21 (sample) municipalities selected to participate in the formal survey. Sample municipalities represented almost 80% of the provincial population. Figure 1 shows municipalities integrating this sample and their estimated population based on INDEC data [11].

[1] Peripheral municipalities are those localities that have disadvantaged conditions due to poor infrastructure, basic public services, state investment, and socioeconomic opportunities for the inhabitants [12,13].

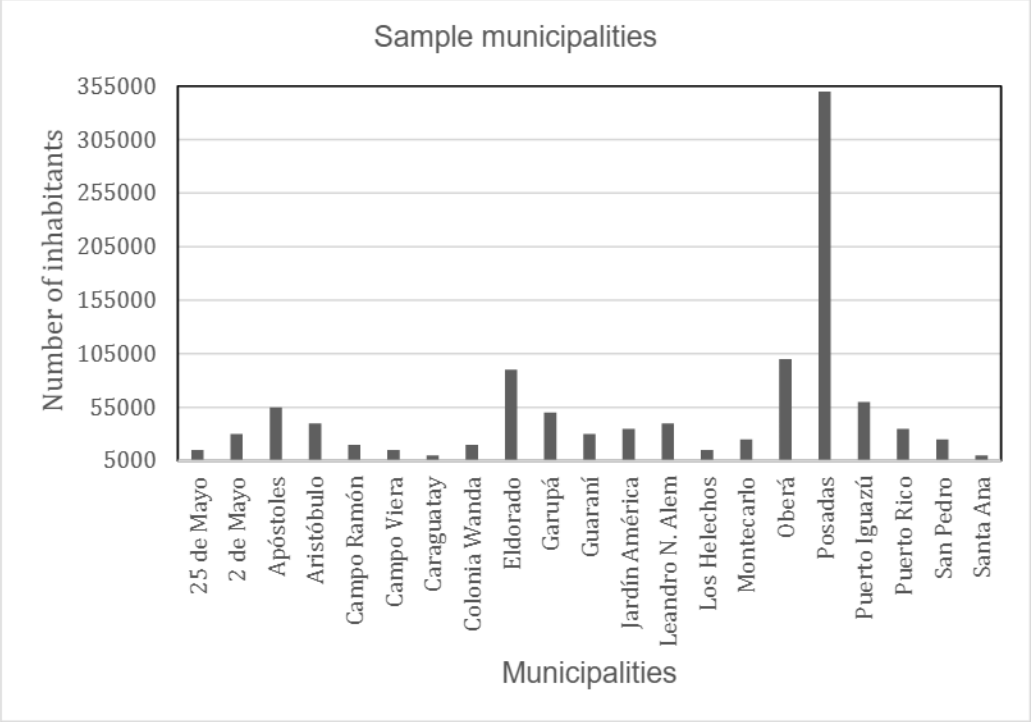

Figure 1: Sample municipalities and their respective populations by 2023. Source: Own elaboration using Microsoft Excel v.2022.

The survey process was carried out over 3 months and made it possible to capture a variety of experiences and perspectives regarding circular economy, by including both localities engaged in household waste management activities (typically larger towns) and other municipalities with isolated circular economy initiatives, as well as those lacking of plans to manage the waste they generate (generally smaller or peripheral municipalities).

Challenges during the data collection process included the lack of answers from some municipalities, and, therefore, it was necessary to send a formal request to the community authorities for them to participate. Apart from that, it was necessary to track persistently and individually several sample municipalities to obtain answers.

Step 3: Data purging and analysis

The information obtained from the questionnaire and its corresponding answers was verified one by one. In several instances, inconsistencies in units (kilograms and tonnes) were detected, and in some cases, it was necessary to contact the respondent. The section below presents the results in a graphical and tabular form, based on the information collected.

- The answers by the agents reveal that most municipalities do not have a specific area or department dedicated to waste management. Only the most populated cities (categorized as having a “high” population) have a specific department responsible for waste management. In most cases (municipalities with “low” and “medium” populations), the Secretary of Public Works is in charge of waste management.
- The disposal of household waste in the sanitary landfills of the province reached approximately 224,000 tons in 2023.

Collected data through this research (surveys for municipalities and other details about recycling from private companies) are presented in Table 2.

Table 2: Summary of collected data.

Variable	Value	Unit	Observations
Inhabitants included in the sample	942,277	inhabs.	Number of inhabitants for the included sample municipalities that answered the questionnaire
Tonnes managed by private recycling companies (2023)	7,419.32	t	Inorganic materials recovered by the sample municipalities
Tonnes managed by AESA (2023)	178,292.04	t	Amount of waste sent for final disposal based on the sample municipalities

Tonnes of organic waste for composting in the sample municipalities (2023)	793	t	Organic fraction recovered by the sample municipalities
Tonnes of pruning in the sample municipalities	13,640	t	Vegetal material managed by the sample municipalities
Recycled tonnes by the sample municipalities	1,075.6	t	Inorganic fraction managed by the sample municipalities
Managed tonnes of bulky waste (2023)	15,970	t	Furniture, appliances, and other waste managed by the sample municipalities
Total amount of waste generated by the sample municipalities	**249,378.44**	t	Including all the fractions

Source: Own elaboration.

