USING SUSTAINABILITY INDICATORS AS TOOL TO ASSESS SELECTIVE COLLECTION EFFECTIVENESS AFTER IMPLEMENTING THE NATIONAL SOLID WASTE POLICY: STUDY ABOUT ALTO TIETÊ REGION, SP

USO DE INDICADORES DE SUSTENTABILIDADE COMO FERRAMENTA PARA AVALIAR A EFETIVIDADE DA COLETA SELETIVA APÓS A IMPLEMENTAÇÃO DA POLÍTICA NACIONAL DE RESÍDUOS SÓLIDOS: ESTUDO SOBRE A REGIÃO DO ALTO TIETÊ, SP

USO DE INDICADORES DE SOSTENIBILIDAD COMO HERRAMIENTA PARA EVALUAR LA EFECTIVIDAD DE LA RECOLECCIÓN SELECTIVA TRAS LA IMPLEMENTACIÓN DE LA POLÍTICA NACIONAL DE RESIDUOS SÓLIDOS: ESTUDIO SOBRE LA REGIÓN DEL ALTO TIETÊ, SP

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ABSTRACT
This study assessed selective collection performance in the municipalities of the Alto Tietê Region after implementation of the Brazilian National Solid Waste Policy (PNRS) and discussed its implications for regional management. Two indicators from the National Sanitation Information System (SNIS) were analyzed from 2010 to 2021: door-to-door selective collection coverage in relation to the urban population (IN030) and recovered mass per capita (IN032). The temporal analysis was complemented by a socio-spatial comparison using 2021 municipal population and the 2010 Municipal Human Development Index (IDHM). Results revealed marked differences among municipalities within the same region: four reached 100% door-to-door coverage in 2021, whereas others showed low coverage or discontinuous time series. Recovered mass per capita was also heterogeneous, indicating that territorial coverage and the amount effectively recovered represent distinct dimensions of service performance. The descriptive comparison suggests that population scale and socioeconomic conditions alone are insufficient to explain municipal differences and should be interpreted together with institutional continuity, service design, infrastructure, the role of cooperatives, and monitoring capacity. The integrated use of indicators can help identify gaps, guide corrective actions, and support regional planning for selective collection.
KEYWORDS: Sustainability indicators; Regional management; Alto Tiete region; Solid waste; Selective collection.

RESUMO
Este estudo avaliou o desempenho da coleta seletiva nos municípios da região do Alto Tietê após a implementação da Política Nacional de Resíduos Sólidos (PNRS) e discutiu suas implicações para a gestão regional. Foram analisados dois indicadores do Sistema Nacional de Informações sobre Saneamento (SNIS) entre 2010 e 2021: a taxa de cobertura da coleta seletiva porta a porta em relação à população urbana (IN030) e a massa recuperada per capita (IN032). A análise temporal foi

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complementada por uma leitura socioespacial com população municipal de 2021 e Índice de Desenvolvimento Humano Municipal (IDHM) de 2010. Os resultados mostraram diferenças expressivas entre municípios pertencentes à mesma região: quatro alcançaram 100% de cobertura porta a porta em 2021, enquanto outros apresentaram cobertura reduzida ou séries descontínuas. A massa recuperada per capita também apresentou comportamento heterogêneo, indicando que cobertura territorial e quantidade efetivamente recuperada representam dimensões distintas do serviço. A comparação descritiva sugere que diferenças de escala populacional e condições socioeconômicas, isoladamente, não são suficientes para explicar o desempenho municipal, devendo ser consideradas em conjunto com continuidade institucional, desenho do serviço, infraestrutura, atuação de cooperativas e capacidade de monitoramento. O uso integrado de indicadores contribui para identificar lacunas, orientar ações corretivas e apoiar o planejamento regional da coleta seletiva.
PALAVRAS-CHAVE: *Indicadores de sustentabilidade; Gestão regional; Região do Alto Tietê; Resíduos sólidos; Coleta seletiva.*

RESUMEN
Este estudio evaluó el desempeño de la recolección selectiva en los municipios de la región del Alto Tietê después de la implementación de la Política Nacional de Residuos Sólidos (PNRS) y discutió sus implicaciones para la gestión regional. Se analizaron dos indicadores del Sistema Nacional de Información sobre Saneamiento (SNIS) entre 2010 y 2021: la tasa de cobertura de la recolección selectiva puerta a puerta en relación con la población urbana (IN030) y la masa recuperada per cápita (IN032). El análisis temporal se complementó con una comparación socioespacial basada en la población municipal de 2021 y el Índice de Desarrollo Humano Municipal (IDHM) de 2010. Los resultados mostraron diferencias expresivas entre municipios de una misma región: cuatro alcanzaron una cobertura puerta a puerta del 100% en 2021, mientras otros presentaron baja cobertura o series discontinuas. La masa recuperada per cápita también presentó un comportamiento heterogéneo, lo que indica que la cobertura territorial y la cantidad efectivamente recuperada representan dimensiones distintas del desempeño del servicio. La comparación descriptiva sugiere que la escala poblacional y las condiciones socioeconómicas, por sí solas, no son suficientes para explicar las diferencias municipales y deben interpretarse junto con la continuidad institucional, el diseño del servicio, la infraestructura, la actuación de cooperativas y la capacidad de monitoreo. El uso integrado de indicadores puede contribuir a identificar brechas, orientar acciones correctivas y apoyar la planificación regional de la recolección selectiva.
PALABRAS-CLAVE*: Indicadores de sostenibilidad; Gestión regional; Región del Alto Tietê; Residuos sólidos; Recolección selectiva.*

1- INTRODUCTION

Brazil has historically faced persistent challenges in municipal solid waste management. In response, the Política Nacional de Resíduos Sólidos (PNRS) [National Solid Waste Policy], established by Law No. 12,305/2010, created a national framework for addressing waste management and assigned selective collection a central role in municipal policy. Selective collection is an important strategy for reducing improper disposal and increasing the recovery of recyclable materials (Nogueira, 2014).

