Theoretical analysis of the amount of energy that can be produced from MSW. A case study of the city of São Paulo - Brazil

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1. Introduction

According to the world cinerarium, the population has been reached 7.8 billion in 2020, in this way, studies carried out revealed that the population is estimated to reach 8.8 billion by 2030 (OTTOSEN et al., 2021). To Ouda et al, (2016), population growth will take place in developing countries, which will also lead the natural resource consumption, and consequently the generation of Municipal Solid Waste (MSW).

Due to the studies carried out by International Energy Agency (IEA) in 2013 apud Dalmo et all. (2019), the MSW generation around the world was estimated to be 1.3 billion tons, with an annual growth projection reaching 2.7 billion in 2050. Specifically in Brazil, daily generation was 224.000 tons/day in 2022 with a projection of 331.232 tons/day for 2050, and a population of 214.3 and 233 million inhabitants respectively (ABRELPE, 2022).

The management of Municipal Solid Waste (MMSW), according to Khan et al. (2022) is a fundamental and indispensable public service for humanity. In this way, when we look at the literature, we can check that the technologies employed for waste disposal and utilization are well-reviewed (PADILHA & MESQUITA, 2022). As such wise, we can point 3 different routes for the disposal of the MSW, all those routes have profitability, and environmental and social acceptability: for Carneiro & Gomes, (2019), the thermal route (gasification, pyrolysis, incineration), bio-conversion route (anaerobic digestion, composting) for Prajapati et all. (2021), and landfilling, according to Nanda (2021).

For Hamad et al. (2014), the conversation of waste into energy, which is called Waste-to-Energy (WtE) technology, is not a revolutionary idea, but it is renewable energy. This technology has a fundamental role in the sustainability of MSW management projects, due to all processes being under pollutant control (BRUNNER & RECHBERGER, 2015).

Kalyani & Pandey (2014), point out in their studies that WtE can be considered a sustainable option for waste management and as one of the most significant future renewable energy sources which is economically viable and environmentally sustainable. However, Baran et all. (2016), concluded that WtE is not only a sustainable waste management solution, but also economically feasible, especially for developed countries.

According to Kumar & Samadder (2017) the WtE can be recovered majorly by two conversion techniques: namely biological conversion and thermal conversion. In biological conversion, the most common technology is anaerobic digestion, while incineration is the most widely used technology for energy recovery under thermal conversion. However, Chiang &

Lee (2022), point out in their studies that incineration is the most used method for recovering energy from municipal solid waste.

To Tsai & Chou (2006) incineration plants are used to support the energy recovery from waste through the waste treatment process and energy conversion process. Nonetheless, the incinerator burns solid waste and generates energy (e.g., electricity) with the heat, but produces dioxins (also called PCDDs/PCDFs or chlorinated organics) which have serious adverse effects on human health. Thus, Kuo et al. (2008), many countries have strict regulations for dioxin emission, which is why there is a specific place where the gas emission from the incineration can be treated before the emission directly into the atmosphere.

The main objective of this thesis is to theoretically present, based on the available literature, an overview of the potential for the energy use of MSW in São Paul - Brazil. Showing the data found in studies already carried out, thus exemplifying the estimates of the theoretical potentials of electric energy generation by the following systems. (1) generation of electricity from incineration; (2) electricity generation from gasification; (3) electricity generation from landfill gas.

2. Theorical reference

2.1. General panorama of waste management and collection Brazil

According to Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE), (2022), Based on the recorded history and trends, the data collection from the MSW sector showed the existence of new social dynamics, due to the resumption of face-to-face activities, hybrid models, online commerce and delivery services, which consequently result in a direct influence on the processes of consumption, disposal and waste generation, showing a new approach to the management of discarded materials, and highlighting the relevance of this sector. This is due both to its important role in controlling public health and the need to properly manage the growing volume of material generated, which highlighted the urgency of new investments to meet this demand.

Due to the resumption of most activities to the prevailing pre-pandemic model, the waste generation centres were once again being moved from homes to offices, schools, shopping centres, among other locations. In addition, the hybrid work model began to be adopted on a larger scale, leading to a diversification of waste disposal sites, but making the residences also continue to play a relevant role in the generation of waste (ABRELPE, 2022).