Based on the data gathered in Table 2 and the individual responses from the municipalities, several indicators were evaluated.

Using the data on the amount of waste generated by each municipality during 2023 and their respective populations, the Per Capita Waste Generation (PCWG) index was estimated.

$$GPC\ \frac{[Kg*día]}{[persona]} = \frac{Cantidad\ total\ de\ residuos\ por\ [Kg*año]}{Cantidad\ de\ habitantes\ [persona]} * \frac{365\ [día]}{1\ [año]} \quad (8)$$

The estimates varied depending on the municipality assessed. It was determined that each person generates between 0.2 kg and 0.8 kg of waste per day.

As shown in Table 2, only a portion of the waste generated in the province is recycled or composted. This indicator is represented as the Circularity Index (CI), which is calculated as the ratio between the amount recovered through recycling and composting and the total amount generated during the same period.

$$IC = \frac{cantidad\ compostada + cantidad\ reciclada}{cantidad\ total\ generada} * 100\ \% \quad (9)$$

Of the 249,378.44 tons of waste generated in 2023 by the sample municipalities, approximately 15.36% returns to the productive or biological cycle, representing the percentage CI.

Figure 2 shows the composition of the CI, highlighting the difference between the amount of composted organics and recycled materials. Thus, those recyclables that enter the technical cycle (potentially recyclable inorganic materials such as plastics, cardboard, and metals, among others) have an indicator close to 10%, while organic waste, which is returned to the soil in the form of nutrients through the biological cycle, has a value below 6%. For this reason, the waste that attains a second life (either through recycling or by being returned to the soil) represents the combined total of both.

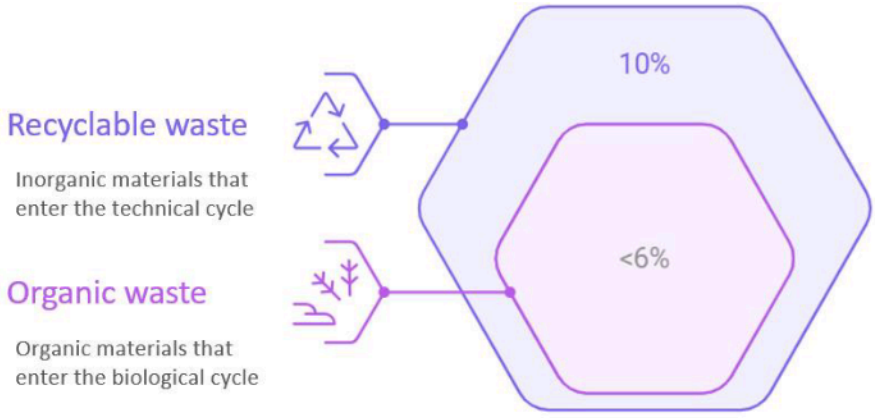

Figure 2: Circularity indexes differentiated from the sample.
Source: Own elaboration.

As it is shown in Figure 3, the analysis results and answers for the questionnaires indicated that a great number of inhabitants have access to an "eco-point" in the province (66.7%), while approximately 23% could access composting programs in 2023 (23.8%, to be specific).

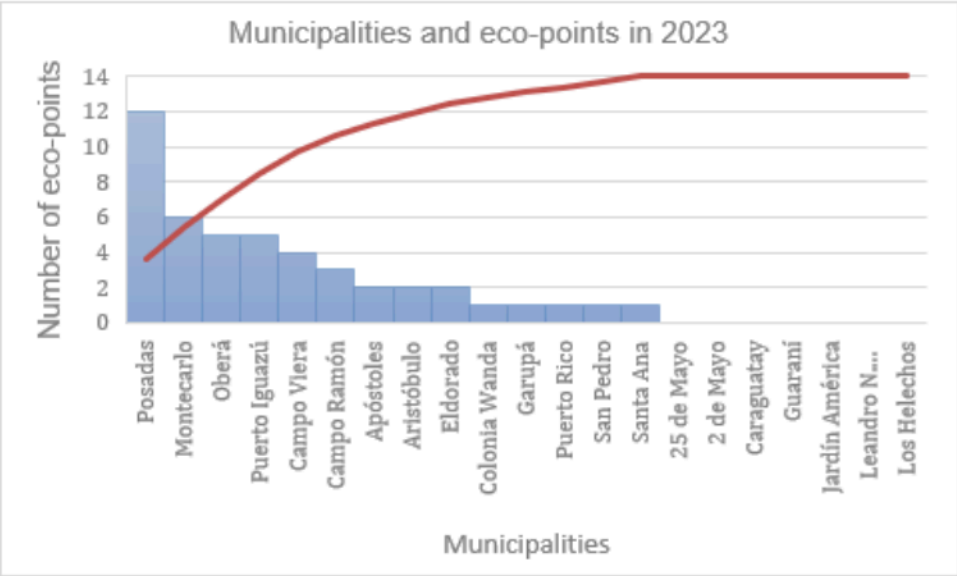

Figure 3: Eco-points in the municipalities of Misiones
Source: Own elaboration using Microsoft Excel v.2022.