Under the PNRS, municipalities are required to incorporate selective collection into their Planos de Gestão Integrada de Resíduos Sólidos (PGIRS) [Integrated Solid Waste Management Plans]. The policy defines selective collection as the collection of previously segregated solid waste according to its constitution or composition (Brasil, 2010). Separating recyclable materials such as plastics, glass, paper and metals in households, businesses, schools, commercial establishments, companies and health

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facilities facilitates collection and subsequent routing to sorting and recycling systems (Ribeiro and Besen, 2007).

Implementing selective collection in metropolitan regions can generate environmental and social benefits by reducing improper disposal, relieving pressure on final-disposal facilities, supporting recycling cooperatives and strengthening public participation. Responsibility for waste management is shared among public authorities, businesses and the community, and the technical and economic feasibility of collection systems depends on local conditions and investment capacity (Feitosa et al., 2018). Population size, income and the organization of the recycling market can also affect municipal performance, making comparison with other territories useful for identifying practices that may be adapted to local conditions (Expósito and Velasco, 2018). Evidence from other waste streams likewise emphasizes the importance of material recovery. In the Brazilian construction sector, Freitas and Dalmas (2022) highlighted recycling as a strategy for reducing environmental impacts associated with improper disposal. Although construction and demolition waste is not directly comparable to household recyclables, the study reinforces the broader role of recovery within integrated waste-management policies.

Waste management in metropolitan areas is also shaped by the degree of coordination among public authorities and other stakeholders. Ianoş et al. (2012) identify weak horizontal cooperation as an important challenge to metropolitan waste management. Improving selective collection therefore involves more than formal compliance with legal requirements; it also requires governance arrangements capable of supporting service continuity, environmental quality and sustainable development. Waste management is directly or indirectly related to several Sustainable Development Goals of the 2030 Agenda (Boojh, 2022), and sustainability indicators can support the evaluation of municipal actions, the definition of targets and the monitoring of service performance (Pires, Singh and Valadão Junior, 2019).

Sistema Nacional de Informações sobre a Gestão dos Resíduos Sólidos (SINIR) [National Information System on Solid Waste Management] and Sistema Nacional de Informações de Saneamento (SNIS) [National Sanitation Information System] are official means to provide indicators and data on solid waste management and sanitation in Brazil, respectively, as established by the PNRS. SNIS currently includes ten specific indicators for selective collection (Sá, 2021). The integrated assessment of some of these indicators provides information on the effectiveness of municipalities' management of selective solid waste collection, and it enables public administrators to both review and improve sustainability performance-related actions, planning, monitoring and assessment. Thus, using sustainability indicators linked to selective collection services implemented in municipalities can significantly help improve urban waste management in metropolitan regions.

Alto Tietê metropolitan region, which is located in São Paulo State, Brazil, is the study area. It hosts areas aimed at protecting the spring of Tietê River, which crosses almost the entire East–west extent of São Paulo State and provides important services to several municipalities across the state. In addition, this region hosts preservation areas in the Atlantic Forest, which is an important biodiversity hotspot. Approximately 64% of its territory is located in environmental protection and spring areas, and

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its cities form part of São Paulo capital's Green Belt Biosphere Reserve. Thus, Alto Tietê plays a key role in providing essential ecosystem, economic and social services, such as water supply for millions of people, to enable the sustainability of São Paulo metropolitan region (Candido et al., 2010; Pagani, 2012). This factor highlights the importance of investigating the effectiveness of selective collection services developed by municipalities belonging to this region.

Accordingly, this study aimed to assess the performance of selective collection services in municipalities of the Alto Tietê Region, São Paulo State, Brazil, after implementation of the PNRS, using sustainability indicators to examine temporal differences and to discuss how socio-spatial and institutional characteristics may help contextualize the observed municipal patterns.

2- METODOLOGY

The study was conducted in Alto Tietê Region, São Paulo State, Brazil. This region comprises 11 municipalities (Arujá, Biritiba Mirim, Ferraz de Vasconcelos, Guararema, Guarulhos, Itaquaquecetuba, Mogi das Cruzes, Poá, Salesópolis, Santa Isabel and Suzano) (Figure 1) and is home to approximately three million people. It stands out for its diversified economy and significant natural resource reserves. As part of Região Metropolitana de São Paulo (RMSP) [São Paulo Metropolitan Region], which is the country's largest wealth hub, Alto Tietê Region emerged as one of the most important areas in the state. Part of the Atlantic Forest vegetation is preserved to help protecting the springs, since this biome is one of the main hotspots for biodiversity conservation. The municipality of Guarulhos exemplifies this environmental importance, since it has nine nature conservation units that, collectively, account for 42.4% of the municipality's territory (Freitas, Paranhos Filho and Dalmas, 2023; Fonseca, Andrade and Oliveira, 2014). Mogi das Cruzes also stands out for its water potential, since it holds springs from two important hydrographic units in São Paulo State: Alto Tietê and Paraíba do Sul (Gouveia and Gouveia, 2014).