The figure 1 and tables below summarize information on MSW generation in Brazil during the year 2022, reaching a total of approximately 81.8 million tons, which corresponds to 224 thousand tons per day. As a result, each Brazilian produced, on average, 1.043 kg of waste per day.

Table 1.MSW per capita generation by region in 2022. (ABRELPE, 2022).

Region	Year	Per capita generation (Kg/capita/Year)
North	2022	0.884
Northeast	2022	0.955
Midwest	2022	0.993
South	2022	0.776
Southeast	2022	1.234
Brazil Average	2022	1.046

Table 2.MSW per capita generation by region in 2021 (ABRELPE, 2022).

Region	Year	Per capita generation (Kg/capita/Year)
North	2021	0.895
Northeast	2021	0.968
Midwest	2021	1.014
South	2021	0.802
Southeast	2021	0.802
Brazil Average	2021	1.062

Table 3.MSW generation by region in 2022 (ton/year). (ABRELPE, 2022).

Region	Year	Total generation (Ton/Year)
North	2022	6173.684
Northeast	2022	20200.39
Midwest	2022	6127.414
South	2022	8668.857
Southeast	2022	40641.17
Total In Brazil	2022	81811.51

Table 4.MSW generation by region in 2021 (ton/year). (ABRELPE, 2022).

Region	Year	Total generation (Ton/Year)
North	2021	6177.019
Northeast	2021	20365.44
Midwest	2021	6184.989
South	2021	8902.343
Southeast	2021	41034.42
Total In Brazil	2021	82664.21

