

**Spatial Distribution of Residential Solid Waste Generation in
Brazil: Estimating residential solid waste generation and CO₂eq
emissions based on the nominal income, towards the
achievement of the Sustainable Development Goals.**

by

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We acknowledge with respect the Lekwungen peoples on whose traditional territory the university stands and the Songhees, Esquimalt and WSÁNEĆ peoples whose historical relationships with the land continue to this day.

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Abstract

The generation of solid waste is a natural consequence of human life. Its rate has increase rapidly along the years, mostly due to the population growth, urbanization process coupled to industrialization and economic development. The uncontrolled disposal of solid waste in unsuitable sites, dump sites, has poses a threat to public health and the environment. In this regard Global efforts has been made to rethink municipal solid waste management toward sustainability.

Middle- and low-income countries, such as Brazil, should seize the opportunity and centre efforts in the development and strengthen of an inclusive municipal solid waste management, supported by an innovative public policy where all government levels are integrated and focused on resource recovery and recycling through the organization and strengthening of waste pickers, in order to act directly in the income improvement of a marginalized portion of society as a result of the revenue generated by recovered and recycled materials sales, as well as reduce the CO₂eq emissions consequent from the disposal of solid waste, among others, hence moving these countries towards the achievement of the SDG goals.

In this regard, a well managed inclusive municipal solid waste system requires a reliable data source to support decision makers in the design of public policies with effective actions in the field, otherwise innovative and modern public policies will be filled with fruitless actions, thus, wasting the aptitude of the municipal solid waste management system in help middle- and low-income countries to successfully carry out the SDGs goals. Nevertheless, the estimation methods are a valuable tool for decision makers in middle- and low income countries to outrun the lack of solid waste information and doing so, increase the effectiveness of public polices towards a sustainable and inclusive municipal solid

waste system, focused on mitigate negative impacts in the environmental sphere and potentiate the positive outcomes in the public health and human development sphere in these countries.

This research proposed an estimate method based on the nominal income which is able to provide a reliable estimate of the residential solid waste generation, as well as its spatial distribution in the municipal level and within the municipal boundaries. The proposed approach has the ability to differentiate spatial distribution of the residential solid waste generation, weighting not just the number of people living in a determined space, but also the purchase power of those people, providing a more accurate view of the issue, which benefits decision makers to design and plan their polices and actions.

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1. Introduction

For decades, municipal solid waste management (MSWM) aimed to remove solid waste generated in inhabited areas and dispose of it in remote areas within the municipality, assuming waste as a hazard or a remnant of prior social, political, and economic processes. The main concern of this system was to eliminate the unpleasant aspect of garbage and provide a means to improve public health (Moore, 2012; Shekdar, 2009). However, the uncontrolled disposal of solid waste in unsuitable sites (dump sites), associated with a lack of municipal solid waste collection (mostly in informal settlements), makes municipal solid waste one of the most pressing universal urban problems, posing a threat to the public health and the environment (J. Gutberlet, 2015; Jutta Gutberlet, 2015; Rouse, 2006). This threat demands global efforts to rethink municipal solid waste management toward a goal of greater sustainability (Kawai & Tasaki, 2016; Singh et al., 2011; Yadav & Samadder, 2017).

The solid waste generation rate has increased rapidly over the years, mostly due to population growth and urbanization, coupled with industrialization and economic development. Approximately 2.01 billion tonnes of municipal solid waste are currently generated annually in the world, with at least 33 percent of it not managed in an environmentally safe manner. This amount is predicted to reach around 3.40 billion tonnes annual of solid waste by the year 2050 (Karak et al., 2012; Kaza et al., 2018; Laurent et al., 2014; Yadav & Samadder, 2017). This projected growth co-relates to rising income levels around the world. Greater affluence equals greater waste. There is a positive correlation between waste generation and income level (Kaza et al., 2018). The amount of solid waste generated is strongly linked to the economic status of a society, in other words,

the residential solid waste generation is directly proportional to the economic status of the people (Shekdar, 2009; Yadav & Samadder, 2017).

With the mission of moving away from the fundamental thinking of waste management as a process of collection and disposal of waste at landfills, to waste management as a resource management process, the Global Waste Management Outlook inserts waste and resource management as part of the circular economy, addressing the issue upstream at its source, through product design that generates less waste, reducing the quantities of waste generated, avoiding the use of hazardous substances, minimizing and reusing materials and, where residues do occur, preserving their intrinsic economic value for recycling and recovery (UNEP, 2016).

In this regard, municipal solid waste management should be based on the concept of resource efficiency and the exploitation of secondary raw materials, instead of a production and consumption process that produces excess waste which then must be disposed of in order to mitigate its negative impact on the environment and public health. Solid waste should constitute a secondary source of resources, a substitute for raw materials, ensuring sustainable production and consumption (Bartolacci et al., 2019; Bergeron, 2017; Gutberlet, 2016; Massarutto, 2015; UNEP, 2016). Therefore, by prioritizing recycling over disposal, municipal solid waste management not only generates additional revenue, it reduces disposal costs and negative impacts, as well (Kinnaman, 2006).

The Global Waste Management Outlook (UNEP, 2016) places waste management as a key asset to address Sustainable Development Goals (SDGs). Its strong relationship to health, climate change, poverty reduction, food and resource security, and sustainable production and consumption, make waste management an entry point to overcoming many difficult challenges regarding sustainable development.

The SDGs rely on the logic that the 17 goals depend on each other. In other words, policymakers must direct their strategies and policies towards the interactions between goals, seeking to identify how one sector could affect another positively or negatively, instead of simply ticking off the targets. The problem in achieving the SDGs is that governments, through their policymakers and planners operate, in a compartmentalized way. Energy, environment, health, agriculture, etc. are handled by different, compartmentalized agents. The SDGs urge for a systematic consideration of the overlaps between one goal and the others. Policymakers from economic, social and environmental spheres will have to direct their efforts jointly towards the identification of allies, in which the interaction between them will affect or be affected in a positive way. On the other hand, negotiations must be placed in order to mitigate negative interactions between goals (Allen et al., 2019; Guerrero et al., 2013; Gutberlet, 2021; ICSU, 2017; Janoušková et al., 2018; Nilsson et al., 2016; Weitz et al., 2017, 2018).

The unsustainable production and consumption processes in middle- and low-income countries, allied to a poorly managed municipal solid waste system corroborate with the escalation of the negative impacts of solid waste in contaminating the air, water and soil (Silva, 2017; Yadav & Samadder, 2017; Zia et al., 2017), generating green-house gas (GHG) emissions (De La Barrera & Hooda, 2016; King et al., 2016; King & Gutberlet, 2013; UNEP, 2013), human health issues (Gutberlet & Uddin, 2017), as well as resource shortages, given that the recyclable part of solid waste has been wasted in landfills, instead of reinserted in the productive chain, avoiding natural resources extraction (Silva, 2017; Zurbrügg et al., 2014).

Nevertheless, a well-managed and inclusive municipal solid waste management system, particularly in middle- and low-income countries, presents an opportunity for governments and communities to deliver jobs and livelihood,

protect public health and improve the environment (UNEP, 2013). For instance, developing a national strategy in solid waste management, able to engage different levels of government and stakeholders, focused on resource recovery and recycling, constitute a powerful tool for middle- and low-income countries to tackle the challenges towards the achievements of the SDGs (Gutberlet, 2021; UNEP, 2013).

In order to fulfill the potentiality of the municipal solid waste system as a tool able to move countries towards the achievements of the SDGs, middle and low-income countries must center efforts on developing and maintaining reliable databases to quantify and characterize the solid waste (Karak et al., 2012; Shekdar, 2009; Zia et al., 2017). They must create solid waste policies that support the inclusion of waste pickers in the formal municipal solid waste management system, as recycler and collector agents (Gutberlet, 2010, 2015; Gutberlet et al., 2017). And promote educational actions to raise awareness in order to motivate communities' participation in recycling programs (Csutora, 2012; Wang et al., 2020).

A database that quantifies and characterizes solid waste, updated and available, is a key element for planning and selecting the handling, treatment, and disposal options of solid waste (Beigl et al., 2008; Cho et al., 2012; Younes et al., 2015). Such databases provide the necessary information on the matter to allow policy makers and planners to understand the subject and make proper forecasts in order to design effective actions (Allesch & Brunner, 2014; Basnayake et al., 2019; Bergeron, 2017; Dias et al., 2012; Edjabou et al., 2017; Gautam et al., 2020; Goulart Coelho et al., 2017; Henriksen et al., 2019; Younes et al., 2015; Zurbrügg et al., 2014).

While high-income countries normally keep such information collected daily, middle and low-income countries struggle to consolidate a national database on the quantification and characterization of the solid waste (Karak et al., 2012; Shekdar, 2009; Zia et al., 2017). Problems such as "short history" (small time series), insufficient data (the database keeps just basic information about the issue), completeness (missing information), continuity (gaps in the data) and so on (Hunziker et al., 2017; Sebastian-Coleman, 2013), contribute for a poor municipal solid waste management system in these countries (Karak et al., 2012).

The waste pickers are composed of people who see in the activity of recovery and sale of recyclable materials from solid waste the only, or more feasible, way to make a livelihood through work. Given the restrictions inflicted by the job market regarding the level of their skills, or by the social position they occupy in society, this marginalized part of the population is usually placed at society's bottom. Even though these workers are frequently stigmatized by society, as they make their livelihood through what society calls garbage, they are responsible for executing an essential social and environmental service (Gutberlet, 2010, 2015, 2016; Gutberlet & Uddin, 2017; IPEA, 2012; Pereira & Goes, 2016).

In order to overcome society's stigmatized perception about their activity, waste pickers worldwide are organizing themselves in seeking political representation, through the organization of social movements aiming for social recognition of the economic-productive strength of their activity, and to be considered professional citizens, under the aegis of cooperatives and/or associations, ultimately seeking better wages through collective work. The aforementioned is slowly changing society's perception about waste pickers and their activity, however they are still largely unsupported by the public administration, sidelined from the formal municipal solid waste management

system, even though their performance helps ameliorate the consequences of neglected public cleaning (Almeida, 2008; Navarrete-Hernandez & Navarrete-Hernandez, 2018; Severi, 2014; Silva, 2017).

As a middle-income country, Brazil struggles to shift the concept of municipal solid waste management as an instrument of collection and disposal of garbage to a modern approach of inclusive municipal solid waste management focused on resource recovery and recycling, prioritizing the inclusion of informal and organized waste pickers as the mainly resource recovery and recycling agents. In 2010 an important benchmark in the solid waste management system was achieved in Brazil. After 20 years of negotiations in the Brazilian Congress, the National Solid Waste Policy (PNRS - Política Nacional de Resíduos Sólidos - Lei nº 12.305/10) came into force (Política Nacional de Resíduos Sólidos, 2010; IPEA, 2012).

This policy is based on the tripod of reduction of solid waste through sustainable consumption habits, solid waste recovery and recycling, and environmentally adequate disposal sites (landfills). The PNRS established the reverse logistics of waste and packaging, sharing the responsibility among all stakeholders, from the producer till the final consumers. Moreover, it institutes mechanisms to promote the engagement of all government levels, as well as private sectors in the elaboration of solid waste management plans. Other than that, the PNRS, on the direct influence of the National Movement of Waste Pickers (MNCR - Movimento Nacional de Catadores de Materiais Recicláveis), includes the waste pickers as an important stakeholder in the recycling process and in the collection process, demonstrating concerns about social inclusion and poverty eradication. Furthermore, the PNRS highlights recycling as a key action towards the achievement of the goals established by the Brazilian National Plan on

Climate Change (Política Nacional de Resíduos Sólidos, 2010; Ministério do Meio Ambiente, 2015; Rossi, 2019; Silva, 2017).

Advances have been observed in municipal solid waste management in Brazil since the PNRS came into force. However, such advances mostly regard the environmental adequate disposal sites (landfills) and collection coverage (CETESB, 2019; Ministério das Cidades, 2012; Ministério do Desenvolvimento Regional, 2019a), addressing just one of the three main goals established by the PNRS. On the other hand, in the last decade, Brazil showed an increase of over 18% in residential solid waste generation (residential and public) and extremely low performance in the residential solid waste recovery and recycling, with just around 7% of the recyclable's materials recovered from recycled residential solid waste (Fattor & Vieira, 2019; Ministério das Cidades, 2012; Ministério do Desenvolvimento Regional, 2019a).

The number of active, informal and organized waste pickers in Brazil are difficult to estimate, mostly due to social bias around this activity. The estimated number of waste pickers range in average between 400,000 and 600,000, depending on the consulted source. The Brazilian Institute of Geography and Statistics (IBGE) estimates the number of waste pickers to be under 100,000, while the National Movement of Waste Picker (MNCR) points to a number over 800,000. In fact, the amount of recyclable materials recovered in the residential solid waste stream in the country are largely due to the work of waste picker cooperatives and associations. The work of informal waste pickers, which collect recyclable materials on the streets and sell it to middleman, is not recognized in the national statistics (Almeida, 2008; IPEA, 2012; Silva, 2017).

In this regard, this research argues for middle- and low-income countries, such as Brazil, to focus efforts on inclusive municipal solid waste management that is supported by an innovative public policy in which all government levels are

integrated and focused on resource recovery and recycling through the organization and strengthening of waste pickers. This has the power to directly affect the income of this marginalized part of society as a result of the revenue generated by the collection, separation and sale of recovered and recycled materials, thus moving the country towards the achievement of SDG 1, no poverty (Gutberlet, 2010, 2012, 2016; Lane, 2011; Sembiring & Nitivattananon, 2010; Wilson et al., 2006, 2013).

Moreover, prioritizing resource recovery and recycling over landfill disposal reduces greenhouse gas emissions (GHG) into the atmosphere which contributes to a positive measure to overcome SDG 13, climate actions (De La Barrera & Hooda, 2016; Eriksson et al., 2015; King et al., 2016; King & Gutberlet, 2013). Hence, The GHG emissions reduction, measured in tons of carbon dioxide equivalent (tCO₂eq), which is the amount of CO₂ or the equivalent of others GHG corresponding to CO₂ emissions not released into the atmosphere (UNFCCC, 2008, 2016, 2018), can be translated into certificated emissions reductions (CER), through the implementation of Clean Development Mechanisms (CDM). The CERs are traded on financial markets and exhibit characteristics of financial assets. In Brasil it is negotiated in the São Paulo Commodities and Futures Exchange (BMF - Bolsa de Mercadorias e Futuro de São Paulo) as a commodity and its price varies daily according to supply and demand (Gavard & Kirat, 2018). The reductions of GHG emissions due to resource recovery and recycling, thus, can be traded with high-income countries or corporations, generating revenue for middle- and low-income countries, affecting positively the SDG 10, reducing world inequalities, as well as SDG 1, no poverty (Jutta Gutberlet, 2021).

Lastly, the benefits of inclusive municipal solid waste management can indirectly influence progress of SDG 12, responsible production and consumption, with the reintroduction of recovered and recycled materials into the productive

chain, relieving the pressure of the raw materials extraction, SDG 15, life and land, by reducing the amount of solid waste disposed in landfills and on dump sites. Such reduction implies a reduction in costs of the solid waste management system, creating financial surplus which can be diverted towards SDG 4, quality education, or also tackle SDG 5, gender equality, as an important part of the informal and organized waste pickers workforce are composed of women (Gutberlet, 2021; Nunn & Gutberlet, 2013).

Even though the Brazilian National Policy of Solid Waste provides the elements to support an inclusive municipal solid waste management system, the country still struggles to develop and maintain a reliable national database on solid waste, to include waste pickers in the formal municipal solid waste management system, and to strengthen its organizations and improve society's participation in the selective collection and recycling programs. In this regard, important questions need to be addressed, such as: How to close the gaps in the national database on solid waste, turning it in a reliable source of information able to support the elaboration of municipal solid waste management plans? What is the social and economic impact on the waste pickers' livelihood with the inclusion of the waste pickers cooperatives and associations in formal municipal solid waste management? How to raise awareness in Brazilian society about the need to participate in the separation of recyclable materials from the residential solid waste, improving participation in recyclable programs?

The use of estimation models and methods are largely documented in the literature. Such procedures are a feasible tool to remedy ill-maintained databases and provide reliable data to support planners in the design of effective action on this matter (Beigl et al., 2008; Cho et al., 2012; Dias et al., 2012; Gautam et al., 2020; Kawai & Tasaki, 2016; Reynolds et al., 2016). Moreover, quantifying residential solid waste generation as well as estimated potential revenues and the

reduction in CO₂eq emissions, is an efficient way to demonstrate the impact of such programs in the social, economic and environmental sphere in the country, along with raising society's awareness on this matter.

In order to address the aforementioned questions, this research aims to apply an approach to estimate residential solid waste based on the nominal income in Brazil, expecting to produce a normalized national spatial and relational database on residential solid waste that can provide reliable data. Reliable data will enable the calculation of the potential revenue from sales of recyclable materials, potential CO₂eq emissions from the residential solid waste stream, potential CO₂eq emissions reductions due to recycling and, lastly, develop a household waste footprint calculator as a tool to educate society about the importance of separation of recyclable material from the residential solid waste stream, and to encourage their participation in recycling programs.

The next section will describe the methodological procedures adopted in order to fulfill the above-mentioned research goals. Such methodological procedures will be detailed from the data collection until the development of the household solid waste footprint calculator, going by the residential solid waste estimate approach based on the nominal income, the estimate of potential CO₂eq emissions from the residential solid waste stream, considering two distinct scenarios. While the first scenario considers the total absence of recycling, in this case all the residential solid waste are disposed in landfills, the second scenario considers that 70% of the recyclable materials from the residential solid waste stream are diverted to recycling programs. The potential CO₂eq emissions reduction will be estimated through the comparison of the results of the two aforementioned scenarios, as well as the potential carbon credits generated along with the potential revenue from the sales of recyclable materials and reduction of landfills fees due to disposal avoidance. Lastly, the development of the household

solid waste footprint calculator will be detailed in addition to the household solid waste score.

The following section will present and discuss the results obtained at the national level, going by all Brazilian territorial division levels (country, region, state, mesoregion, microregion, municipality and census area), in conjunction with the results of the household solid waste footprint calculator. Finally, the last section will present the considerations and conclusion extracted from the applied methodology in Brazil.

As a Brazilian student living in Canada, I had the opportunity to experience how solid waste management systems deal with recyclable materials and organic matter in this country. In the province of British Columbia, such portion of the residential solid waste is almost entirely diverted to recycling and composting facilities, which unburdens the landfills of these waste loads. The success of this system is due to the massive society participation, which clean up and separate the recyclable materials from the household waste to be collected by the selective collection service. Therefore, the idea of demonstrating the spatial distribution of the residential solid waste and its potential to improve Brazil's society and environment, motivated by the Canadian experience, boosted me to contribute, through this research, to help to raise Brazilian society awareness regarding this issue.

2. Methodology

In order to accomplish the research goals, this section aims to detail the methodological procedures used to estimate residential solid waste generation, potential CO₂eq emissions from the residential solid waste stream, potential CO₂eq emissions reduction through recycling, and the potential revenue from recycling sales, trade of carbon credits and costs reduction from avoiding residential solid waste disposal in landfills. As well to outline procedures for developing a household solid waste footprint calculator and the household solid waste footprint score.

2.1. Data Collection

The first step towards the achievement of the research goals was gathering baseline data. Data from population and nominal income were acquired in the census area level, while residential solid waste generation data was acquired for the 5570 Brazilian municipalities. The utilized spatial data refers to the Brazilian territorial division contemplating all its levels, from the national territory to census areas, except the sub-districts.

Since the last Brazilian census research was performed in 2010, this year was selected as baseline for the research. As of this year, population and nominal income data from census area were estimated until 2019, which allowed an analysis of the proposed approach between 2010 and 2019. Regarding the residential solid waste generation, municipal data was acquired for the same time frame. Lastly, this research used the last available spatial data from the Brazilian

territorial division. The acquired data were not assessed regarding its quality, being used as available in the data source.

2.1.1. Population Data

The population data were acquired from the Brazilian population census research held by the Brazilian Institute of Geography and Statistics (IBGE - Instituto Brasileiro de Geografia e Estatística) in 2010. Since IBGE does not estimate population for census area, the number of inhabitants for census area from 2011 to 2019 was estimated using the population growth rate (**eq.01**) for each Brazilian municipality times the census area population in 2010 (**eq.02**). The census area population was extracted from the basic file in the Brazilian population census research (IBGE, 2011).

$$PGR = \frac{P_{Myear}}{P_{M2010}} \quad \text{eq.01}$$

where:

PGR- population growth rate;

P_{Myear}- Municipal population from a determinate year;

P_{M2010}- Municipal population from 2010.

$$P_{CAyear} = P_{CA2010} * PGR \quad \text{eq.02}$$

where:

P_{CAyear}- Census Area population from a determinate year;

P_{CA2010}- Census Area population from 2010;

PGR- Population growth rate in a determinate municipality.

The population data for the census areas from 2010 to 2019 were stored in the open-source database system PostgreSQL and the calculations were executed through Structured Query Language (SQL). After that, population tables were created for all the other Brazilian territorial divisions and populated through the sum of census areas population for each territorial division.

The population data were used in per capita analysis from estimated residential solid waste and CO₂eq emissions. All tables were created with the Brazilian territorial division codes, for further spatial analysis, including codes from census area, district, municipality, microregion, mesoregion, state and region.

2.1.2. Nominal Income Data

The nominal income data is one of the variables included in the Brazilian population census research. This variable is defined as the sum of income declared by persons responsible for the households researched in a determinate census area. The nominal income is available in the Brazilian population census research as total monthly income of the households responsible (IBGE, 2011). In order to obtain an annual nominal income for the census area in 2010, the monthly nominal income of each census area was multiplied by 12, which corresponds to the twelve-months of the year (**eq.03**).

$$I_{2010} = I_{monthly} * 12 \quad \text{eq.03}$$

where:

I_{2010} - Annual nominal income in 2010;

$I_{monthly}$ - Monthly nominal income in 2010;

To update the nominal income values from 2011 to 2019, this research used the monthly minimum wage as published in the Official Diary of the Union (DOU - Diário Oficial da União) for each year as an update base (**table 01**). For this matter, an update rate was calculated based on the minimum wage value in 2010, by dividing the monthly minimum wage value in a determinate year by the minimum wage value in 2010 (**eq.04**).

$$MWR = \frac{MW_{year}}{MW_{2010}} \quad \text{eq.04}$$

where:

MWR - update rate;

MW_{year} - minimum wage value in a determinate year;

MW_{2010} - minimum wage value in 2010.

YEAR	MONTHLY MINIMUM WAGE VALUE	UPDATE RATE
2010	R\$510.00	1.00
2011	R\$545.00	1.07
2012	R\$622.00	1.22
2013	R\$678.00	1.33
2014	R\$724.00	1.42
2015	R\$788.00	1.54
2016	R\$880.00	1.73
2017	R\$937.00	1.84
2018	R\$954.00	1.87
2019	R\$998.00	1.96

Table 01 - Monthly minimum wages values from 2010 to 2019 and its respective update rate having 2010 value as baseline (source: DOU – Diario Oficial da Uniao).

Since the minimum wage is a national law in Brazil, this rate was applied for all census areas (**eq.05**).

$$I_{year} = I_{2010} * UR \quad \text{eq.05}$$

where:

I_{year} - Nominal income for a determinate year;

I_{2010} - Nominal income in 2010;

UR - Minimum wage update rate;

The nominal income data was stored in the open-source database system PostgreSQL and the calculations were executed through Structured Query Language (SQL). After that, population tables were created for all the other Brazilian territorial divisions and populated through the sum of census areas population for each territorial division.

The nominal income data was used to establish the relationship between municipal nominal income and municipal residential solid waste generation to estimate residential solid waste and CO₂eq emissions. All tables were created with the Brazilian territorial division codes, for further spatial analysis, including codes from census area, district, municipality, microregion, mesoregion, state and region.