It is worth noting that the region is named after the Tietê River, due to the location of the municipalities along its course (Alto Tietê, 2024). It is therefore crucial to proper solid waste management in this region in order to preserve the region’s environmental quality and its natural resources and, consequently, the ecosystem services they provide.

Secondary data on selective collection in the Alto Tietê Region were obtained from Table IN03 of the Diagnóstico Temático sobre o Manejo de Resíduos Sólidos Urbanos [Thematic Diagnosis on Urban Solid Waste Management], published through the National Sanitation Information System (SNIS). The analysis covered 2010-2021 and used the annual municipal series to examine changes after implementation of the PNRS. Two indicators directly related to selective collection were selected and analyzed graphically over time.

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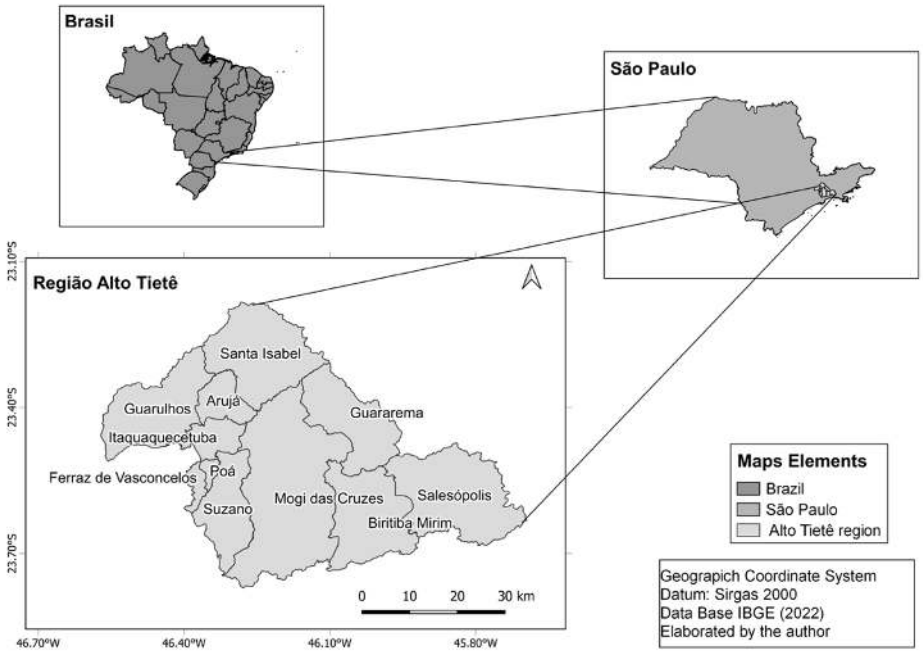

Figure 1 - Location of the municipalities within the Alto Tietê Region. Source: Prepared by the authors (2025).

The first indicator, “door-to-door selective collection coverage rate in relation to the urban population” (IN030), expresses the share of the urban population served by door-to-door selective collection (%). The second, “recovered mass per capita” (IN032), expresses the amount of recyclable material recovered through selective collection in kg/inhabitant/year. The indicators capture distinct dimensions of the service: IN030 describes territorial and population coverage, whereas IN032 describes the quantity effectively recovered relative to population. Neither indicator, when analyzed in isolation, identifies the behavioral, institutional or infrastructural causes of municipal performance. They were selected because they are used in assessments of selective collection systems and can support strategic decision-making (Ferreira et al., 2017; Zon, 2020).

To complement the temporal analysis, a comparative socio-spatial assessment was conducted using 2021 municipal population estimates and the Municipal Human Development Index (IDHM, 2010). These variables were treated as contextual attributes rather than causal determinants. For Figure 4, municipalities with IN030 data for 2021 were grouped into three descriptive coverage classes by dividing the theoretical 0-100% scale into three equal-width intervals: lower coverage (0-33.3%), intermediate coverage (>33.3-66.6%) and higher coverage (>66.6-100%). Municipalities without comparable 2021 data were identified separately. The classes are analytical devices for visualization and do not represent regulatory standards or normative performance thresholds. Population data were obtained from IBGE estimates for 2021, whereas IDHM values refer to the 2010 Human Development Atlas (IBGE, 2021; UNDP, 2013). The socio-spatial variables were used descriptively to contextualize differences among municipalities; no inferential statistical test was applied to establish associations or causal relationships.