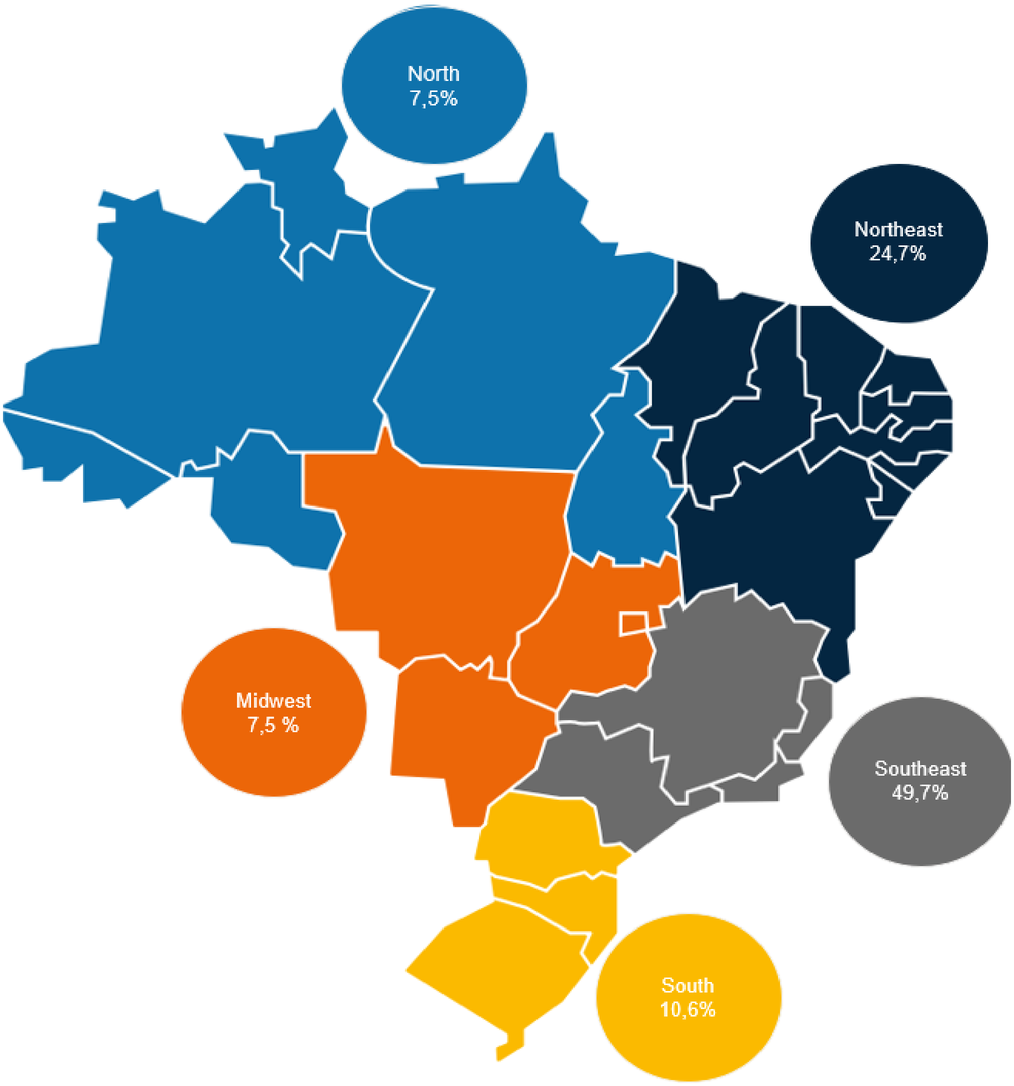

Figure 1.Participation of regions in MSW generation (%) in 2022, Adapted from ABRELPE, (2022).

2.2. National law on solid waste management

For the researchers Maiello et al. (2018), the field of Brazilian public policies, has a physical distance, and a structural distance, between the main government instances, being the instances that formulate norms and guidelines of national scope and the instances executioners.

Regarding the issue of distance mentioned earlier, this in turn is related to the difficulty of effective coordination between the different government bodies, which translates into problems of policy integration, both vertically (between different levels of government) and horizontally. At the same level of government, between sectors of public policies that are necessarily complementary, such as sanitation and the environment. Coordination difficulties - an example of a failure in the functioning of the administrative machinery - become evident not only at the local scale, where policies gain materiality, but also at regional scales, where there is a need for articulation of policies, such as the metropolitan scale. Different studies show that many metropolitan regions, established by state governments, lack effective governance and planning actions; competitive logics between municipalities often prevail over cooperative purposes (KLINK, 2009)

The Federal Law nº 12.305/2010, which establishes the National Solid Waste Policy (PNRS), in turn, presents different problems for its effective application, with greater focus on the low budget availability and the weak institutional and management capacity of many Brazilian municipalities, especially the small ones (HEBER & SILVA, 2014). To face these challenges and demands, this law establishes a very important milestone for the country, as it creates shared management guidelines, such as the formation of inter-municipal solid waste management consortia. In addition, the PNRS defines the protection of human health and sustainability as guiding principles for all government actions in this area, identifying goals for eradicating dumps and promoting environmentally appropriate solutions for the final disposal of MSW (BRAZIL, 2010).

2.2.1. Theoretical-conceptual framework: institutionalist approaches and integrated MSW management

Through several Brazilian academic debates on administration and public policies in general, and environmental management specifically, many researchers admit and recognize the fundamental importance of the institutional dimension, thus, adopting the institutionalist perspective for analysis (DA SILVA FILHO et al., 2009; CAVALCANTE, 2011; HEBER & SILVA, 2014; DO SANTOS & DO SANTOS, 2014). Faced with the assumption, in transformation, multidimensional, characterized by the presence of multiple actors and, therefore, by deep uncertainties and instability, such as the reality of MSW management in Brazil, the institutionalist approach offering a "guide for analysis", allowing to focus on the need to build standards in search of coordinated action and cooperation between the different bodies involved (CAVALCANTE, 2011).

For De Abreu et al. (2014), the use of institutionalist theory to study the management of basic sanitation services, and especially for solid waste, is not a recent approach in the Brazilian literature. Consequently, several other researchers have been using case studies linked by this theoretical-methodological bias, and therefore, all these researchers have adopted the framework of an actor-centred institutionalism, thus considering both formal and informal institutions, focusing on different actors. and the relationships between them (DA SILVA FILHO et al., 2009; CAVALCANTE, 2011; HEBER & SILVA, 2014; DE ALMEIDA et al., 2015).

According to the federal law PNRS, Chapter II, XI, defines integrated management of solid waste: “[...] the set of actions aimed at solving the problem of solid waste, in order to consider the political, economic, environmental dimensions, cultural and social, with social control and under the premise of sustainable development [...]” (BRAZIL, 2010).