2.1.3. Residential Solid Waste Data

The residential solid waste generation data was extracted from the National Sanitation Information System (SNIS - Sistema Nacional de Informações sobre Saneamento). This data was available for municipalities in kg/hab.day from 2010 to 2019 (Ministério das Cidades, 2012, 2013, 2014, 2015, 2016, 2017, 2018; Ministério do Desenvolvimento Regional, 2019a, 2019b, 2020) . In order to obtain

the annual amount of municipal residential solid waste generation, the values were multiplied by 365 days and by the municipal population and divided by 1000 having as a result the annual amount of municipal residential solid waste in ton/year.

The residential solid waste generation data were stored in the open-source database system PostgreSQL and the calculations were executed through Structured Query Language (SQL). After that, residential solid waste tables were created for all the other Brazilian territorial divisions, except for district and census area, and populated through the sum of municipal residential solid waste for each territorial division.

The residential solid waste data was used to establish the relationship between municipal nominal income and municipal residential solid waste generation to estimate residential solid waste and CO₂eq emissions. All tables were created with the Brazilian territorial division codes, for further spatial analysis, including codes from census area, district, municipality, microregion, mesoregion, state and region.

2.1.4. Spatial Data

Spatial data comprises the relative geographic information about the earth and its features, it is fundamental for any mapping activities (Janipella et al., 2019). In order to create spatial analysis from the results of this research, ESRI shapefiles were obtained from the IBGE website (<https://www.ibge.gov.br>) corresponding to the Brazilian Territorial Division boundaries. The ESRI shapefiles were translated into a Structured Query Language (SQL) file through the library shp2pgsql and imported as spatial table into the database PostgreSQL

using the spatial extension PostGIS. As a result, seven spatial tables were created, census area, municipality, microregion, mesoregion, state, region and country, in the database (**Figure 01**).

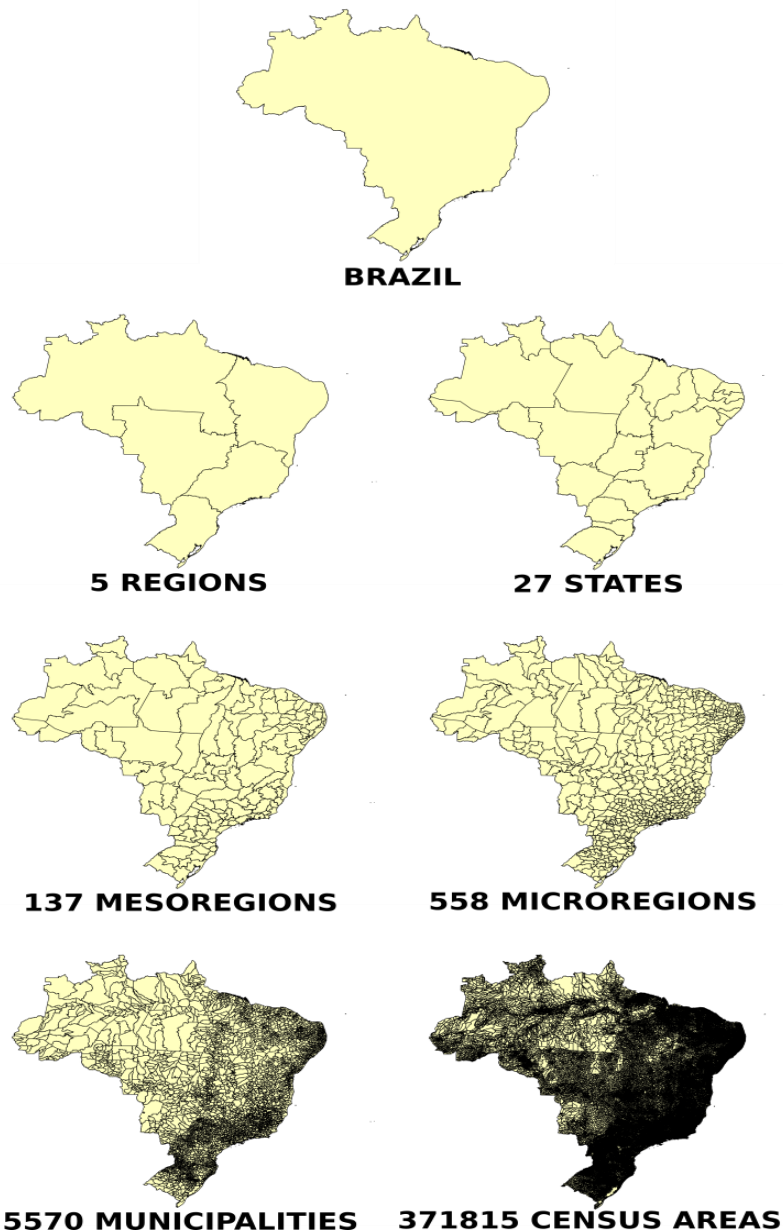


Figure 01 – Brazilian Territorial Division (IBGE,2017).

2.2. Residential Solid Waste Estimate Based on Nominal Income

The first step to estimate the residential solid waste generation based on nominal income was to calculate the correlation coefficient between municipal residential solid waste and municipal nominal income from the 5570 Brazilian municipalities. The correlation coefficient indicates the strength of a relationship between two variables. Such coefficient can assume any value between -1 perfect negative correlation to 1 perfect positive correlation. In case of a 0 coefficient a none relationship is observed between the two variables. The correlation is calculated through the equation (eq.06).

$$r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \quad \text{eq.06}$$

where:

r_{xy} – the correlation coefficient of the linear relationship between the variables x and y ;

x_i – the values of the x -variable in a sample;

\bar{x} – the mean of the values of the x -variable;

y_i – the values of the y -variable in a sample;

\bar{y} – the mean of the values of the y -variable.

The correlation coefficient was calculated using the following query into the PostgreSQL database from 2010 to 2019.

```
SELECT corr(<variable y>, <variable x>) FROM (SELECT c.<variable x>, a.<variable y> FROM
<table y> as a LEFT JOIN <table x> as c ON a.<code y> = c.<code x>) as tab
```

The next step was calculating the linear regression between municipal nominal income, independent (explicative) variable and the municipal residential

solid waste, dependent variable (explained by the independent variable). The used database contains information about total nominal income and total of residential solid waste for each of the 5570 Brazilian municipalities. In order to determine the best fit line through the used database, two coefficients were calculated, the slope of the line (**eq.07**) and the line intercept (**eq.08**).

$$m = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2} \quad \text{eq.07}$$

where:

m - slope;

x_i - independent variable (municipal nominal income);

\bar{x} - the mean of the values of the x -variable;

y_i - dependent variable (municipal residential solid waste);

\bar{y} - the mean of the values of the y -variable;

$$b = \bar{y} - m\bar{x} \quad \text{eq.08}$$

where:

b - intercept;

\bar{y} - the mean of the values of the y -variable;

m - slope;

\bar{x} - the mean of the values of the x -variable;

The slope and intercept coefficients were calculated using the following query into the PostgreSQL database from 2010 to 2019.

```
SELECT slope, ybar - xbar * slope AS intercept FROM (SELECT sum((x - xbar) * (y - ybar)) /
sum((x - xbar) * (x - xbar)) AS slope, max(ybar) AS ybar, max(xbar) AS xbar FROM (SELECT
avg(a.<variable y>) OVER (ROWS BETWEEN UNBOUNDED PRECEDING AND UNBOUNDED
FOLLOWING) AS ybar, a.<variable y> AS y, avg(b.<variable x>) OVER (ROWS BETWEEN
UNBOUNDED PRECEDING AND UNBOUNDED FOLLOWING) AS xbar, b.<variable x> AS x
FROM <table y> as a, <table x> as b WHERE a.<code y> = b.<code x>) AS tab) AS tab1;
```

After the calculation of the two coefficients, slope and intercept, the municipal residential solid waste was estimated for the 5570 Brazilian municipalities through the **eq.09**.

$$\hat{y} = b + mx \quad \text{eq.09}$$

where:

\hat{y} - estimated value of variable y;

b - intercept;

m - slope;

x - value of variable x;

Thereafter the coefficient of determination (R-squared) was computed. This coefficient is one of the most popular measure of goodness of fit for linear models (Piepho, 2019). The R-squared gives you the percentage variation in y explained by x-variables and vary from 0 to 1. The higher the coefficient, higher is the percentage of points the line passes through when the data points and line are plotted (Glen, 2019). The coefficient of determination was calculated through **eq.10**.

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \quad \text{eq.10}$$

where:

R^2 - coefficient of determination (R-squared);

\hat{y}_i - estimated values of y-variable;

y_i - values of y-variable;

\bar{y} - mean of the values of y-variable;

After calculating the coefficient of determination, the residual (difference between the actual y value and the estimated y value) was calculated, using the **eq.11**.

$$\text{Residual} = 1 - \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2} \quad \text{eq.11}$$

where:

\hat{y}_i - estimated values of y-variable;

y_i - values of y-variable;

\bar{y} - mean of the values of y-variable;

Therefore, the **eq.12** was defined and applied to estimate the municipal residential solid waste from the 5570 Brazilian municipalities. From the estimate of municipal residential solid waste, values for microregion, mesoregion, state, region and Brazil were computed through the sum of the municipality's values belonging to each area.

$$\hat{Y} = mx + b + E \quad \text{eq.12}$$

Where:

\hat{Y} - estimated value (dependent variable);

m - slope;

x - value of x -variable (independent variable);

b - intercept;

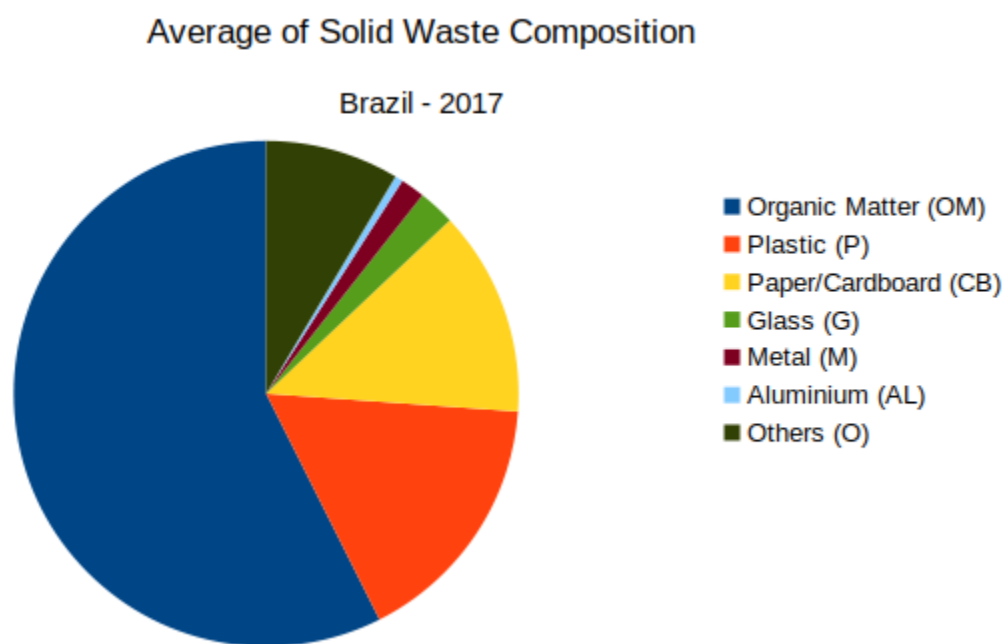
E - residual;

The aforementioned procedures were executed for each year from 2010 to 2019 and the results acquired were stored in a table on the database. All calculations were executed through a SQL query in the PostgreSQL database. Such table contains the Brazilian territorial division codes, for further spatial analysis, including codes from census area, district, municipality, microregion, mesoregion, state and region.

2.3. CO₂eq Emissions Estimate from Residential Solid Waste Stream

Subsequently to the estimate of municipal residential solid waste this research aimed to estimate the CO₂eq emission from the recyclable materials found in the residential solid waste stream. In this regard two scenarios were considered: the first scenario considered that the total amount of recyclable materials been discharged and disposed in landfills; the second scenario took into account that the total amount of recyclable materials was diverted into recycling process.

In order to estimate the CO₂eq emissions from the recyclable materials found in the residential solid waste stream, the first step was establishing the general composition of the residential solid waste stream in Brazil. According to Silva (2017) in average the residential solid waste collected and disposed in Brazil has the following composition: 57.41% of organic matter (food scraps, spoiled food and bathroom waste¹); 16.46% of plastic; 13.16% of cardboard and paper; 2.34% of glass; 1.56% of metals (except aluminum); 0.51% of aluminum; and 8.56% of others materials (**Graph 01**).



Graph 01 - Average composition of solid waste in Brazil (Silva, 2017).

The aforementioned residential solid waste average composition waste adopted as a constant. The percentages were converted into rates (**Table 02**) and applied to the estimate of residential solid waste for all areas and years. The percentage of other materials (8.56%) was not considered in the estimate of the

¹In Brazil, culturally toilet paper is not flushed after used, but collected in trash cans and discharged as organic waste.

CO₂eq emissions and the percentage of organic matter (57.41%) was considered to compute to estimate the potential CO₂eq emissions, but just the recyclable part of the residential solid waste (34.03%) was used to estimate the potential CO₂eq emissions reduction and potential revenue due to recycling process.

MATERIAL	COMPOSITION RATE
Organic Matter	0.5741
Plastic	0.1646
Cardboard and Paper	0.1316
Glass	0.0234
Metal (except aluminum)	0.0156
Aluminum	0.0051

Table 02 – Residential solid waste composition rate by material type.

Nevertheless, the amount of organic matter, plastic, cardboard and paper, glass, metals and aluminum were calculated over the total estimated amount of residential solid waste for each municipality in Brazil (**eq.13**).

$$RSW_i = RSW_{total} * c_i \quad \text{eq.13}$$

where:

RSW - Estimated Residential Solid Waste;

i - Material type;

c - Composition rate;

In order to estimate the potential municipal CO₂eq emissions from the residential solid waste stream, this research adapted the methodology developed by King & Gutberlet (2013). Such methodology measured the GHG emissions reductions achieved through recycling using the CDM GHG accounting methods. The calculations were based on the emissions associated with hydroelectricity

(the primary energy source for electricity in Brazil) and the fossil fuel consumption in the production process from virgin materials. Therefore, the coefficients found in the aforementioned methodology were applied in the total amount estimated for each material that composes the municipal residential solid waste, except for the parcel described as other materials. The estimation process considered two scenarios regarding the municipal residential solid waste.

In the first scenario, the potential CO₂eq emissions were estimated considering that the total amount of each material was disposed in landfills, meaning that in this scenario the recycling process was nonexistent and no resources were recovered and reintroduced into the production chain from the residential solid waste stream. In the second scenario, the estimate of potential CO₂eq emissions considered that 70%² of the total amount of each material was diverted to recycling, thus the resources were recovered and reintroduced in the production chain. **Table 03** shows adapted coefficients used to compute the estimate CO₂eq for the two scenarios above described.

Material Type	Coefficient for virgin materials	Coefficient for recycling process
Organic Matter	5.877	N/A
Plastic	0.828	0.183
Cardboard and Paper	0.898	0.323
Glass	0.935	0.922
Metals	1.264	0.392
Aluminum	3.872	0.154

Table 03 – Coefficients to estimate CO₂eq Emissions (adapted from King & Gutberlet, 2013).

²In Brazil around 30% of the recyclable materials (It might vary from 15% to 50%) are considered rejects and are disposed in landfills. These rejects are usually composed by recyclable materials that, even though are believable to be recycled, its recycling is not economic feasible or composed by materials in which its quality is beyond recycling due to impurities (dirt) on the materials (ABRELPE, 2020; Cembranel et al., 2021; Varella & Lima, 2011).

Therefore, the estimates for potential municipal CO₂eq emissions from residential solid waste stream for each material were calculated taking into account the two scenarios above mentioned through **eq.14** in the first scenario, where the recycling process was considered nonexistent and **eq.15** in the second scenario which assumed that 70% of the recyclable materials were recovered through recycling process.

$$CO_2eq_i = RSW_i * CVM_i \quad \text{eq.14}$$

where:

RSW - Estimated Residential Solid Waste;

i - Material type;

CVM_i - Coefficient for virgin material;

$$CO_2eq_i = RSW_i * CRP_i \quad \text{eq.15}$$

where:

RSW - Estimated Residential Solid Waste;

i - Material type;

CRP_i - Coefficient for recycling process;

Hence, the total estimated potential amount of municipal CO₂eq emissions considering the first scenario, where all materials were disposed in landfills, were acquired through the sum of the estimated potential amount of municipal CO₂eq emissions for each material **eq.16**. The same process was applied to estimate the potential total amount of municipal CO₂eq emissions in the second scenario, considering that 70% of the materials were diverted into recycling process **eq.17**.

$$CO_2eq_{total,VM} = \sum CO_2eq_{i,VM} \quad \text{eq.16}$$

where:

i- Material type;

VM- Virgin Material;

$$CO_2eq_{total,RP} = \sum CO_2eq_{i,RP} \quad \text{eq.17}$$

where:

i- Material type;

RP- Recycling process;

Thus, the estimated potential CO₂eq emission reduction through municipal residential solid waste stream diversion from disposal in landfill was acquired by the difference between the estimated total amount of CO₂eq measured in scenario one and the estimated total amount of CO₂eq measured in scenario two **eq.18.**

$$CO_2eq_{reduction} = CO_2eq_{VMtotal} - CO_2eq_{RPtotal} \quad \text{eq.18}$$

where:

RP- Recycling process;

VM- Virgin Material;

The estimate of potential CO₂eq emissions was calculated using a SQL query and was executed in the PostgreSQL database. The obtained results were stored as tables in the database. All created tables contain the Brazilian territorial division codes, for further spatial analysis, including codes from census area, district, municipality, microregion, mesoregion, state and region.

2.4. Estimated Potential Revenue from Recyclable Materials sale, Carbon Credit and Cost Reduction in the Municipal Solid Waste Management

The above-mentioned methodological procedures allowed the calculation of the potential revenue from recyclable material sale. Considering a scenario where 70% of the total estimated amount of recyclable material from the residential solid waste stream are diverted to the recycling process and adopting an average market value³ (**table 04**) by ton of recyclable materials traded a potential revenue was calculated for each of the 5570 Brazilian municipalities by material type **eq.19** and total **eq.20**.

YEAR	PLASTIC (R\$/ton)	CARDBOARD/PAPER (R\$/ton)	GLASS (R\$/ton)	METALS (R\$/ton)	ALUMINUM (R\$/ton)
2010	1,800.00	400.00	200.00	250.00	3,200.00
2011	1,800.00	400.00	200.00	250.00	3,200.00
2012	1,800.00	400.00	200.00	250.00	3,200.00
2013	1,800.00	400.00	200.00	250.00	3,200.00
2014	1,800.00	400.00	200.00	250.00	3,200.00
2015	1,700.00	450.00	220.00	250.00	4,100.00
2016	1,400.00	600.00	150.00	280.00	3,500.00
2017	1,600.00	420.00	120.00	400.00	4,000.00
2018	2,200.00	600.00	180.00	550.00	5,300.00
2019	2,200.00	600.00	180.00	550.00	5,300.00

Table 04 - Average market value by ton of recyclable materials (adapted from CEMPRE – <http://www.cempre.org.br>).

³The market value of the recyclable materials varies under the influence of many factors. The quantity (bigger quantities get better quotation), quality and the way it is traded (pressed or in bulk) affect the price of the ton of recyclable materials. Other than that, in Brazil the value varies from state to state and even between cities in the same region. In order to calculate the potential revenue from the recyclable materials sale an average value was adopted for all municipalities in Brazil.

$$PR_i = RSW_i * V_i \quad \text{eq.19}$$

where:

PR – Potential revenue;

RSW – Residential solid waste;

V – Material value;

i – Material type;

$$PR_{total} = \sum PR_i \quad \text{eq.20}$$

where:

PR – Potential revenue;

i – Material type;

The Kyoto Protocol allowed countries that have CO₂eq emission units to spare, emissions permitted but not used, to sell this excess capacity to countries that are over their targets. Thus, a commodity was created in the form of emission reductions (UNFCCC, 2008). The estimated potential CO₂eq emissions reduction was converted to carbon credits. As mentioned before, in Brazil, the CER is traded in the São Paulo Commodities and Futures Exchange, its value varies daily in the trading floor. In 2020 its value fluctuated from R\$88.90 to R\$121.10. In order to estimate the potential revenue from trade of this commodity an average value of R\$105.00 per unit of CER was adopted. In this regard the total estimate CO₂eq emissions reduction was multiplied by the average value of the CER.

Lastly a cost reduction in the landfill fees, due to the diversion of recyclable materials to the recycling process was calculated assuming an average fee value⁴

⁴Landfill fees in Brazil vary from city to city and in most of the cases are not available in the official channels. The adopted value used in this research is an average of the fees available on the internet in the official websites from few municipalities.

of R\$85.00 for ton of solid waste disposed in landfills. This cost reduction was estimated by multiplying the average fee value by the estimated amount of recyclable materials from the residential solid waste stream.

The estimate of potential revenue from recyclable materials sale, revenue from carbon credit and cost reduction of landfill fee were calculated using a SQL query and was executed in the PostgreSQL database. The obtained results were stored as tables in the database. All created tables contain the Brazilian territorial division codes, for further spatial analysis, including codes from census area, district, municipality, microregion, mesoregion, state and region.

2.5. Residential Solid Waste Estimates in the Census Areas.

The service of collecting residential solid waste is a municipal responsibility in Brazil (Política Nacional de Resíduos Sólidos, 2010). In this regards the municipality has autonomy to create a public company to execute the service or it can sub-contract one or more private companies to deal with the task. Therefore, the knowledge of the spatial distribution of the residential solid waste generation within the municipal border is primordial for urban planners and policy makers in the development of actions and policies towards a sustainable and inclusive municipal solid waste management.

In order to fill the lack of residential solid waste information within the municipal border, this research suggests an approach to estimate residential solid waste in the municipal census areas based on the rate of municipal residential solid waste by municipal nominal income (**eq.21**).

$$wr_{xy} = \frac{RSW_{total}}{Ninc_{total}} \quad \text{eq.21}$$

where:

wr_{xy} - waste rate of municipal residential solid waste by municipal nominal income;

RSW_{total} - Estimate municipal residential solid waste;

$Ninc_{total}$ - Municipal nominal income;

The waste rate (wr_{xy}) represents the amount of residential solid waste generated by one monetary unit in a determinate municipality. Once the nominal income of the census areas is known, the estimated amount of residential solid waste in the census areas was obtained by multiplying the census area nominal income by the municipal waste rate **eq.22**.

$$RSW_{ca} = Ninc_{ca} * wr_{xy} \quad \text{eq.22}$$

where:

RSW_{ca} - Estimate census area residential solid waste;

$Ninc_{ca}$ - Census area nominal income;

wr_{xy} - waste rate of municipal residential solid waste by municipal nominal income;

This procedure does not change the estimate amount of residential solid waste in a given municipality, but it weighted the spatial distribution of the estimated amount of residential solid waste among the census areas, meaning that instead of an even distribution of the residential solid waste, the spatial distribution will consider the nominal income of each area in the distribution. In other words, wealthy neighbourhoods will present higher rates of residential solid waste per capita than poorer neighbourhoods.

2.6. Household Solid Waste and CO₂eq Emissions Footprint Calculator.

An effective residential solid waste management system with focus on resource recovery and recycling relies on the effective participation of society. Since, the separation and diversion of the recyclable materials from the residential solid waste stream depends on household residents' will, a good solid waste policy will not succeed without a massive adhesion of society's members. In order to stimulate society's participation in governmental programs, policy makers usually apply a reward system where the participation is rewarded through some financial benefits (e.g., tax discounts) or a punitive system that aims to punish citizens for their non-compliance with the policy goals (e.g., fine application). Both systems can work together and may present improvement in society's participation, however those measures demand a strong system of supervision which needs a large number of personnel and financial and structural resources to be ineffective.