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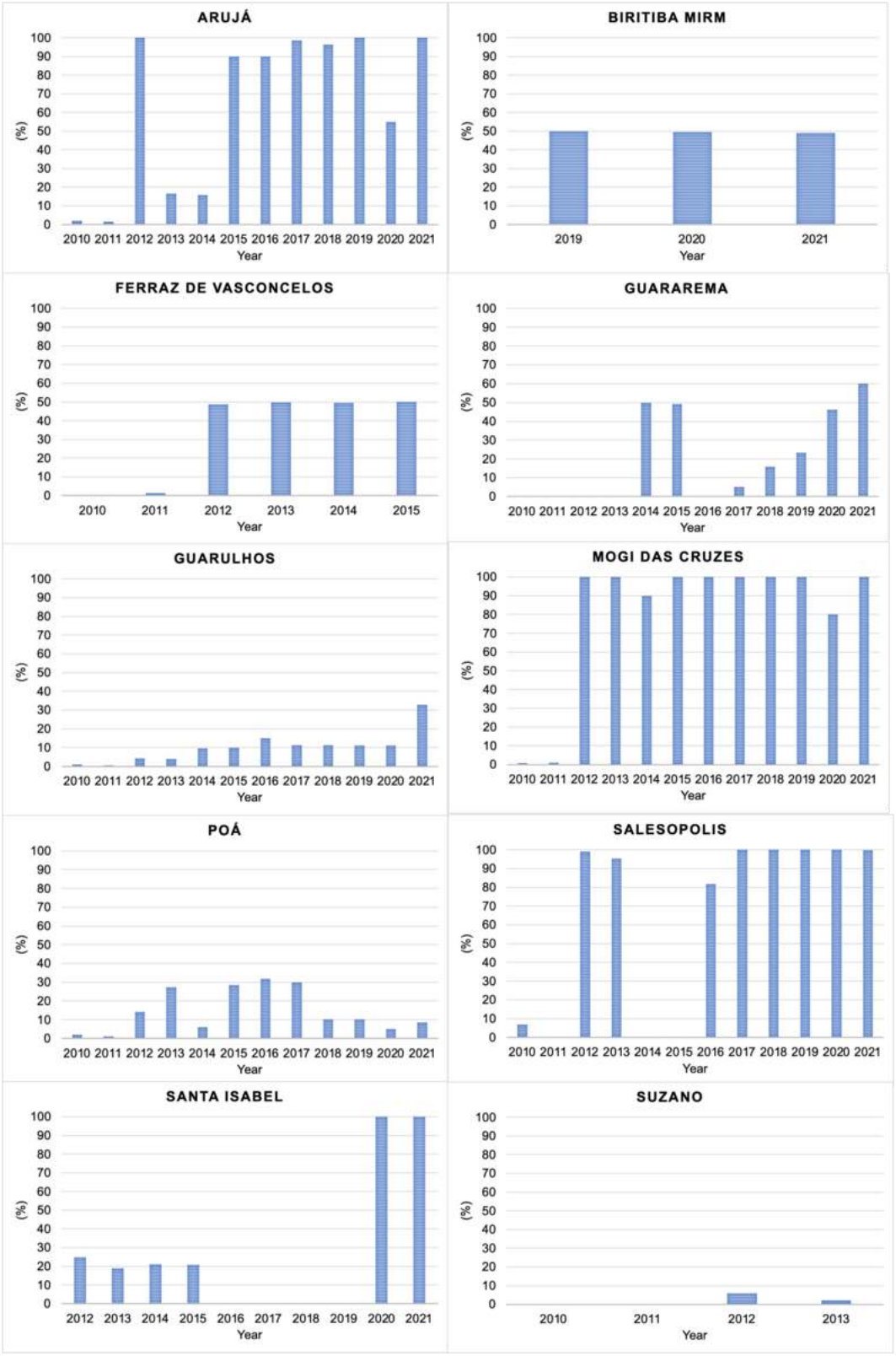

Figure 2 - Door-to-door selective collection coverage rate (%) in the municipalities of the Alto Tietê Region from 2010 to 2021. Source: Prepared by the authors based on data published by SNIS (2010–2021).

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Figures 2 and 3 present the annual series used in the temporal analysis.