Figure 3 shows that the number of "eco-points" corresponds directly to the most populated cities in the province: Oberá and Posadas.

More than 70% of the surveyed municipalities reported having urban waste recuperators who contribute to the circular flows of residual materials. Nevertheless, the answers to the questionnaire indicated that municipalities rarely coordinate their activities with companies or local cooperatives that manage waste within the area. Only the largest cities have plans that articulate some activities of the municipality with urban waste recuperators.

At the provincial level, according to data provided by recycling companies and the company responsible for landfill disposal in Misiones Province, over ten thousand tonnes of recyclable materials were circulated in 2023. This figure represents 4% of the waste disposed of in the province's landfills during this same year.

Undoubtedly, the activities carried out by each municipality on a "micro" scale contribute to the "macro" circularity rate if individuals and companies are taken into account, thus reducing the portion corresponding to sustainable behaviour. Evidently, circular initiatives can be achieved through small contributions from each actor or party, as the popular saying goes: "unity is strength" or "little streams make big rivers" (adapted from Calvo [14,15]).

According to studies conducted by the research team and by Sambiassi *et al.* [16], the largest amount of waste found in households in the largest cities of Misiones is compostable (around 50%).

It is important to note that in most municipalities, one of the most significant expenses is related to waste management, according to the "Manual for Calculating the Cost of Comprehensive Urban Solid Waste Management and the Use of the GIRSU Online Cost Matrix" [17]. Having said this, it is evident that waste management is a multi-criteria problem, where the best option is a plan tailored to the region and which is likely to be the result of environmental, economic, social, and technical dimensions.

Similar studies have been conducted using non-probabilistic samples, also known as purposive samples, in which the researcher deliberately selects the participants of the study (Sampieri, 2014) [9]. Among these studies, Camuci and Andrade Gonçalves (2020) [18] stand out, who investigated 25 municipalities, as well as Fratta *et al*. (2019) [19], who conducted a diagnosis of urban solid waste management in the municipalities of the ABC Paulista, Brazil, through the application of sustainability indicators.

Purposive studies aim to propose adaptations for those specific municipalities, while stratified evaluations can reach and diagnose larger regions. It is worth noting that the diagnosed region (Misiones Province) has two municipalities that implement differentiated collection and other practices. Nonetheless, in most municipalities, CE practices are still in their initial stages.

In this context, studies such as those carried out by Sá *et al*. (2022) [20] have evaluated the sustainability of selective collection programs in multiple Brazilian cities, using indicators across political, economic, social, and environmental dimensions. These methodological approaches make it possible to identify areas for improvement and guide public policies toward more efficient and sustainable urban solid waste management. Hence, it is relevant to note that, once the diagnosis is completed, it is possible to define the actions to be taken. For this purpose, several studies have employed multi-criteria analysis

techniques [21, 22, 23, 24, 25], which allow strategies to be prioritized while simultaneously considering environmental, economic, social, and technical criteria.

4 Conclusions

Thanks to this study, it was possible to determine the Circularity Index and to prepare the Circular Economy Report for Misiones for 2023.

The applied methodology made it possible to obtain quantitative information to understand the figures and practices of municipalities in Misiones, regarding the circular economy. A combined initial round of exploratory surveys with a formal survey targeted to a sample of representative municipalities facilitated the collection of variables and difficulties they face in managing their generated waste. In several instances, it has been necessary to contrast and validate part of the information through additional surveys for the respondents, ensuring the accuracy of the collected data in formal questionnaires.

Based on the information provided by municipalities, recycling companies, and the estimated tonnes of waste disposed of in sanitary landfills during the assessed period (2023), it has been possible to calculate the circularity index for the province. Results reflected clear patterns and trends of the differences regarding management for the largest and the smallest populations. It should be noted that those municipalities with a higher level of security circularity are generally the most populated. In spite of this, differentiated levels of commitment and adoption of circular strategies have also been identified among the different localities.

A common challenge these municipalities face is the absence of a local department responsible for waste management, particularly in smaller municipalities and those that still lack “eco-points” and “clean points”.

These findings not only enrich academic knowledge on the status of circular economy, but also provide key insights for designing public policies and formulating effective strategies for waste management in the municipalities of Misiones.

Recommendations

It is suggested to use simple questions in the questionnaire targeted to municipality officials for this type of study. In addition, it is suggested to standardize measurement criteria in the questions, such as expressing quantities only in tonnes or kilograms. It is also important to include clarifications in the questions (for example: 1 tonne = 1,000 kg) and to provide definitions of terms such as bulky waste, household waste, solid waste, organic waste, and inorganic waste. These aspects decrease the possibility of errors and clarify potentially doubts for the respondents.

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