An option to the aforementioned measures is to raise society's awareness regarding the issue to be overcome. Raising society's awareness around a problem is not as fast as the reward and punitive systems, but can be more effective in the long run, when the issue becomes assimilated by society it turns into a social norm and starts to be reproduced to new generations. Stimulate society's participation in separation and diversion of recyclable materials from the residential solid waste stream requires, among others, available information about quantities, characteristics, impacts, benefits, etc. about solid waste (Csutora, 2012; Wang et al., 2020).

Aiming to provide information about household solid waste generation, CO₂eq emission and potential revenue from recyclable materials, a household solid waste footprint calculator was developed based on the resident location and

annual household income. The calculator uses the address and the total annual income (sum of income of all household's heads) provided by the resident and estimate the annual amount of solid waste generated in the household through the municipal waste rate. The resident has the option to provide the percentage of waste separated and directed to recycling.

Next the calculator will estimate the solid waste composition. This is used to estimate potential revenue from the resource's sale. Using the percentages of solid waste separated and directed to recycling, provided by the resident, the calculator will estimate the revenue generated by the household and compute the balance between potential revenue and generated revenue. Still considering the percentages of solid waste separated and directed to recycling, provided by the resident, the calculator provides an estimated value based on avoiding residential solid waste disposed in landfills.

Through estimating the solid waste composition CO₂eq emissions are calculated and weighted by the percentage of solid waste separated and directed to recycling, providing the amount of carbon credits generated. Lastly, the calculator compares the household results with the average values for census areas, municipality, mesoregion and microregion, state, region and Brazil and computes a waste footprint score.

The waste footprint score is calculated based on four parameters, the first two are provided by the users, regarding the percentage of waste diverted into recycling and composting. The system punctuates the percentage of the residential solid waste diverted to composting giving scores from 0 for 0% of solid waste diverted to composting to 4 for 100% of the solid waste diverted. The same punctuation is applied to the percentage of solid waste diverted to recycling, however for the recycling percentage an average between the percentage of each material is considered (**table 05**).

Classes	0%	1% - 25%	25% - 50%	50% - 75%	75% - 100%
Composting	0	1	2	3	4
Recycling	0	1	2	3	4

Table 05 – Punctuation for percentage of composting and recycling.

The last two parameters are the estimated household solid waste disposed in landfills and the estimated household CO₂eq emissions from solid waste disposed in landfills. These two parameters are compared to the national average and punctuated regarding the percentage in relation to the national average. Hence, amounts less than 25% of the national average get the maximum score. On the other hand, amounts over the national average get smaller points and amounts over 100% of the national average get no points. For example, if the national average is 1 ton per capita and the household is 0.200 ton per capita, this household gets the maximum points. On the other hand, if the waste generation in this household is 2 tons per capita, no points are awarded (**table 06**).

Classes	Solid Waste	CO ₂ eq Emissions
less than 25% of the average	8.5	8.5
25% to 50% of the average	7	7
50% to 75% of the average	6	6
75% to National Average	5	5
NA to 25% over average	4	4
25% to 50% over average	3	3
50% to 75% over average	2	2
75% to 100% over average	1	1
More than 100% over average	0	0

Table 06 – Punctuation for household solid waste and household CO₂eq emissions.

The household solid waste footprint score is computed through the sum of the points of each parameter, assuming values from 0 to 25, where 0 represents a very high household solid waste footprint and 25 represents a very low household solid waste footprint (**Table 07**).

Punctuation	Classes
0 to 5	Very High
6 to 10	High
11 to 15	Moderate
16 to 20	Low
21 to 25	Very Low

Table 07 – Household Solid Waste Footprint Score.

Figure 02 illustrate the procedures executed by the household solid waste footprint calculator.

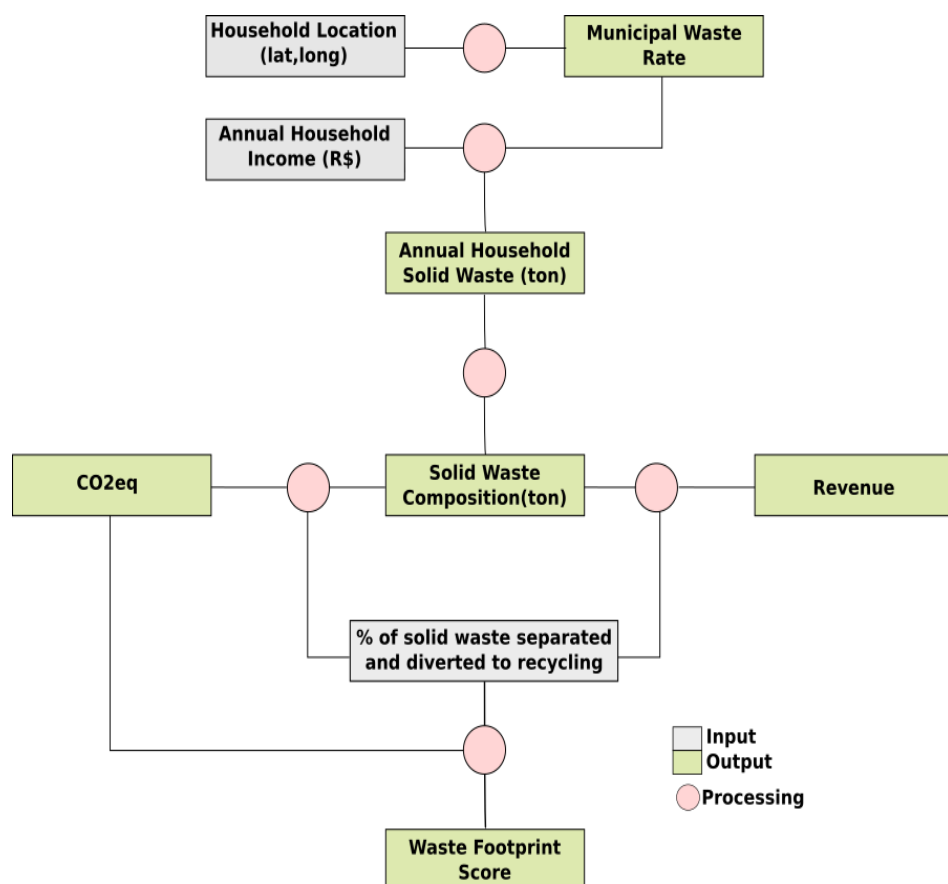
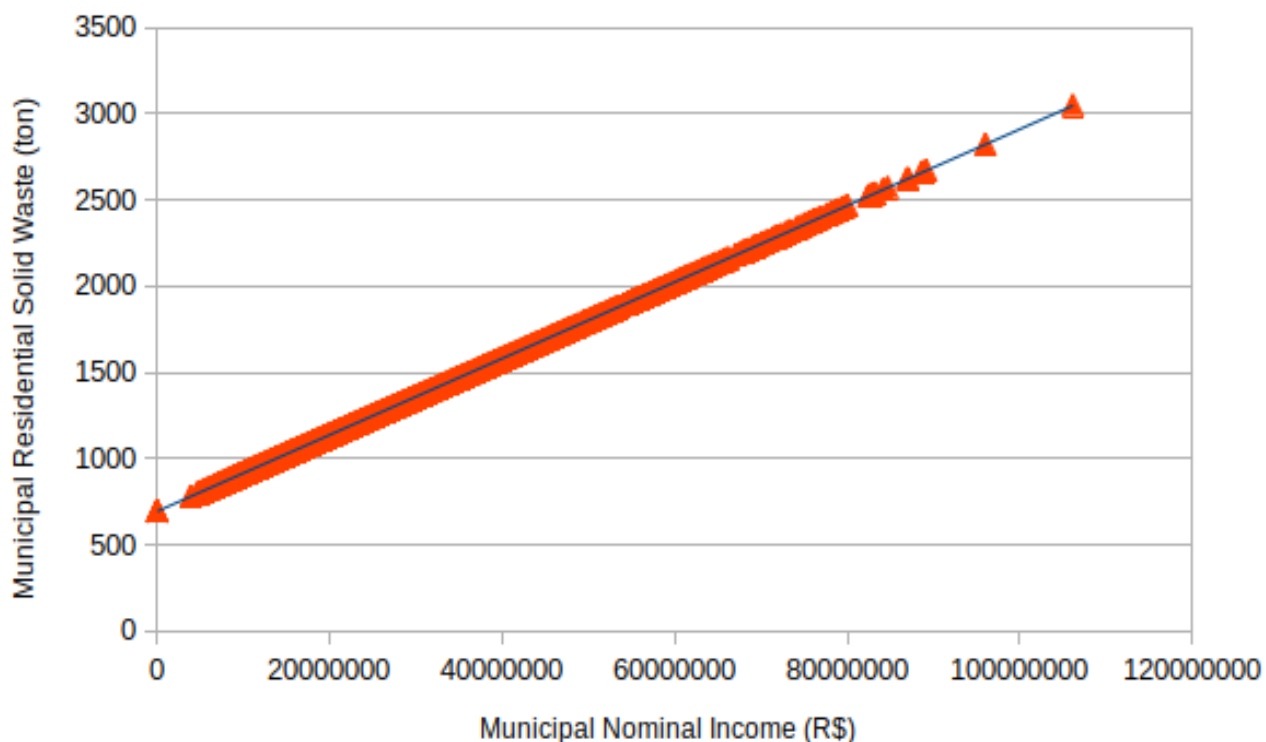


Figure 02 - Household solid waste and CO₂eq Emissions footprint calculator schema.

3. Results

The results obtained through the application of the methodological procedures above described are presented and detailed in this section. The starting point in this research was to verify the correlation between municipal residential solid waste generation and municipal nominal income. As a result of the calculation a correlation coefficient of 0.984 was found, for all years, when considering the municipal residential solid waste and municipal nominal income (**Graph 02**). It points to a strong positive correlation between those two variables. Such results demonstrate a linear relationship between both variables, which was a determinant to move forward in the estimation process.

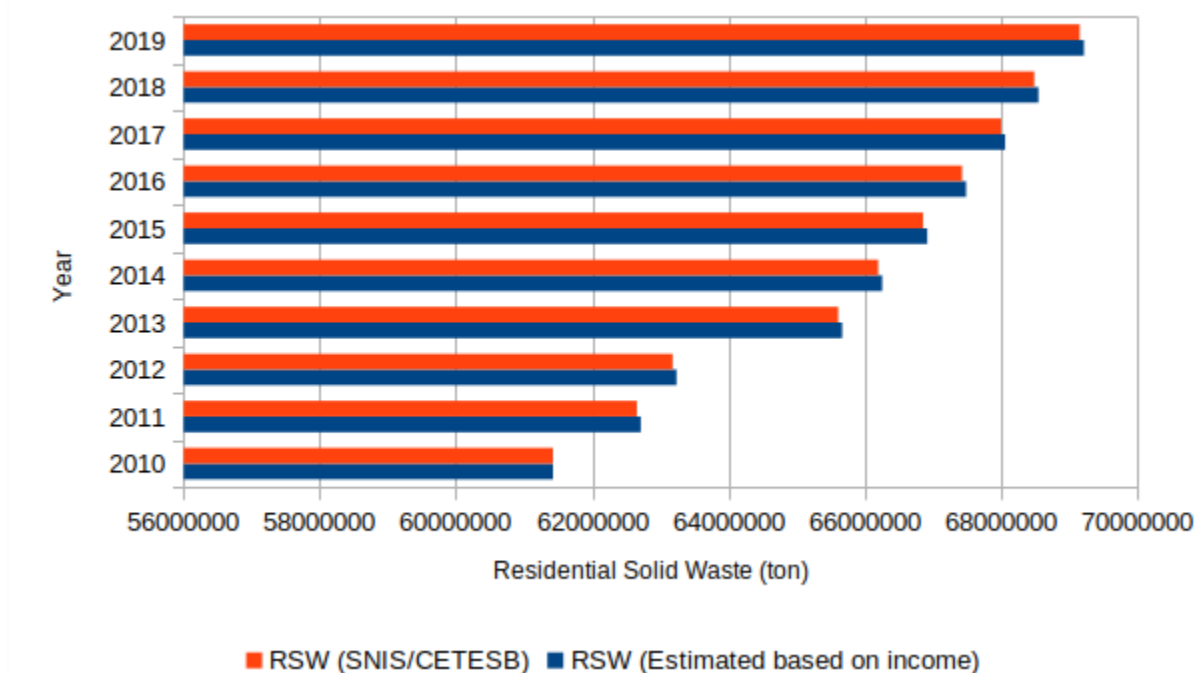


Graph 02 – Scatter XY between Municipal Nominal Income and Municipal Residential Solid Waste – 2010.

3.1. Spatial Distribution of Estimated Residential Solid Waste and CO₂eq Emissions in Brazil

The estimated values for the Brazilian municipalities were aggregated in larger areas, providing the estimated quantities for microregion, mesoregion, state, region and Brazil. In this regard, this section starts describing the national panorama, increasing the geographic scale and analyzing the spatial distribution of the estimated residential solid waste generated, and the CO₂eq emissions, in the Brazilian regions, states, mesoregions, microregions and municipalities.

The estimated quantities of residential solid waste, obtained through the estimation process based on nominal income, in Brazil were close to those in the acquired data, with a variation of less than 1% throughout the years (**Graph 03**).

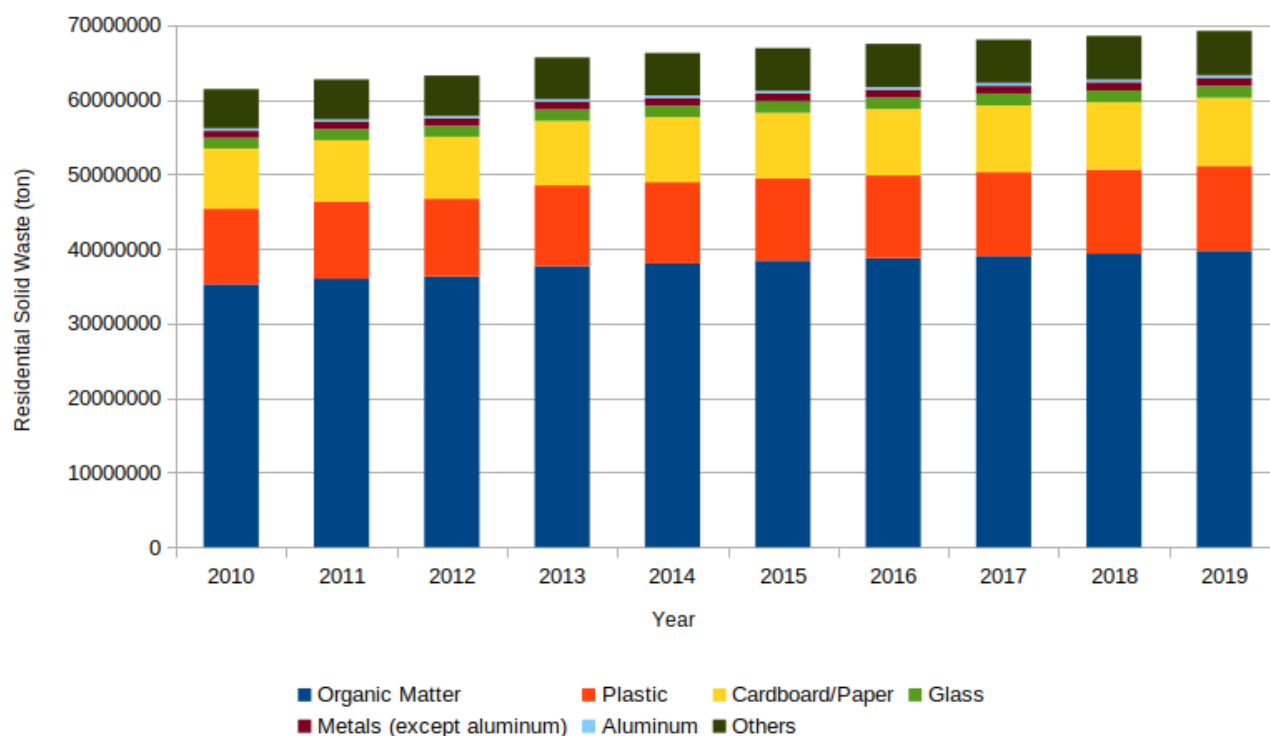


Graph 03 - Comparison between the data obtained through estimate residential solid waste based on income and the collected data from SNIS (Ministério das Cidades, 2012, 2013, 2014, 2015, 2016, 2017, 2018; Ministério do Desenvolvimento Regional, 2019a, 2019b, 2020) from 2010 to 2019.

From 2010 to 2019 the estimated amount of residential solid waste showed an accumulated increase around 12%. This increase was not evenly distributed

throughout the years, been the first period from 2010 to 2014 responsible for more than half of this rate, with higher increase rate, just under 4%, from 2013 to 2014. The estimated amount of residential solid waste in Brazil jumped from 61.4 million tons in 2010, around 325 kg.hab/year (0.89 kg.hab/day), to 69.2 million tons in 2019, averaging 329 kg.hab/year (0.9 kg.hab/day), with an accumulated estimated total amount of 659.5 million tons in the last decade.

Around 34% of the estimated amount of residential solid waste is composed of recyclable materials (plastic, cardboard and paper, glass, metals except aluminum and aluminum) (**Graph 04**) which represents an accumulated estimated amount of 224.2 million tons of resources with potential to be reintroduced in the chain of production in the decade (**table 08**).



Graph 04 – Estimate amount of residential solid waste in Brazil by composition from 2010 to 2019.

YEAR	RESIDENTIAL SOLID WASTE (Million Tons/Year)	RECYCLABLE MATERIALS (Million Tons/Year)
------	--	---

2010	61.4	20.9
2011	62.7	21.3
2012	63.2	21.5
2013	65.7	22.3
2014	66.2	22.5
2015	67.0	22.8
2016	67.4	23.0
2017	68.1	23.1
2018	68.6	23.3
2019	69.2	23.5
DECADE	659.5	224.2

Table 08 - Estimated amount of residential solid waste in Brazil from 2010 to 2019.

Assuming a scenario where the total estimated amount of residential solid waste was disposed in landfills or dumpsites, approximately 255.4 million tCO₂eq were released in the atmosphere from the residential solid waste stream in 2019 and just over 2.4 billion tCO₂eq in the last decade. The average of CO₂eq emissions per capita from the residential solid waste stream was estimated around 1.2 tCO₂eq in 2019 which represents 45.9% of the carbon footprint per capita in Brazil.

In this scenario, in 2019, the potential recyclable materials portion was responsible for an estimated CO₂eq emissions of 21.9 million tCO₂eq or 8.6% of the total emissions in 2019 from the residential solid waste stream. Moreover, no resources were recovered in this scenario, therefore the potential revenue from the recyclable materials was nonexistent. As well as no cost reduction in the landfill fee and no carbon credit generated.

On the other hand, considering a scenario where 70% of the potential portion of the recyclable materials were diverted to recycling the amount of CO₂eq emissions accumulated dropped from 2.4 billion tCO₂eq to 2.2 billion tCO₂eq in the decade, a decrease around 5.8% in the emissions. The recyclable materials,

in this scenario, were estimated at a total emission of just under 5 million tCO₂eq from this portion of the residential solid waste stream in 2019. Comparing this number with the estimated amount of CO₂eq emissions in the first scenario, the recycling process released about three times less CO₂eq than the extraction and use of raw materials. Nonetheless, diverting the recyclable materials from the residential solid waste stream to recycling would generate a potential revenue of around R\$23.2 billion in resource sales in 2019, such amount is 79% of the current budget for the major federal government's social program called "Bolsa Familia", which is R\$29.485 billion and benefits around 13 million families.

Throughout the decade, a volume of just over R\$179 billion would be raised with the sale of recyclable materials. Furthermore, recycling would be responsible for CO₂eq emission reductions estimated at 14.8 million tCO₂eq in 2019 and an accumulated reduction just over 141 million tCO₂eq over the decade. If traded as a commodity in the carbon credit market, this would raise around R\$1.55 billion and R\$14.8 billion respectively, considering the average value of R\$105.00 per CER. Lastly, diverting the recyclable materials to recycling means that in the decade 156.9 million tons of solid waste would not be disposed in landfills, generating a cost reduction in landfill fee around R\$13 billion, considering the average value of R\$85.00 per ton disposed in landfills. In total, an estimate potential amount of approximately R\$200 billion would be raised in the last decade from the recyclable materials diverted from the residential solid waste stream to recycling.

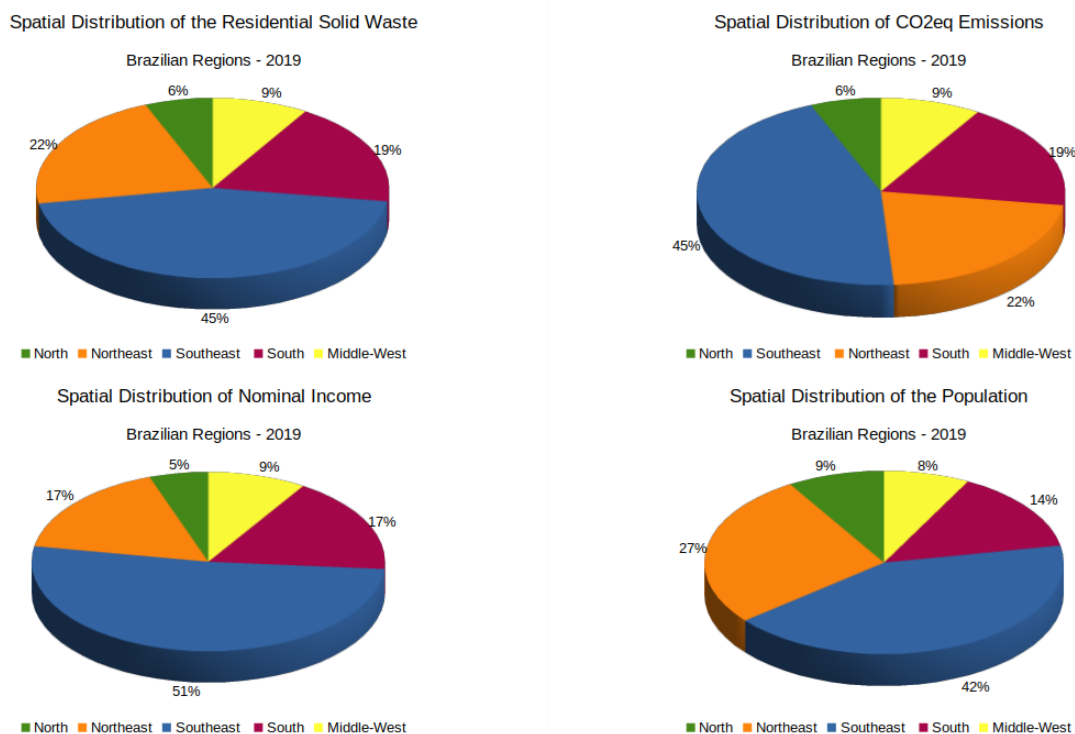
According with SNIS just 7% of the amount of recyclable material from the residential solid waste stream was directed to recycling over the last decade. Meaning that from the estimated potential revenue from recyclable materials sale of R\$179 billion, only an estimated R\$12.5 billion were raised through the recycling of 10.9 million tons of recyclable materials from the residential solid

waste stream and an estimated R\$928.20 million in cost reduction in landfill fees over the decade.

The residential solid waste generated in Brazil and consequently CO₂eq emissions from the residential solid waste stream are not evenly distributed among the Brazilian territory. Following the nominal income concentration and population distribution and density, in 2019, the Southeast (**Figure 03**), was responsible for just under 45% of the total estimated residential solid waste and CO₂eq emissions in the country, holding more than 50% of the nominal income and around 42% of the national population (**Graph 05**). On the other hand, in 2019, the North (**Figure 03**) contributes with just 6% of the total estimated amount of residential solid waste and CO₂eq emissions from the residential solid waste stream (**Graph 05**), even though the region is slightly more populated than the Mid-West, it holds just 5% of the national nominal income (**Table 09**).