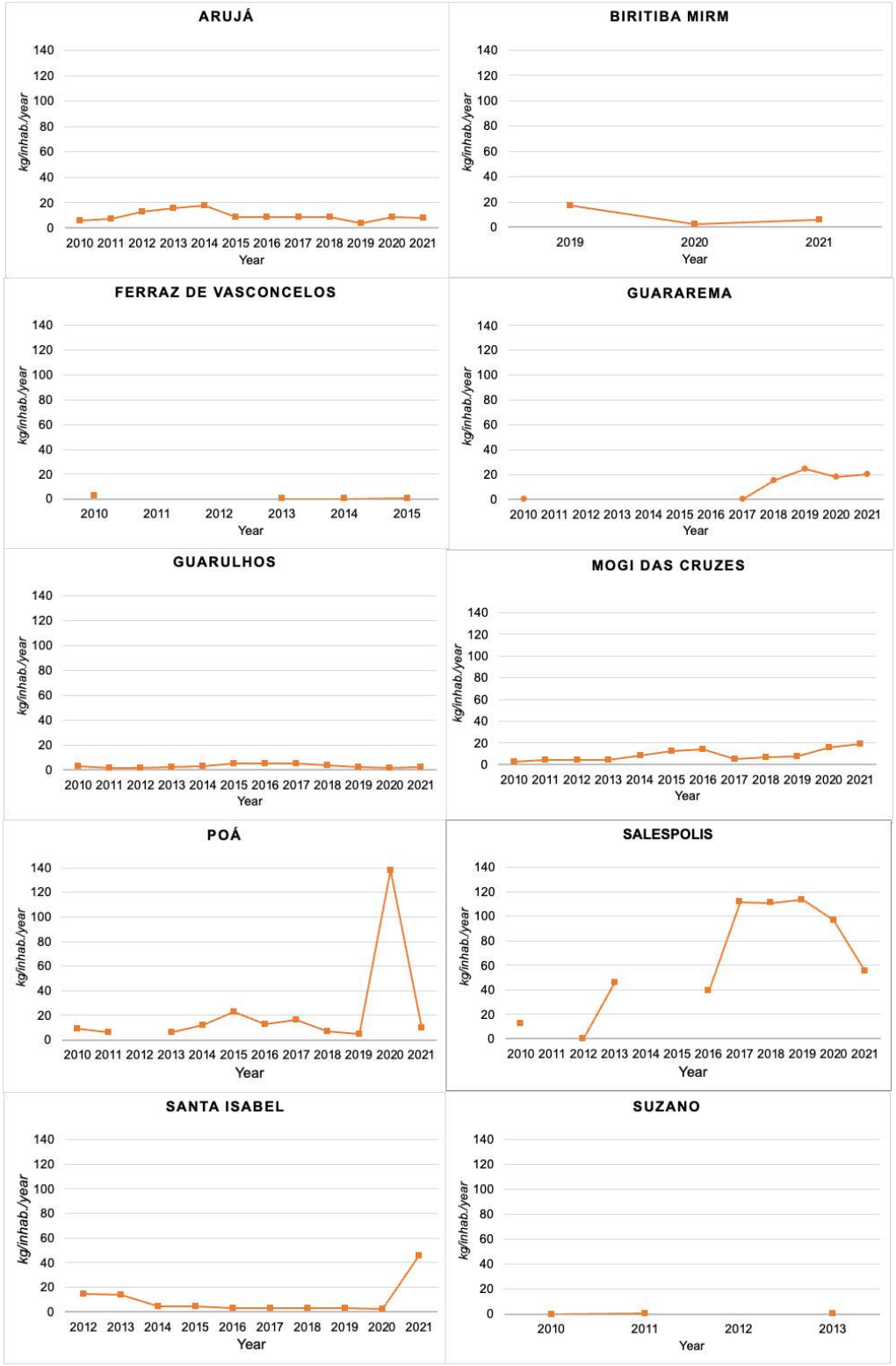

Figure 3 - Recovered mass per capita (kg/inhab./year) in the municipalities of the Alto Tietê Region between 2010 and 2021. Source: Prepared by the authors based on data published by SNIS (2010 to 2021).

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Figure 4 summarizes the 2021 coverage classes, and Table 1 relates the selective collection indicators to population and IDHM. The socio-spatial comparison is discussed in the Results and Discussion section.

3- RESULTS AND DISCUSSION

Itaquaquecetuba was the only municipality in the Alto Tietê Region that did not report data for the two indicators analyzed. It is therefore absent from Figure 2, which presents door-to-door selective collection coverage, and Figure 3, which presents recovered mass per capita. Diário de Suzano (2021) reported that the municipality did not provide selective collection at that time, although projects for implementing the service were under discussion. Data completeness also varied across the remaining municipalities. Only Arujá, Guarulhos and Mogi das Cruzes reported both indicators throughout the entire 2010-2021 period. The other municipalities presented gaps or discontinued series. Such discontinuities constrain longitudinal comparison and may reflect changes in service provision, data-reporting routines or municipal administration; the available data alone do not allow a single cause to be established.

Arujá showed a marked increase in door-to-door selective collection coverage over the analyzed period, reaching 100% in 2021. Coverage fell from 100% in 2019 to 55% in 2020 before returning to 100% in 2021 (Figure 2). The 2020 reduction coincided with restrictions imposed during the COVID-19 pandemic, when the Cooperativa de Reciclagem de Arujá (CORA) [Arujá Recycling Cooperative] temporarily suspended activities.

According to the Municipal Department of the Environment, CORA temporarily suspended its operations because of the risk of COVID-19 transmission among workers (Arujá Repórter, 2020). Arujá's recovered mass per capita increased between 2010 and 2014 and then declined, reaching its lowest value in 2019 (Figure 3). Biritiba Mirim reported data only for 2019-2021. Its door-to-door coverage remained close to 50%, with a slight decline during the period (Figure 2), while recovered mass per capita also decreased and reached approximately 2.46 kg/inhabitant/year in 2020 (Figure 3). The Biritiba Mirim municipal website reported the temporary suspension of activities at Cooperativa de Reciclagem de Biritiba Mirim (COOPERALTO) during the pandemic (Biritiba Mirim, 2020). This interruption provides relevant context for the 2020 variation, although the available series does not allow its effect on the indicators to be isolated.

Ferraz de Vasconcelos reported door-to-door coverage data from 2011 to 2015. Coverage increased from 1.23% in 2011 to values close to 50% between 2012 and 2015 (Figure 2). Recovered mass per capita was available for 2010 and 2013-2015 and remained low relative to most other municipalities (Figure 3). Guararema presented a discontinuous series, with no data for 2012, 2013 and 2015. Its door-to-door coverage increased from 0.11% in 2010 to 59.88% in 2021, despite a decline in 2020 (Figure 2). Recovered mass per capita rose from 0.3 kg/inhabitant/year in 2010 to 20.4 kg/inhabitant/year in 2021, with a peak of 24.46 kg/inhabitant/year in 2019 (Figure 3).