The excerpt from the law mentioned above draws our attention to the multidimensionality and the need for integration not only in the way solid waste is understood and “managed”; it is a broad and complex topic, which transcends public health because it has social, economic, and environmental value (BAPTISTA, 2014). The integrated nature of solid waste management refers both to the need for intersectoral policies and to the different social, environmental and health aspects that involve this basic sanitation sector. The general impacts that can be caused by problems related to the inadequate management of MSW highlight the importance of an integrated approach to the management of these services.

For Pimenteira (2011), leachate, the main by-product of waste decomposition, and especially of its organic component, when not treated and disposed of properly, results in one of the most serious causes of soil pollution, even affecting the water table. and, consequently, groundwater sources. In addition, for Gouveia (2012), solid waste, when not managed correctly, can have impacts on the air, releasing particles and other atmospheric pollutants. One of the ways that solid waste impacts the air is through the anaerobic decomposition of its organic component that produces GHG (greenhouse gas) and especially methane (CH4), considered one of the main causes of global warming.

The dynamics presented above prove the need for an integrated approach in the management of MSW which, although recognized by the National Solid Waste Policy (PNRS) as one of the fundamental principles, does not find an easy application in the currently existing practices of management and management. Putting the integrated management principle into practice means reducing negative impacts and seeking solutions that produce positive externalities, that is, benefits, in the sectors or scope of human action, directly or indirectly related to the production of solid waste. For example, to solve the issue of GHG production, an integrated management response is to capture the gases produced by the decomposition of MSW for energy production. However, currently, only 2% of landfills in Brazil are equipped for this type of procedure (MAIELLO et al., 2018).

2.2.2. Waste-to-energy on the PNRS

The National Solid Waste Policy (PNRS), which was established by Law No. 12,305/10 and its Regulatory Decree, included as some of its objectives the adoption, development, and improvement of appropriate technologies to minimize environmental impacts inherent to the management and disposal of waste (article 7, IV), including the recovery and use of energy as alternatives for this purpose (article 7, XIV). These objectives were brought about because of the fact that the PNRS was mandated by Law No. 12,305/10 (BRAZIL, 2022).

The conversion of solid waste into fuel, thermal energy, or electricity by processes such as anaerobic digestion, landfill gas recovery, incineration, and co-processing is known as energy recovery. It was also included as one of the options for environmentally appropriate final disposal (art. 9, paragraph 1), as an alternative for better use of materials that are currently considered waste and are sent to final disposal units because they are not technically or economically viable for recycling. It is vital to note that energy recovery projects must demonstrate their technical and environmental feasibility, as well as execute a hazardous gas emission monitoring program certified by the environmental agency (BRAZIL, 2022).

The Ministry of the Environment, the Ministry of Mines and Energy (MME), and the Ministry of Regional Development (MDR) published Intermenstrual Ordinance number 274. in April 2019, in order to comply with the provisions of the PNRS regulatory Decree. This ordinance regulates the energy recovery of MSW in Brazil and establishes the bases and operational guidelines for the energy use of such materials (BRAZIL, 2019).

The MMA and the MME came up with a solution in the year 2020 that enabled the inclusion of energy recovery from urban solid waste as a specified source in auctions for the purchase of electricity from new generating projects beginning in the year 2021. These auctions began in 2021. Both the criteria for the auctions and MME Ordinance number 435/2020 were made public by MME Ordinance number 480/2021. The auctions aim to contract energy from the energy recovery of municipal solid waste (MSW), with the goal of providing the expansion of the distributors' market beginning in 2026 and with a supply forecast ranging from 15 to 25 years. The supply forecast ranges from 15 to 25 years (BRAZIL, 2021).

The utilization of MSW recovery systems allows waste to be used to generate energy, with solid waste only being disposed of in landfills when all other options for recovery have been exhausted. The collection and combustion of biogas produced in landfills must be expanded since it greatly cuts GHG emissions while also producing electricity (BRAZIL, 2022).

It is anticipated that the waste sector will require around R$ 15 billion in investments from the implementation of various technologies over the next ten years to encourage energy recovery, according to the Brazilian Front for Energy Recovery of Waste (Fbrer). This is in addition to carrying out improvements in the operational part of sanitary landfills, considering that the useful life of a landfill is approximately 25 years (LISBOA, 2020).