Figure 03 – Brazilian Regions.



Graph 05 – Spatial distribution of estimate residential solid waste, CO₂eq emissions, population and nominal income by Brazilian regions – 2019.

Region	Population (hab.)	%	Nominal Income (R\$)	%	Estimate RSW (ton)	%	Estimate CO ₂ eq Emissions (tCO ₂ eq)	%
North	18,414,906	8.76	171,585,975,149.95	5.41	4,306,105.627	6.22	15,888,650.885	6.22
Northeast	57,071,601	27.16	534,150,920,564.51	16.84	14,890,335.010	21.51	54,942,297.069	21.51
Southeast	88,371,413	42.06	1,631,810,746,471.55	51.44	31,084,911.834	44.90	114,696,980.237	44.90
South	29,950,103	14.26	548,889,624,850.90	17.30	12,835,967.053	18.54	47,362,098.605	18.54
Middle-West	16,291,484	7.75	286,032,456,245.08	9.02	6,108,480.579	8.82	22,539,046.594	8.82
Brazil	210,099,507	100	3,172,469,723,281.99	100	69,225,800.103	100	255,429,073.390	100

Table 09 – Population, nominal income, estimate residential solid waste and CO₂eq emissions by Brazilian regions – 2019.

Regarding the estimated residential solid waste per capita in 2019, the North and Northeast presented, an inferior amount in relation of the national estimate residential solid waste per capita with 233.8 and 260.9 kg.hab/year respectively against the 329 kg.hab/year from the national estimate. Moreover, the Southeast, Mid-West and South in 2019 showed estimated residential solid

waste per capita values over the national estimate with 351.7, 374.9 and 428.5 kg.hab/year respectively.

At the state level, the estimated residential solid waste generation is even more unequal. From the 27 states, 20 had an estimated residential solid waste generation of less than 3 million tons in 2019. Together these states are responsible for almost one third of the national estimated residential solid waste generation and CO₂eq emissions (32.71%). In this range we have all states of the North, Mid-West and Northeast (except Bahia) as well as one state in the Southeast (**Figure 04**). The population in these states represents 38.52% of the national population, however it holds just over 28% of the nominal income (**Table 10**).

With an estimate amount of residential solid waste generation between 3 million tons and 7.5 million tons in 2019, one can notice five Brazilian states in this range. All three states in the South, Bahia (Northeast) and Rio de Janeiro (Southeast) compose this range (**Figure 04**) with an estimated amount of residential solid waste generation and CO₂eq emissions just over 32% of the national estimate. Regarding the population and nominal income, those 5 states concentrate 29.55% and 32.7% of the national estimate respectively (**Table 10**).

Lastly, the state of São Paulo and Minas Gerais (**Figure 04**), both in the Southeast, generated an estimated amount of residential solid waste over 7.5 million tons in 2019. Together, both states were responsible for over 35% of the total estimated amount of residential solid waste and CO₂eq emissions in Brazil in 2019. Moreover, those states hold 31.9% of the Brazilian population and 38.9% of the national nominal income in 2019 (**Table 10**).

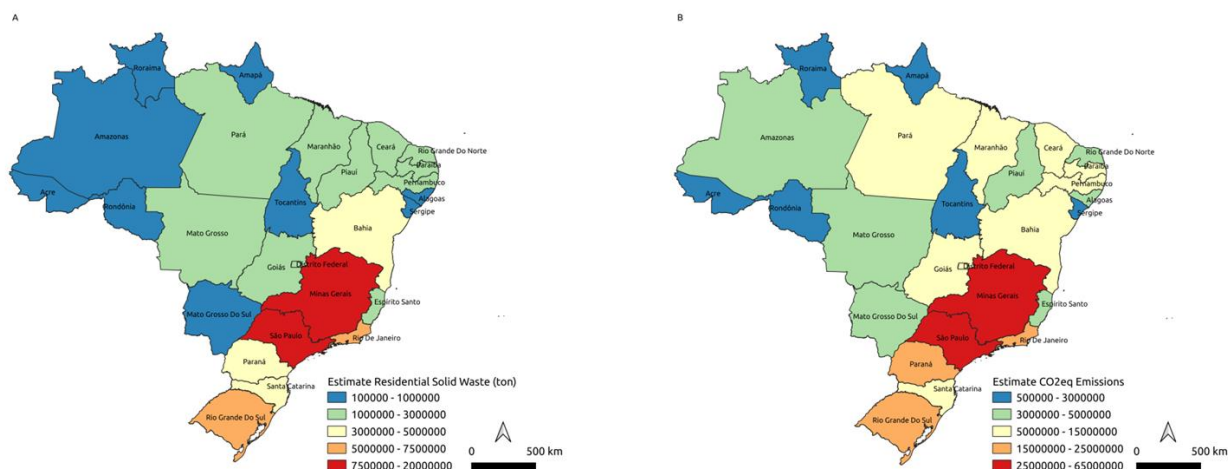


Figure 04 – Estimate amount of residential solid waste (A) and CO₂eq emissions (B) by Brazilian states – 2019.

# of States	Population (hab)	%	Nominal Income (R\$)	%	Estimate RSW (ton)	%	Estimate CO ₂ eq Emissions (tCO ₂ eq)	%
20	80,923,571	38.52	900,859,115,288.51	28.40	22,643,444.065	32.71	83,549,687.067	32.71
05	62,088,120	29.55	1,037,314,043,848.55	32.70	22,176,940.741	32.04	81,828,385.017	32.04
02	67,087,816	31.93	1,234,296,564,144.93	38.91	24,405,415.297	35.25	90,051,001.304	35.25
27	210,099,507	100	3,172,469,723,281.99	100	69,225,800.103	100	255,429,073.390	100

Table 10 – Population, nominal income, estimate residential solid waste and CO₂eq emissions by Brazilian states – 2019.

Up-scaling the spatial distribution of the estimated residential solid waste generated in Brazil to a mesoregion level (**Figure 05**), the inequalities regarding population density and distribution and the nominal income concentration become more evident in the country, reflected in the estimated generation of residential waste and CO₂eq emissions in Brazil. From the 137 mesoregions in Brazil, 12 were highlighted given the amount of estimated residential solid waste generation and CO₂eq emissions in the national scenario (**Table 11**). Together those mesoregions compose 17.75% of the Brazilian municipalities and account for 39.1% of the national estimated residential solid waste generation and CO₂eq emissions. Just three of those mesoregions are not in the South and Southeast, one being in the Northeast and two in the Mid-West. In total those areas

concentrate 48.4% of the national nominal income and 35.7% of the country's population in 2019.

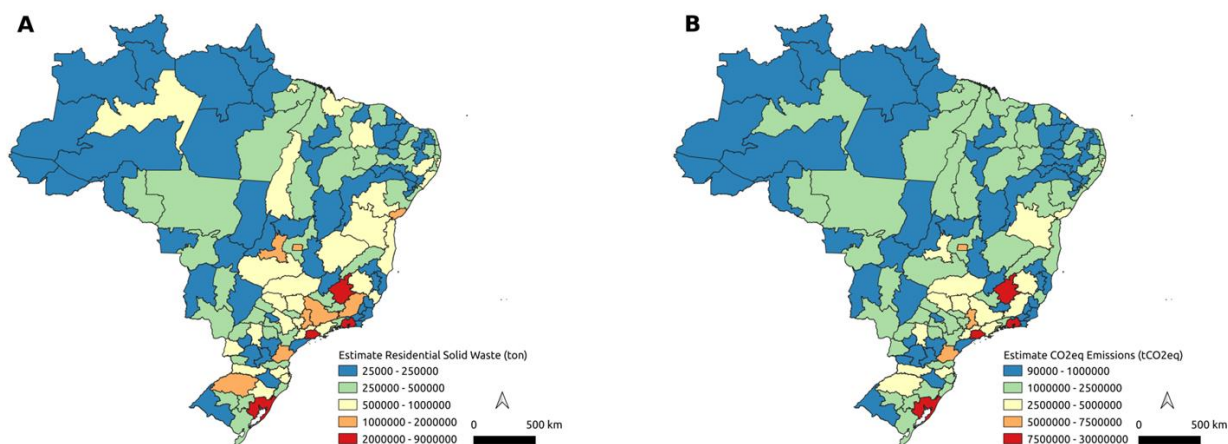


Figure 05 – Estimate amount of residential solid waste (A) and CO₂eq emissions (B) by Brazilian mesoregions – 2019.

Mesoregion	Cities	Population	Income (R\$)	RSW (ton)	RSW (ton.hab)	CO ₂ eq
M. São Paulo	45	23,373,269	519,104,281,884.19	8,053,870.520	0.345	29,717,138.427
M. Rio de Janeiro	30	13,441,328	286,353,999,017.21	4,462,322.293	0.332	16,465,058.500
M. Belo Horizonte	105	6,817,772	128,126,760,905.29	2,342,618.320	0.344	8,643,783.474
M. Porto Alegre	98	5,144,711	109,909,957,875.26	2,039,505.179	0.396	7,525,357.844
Campinas	49	4,314,102	86,517,228,968.99	1,499,101.744	0.347	5,531,379.468
Distrito Federal	1	3,015,254	91,606,974,739.70	1,395,051.734	0.463	5,147,456.165
M. Curitiba	37	3,956,861	80,605,646,597.80	1,363,982.529	0.345	5,032,817.144
NW Rio-grandense	216	1,979,423	34,948,012,717.37	1,346,845.670	0.680	4,969,585.630
Centro Goiano	82	3,586,003	61,645,816,527.15	1,246,047.359	0.347	4,597,660.438
M. Salvador	38	4,601,261	68,347,106,811.32	1,181,585.067	0.257	4,359,807.737
S/SW de Minas	146	2,615,702	37,524,189,118.70	1,121,502.232	0.429	4,138,114.333
Zona da Mata	142	2,311,571	32,304,646,363.08	1,027,118.329	0.444	3,789,856.999
Total	989	75,157,257	1,536,994,621,526.06	27,079,550.976	0.360	99,918,016.159
Brazil	5570	210,099,507	3,172,469,723,281.99	69,225,800.103	0.329	255,429,073.388
%	17.76	35.77	48.45	39.12	+9.35	39.12

Table 11 – Population, nominal income, estimate residential solid waste and CO₂eq emissions from the top 12 Brazilian mesoregions – 2019.

In relation to the Brazilian microregions, seven of 558 had an estimated amount of residential solid waste over one million tons in 2019. These areas are located in the South and Southeast, except for Brasilia (Federal District) which is in the Mid-West (**Figure 06**). The estimated amount of residential solid waste generated and CO₂eq emissions in these areas account for 24.47% of the national estimate, however just under 2% of the Brazilian municipalities are located in these microregions. The seven areas, together, held 34.33% of the national nominal income and 21.93% of the national population in 2019, presenting an estimated residential solid waste generation and CO₂eq emissions per capita of 368 kg.hab and 1.357 tCO₂eq respectively, about 11% over the national average in 2019 (**Table 12**).

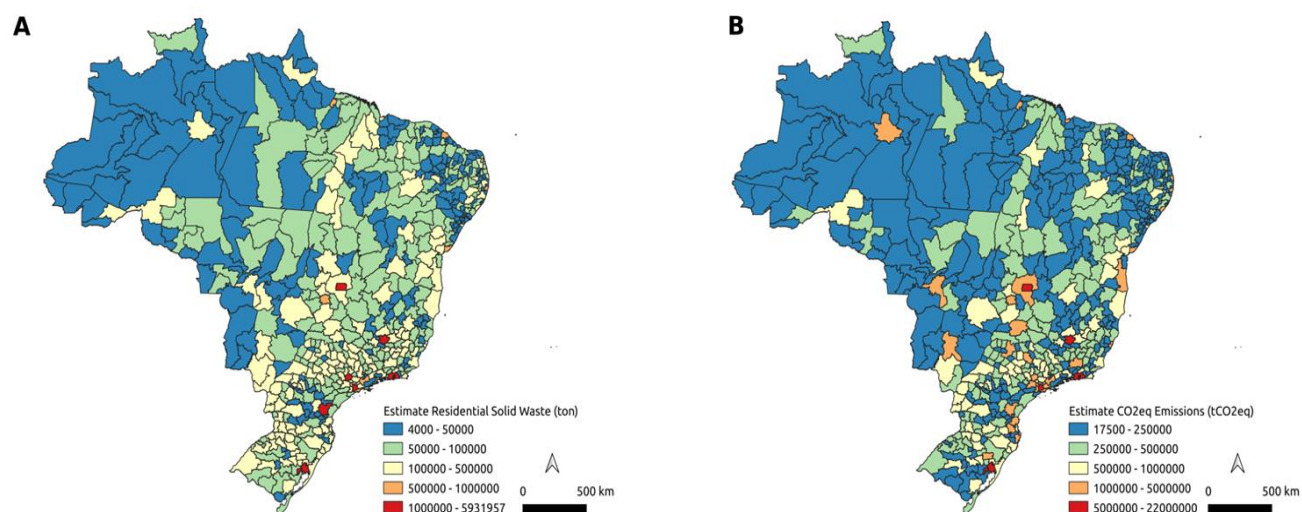


Figure 06 – Estimate amount of residential solid waste (A) and CO₂eq emissions (B) by Brazilian microregions – 2019.

Microregion	Cities	Population	Income (R\$)	RSW (ton)	RSW (ton.hab)	CO ₂ eq
São Paulo	8	15,041,887	388,593,469,274.78	5,931,957.271	0.394	21,887,711.615
Rio de Janeiro	16	12,376,727	270,883,755,723.97	4,174,475.427	0.337	15,402,962.318
Belo Horizonte	24	5,230,434	107,448,432,058.45	1,722,539.533	0.329	6,355,819.309
Porto Alegre	22	3,886,817	90,834,286,285.24	1,462,657.266	0.376	5,396,906.780
Brasília	1	3,015,254	91,606,974,739.70	1,395,051.734	0.463	5,147,456.165
Curitiba	19	3,477,371	74,341,626,926.07	1,200,841.938	0.345	4,430,861.661
Campinas	16	3,049,727	65,508,994,271.47	1,055,362.652	0.346	3,894,072.790
Total	106	46,078,217	1,089,217,539,279.68	16,942,885.821	0.368	62,515,790.638
Brazil	5570	210,099,507	3,172,469,723,281.99	69,225,800.103	0.329	255,429,073.388
%	1.90	21.93	34.33	24.47	+11.60	24.47

Table 12 – Population, nominal income, estimate residential solid waste and CO₂eq emissions from the top 7 Brazilian microregions – 2019.

The majority of the Brazilian municipalities, around 74%, had less than 25 thousand inhabitants in 2019. These municipalities shelter just under 19% of the national population, concentrating about 11% of the national income and accounting for just over 30% of the total estimated amount of the residential solid waste generation and CO₂eq emission in Brazil in 2019. On the other hand, 48 municipalities, less than 1% of the Brazilian municipalities, shelter 31% of the national population, concentrating over 46% of the national income and responsible for 32% of the total estimated amount of residential solid waste generated and CO₂eq emissions in Brazil in 2019 (**Table 13**).

Class	Cities (#)	Population (hab.)	Income (R\$)	RSW (ton)	CO ₂ eq (tCO ₂ eq)
under 25K hab.	4138	39,630,854	370,144,498,312.39	21,255,431.261	78,428,203.215
25K hab. to 50K hab.	754	25,815,386	247,660,082,401.56	6,610,025.786	24,389,645.995
50K hab. to 100K hab.	349	23,948,861	274,304,865,723.80	5,484,549.706	20,236,868.974
100K hab. to 500K hab.	276	54,191,850	800,653,408,366.50	13,202,622.810	48,714,983.524
over 500K hab.	48	66,512,556	1,479,706,868,477.74	22,654,279.905	83,589,669.117

Table 13 – Population, nominal income, estimate residential solid waste and CO₂eq emissions from the Brazilian municipalities by class of inhabitants – 2019.

The aforementioned confirms the imbalance of the population distribution and density in Brazil (**Figure 07**) (**Graph 06**), the income inequality among the municipalities (**Figure 08**) (**Graph 07**), as well as its reflection in the estimated municipal residential solid waste generation (**Figure 09**) (**Graph 08**) and CO₂eq emissions from the residential solid waste stream in Brazil (**Figure 10**) (**Graph 09**).

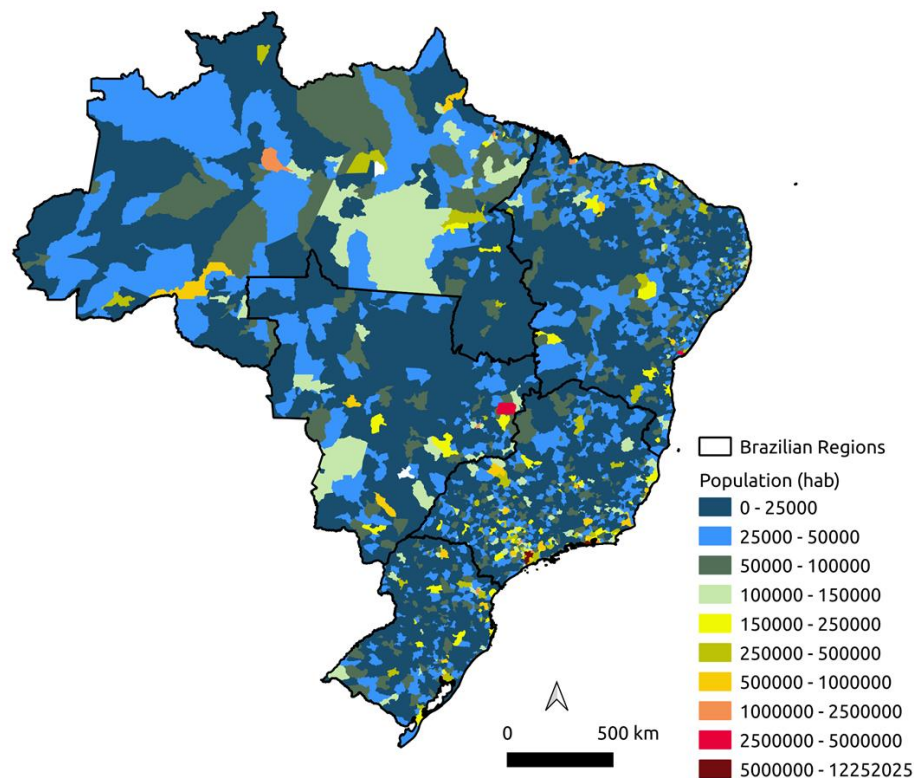
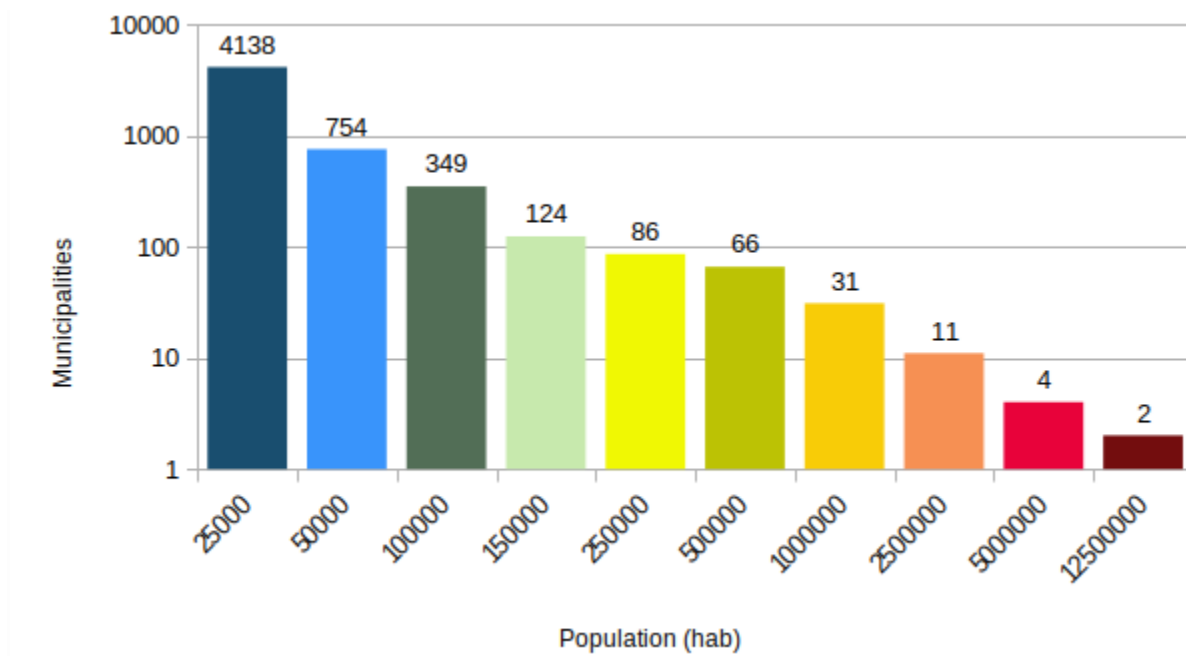


Figure 07 – Spatial distribution of the Brazilian population by municipalities in 2019.



Graph 06 - Histogram of frequency from the population distribution by Brazilian municipality – 2019.

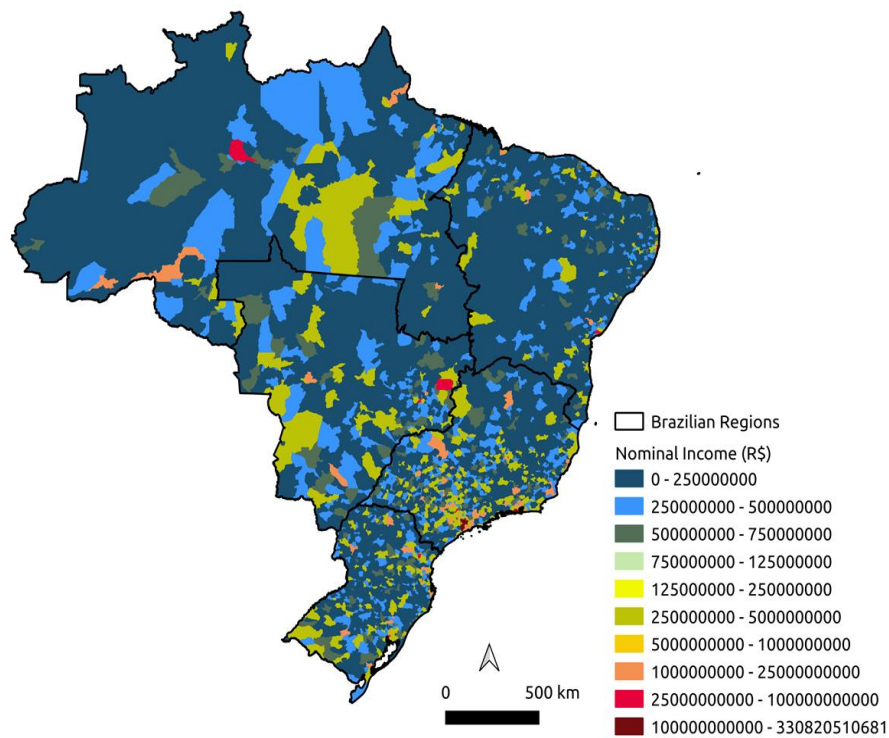
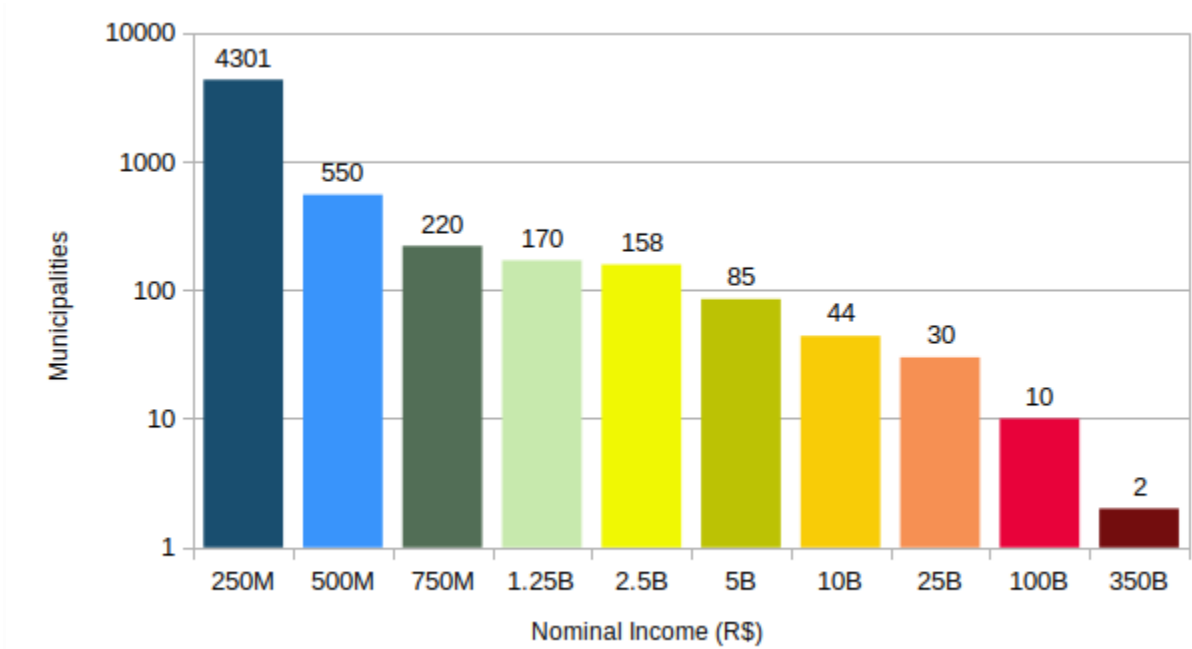


Figure 08 – Spatial distribution of the nominal income by municipalities in 2019.