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The municipality of Guarulhos reported data for all analyzed years and remained among the municipalities with the lowest values for the two indicators. Door-to-door coverage increased from 0.98% in 2010 to 32.73% in 2021 (Figure 2), while recovered mass per capita decreased from 3.1 to 2.1 kg/inhabitant/year over the same period (Figure 3). Municipal communication from 2021 documented the expansion of weekly door-to-door selective collection, initially serving 18 neighborhoods and with gradual extension planned for the rest of the city (Guarulhos, 2021). The contrast between the expansion strategy and the 2021 SNIS coverage indicator illustrates the importance of distinguishing planned or geographically available service from the proportion of the urban population effectively recorded as covered by the indicator. This issue is particularly relevant in Guarulhos because of its large population and the corresponding operational scale of waste generation and collection. Research focused on the municipality provides additional context: Freitas et al. (2024) identified increasing municipal solid waste generation and a marked imbalance between ecological footprint and local biocapacity, reinforcing the need to interpret selective collection within the broader environmental pressures associated with a large metropolitan municipality.

Mogi das Cruzes was one of the three municipalities with data for the entire analyzed period. Door-to-door coverage reached 100% in 2012 and remained at or near that level in most subsequent years, except for 2014 (90%) and 2020 (80%) (Figure 2). Recovered mass per capita was comparatively high but showed a marked decline in 2016 before increasing again in later years (Figure 3). Poá, in contrast, showed substantial variation in coverage, reaching 31.9% in 2016 and only 8.52% in 2021 (Figure 2). Its recovered mass per capita displayed an exceptional peak in 2020, despite low door-to-door coverage in the same period (Figure 3).

Salesópolis did not report data for 2011, 2014 and 2015, but door-to-door coverage reached 100% in 2021 (Figure 2). Recovered mass per capita exceeded 100 kg/inhabitant/year between 2017 and 2019, declined thereafter, and reached 55.18 kg/inhabitant/year in 2021 (Figure 3). Santa Isabel reported door-to-door coverage for 2012-2015 and again for 2020-2021; coverage reached 100% in the final two reported years (Figure 2). Its recovered mass per capita series was available for 2012-2021 and increased sharply in 2021 (Figure 3). Suzano reported door-to-door coverage only for 2010-2013, with a maximum of 5.9% in 2012 (Figure 2). Its recovered mass per capita values were also low in the available years, and no value was reported for 2012 (Figure 3).

To synthesize the most recent comparable situation without assigning normative judgments, municipalities with 2021 IN030 data were grouped into three descriptive classes based on equal-width intervals of the 0-100% coverage scale. As shown in Figure 4, Arujá, Mogi das Cruzes, Salesópolis and Santa Isabel were classified as having higher coverage (>66.6-100%); Biritiba Mirim and Guararema as having intermediate coverage (>33.3-66.6%); and Guarulhos and Poá as having lower coverage (0-33.3%). Ferraz de Vasconcelos, Itaquaquecetuba and Suzano were identified separately because comparable 2021 data were not available. This classification is intended solely as a descriptive visualization and does not replace the temporal analysis in Figure 2.

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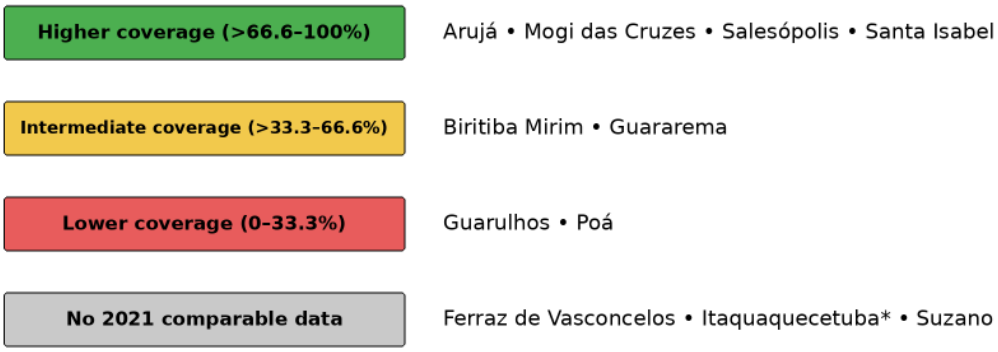

Figure 4 - Descriptive classification of door-to-door selective collection coverage in the municipalities of the Alto Tietê Region in 2021. Source: Prepared by the authors based on SNIS data (2021).[5]

Table 1 - Socio-spatial context and selective collection performance in the municipalities of the Alto Tietê Region

Municipality	Population (2021)	IDHM (2010)	Door-to-door coverage	2021 coverage class
Arujá	92,453	0.784	100% (2021)	Higher
Biritiba Mirim	33,265	0.712	49% (2021)	Intermediate
Ferraz de Vasconcelos	198,661	0.738	50% (2015, latest reported)	No 2021 data
Guararema	30,465	0.731	59.88% (2021)	Intermediate
Guarulhos	1,404,694	0.763	32.73% (2021)	Lower
Itaquaquecetuba	379,082	0.714	No indicator data	No 2021 data
Mogi das Cruzes	455,587	0.783	100% (2021)	Higher
Poá	119,221	0.771	8.52% (2021)	Lower
Salesópolis	17,363	0.732	100% (2021)	Higher
Santa Isabel	58,529	0.738	100% (2021)	Higher
Suzano	303,397	0.765	5.9% (2012, best reported)	No 2021 data

Source: Selective collection indicators obtained from SNIS (2010–2021) and analyzed in this study; population data from IBGE (2021); and IDHM data from the Human Development Atlas (UNDP, 2013).[6].