Graph 07 - Histogram of frequency from the nominal income distribution by Brazilian municipality – 2019.

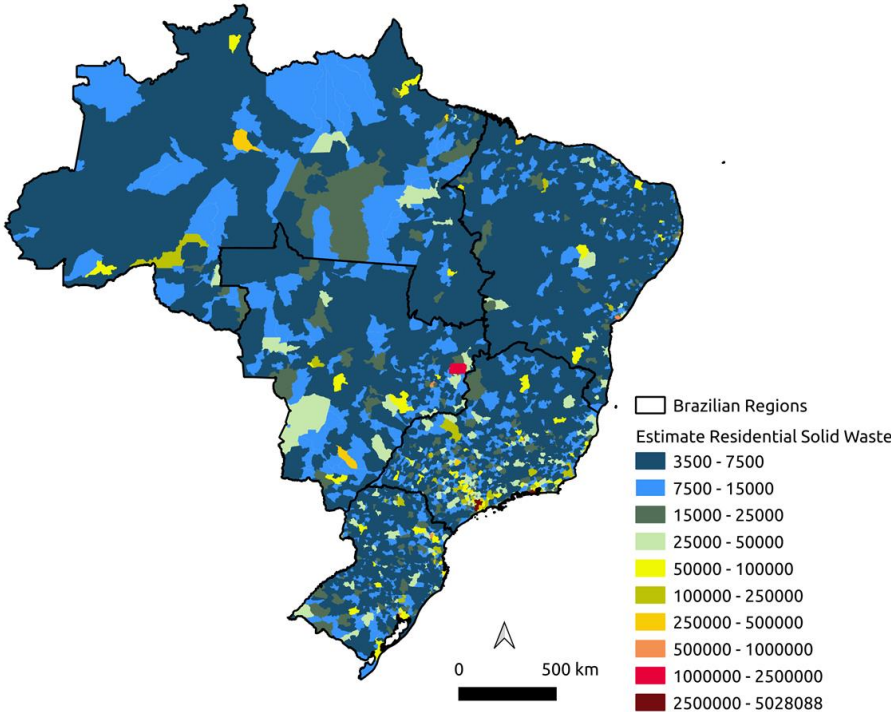
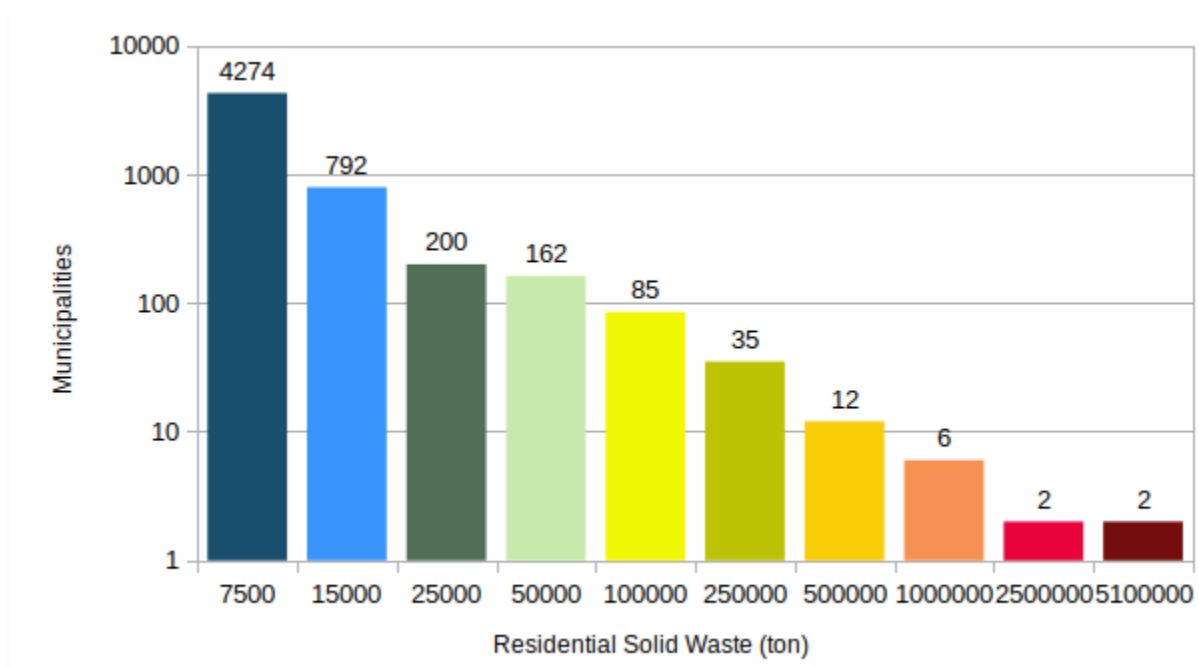


Figure 09 – Spatial distribution of the estimate residential solid waste by municipalities in 2019.



Graph 08 - Histogram of frequency from the estimate residential solid waste distribution by Brazilian municipality – 2019.

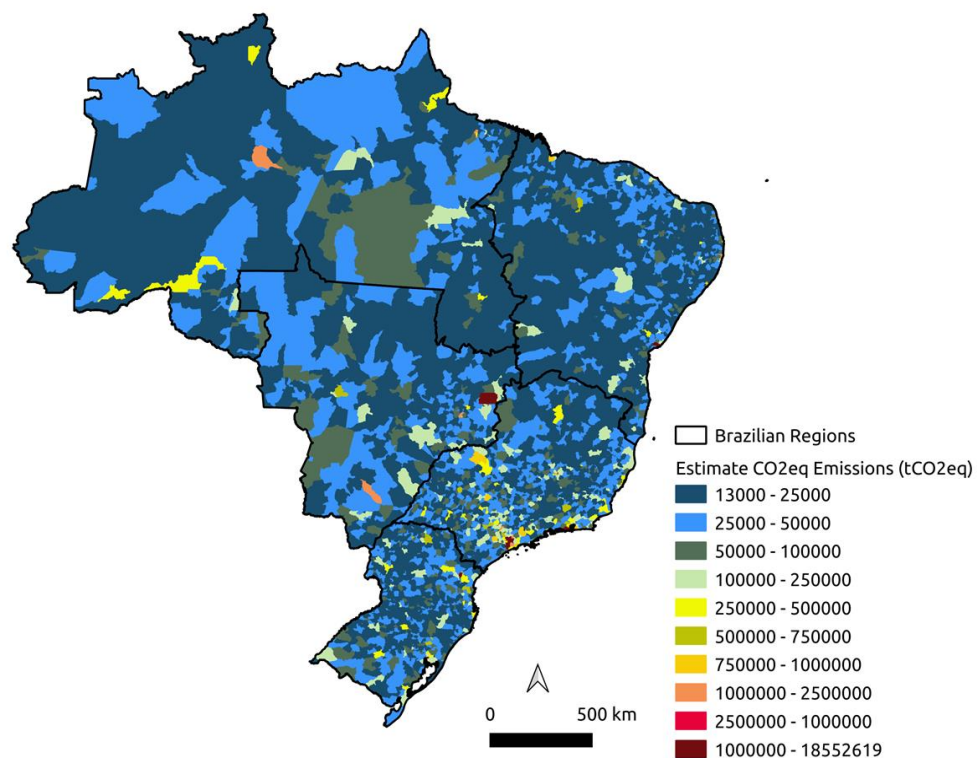
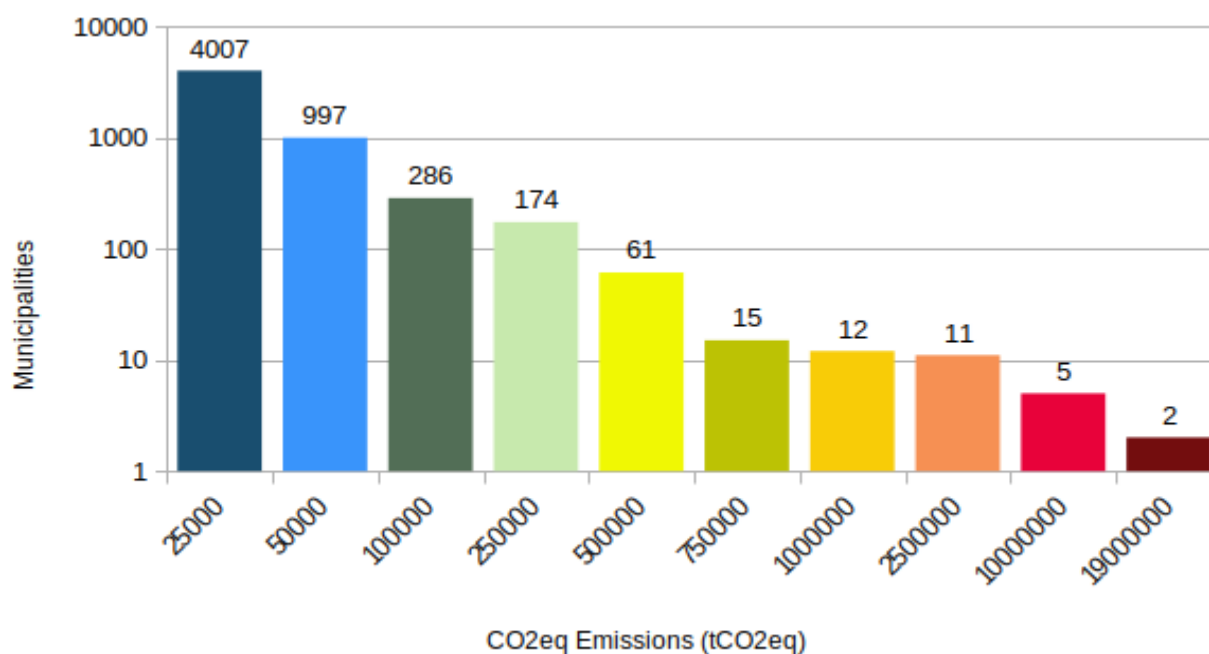


Figure 10 – Spatial distribution of the estimate CO₂eq emissions by municipalities in 2019.



Graph 09 - Histogram of frequency from the estimate CO₂eq emissions distribution by Brazilian municipality – 2019.

The twenty Brazilian municipalities with higher estimated amount of residential solid waste generation and CO₂eq emission are distributed in the five Brazilian regions. In total, these municipalities accounted for a quarter (25.7%) of the national estimated residential solid waste generation and CO₂eq emissions from the residential solid waste stream. Fifteen municipalities in this list are state capitals while the other five municipalities are located in the São Paulo state (four municipalities) and Rio de Janeiro (one municipality) (**Figure 11**).

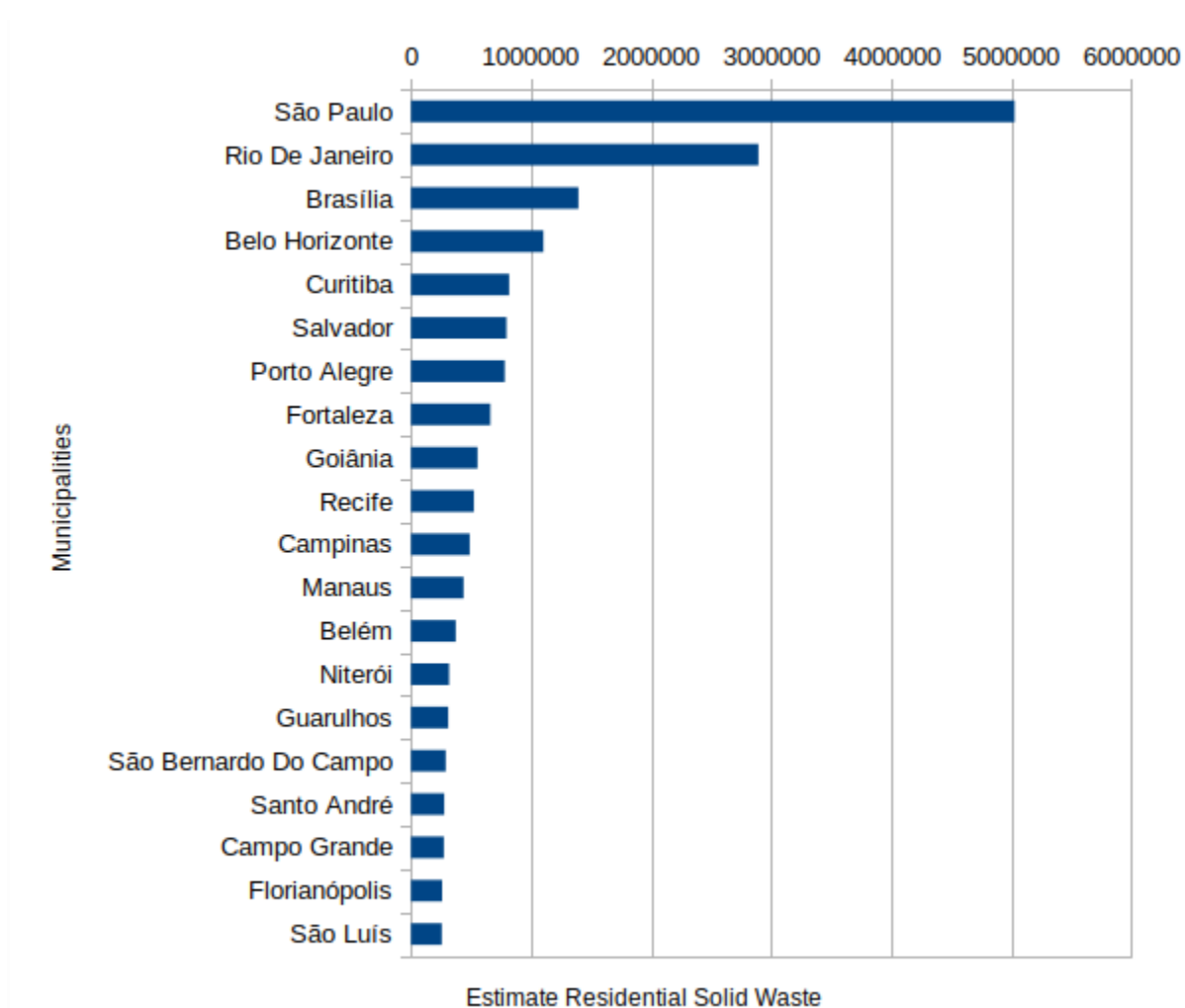
The estimated amount generated in those municipalities in 2019 are showed in **Table 14** and highlighted in **Graph 10**.

Municipality	State	Region	Population (hab)	Estimated RSW (ton)	Estimated CO ₂ eq (tCO ₂ eq)
São Paulo	SP	SE	12252025	5028088.19	18552619.19
Rio De Janeiro	RJ	SE	6718897	2894479.04	10680036.9
Brasília	DF	MW	3015254	1395051.73	5147456.17
Belo Horizonte	MG	SE	2512066	1102861.97	4069335.59
Curitiba	PR	S	1933135	818056.02	3018459.75
Salvador	BA	NE	2872328	795734.24	2936096.94
Porto Alegre	RS	S	1483759	781336.14	2882970.9
Fortaleza	CE	NE	2669344	660904.69	2438603.43
Goiânia	GO	MW	1516112	554114.83	2044570.62
Recife	PE	NE	1645736	524254.45	1934391.93
Campinas	SP	SE	1204082	489571.62	1806419.36
Manaus	AM	N	2182772	438530.75	1618088.95
Belém	PA	N	1492745	373206.82	1377057
Niterói	RJ	SE	513592	318555.27	1175403.92
Guarulhos	SP	SE	1379179	310373.5	1145214.87
São Bernardo Do Campo	SP	SE	838936	290248.51	1070957.75
Santo André	SP	SE	718775	277508.66	1023950.32
Campo Grande	MS	MW	895989	274259.25	1011960.67
Florianópolis	SC	S	500971	260141.31	959868.32
São Luís	MA	NE	1101886	256498.52	946427.19
Total			47447583	17843775.52	65839889.74

Table 14 – Estimated amount of residential solid waste generation and CO₂eq emissions in the top 20 Brazilian municipalities – 2019.



Figure 11 – Top 20 Brazilian municipalities with higher estimated amount of residential solid waste generation and CO₂eq emission in 2019.



Graph 10 – Top 20 Brazilian municipalities with higher estimated amount of residential solid waste generation and CO₂eq emission in 2019.

Under different circumstances, the twenty Brazilian municipalities with lower estimated amounts of residential solid waste generation and CO₂eq emission are concentrated in the North and Northeast in Brazil (**Figure 12**). In total these municipalities accounted for less than 1% (0.11%) of the national estimated residential solid waste generation and CO₂eq emissions from the residential solid waste stream. Thirteen municipalities in this list are located in the Northeast where six are in the Paraíba state, five in the Piauí state and two in the Rio Grande do Norte state. Five in the North region, all in the Tocantins state and two in the Southeast region, one in São Paulo state and one in Minas Gerais state.

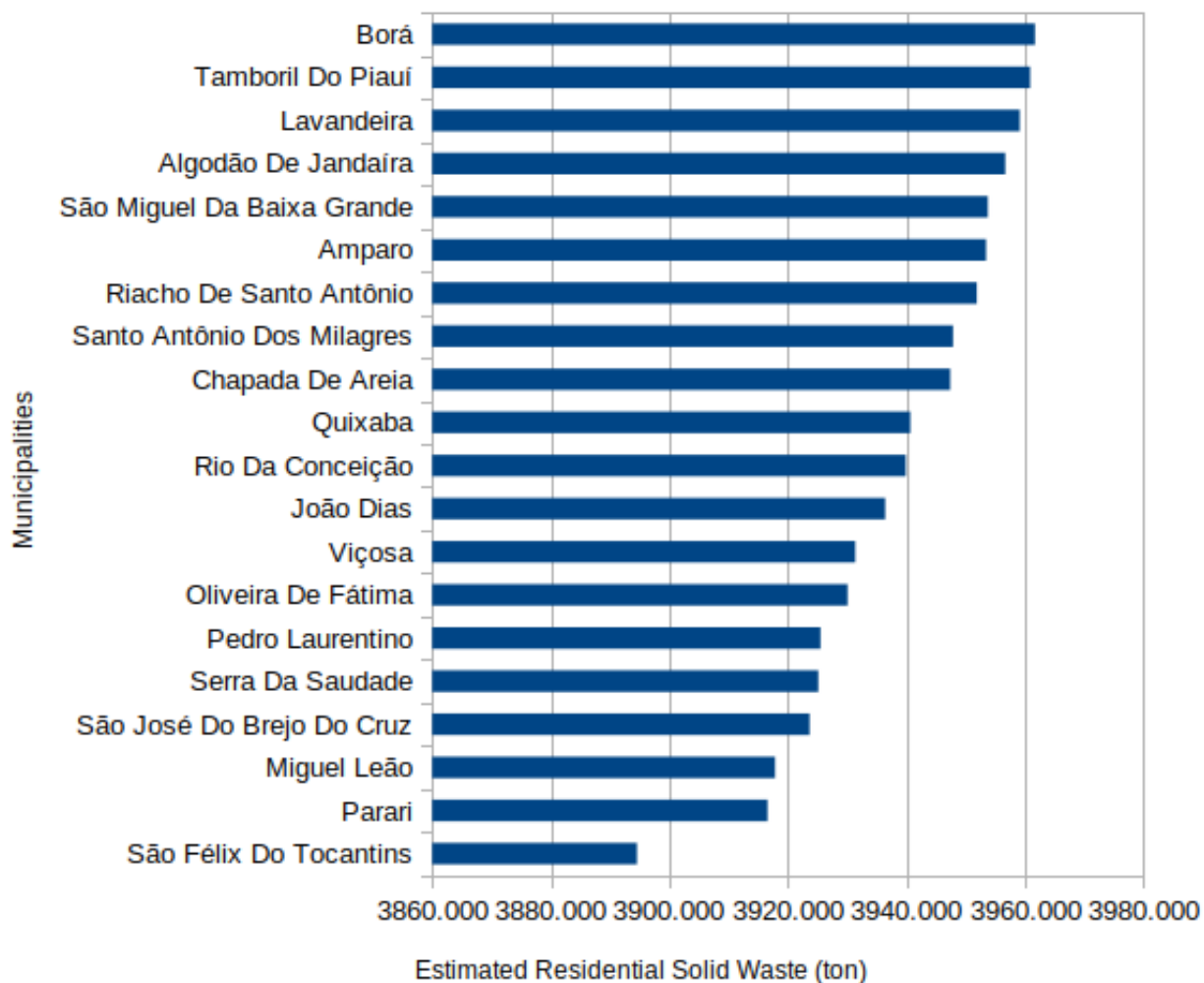
The estimated amount generated in those municipalities in 2019 are showed in **Table 15** and highlighted in **Graph 11**.



Figure 12 – Top 20 Brazilian municipalities with lower estimated amount of residential solid waste generation and CO₂eq emission in 2019.

Municipality	State	Region	Population (hab)	Estimated RSW (ton)	Estimated CO ₂ eq (tCO ₂ eq)
São Félix Do Tocantins	TO	N	1585	3894.561	14370.131
Parari	PB	NE	1771	3916.586	14451.405
Miguel Leão	PI	NE	1246	3917.863	14456.114
São José Do Brejo Do Cruz	PB	NE	1801	3923.674	14477.556
Serra Da Saudade	MG	SE	781	3925.139	14482.959
Pedro Laurentino	PI	NE	2536	3925.523	14484.379
Oliveira De Fátima	TO	N	1112	3930.109	14501.304
Viçosa	RN	NE	1719	3931.385	14506.007
João Dias	RN	NE	2654	3936.432	14524.635
Rio Da Conceição	TO	N	2130	3939.908	14537.457
Quixaba	PB	NE	1955	3940.676	14540.289
Chapada De Areia	TO	N	1406	3947.394	14565.080
Santo Antônio Dos Milagres	PI	NE	2161	3947.882	14566.877
Riacho De Santo Antônio	PB	NE	1948	3951.897	14581.695
Amparo	PB	NE	2238	3953.450	14587.428
São Miguel Da Baixa Grande	PI	NE	2452	3953.743	14588.505
Algodão De Jandaíra	PB	NE	2567	3956.691	14599.379
Lavandeira	TO	N	1923	3959.113	14608.318
Tamboril Do Piauí	PI	NE	2920	3960.875	14614.817
Borá	SP	SE	837	3961.690	14617.827
Total			37742	78774.591	290662.162

Table 15 – Estimated amount of residential solid waste generation and CO₂eq emissions in the last 20 Brazilian municipalities – 2019.



Graph 11 – Top 20 Brazilian municipalities with lower estimated amount of residential solid waste generation and CO₂eq emission in 2019.

3.2. Spatial Distribution of Estimated Residential Solid Waste and CO₂eq Emissions within Municipal Boundaries.

The estimated amount of residential solid waste generation and CO₂eq emissions from the residential solid waste stream within the municipal boundary was obtained through the application of the methodological procedure described in the section 2 subsection 2.5 of this research. In this regard a municipal waste

rate was calculated for each Brazilian municipality and used to estimate the residential solid waste in the census area level (**Figure 13**).

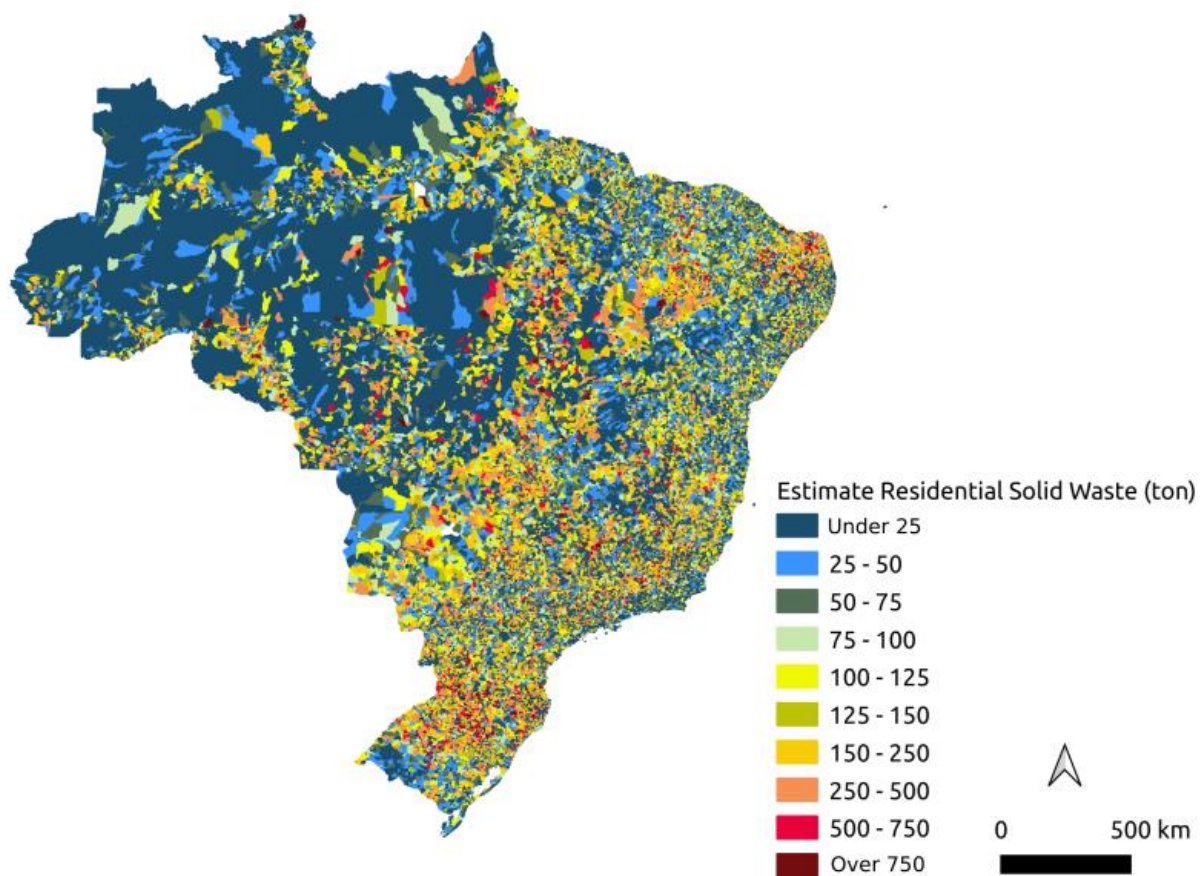


Figure 13 - Spatial distribution of the estimate residential solid waste by census area in 2019.

For instance, this research analyzed the city of São Paulo as a case study to demonstrate the obtained results of the spatial distribution of the estimated amount of residential solid waste generation and CO₂eq emissions from the residential solid waste stream within the municipal boundary. Located in the Brazilian southeast, in São Paulo state (**Figure 14**), the city of São Paulo is the largest megacity in Brazil and one of the most important in Latin America, home to several transnational company headquarters and numerous specialized and

diversified services in telecommunications, culture, education, health, gastronomy, and so on. According to SNIS, the coverage of residential solid waste collection reached 99.1% in relation to the total population, and the selective collection around 80% of the urban population. However, just 0.88% of the recyclable materials were recovered in recycling facilities. There are 25 waste pickers cooperatives registered in the SNIS in the city, with a workforce of 739 workers (Ministério do Desenvolvimento Regional, 2020).



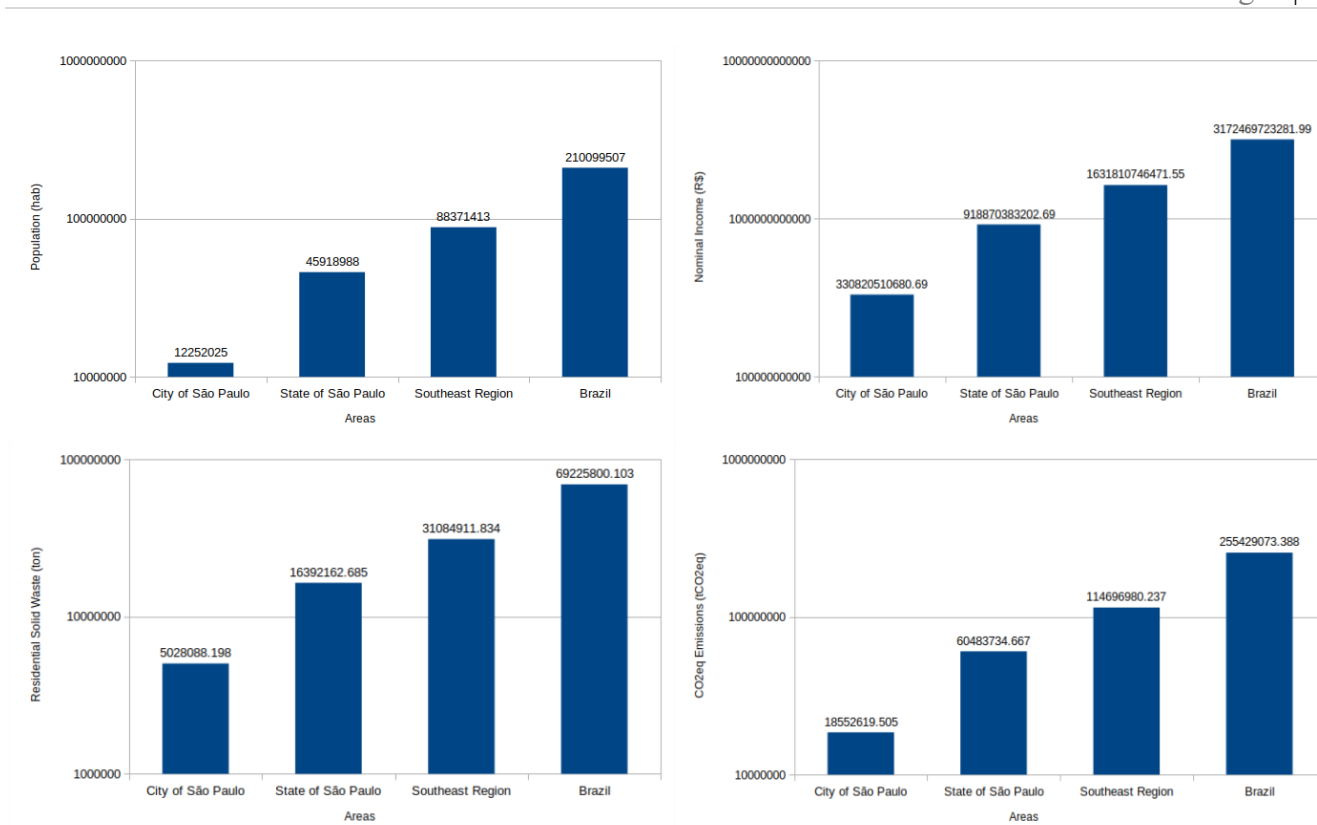
Figure 14 – Location of the city of São Paulo.

The numbers surrounding the city are impressive. Over 12 million inhabitants live in its 1,521.110 square kilometres area, with a demographic density just under 8 thousand inhabitants per square kilometre. The city of São

Paulo gathers around 5.8% of the national population, 13.8% of the population in the Southeast and 26.6% of the state population. Regarding nominal income, it holds 10.4% of the national income, 20.2% of the income in the Southeast and 36% of the state income. As a result, the city of São Paulo generates around 7.2% of the national estimated amount of residential solid waste and CO₂eq emissions, an estimate of 16.1% for the Southeast and 30.6% for the state (**Table 16**) (**Graph 12**).

Area	Population (hab)	Income (R\$)	RSW (ton)	CO ₂ eq (tCO ₂ eq)
City of São Paulo	12,252,025	330,820,510,680.69	5,028,088.198	18,552,619.505
State of São Paulo	45,918,988	918,870,383,202.69	16,392,162.685	60,483,734.667
Southeast Region	88,371,413	1,631,810,746,471.55	31,084,911.834	114,696,980.237
Brazil	210,099,507	3,172,469,723,281.99	69,225,800.103	255,429,073.388

Table 16 - Comparison between the city of São Paulo population, income and estimate residential solid waste and CO₂eq emissions with São Paulo state, Southeast and Brazil – 2019.



Graph 12 - Comparison between the city of São Paulo population, income and estimate residential solid waste and CO₂eq emissions with São Paulo state, Southeast region and Brazil – 2019.

The city of São Paulo is composed of 96 neighbourhoods (**Figure 15a**) and divided into 19,205 census areas (**Figure 15b**). The population is not evenly distributed throughout the city. The neighbourhood of Grajaú had 394,027 inhabitants in 2019, while the Marsilac neighbourhood, on the other extreme, counts just 8,944 inhabitants (**Figure 16**).

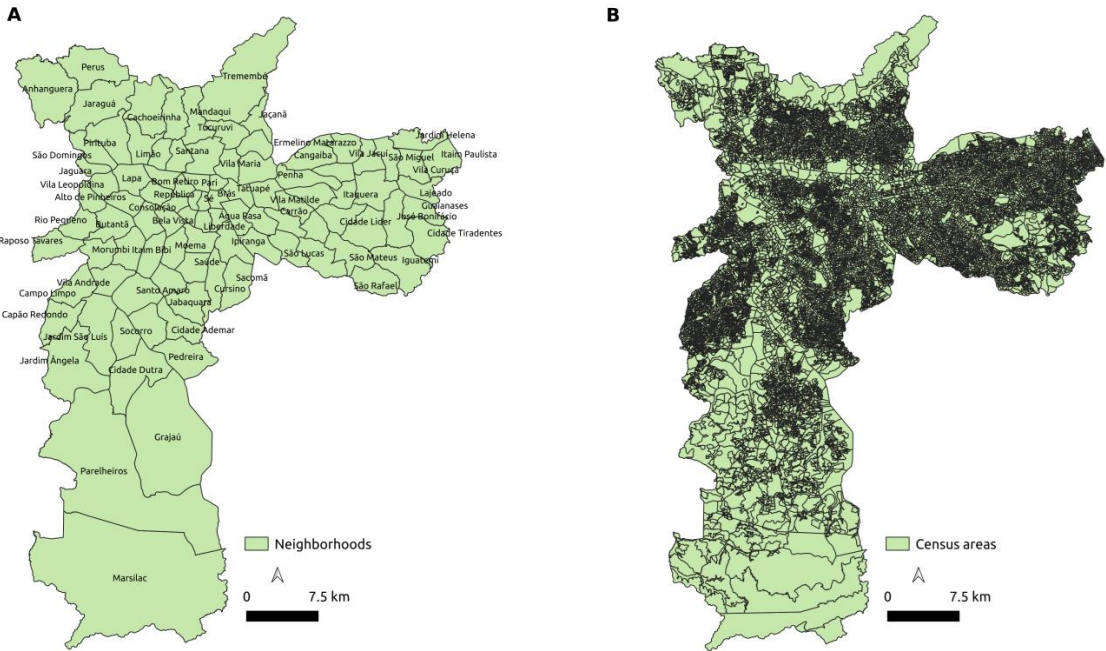


Figure 15 - The city of São Paulo neighbourhood's division (A) and census areas division (B).

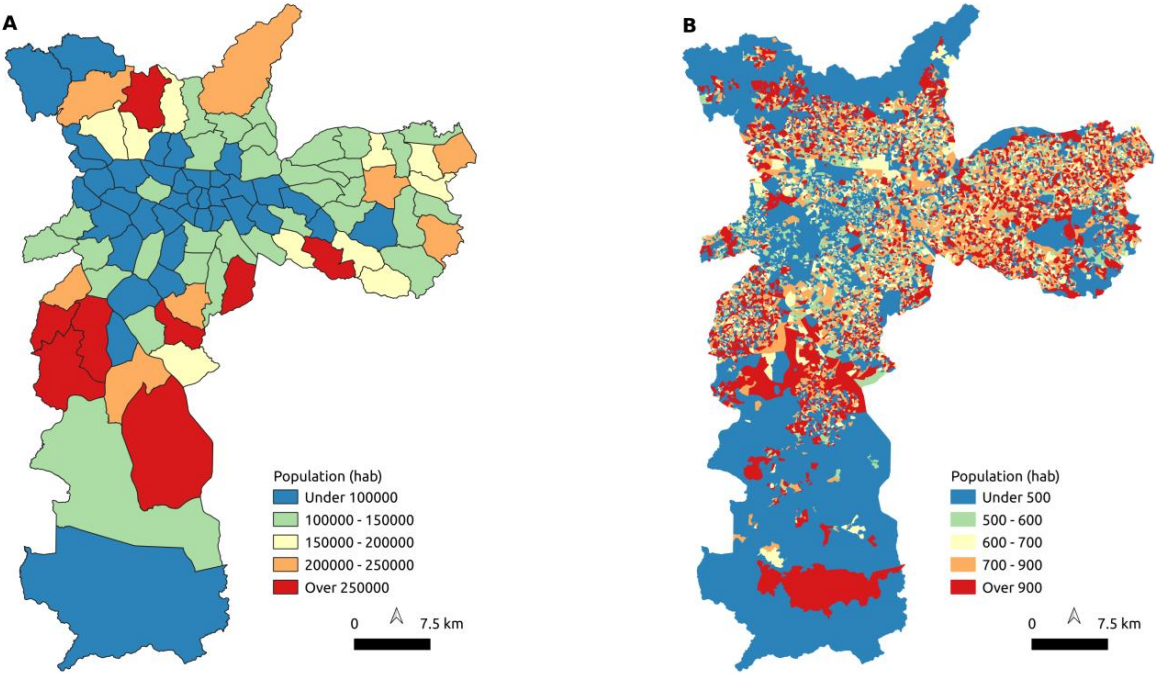


Figure 16 - The city of São Paulo population distribution by neighbourhoods (A) and census areas (B) – 2019.

The estimated nominal annual income per capita in the city was around R\$27,001.29 in 2019, which corresponds to just over twice the annual minimum wage. However, income variations within São Paulo's neighbourhoods range from R\$8,366.17, around 62% of the annual minimum wage in the poorest neighbourhood, to R\$118,767.29, just under 9 times the annual minimum wage in the richest neighbourhood (**Figure 17**).

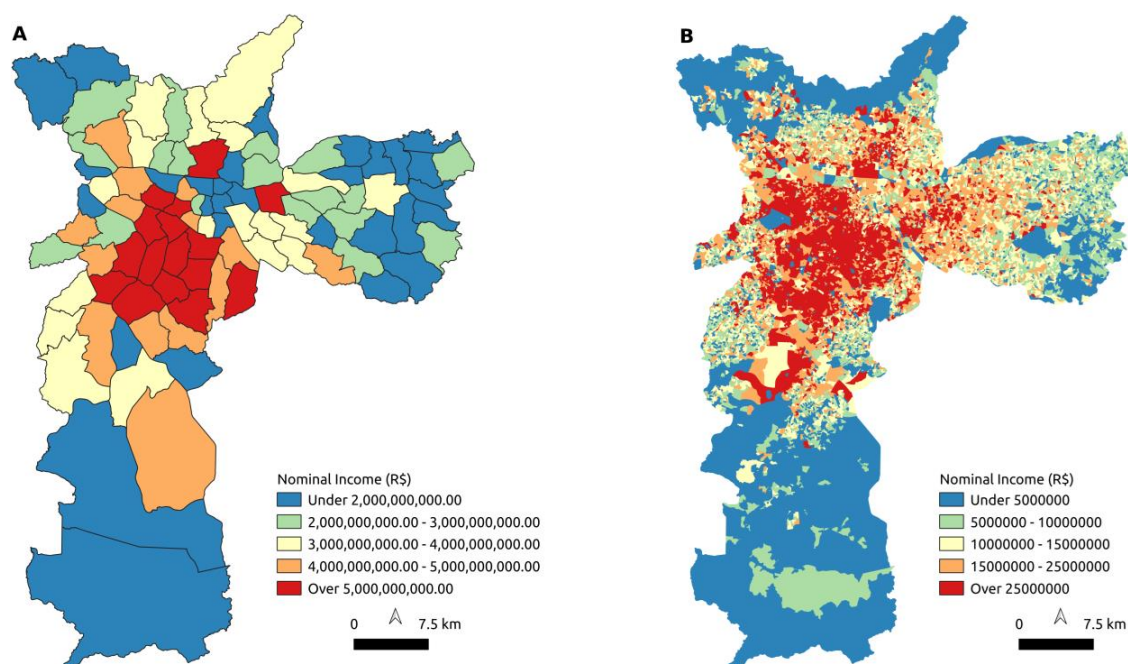
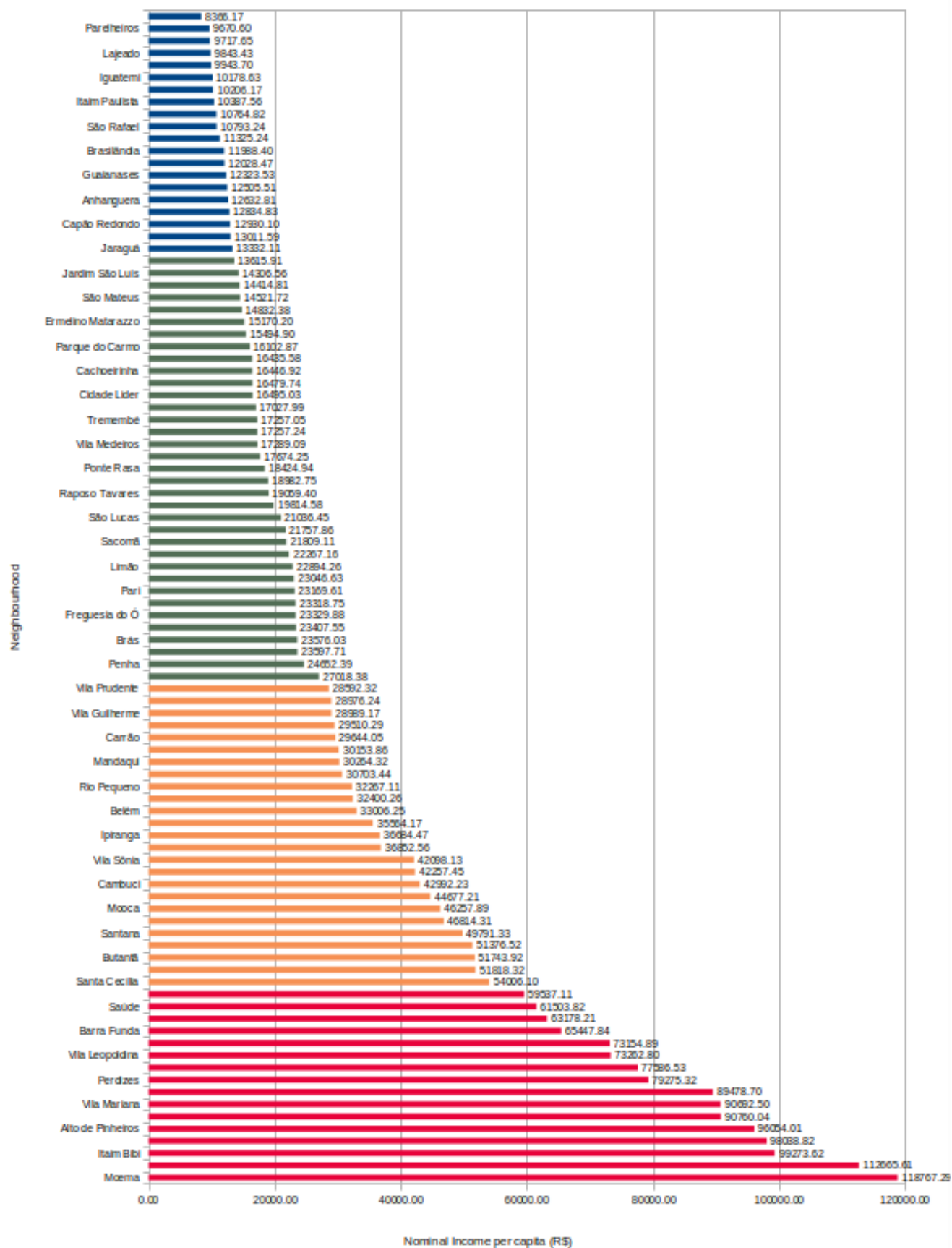


Figure 17 - The city of São Paulo nominal annual income distribution by neighbourhoods (A) and census areas (B) – 2019.

From the 96 neighbourhoods in the city of São Paulo, 54 presented an estimated nominal annual income per capita inferior to the city's average, and 20 of those were below the annual minimum wage in 2019. These 54 neighbourhoods represent around 69% of the city's population (8,456,552 inhabitants), with 42% of those living on less than the annual minimum wage in 2019 (3,611,153 inhabitants).

The remaining 42 neighbourhoods were over the city's average, comprising around 31% of the city's population (3,795,473 inhabitants). From those, 25 neighbourhoods presented a nominal income per capita ranging between the city's average and two times the city's average, representing 64% of those neighbourhood's population and 19% of the city's population (2,432,065 inhabitants). 36% of those neighbourhood's population, 11% of the city's population (1,363,408 inhabitants), received over two times the city's average income in 2019 (**Graph 13**).



Graph 13 - Nominal income per capita by São Paulo's neighbourhood – 2019.

The aforementioned income inequality is reflected in the estimated residential solid waste generation and CO₂eq emissions from the residential solid waste stream in the city of São Paulo's neighbourhoods and census areas (**Figure 18,19**).