Several municipalities showed changes in selective collection indicators in 2020 (Figures 2 and 3). The temporal coincidence with the COVID-19 pandemic suggests that restrictions and operational disruptions may have contributed to part of this variation, although the municipal time series alone cannot isolate the magnitude of that effect. Municipal records document temporary suspension of activities in some locations, and CETESB recommended interruption of manual selective collection and sorting activities because of the risk of SARS-CoV-2 transmission among waste pickers (CETESB, 2020). National analyses also reported reductions in recyclable material collection during the pandemic (Silva, Martins and Ferreira, 2021).

The PNRS established selective collection as a responsibility of municipal solid-waste management and required municipal planning to include targets and arrangements for waste reduction, reuse, selective collection and recycling (Brasil, 2010). The August 2014 deadline originally associated

[5] The 0-100% coverage scale was divided into three equal-width intervals for descriptive visualization; the classes are not regulatory standards. * Itaquaquecetuba did not report the analyzed indicators for the study period
[6] IDHM refers to 2010 and is used as a structural contextual variable. “No 2021 data” indicates that a comparable IN030 value was not available for 2021.

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with Article 54 of Law No. 12,305/2010 referred to environmentally adequate final disposal of rejects, not to universal implementation of door-to-door selective collection. Therefore, the municipal time series analyzed here should be interpreted as evidence of the gradual and uneven implementation of selective collection after enactment of the PNRS, rather than as compliance with a single 2014 deadline. Salesópolis reported selective collection from 2010 onward, while Guararema and Santa Isabel began reporting coverage before 2014 and Biritiba Mirim only from 2019. Ferraz de Vasconcelos and Suzano had discontinued series, and Itaquaquecetuba did not report the two indicators analyzed.

ABRELPE data provide a national reference for the expansion of selective collection initiatives, but they should not be interpreted as population coverage rates. In 2010, 3,205 Brazilian municipalities (57.6% of the total) reported some selective collection initiative (ABRELPE, 2010). In 2021, this number increased to 4,183 municipalities (75.1%) (ABRELPE, 2022). ABRELPE also notes that such initiatives may be partial and may consist of voluntary drop-off points, agreements with waste-picker cooperatives or services that do not cover the entire municipal population. This distinction is important for comparison with IN030, which measures the share of the urban population served by door-to-door selective collection. In the Alto Tietê sample, eight municipalities had comparable IN030 data for 2021: four reported 100% coverage, two were in the intermediate class and two were in the lower-coverage class shown in Figure 4.

Taken together, the results indicate uneven progress in selective collection across the Alto Tietê Region. Reaching high door-to-door coverage does not necessarily imply a similarly high recovered mass per capita, and low coverage does not preclude occasional peaks in recovered mass. The two indicators should therefore be interpreted jointly rather than used as interchangeable measures of municipal performance.

The amount of recyclable material recovered per capita remained low or irregular in several municipalities. Guarulhos, for example, recorded 4.97 kg/inhabitant/year in 2015, whereas João Pessoa, Paraíba State, recorded 25.37 kg/inhabitant/year in the same year (Albuquerque et al., 2018). This comparison does not establish that population size causes lower recovery; rather, it illustrates how municipalities operating at different urban scales can produce substantially different per-capita outcomes and highlights the need to consider collection design, participation, sorting capacity and reporting practices alongside demographic characteristics.

According to SNIS (2021), the mean recovered recyclable material per capita in Brazil reached 8.26 kg/inhabitant/year in 2021. The Southern macro-region recorded the highest mean recovered recyclable material per capita (15.01 kg/inhabitant/year), and it was followed by the Midwestern (8.63 kg/inhab./year), Northern (8.16 kg/inhab./year) and Northeastern (6.68 kg/inhab./year) macro-regions. The Southeastern macro-region recorded the lowest mean recovered recyclable material per capita (6.40 kg/inhab./year). Some municipalities in Alto Tietê Region have not even managed to reach the mean value observed for the Southeastern region, in which they are located. It highlights the need of improving recyclable materials' selective collection services in municipalities belonging to this region, mainly in Guarulhos, which plays a key role in the region's economy and has a large population.

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These findings support the importance of combining service expansion with environmental education and communication that encourage correct source separation. Trielli (2021), analyzing environmental education in municipal solid waste plans in the Alto Tietê Region, observed that the approaches described in the plans were often limited to lectures and argued for more appropriate educational methods. In the present study, however, low recovered mass per capita should not be interpreted as direct evidence of low environmental awareness. The indicator can also be affected by coverage, collection frequency, sorting and recovery capacity, informal recycling flows, data quality and other operational factors. Environmental education is therefore one relevant component of selective collection policy, but its effect cannot be isolated from the available SNIS indicators.