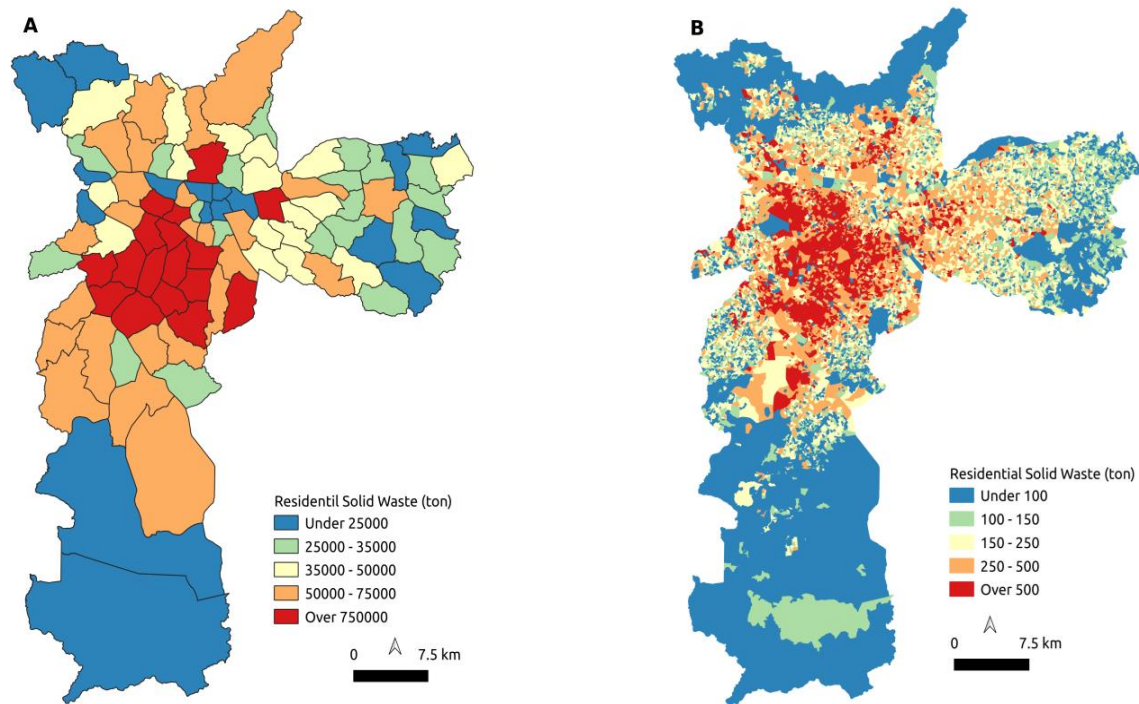


Figure 18 - The city of São Paulo estimated residential solid waste distribution by neighbourhoods (A) and census areas (B) – 2019.

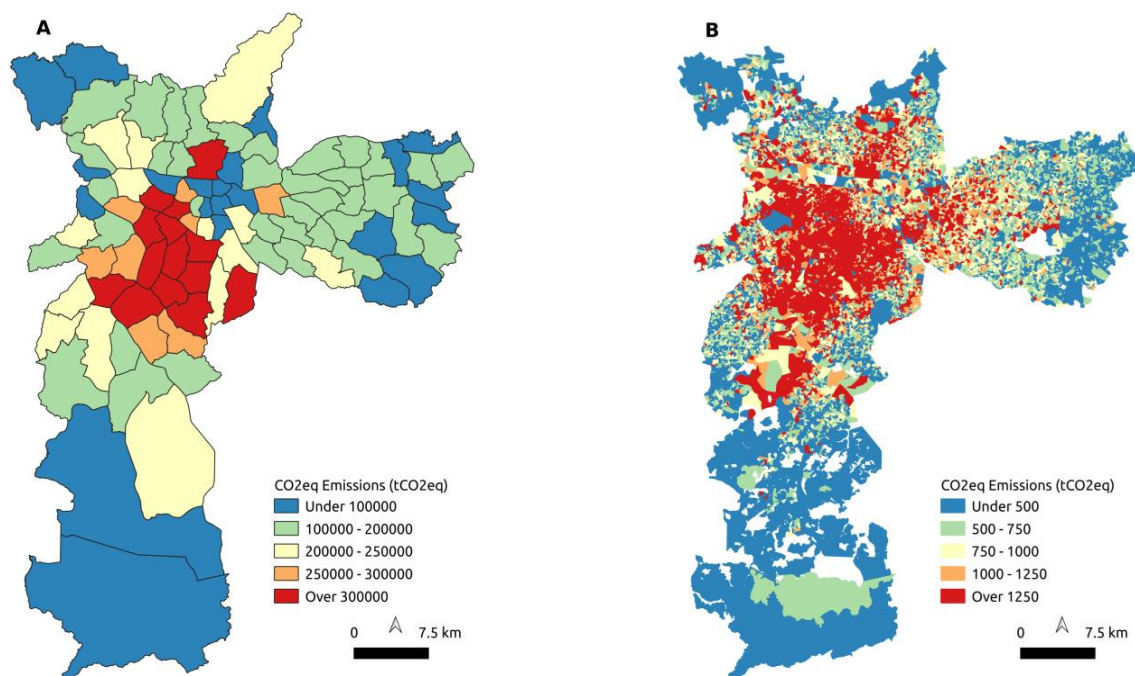
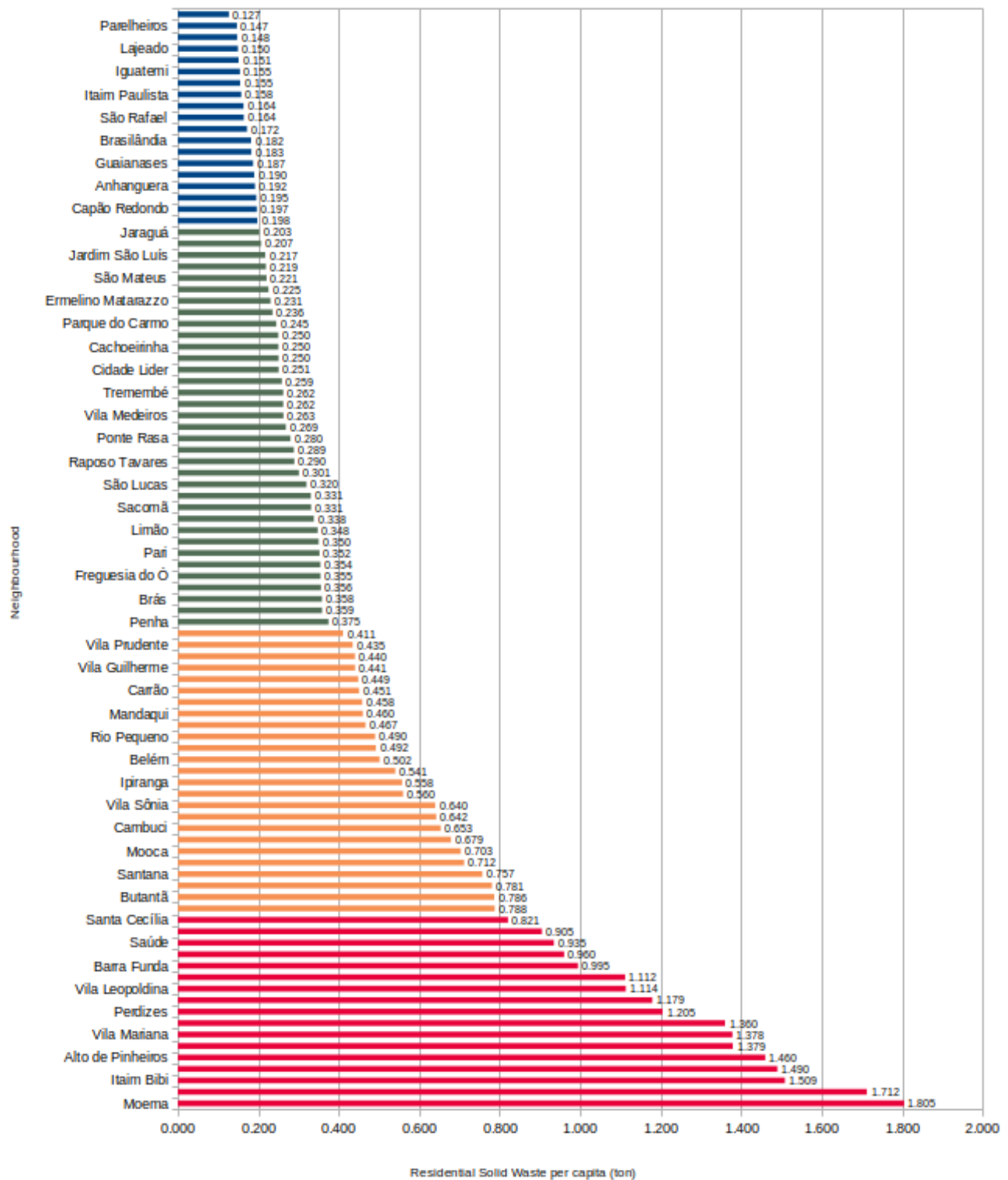


Figure 19 - Estimated CO₂eq emissions distribution by neighbourhoods (A) and census areas (B), in 2019, for the city of São Paulo.

The city of São Paulo had an estimated residential solid waste per capita calculated in 0.410 ton.hab/year and CO₂eq emissions per capita from the residential solid waste stream of 1.514 tCO₂eq.hab/year in 2019. However, looking at the neighbourhoods the estimated residential solid waste per capita vary from 0.127 ton.hab/year in the poorest neighbourhood to an estimated amount per capita of 1.805 ton.hab/year in the richest neighbourhood (**Graph 14**). Such variations become more accentuated in the census areas where the highest estimated amount of residential solid waste per capita reaches around 9 ton.hab/year in the Morumbi neighbourhood in contrast with less than 0.02 ton.hab/year in the Cidade Tiradentes neighbourhood.



Graph 14 – Estimated residential solid waste per capita by São Paulo's neighbourhood – 2019.

The Morumbi neighbourhood, known as an iconic rich neighbourhood in the city of Sao Paulo, for instance, is not as homogeneous as it seems regarding the nominal income distribution and consequent estimated amount of residential solid waste generated within its borders. Morumbi is divided in 126 census areas and had a projected population of 51,042 inhabitants in 2019 (**Figure 20**).

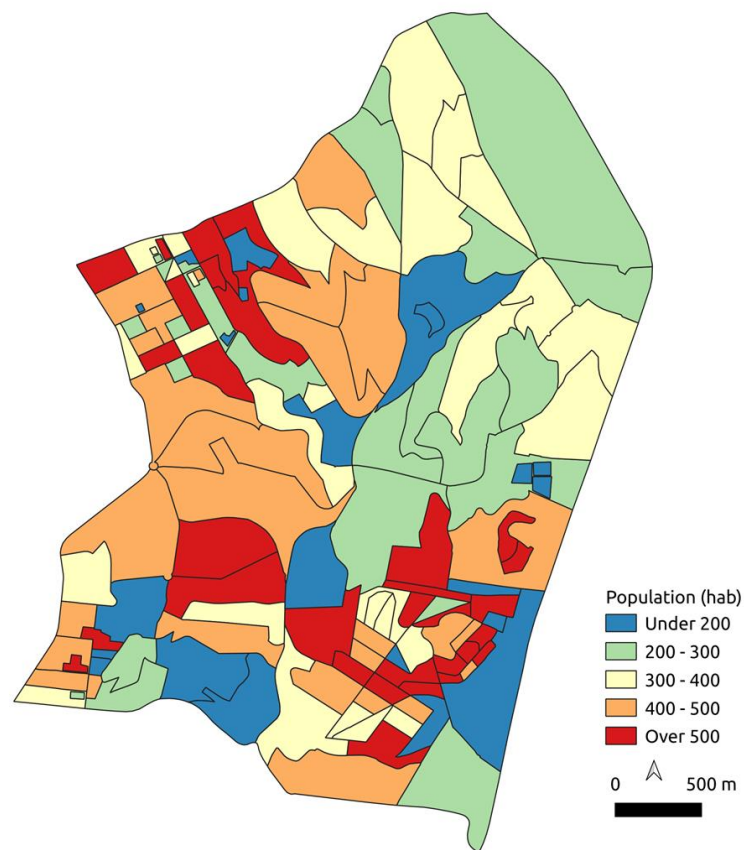


Figure 20 – Population distribution in Morumbi neighbourhood by census areas – 2019.

Even though Morumbi is a rich neighbourhood, about 17% of its population (8,803 inhabitants) live with less than the annual minimum wage in 2019 (**Figure**

21). In this regard, the nominal income per capita within Morumbi's borders ranges from R\$3,795.71 to over R\$600,000.00 annually.

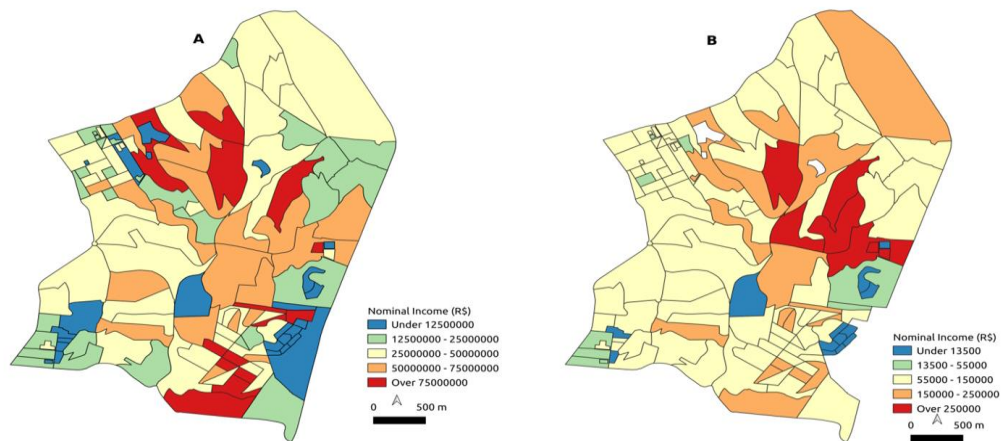


Figure 21 – Total nominal income (A) and nominal income per capita (B) distribution in Morumbi neighbourhood by census areas – 2019.

Therefore, the estimated amount of residential solid waste generated in the neighbourhood varies from 0.058 ton.hab/year in the poorest census area to over 9 ton.hab/year in the richest part of the neighbourhood (**Figure 22**).

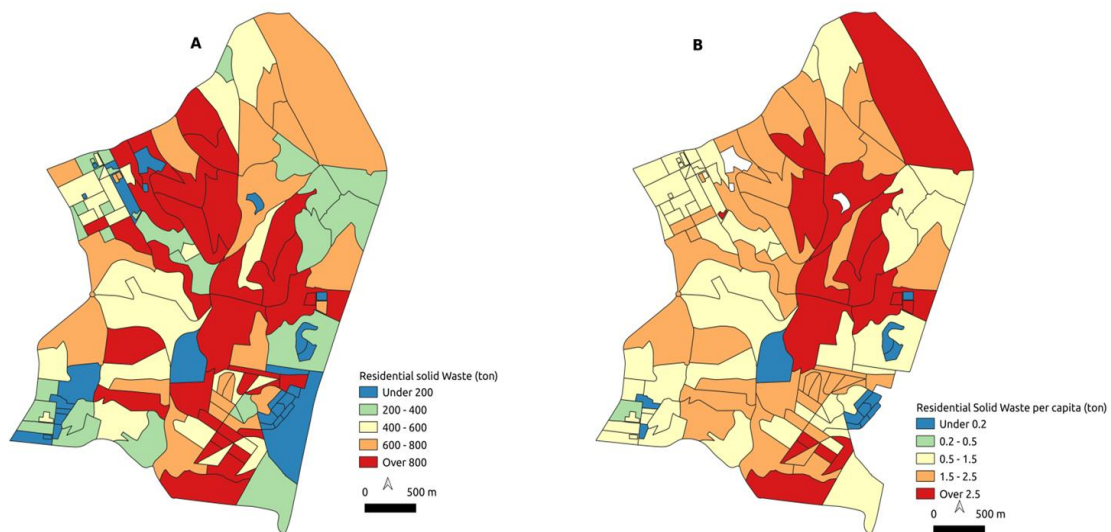


Figure 22 – Total estimated residential solid waste (A) and estimated residential solid waste per capita (B) distribution in Morumbi neighbourhood by census areas – 2019.

The **table 17** shows the estimated values per capita for nominal income, residential solid waste generated and CO₂eq emissions from the residential solid waste stream for the city of São Paulo neighbourhoods.

Neighbourhood	# Census Areas	Population	Income per capita (R\$)	RSW per capita (ton)	Emissions per capita (tCO ₂ eq)
Moema	177	90,962	118,767.29	1.805	6.661
Jardim Paulista	217	96,649	112,665.61	1.712	6.318
Itaim Bibi	208	100,560	99,273.62	1.509	5.567
Morumbi	133	51,042	98,038.82	1.490	5.498
Alto de Pinheiros	79	46,653	96,054.01	1.460	5.387
Consolação	147	62,451	90,760.04	1.379	5.090
Vila Mariana	231	141,014	90,692.50	1.378	5.086
Pinheiros	175	71,025	89,478.70	1.360	5.018
Perdizes	218	120,713	79,275.32	1.205	4.446
Campo Belo	151	71,432	77,586.53	1.179	4.351
Vila Leopoldina	73	41,369	73,262.80	1.114	4.109
Santo Amaro	134	77,410	73,154.89	1.112	4.103
Barra Funda	37	15,467	65,447.84	0.995	3.670
Bela Vista	143	73,022	63,178.21	0.960	3.543
Saúde	224	142,539	61,503.82	0.935	3.449
Lapa	140	70,941	59,537.11	0.905	3.339
Santa Cecília	164	90,159	54,006.10	0.821	3.029
Tatuapé	178	99,623	51,818.32	0.788	2.906
Butantã	146	57,531	51,743.92	0.786	2.902
Liberdade	117	73,730	51,376.52	0.781	2.881
Santana	231	126,110	49,791.33	0.757	2.792
Vila Andrade	228	138,686	46,814.31	0.712	2.625
Mooca	133	80,781	46,257.89	0.703	2.594
Socorro	56	41,202	44,677.21	0.679	2.506
Cambuci	56	38,607	42,992.23	0.653	2.411
Campo Grande	179	109,991	42,257.45	0.642	2.370
Vila Sônia	272	118,224	42,098.13	0.640	2.361
República	141	61,707	36,852.56	0.560	2.067
Ipiranga	167	116,014	36,684.47	0.558	2.057
Cursino	184	119,036	35,564.17	0.541	1.994
Belém	79	46,972	33,006.25	0.502	1.851
Água Rasa	130	92,672	32,400.26	0.492	1.817

Neighbourhood	# Census Areas	Population	Income per capita (R\$)	RSW per capita (ton)	Emissions per capita (tCO ₂ eq)
Rio Pequeno	271	129,144	32,267.11	0.490	1.810
Tucuruvi	175	106,942	30,703.44	0.467	1.722
Mandaqui	185	117,257	30,264.32	0.460	1.697
Vila Formosa	134	103,318	30,153.86	0.458	1.691
Carrão	115	90,601	29,644.05	0.451	1.662
Jabaquara	412	243,972	29,510.29	0.449	1.655
Vila Guilherme	82	59,260	28,989.17	0.441	1.626
Jaguaré	106	54,425	28,976.24	0.440	1.625
Vila Prudente	163	113,020	28,592.32	0.435	1.603
Casa Verde	133	93,240	27,018.38	0.411	1.515
Penha	206	139,325	24,652.39	0.375	1.383
Vila Matilde	147	114,369	23,597.71	0.359	1.323
Brás	56	31,379	23,576.03	0.358	1.322
Jaguara	35	27,177	23,407.55	0.356	1.313
Freguesia do Ó	234	155,307	23,329.88	0.355	1.308
Bom Retiro	50	35,378	23,318.75	0.354	1.308
Pari	28	18,761	23,169.61	0.352	1.299
Pirituba	270	183,432	23,046.63	0.350	1.292
Limão	129	87,566	22,894.26	0.348	1.284
São Domingos	125	92,559	22,267.16	0.338	1.249
Sacomã	355	270,711	21,809.11	0.331	1.223
Sé	46	25,788	21,757.86	0.331	1.220
São Lucas	191	155,355	21,036.45	0.320	1.180
Vila Maria	179	122,751	19,814.58	0.301	1.111
Raposo Tavares	226	108,493	19,059.40	0.290	1.069
Aricanduva	126	97,894	18,982.75	0.289	1.065
Ponte Rasa	163	102,570	18,424.94	0.280	1.033
Artur Alvim	150	114,990	17,674.25	0.269	0.991
Vila Medeiros	221	141,902	17,289.09	0.263	0.970
Campo Limpo	336	230,790	17,257.24	0.262	0.968
Tremembé	326	214,814	17,257.05	0.262	0.968
Jaçanã	153	102,560	17,027.99	0.259	0.955
Cidade Lider	165	138,205	16,495.03	0.251	0.925
Cangaíba	208	149,250	16,479.74	0.250	0.924
Cachoeirinha	230	156,764	16,446.92	0.250	0.922
Cidade Dutra	264	214,239	16,435.58	0.250	0.922
Parque do Carmo	96	74,438	16,102.87	0.245	0.903

Cidade Ademar	381	291,324	15,494.90	0.236	0.869
Neighbourhood	# Census Areas	Population	Income per capita (R\$)	RSW per capita (ton)	Emissions per capita (tCO ₂ eq)
Ermelino Matarazzo	178	124,084	15,170.20	0.231	0.851
Itaquera	285	223,550	14,832.38	0.225	0.832
São Mateus	225	169,347	14,521.72	0.221	0.814
São Miguel	148	100,374	14,414.81	0.219	0.808
Jardim São Luís	390	292,607	14,306.56	0.217	0.802
José Bonifácio	214	135,544	13,615.91	0.207	0.764
Jaraguá	290	201,802	13,332.11	0.203	0.748
Sapopemba	383	310,831	13,011.59	0.198	0.730
Capão Redondo	419	293,550	12,930.10	0.197	0.725
Vila Jacuí	234	155,547	12,834.83	0.195	0.720
Anhanguera	121	71,818	12,632.81	0.192	0.708
Pedreira	273	157,597	12,505.51	0.190	0.701
Guaianases	171	113,498	12,323.53	0.187	0.691
Vila Curuçá	215	162,727	12,028.47	0.183	0.675
Brasilândia	390	289,474	11,988.40	0.182	0.672
Perus	145	87,399	11,325.24	0.172	0.635
São Rafael	213	157,278	10,793.24	0.164	0.605
Grajaú	736	394,027	10,764.82	0.164	0.604
Itaim Paulista	355	244,777	10,387.56	0.158	0.583
Jardim Ângela	416	322,778	10,206.17	0.155	0.572
Iguatemi	218	139,504	10,178.63	0.155	0.571
Jardim Helena	224	147,537	9,943.70	0.151	0.558
Lajeado	247	179,767	9,843.43	0.150	0.552
Cidade Tiradentes	340	231,081	9,717.65	0.148	0.545
Parelheiros	449	143,019	9,670.60	0.147	0.542
Marsilac	106	8,944	8,366.17	0.127	0.469

Table 17 - Estimated values per capita for nominal income, residential solid waste generated and CO₂eq emissions from the residential solid waste stream for the city of São Paulo neighbourhoods.

Lastly, in 2019 the city of São Paulo could have generated a potential revenue around R\$1,68 billion in recyclable materials sales, R\$132 million in tradable carbon credits and R\$102 million in landfill fee cost reduction, adding up to R\$1.9 billion which could have been directed to strengthening waste pickers

cooperatives and associations, promoting the inclusion of informal waste pickers into cooperatives, expanding selective collect and recycling programs, as well as investments in education and social programs. Moreover, the release of just over 1 million tCO₂eq to the atmosphere could be avoided due to the reintroduction of over 1.1 million tons of recyclable materials in the productive chain.

3.3. Household Solid Waste and CO₂eq Emissions Footprint Calculator

An important factor in improving the recycling of the residential solid waste management system in Brazil depends on the collaboration of society in separating the recyclable materials from the residential solid waste stream to be correctly disposed and collected by the municipality's recycling collection services, or to be delivered directly to recycling centres and voluntary collection points (Pontos de Entrega Voluntaria-PEVs) operated by waste picker cooperatives and associations.