The comparative reading in Table 1 shows that selective collection performance cannot be interpreted as a simple function of population size or IDHM. Municipalities with similar socioeconomic indicators recorded markedly different operational results, while some smaller municipalities reached high coverage. Population and IDHM are therefore useful for contextualizing scale and socioeconomic conditions, but they do not, by themselves, explain the observed patterns. Institutional continuity, service design, local infrastructure, the role of cooperatives, data-reporting capacity and the territorial scale of the operation are additional dimensions that should be considered. From an institutional perspective, Camargo et al. (2024), in a critical analysis of the Integrated Solid Waste Management Plan of Guarulhos, emphasize the articulation between the PNRS, local planning, sustainable consumption and reverse-logistics instruments. This supports an interpretation of municipal performance that incorporates governance and implementation capacity rather than relying only on demographic or socioeconomic attributes.

The contrast between Guarulhos and Salesópolis illustrates the role of scale. Guarulhos had the largest population in the region in 2021 (approximately 1.4 million inhabitants) and an IDHM of 0.763, but door-to-door selective collection coverage reached 32.73% and recovered mass was 2.1 kg/inhabitant/year. Salesópolis, by contrast, had fewer than 20 thousand inhabitants and an IDHM of 0.732, while reporting 100% coverage and 55.18 kg/inhabitant/year in 2021. These values do not demonstrate that small population size produces better performance; rather, they show that broad socioeconomic indicators are insufficient to explain the operational differences observed between municipalities.

A second contrast is observed between Mogi das Cruzes and Poá, whose IDHM values are relatively close (0.783 and 0.771, respectively). Mogi das Cruzes maintained coverage close to 100% for most of the analyzed period, whereas Poá reached 8.52% in 2021. At the same time, Poá recorded an exceptionally high recovered mass per capita in 2020. The divergence reinforces that IN030 and IN032 measure different dimensions: the first refers to population coverage by door-to-door collection, whereas the second reflects the amount recovered relative to population. A high value for one indicator in a specific year therefore should not be assumed to represent high overall performance in all dimensions of the selective collection system.

The discontinuity of information for Ferraz de Vasconcelos and Suzano, together with the absence of the analyzed indicators for Itaquaquecetuba, is also analytically relevant. These gaps restrict

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comparison and prevent robust conclusions about recent performance in those municipalities. The 2010 IDHM must likewise be interpreted cautiously because it predates much of the 2010-2021 time series and is used here only as a structural contextual indicator, not as a time-varying explanatory variable.

Adopting integrated regional management is a possible way of tackling these differences and consolidating selective collection in this region. This management type requires collaboration among cities in Alto Tietê Region to help developing joint waste management strategies, as well as sharing resources and infrastructure, and implementing environmental education policies and programs. This integrated regional management can help meeting the challenges of effectively implementing selective collection in these municipalities, by maximizing the use of available resources and by promoting environmental sustainability regionwide. The PNRS has established incentives for municipalities belonging to the same region to share solid waste management by grouping together in consortia or through other similar solutions (Drummod; Seixas, 2014). According to Lisbinski et al. (2020), setting an inter-municipal waste-management consortium enables more efficient regional waste management in a given region. In addition, it enables reducing transportation costs and cutting the proper waste disposal cost by approximately 30%, a fact that emphasizes the regional viability of this approach.

Results obtained in the study show what has been evident throughout the country. In Brazil, selective collection is incipient, present in only 41% of municipalities, and its efficiency is low, collecting only 10% of potentially recyclable material (Conke and Nascimento, 2018). Despite the proven importance of selective collection in generating jobs and environmental sustainability, it still does not receive widespread support from public authorities, indicating that a significant amount of material is being disposed of inappropriately across the country (Silva et al., 2021).

4- CONCLUSIONS

The Alto Tietê Region has particular environmental relevance because it contains headwater areas of the Tietê River and important Atlantic Forest remnants. In this context, the 2010-2021 series shows that implementation of selective collection remained uneven among municipalities after enactment of the PNRS.

The indicators revealed divergent trajectories within the same metropolitan region. Four municipalities reported 100% door-to-door coverage in 2021, whereas others recorded substantially lower coverage or lacked recent comparable data. Recovered mass per capita did not follow coverage consistently, demonstrating that territorial reach and effective material recovery are distinct dimensions of the service. Low recovered mass should not be interpreted as direct evidence of insufficient environmental awareness, because the indicator is also shaped by collection design, sorting capacity, informal recovery, infrastructure and data-reporting practices. Environmental education remains relevant, but its contribution should be assessed together with these operational and institutional factors.

The socio-spatial comparison further suggests that population size and IDHM, when considered in isolation, are insufficient to account for the municipal differences observed in the selective collection indicators. The contrasts among municipalities point to the relevance of examining these contextual

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attributes together with institutional continuity, governance, service organization, cooperative capacity and monitoring practices. Because the analysis is descriptive, these relationships should not be interpreted as causal. Data gaps in Ferraz de Vasconcelos, Suzano and Itaquaquecetuba also demonstrate that continuity and quality of reporting are themselves important conditions for policy evaluation.

The COVID-19 pandemic may have contributed to changes observed in 2020, particularly where collection and sorting activities were temporarily suspended, but the available municipal series does not allow the effect of the pandemic to be isolated from other operational changes.

Finally, the marked heterogeneity among neighboring municipalities supports the value of regional coordination. Shared infrastructure, intermunicipal cooperation, consistent monitoring and exchange of operational practices may strengthen selective collection across the Alto Tietê Region, while future assessments should combine service indicators with institutional and socio-spatial variables and, where possible, longer and more complete time series.

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