Society's participation in separating recyclables from the residential solid waste stream can be stimulated through educational actions promoted by municipalities supported by educational institutions in synchrony with recycling centres and community organizations (Wang et al., 2020). For example, education for clean separation at the source can become a remunerated task for organized waste pickers who are conducting door to door collection. Another way to tackle the lack of community participation in recycling programs is to implement punitive actions through public policies that foresee fines to households that do not participate in clean separation at the source.

With the objective of raising the awareness in society about the importance of diverting the recyclable portion of residential solid waste towards recycling programs, this research developed a calculator able to estimate residential solid

waste generation by household, based on household income in order to highlight the impact of the waste footprint on climate change and to learn how recycling can aid municipalities to overcome poverty within its boundaries.

The waste footprint and CO₂eq emissions calculator was designed to interact with users. The users provide a set of information and the calculator returns an estimate of the annual residential solid waste generation, the residential solid waste composition, an estimate of the gross amount of CO₂eq emissions from the residential solid waste, as well as an estimate for the emissions reductions due to solid waste diversion into recycling. At the end of the process, the calculator presents a comparison between the household solid waste generation and the national, regional, state, meso and micro regional, municipal and census area averages and stipulates a waste footprint score for the household.

In order to estimate household solid waste generation, a user provides the household address, which is translated into latitude and longitude, the household annual income and sets the percentage of organic matter diverted towards composting and the percentage of plastic, cardboard and paper, glass, metals and aluminum diverted into recycling.

For this piece of the research three random areas were selected within the Federal District of Brasilia (**Figure 23**), in order to hypothetically demonstrate the results obtained through the residential solid waste footprint calculator. Each household represents a different economic class. In this regard, for household A an annual income of R\$300,000.00 was assumed, as well as no diversion of residential solid waste to composting and recycling. For household B an annual income of R\$120,000.00 was stipulated and a diversion rate of around 50% of the organic matter to composting and 100% of aluminum, 80% of plastics, 60% of cardboard and paper, and 100% of glass to recycling. Finally, household C

diverted all recyclable materials to recycling and was stipulated to have an annual income of R\$27,000.00. For all three households, 4 residents living in each house was assumed.

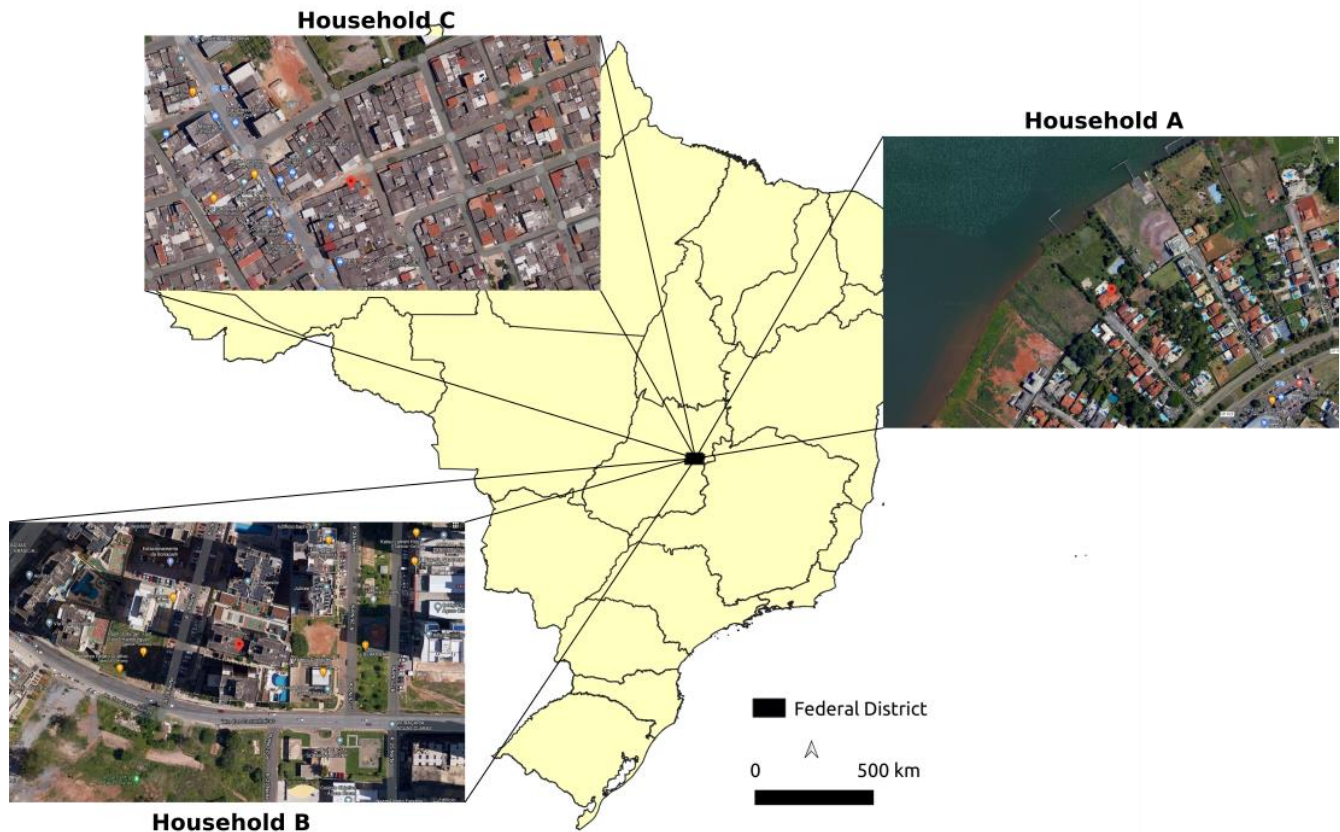
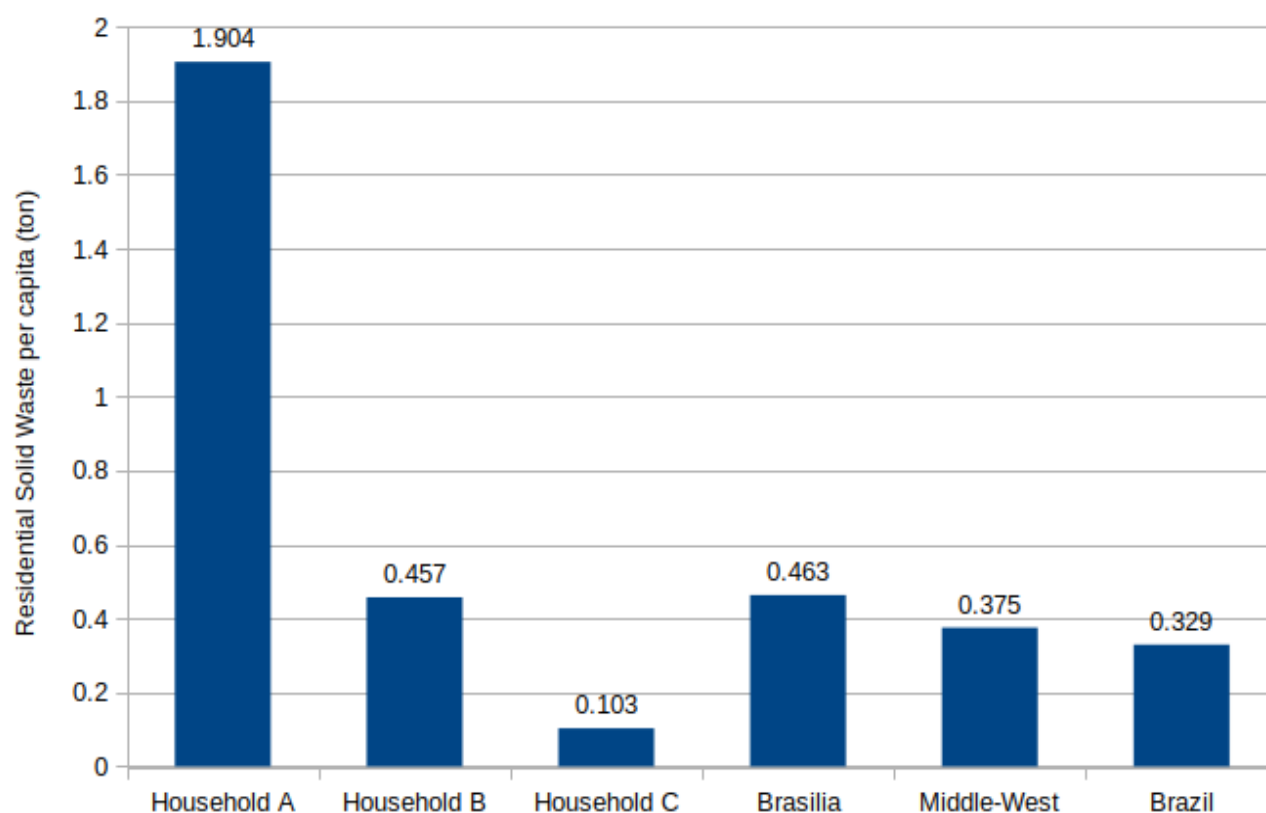


Figure 23 - Location of the three hypothetically households in the Brazilian Federal District.

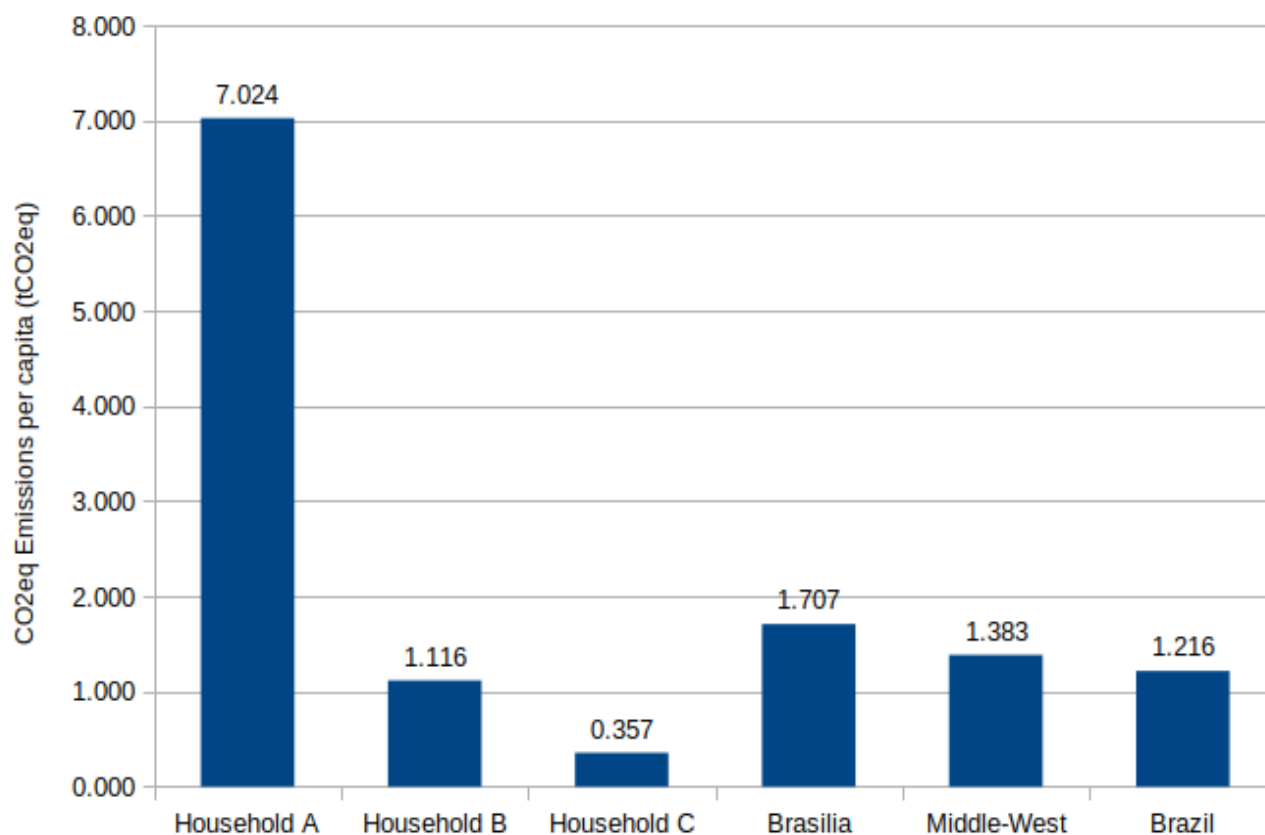
Table 18 shows the results obtained for the three households, while **graph 15** compares the estimated residential solid waste generation per capita between the three households, the city of Brasilia, the Mid-Western region and Brazil and **graph 16** compares the estimated CO₂eq emissions per capita between the three households, Brasilia, the Mid-West and Brazil.

	Household A	Household B	Household C
Income (R\$)	500,000.00	120,000.00	27,000.00
Income per capita (R\$)	125,000.00	30,000.00	6,750.00
Estimated RSW (ton)	7.614	1.827	0.411
Estimated RSW per capita (ton)	1.904	0.457	0.103
Estimated CO ₂ eq Emission (tCO ₂ eq)	28.095	6.742	1.516
Estimated CO ₂ eq Emission Reduction (tCO ₂ eq)	0	2.277	0.089
Potential Revenue from recyclable materials sales (R\$)	4,105.69	982.49	221.30
Generated Revenue from recyclable materials sales(R\$)	0.00	724.05	197.70
Tradable Carbon Credits (R\$)	0.00	398.52	15.58
Landfill Fee Reduction (R\$)	0.00	68.06	25.05
Residential Solid Waste Footprint	HIGH	LOW	VERY LOW

Table 18 – Households results.



Graph 15 - Comparison between the estimate residential solid waste generation per capita for the three households, Brasilia, the Mid-West and Brazil.



Graph 16 - Comparison between the estimate CO₂eq emissions per capita for the three households, Brasilia, the Mid-West and Brazil.

In this hypothetical situation, household A generates an estimated amount of residential solid waste of 7.614 ton/year or 1.904 ton.hab/year, consequently this household is responsible for the release of 28.095 tCO₂eq into the atmosphere, which correspond to 11,967.04 liters of gasoline consumed in a year. Since the household does not participate in composting and recycling programs, there were no reductions in the CO₂eq emissions. Regarding the potential revenue from recyclable materials sales this household could have generated R\$4,105.69 and a reduction in landfill fees of R\$491.73. Since this household does not participate in composting and recycling programs, no carbon credit was generated. Household A presented an estimated residential solid waste generation and CO₂eq emissions of about 78% of the census area average, however it represents more than 300% over the municipality average and more

than 450% over the national average, which gave a high residential solid waste footprint to this household.

Household B generated an estimated amount of residential solid waste of 1.827 ton/year or 0.457 ton.hab/year. Consequently, this household is responsible for releasing 6.742 tCO₂eq into the atmosphere, which correspond to 2,871.75 liters of gasoline consumed in a year. Since the household participates in composting and recycling programs, there was a reduction in the CO₂eq emissions of 2,277 tCO₂eq/year, equivalent to 969.89 liters of gas consumed in a year. Regarding the potential revenue from recyclable materials sales, this household could have generated R\$982.49 and a reduction in landfill fee of R\$142.03. Once this household participates in composting and recycling programs, it would be able to generate R\$724.05 in recyclable materials sale, R\$68.06 in landfill fee reduction and R\$781.46 in tradable carbon credits. Household B presented an estimated residential solid waste generation and CO₂eq emissions about 35% of the census area average, 98% of the municipality average and more than 38% over the national average, which gave a very low residential solid waste footprint to this household.

Lastly, household C generated an estimated amount of residential solid waste of 0.411 ton/year or 0.103 ton.hab/year. Consequently, this household is responsible for releasing 1.516 tCO₂eq in the atmosphere, which corresponds to 645.74 liters of gasoline consumed in a year. Since the household participates in recycling programs, there was a reduction in the CO₂eq emissions of 0,089 tCO₂eq/year, equivalent to 37.91 liters of gas consumed in a year. Regarding the potential revenue from recyclable materials sales, this household could have generated R\$221.30 and a reduction in landfill fee of R\$142.03. Once this household participates in recycling programs, it would be able to generate R\$197.70 in recyclable materials sale, R\$25.50 in landfill fee reduction and R\$15.58 in tradable carbon credits. Household C presented an estimated

residential solid waste generation and CO₂eq emissions about 66% of the census area average, 22% of the municipality average and 31% of the national average, which gave a very low residential solid waste footprint to this household.

4. Final Considerations

Middle and low-income countries commonly present difficulties in building and keeping updated databases regarding residential solid waste generation and waste characteristics in all levels of the public administration. The lack of reliable information regarding residential solid waste generation usually leads policy makers to elaborate inefficient policies, which sometimes are even unfair when the policy predicts some sort of punishment. To overcome this issue, estimation methodologies are frequently applied in order to fill the gaps left by the lack of reliable information needed to provide better background for policy makers to create feasible policies.

Even though Brazil implemented in 2010 a modern and innovative national solid waste policy, its results were below the expected achievements over the last decade, the lack of reliable information being one of the factors for such results. In this way this research proposed an estimation methodology based on income to understand the spatial distribution of residential solid waste in Brazil, at all levels of its territorial organization, basing such analysis on the commonly used estimation methodology supported by the number of inhabitants in a determined area.

The results obtained in the application of the proposed estimation approach were considered satisfactory, since the total estimated variation amount was less than $\pm 1\%$ when compared to the national database, comprised of a mix of information provided by municipalities and estimations based on number of inhabitants. The advantage of the estimation based on income relies on the fact that it is weighted on the residential solid waste generation according with the area's economic development. Since residential solid waste generation has a strong positive correlation with purchasing power, the estimation based on income was able to differentiate the residential solid waste generation in areas with the

same number of inhabitants but different economic development levels. For instance, a wealthy municipality presented a larger estimated amount of residential solid waste than a poor municipality, even though both municipalities counted the same number of inhabitants.

Once a linear relationship between residential solid waste generation and income was established, this research was able to calculate a municipal waste rate which allowed the estimation of residential solid waste generation within the municipal boundary, on the neighbourhood level and the census area level. As a result, this procedure provided a better understanding of the spatial distribution of the residential solid waste within the municipal boundary. Such information is essential to support the municipal solid waste management system, enabling urban planners to take sectoral actions, such as educational campaigns, application of differential fees, elaborate waste collection plans and so on, instead of applying general actions which do not account for particular characteristics of communities, making those actions inefficient and unfair.

Regarding the role that the municipal solid waste management system plays in reducing CO₂eq emission to the atmosphere, and thus contributing directly to achieving the SDG number 13, climate actions, the results pointed for a reduction of around 68% of the CO₂eq emissions from the recyclable materials portion of the residential solid waste stream, through the diversion of it from landfill disposal to recycling programs. The CO₂eq emission reduction from the residential solid waste stream has a potential to improve if it also considered the organic matter portion from the residential solid waste stream diverted to composting programs. However, this research does not estimate the CO₂eq emissions from composting in order to estimate its impact on the total estimated amount of CO₂eq emissions from the residential solid waste stream, thus accounting the CO₂eq emissions reduction from this process.

Moreover, the estimated reduction in CO₂eq released to the atmosphere generated potential carbon credits. In this respect this research strongly suggests that a combined effort between the public administration and non-governmental organizations, supported by educational institutions, can assist the organization of waste pickers into recycling cooperatives and associations and through those, register the recycling initiative as a Clean Development Mechanism. This would enable the waste pickers to trade the carbon credit with governments of high-income countries or multi-national corporations seeking for a carbon surplus in order to meet their climate goals. Using waste pickers cooperatives and associations as CDMs has the power to help municipalities to tackle the SDG number 1, no poverty, by adding financial resources which could be used to improve the income of marginalized portions of society who are often found in the sector of transformation of waste in resource.

Furthermore, the carbon credit trade acts as a tool to facilitate wealth transfer from high income countries towards middle and low-income countries which corroborates to achieving SDG number 10, reduced inequality, both among countries and internally reducing the social gap between the wealthiest and the poorest.

On the subject of potential revenue from recyclable materials sales, it was demonstrated that improving inclusive recycling programs, focused on waste pickers, is a powerful strategy to create job postings and generate income for the lower class in Brazilian municipalities. Prioritizing waste picker cooperatives and associations over private companies, as recycling agents in the municipal solid waste management system will impact positively on the municipalities and consequently the whole country in the achievement of SDG 1, no poverty. Indirectly, the engagement of waste pickers in recycling programs managed by cooperatives and associations acts towards the achievement of SDG 5, gender equality, SDG 3, good health and SDG 8 decent work and economic growth.

Besides, the recyclable materials sales reduce the amount of solid waste directed to landfill disposal, therefore a reduction in landfill fees can be assigned to improving essential services in the municipality, like public education, public health, sanitation and others.

Lastly, residential solid waste and CO₂eq emissions from the residential solid waste stream were developed based on household income. This calculator used the calculated municipal waste rate and aimed to raise society's awareness regarding the residential solid waste impact on the environment, as well as demonstrated the benefits of recycling to generate income and reduction of the CO₂eq emissions to the atmosphere. The calculator was designed as a python script which runs locally. However, it can evolve to an interactive online tool, promoted by government, educational institutions or NGOs in order to increase society's participation in clean residential solid waste separation and recycling, thus helping municipalities implement successfully inclusive solid waste management systems.

In conclusion, a well-managed inclusive municipal solid waste system is a powerful asset to middle- and low-income countries, like Brazil, to overcome the difficult challenges postulated by the SDGs. Its effectiveness to overlap and positively impact the environment, public health and human development place it as a key player for these countries towards the SDGs achievements.

Nevertheless, well managed inclusive municipal solid waste systems require a reliable data source to support decision makers in the design of public policies with effective actions in the field, otherwise innovative and modern public policies will be filled with fruitless actions, thus, wasting the aptitude of the municipal solid waste management system towards successfully carrying out the SDGs goals. In this regard, estimation methods are a valuable tool for decision makers in middle- and low-income countries to outrun the lack of solid waste information and doing so, to increase the effectiveness of public polices geared

towards an inclusive municipal solid waste management system focused on the mitigation of negative impacts on the environmental sphere and potentiate the positive outcomes on the public health and human development spheres in these countries.

Therefore, this research demonstrated that estimating residential solid waste generation and CO₂eq emissions from the residential solid waste stream based on the economic level of a determined area in Brazil, instead of just accounting for the number of inhabitants living in such an area, has the ability to differentiate spatial distribution of the residential solid waste generation weighted on, both the number of people living in this space as well as the purchasing power of those people, providing a more accurate view of the issue for decision makers to design and plan policies and actions. Moreover, through the obtained results this research was able to attest the importance of recycling programs where the engagement of waste pickers, as recycling agents, can act on the SDGs by generating job opportunities in the waste management and recycling sector, livelihood improvements, CO₂eq emission reductions, among other factors, placing the inclusive municipal waste management system as a major player in pursuing sustainable development, particularly in middle- and low-income countries.

A last consideration regards the limitations of the proposed approach. The accuracy of estimate or forecast models relies on the quality of its baseline data, in other words, the better is the baseline data the better is the estimate or forecast results. This approach is not different than the other models. Regarding the baseline data used in this research some limitations were observed. In respect to the nominal income, the last populational census research in Brazil was realized in 2010, which required the adoption of a procedure to update this data. Such procedure considered just the value of the minimum wage from 2011 to 2019 to update the nominal income. In consideration of the residential solid waste data,

even though they are available for all years from 2010 to 2019, the quality of the data is questionable since a great deal of the Brazilian municipalities provide estimated amounts to the national database or do not provide them. In this case the national database estimates it through mix methods in order to fill the database gaps. Just a small number of municipalities provide amounts of residential solid waste weighted by the service provider.

The above-mentioned limit the use of the research results just to support the elaboration of public policies and actions regarding the residential solid waste in order to establish goals, give to urban planners and policy makers a broad understanding of its spatial distribution and its potential towards the achievement of the SDGs challenges, and raise society awareness regarding the benefits of recycling. However, it is not indicated to be used in projects where the accuracy of the information is prime such as to subsidize CDM projects, and so on.

5. References

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