2.3. Solid waste management in of São Paulo city

2.3.1. São Paulo Integrated Solid Waste Management Plan

In São Paulo, in 2014, after broad debates with all sectors of society, the guidelines and strategies of the national legislation to be applied in the city over the next 20 years were consolidated. São Paulo Municipal Decree No. 54,991, of April 2nd, 2014, approved the Solid Waste Integrated Management Plan (PGIRS), bringing unprecedented, extensive, and complex dimensions for the collection, transport, treatment, and final disposal of solid waste (PGIRS, 2014).

The plan contains a series of strategic actions that must be implemented step by step. Expression and support from all relevant parties (governments, businesses, and citizens) will drive change in the culture and management of waste management.

According to PMSP, (2020), the basic principles of the PGIRS are the non-generation, reduction, reuse, recycling, solid waste disposal and destination of waste and materials that cannot be reused in an environmentally correct manner. Based on these parameters, the entire chain will have to recover as much recyclable waste of all types as possible, thus reducing the amount of material disposed of in landfills.

At the PGIRS in São Paulo, the objectives were translated into valuing waste and segregating it at the origin of production. In this program, all those involved seek solutions in social, environmental, political, economic, ethical, and cultural aspects.

In addition to markets and schools, a small number of areas available for disposal will be maintained, encouraging the retention of waste, and carrying out a selective collection program in homes, street markets and grocery stores (PGIRS, 2014).

Encouraging the adoption of standards for the production and consumption of goods and services will encourage the industry to integrate material collectors, implement and manage packaging reverse logistics systems. In addition, the implementation of environmental education programs at the municipal level is essential to raise awareness of non-generation and educate the public and large power generators on the reuse and recycling of materials (PGIRS, 2014).

2.3.2. Shared responsibility

Under the terms of Law nº 13.478/2002, the Municipal Department of Urban Cleaning– (Amlurb) is responsible for implementing the urban cleaning system as well as for the goals and objectives of the Solid Waste Master Plan and, among other attributions, will have a fundamental role in this process, on a permanent basis in the planning and articulation of the sectoral time for compliance with the PGIRS (PMSP, 2020).

The Secretariat and the Regions are also involved in implementing the program in their areas of operation. And, more importantly, each citizen's environmental contribution to sustainable management and the correct disposal of waste. Citizen input and participation are critical to the effectiveness of the PGIRS (PMSP, 2020).

To implement the general guidelines and objectives of the plan, the PGIRS must be updated every four years, ideally together with the city's multi-year plan, to study the construction and commitment of the necessary structures to guarantee the availability of economic-financial services. of waste management (PGIRS, 2014).

2.3.3. Household waste

In São Paulo, there are differences in the production and disposal of dry waste. The greatest generation took place in neighbourhoods with a high concentration of work and services and in areas with a high socioeconomic level of income, and today the highest rate is concentrated in the Pinheiros region, generating 1.7 kg of dry household waste per resident per day (PMSP,2020).

For Florenço (2022), dry waste is materials and waste that can be cleaned and treated to be recycled or reused, such as cardboard, PET bottles, plastic, paper, metal, soda cans, newspaper, Styrofoam, and glass bottles. In relation to dry waste, which is considered all types of material that is not contaminated or dirty by other substances.

Another behavioural trend is the change in consumption habits of São Paulo citizens, as with the increase in income, purchases of hygiene products, personal care (beauty and cosmetics) and cleaning materials, a category of products that generates a large amount of waste after the consumption (PMSP, 2020).

It should be noted that, based on the analysis of data collected by franchisees that offer urban cleaning services, not only has production increased, but the scope of collection of recyclable waste has also expanded. In 2013, only 14 districts offered selective collection of recyclable material (door-to-door collection of recyclable materials), in 2018 this increased to

49 districts. In recent years, the range of services has been further expanded with changes in the total amount of dry waste collected (PGIRS, 2014).

The implementation of selective collection is carried out under the concession regime, essentially by 2 concessionaires, through collection carried out by containers and door-to-door, in addition to associated cooperatives, in defined neighbourhoods. The city is divided into 2 areas (Northwest and Southeast regions) and each company is responsible for collecting dry waste in its region. Selective collection serves the 96 districts of the capital, with service coverage reaching 75% of households in the city. The Figure 2 below show how the São Paulo city is split into 2 companies that are responsible to collect MSW.

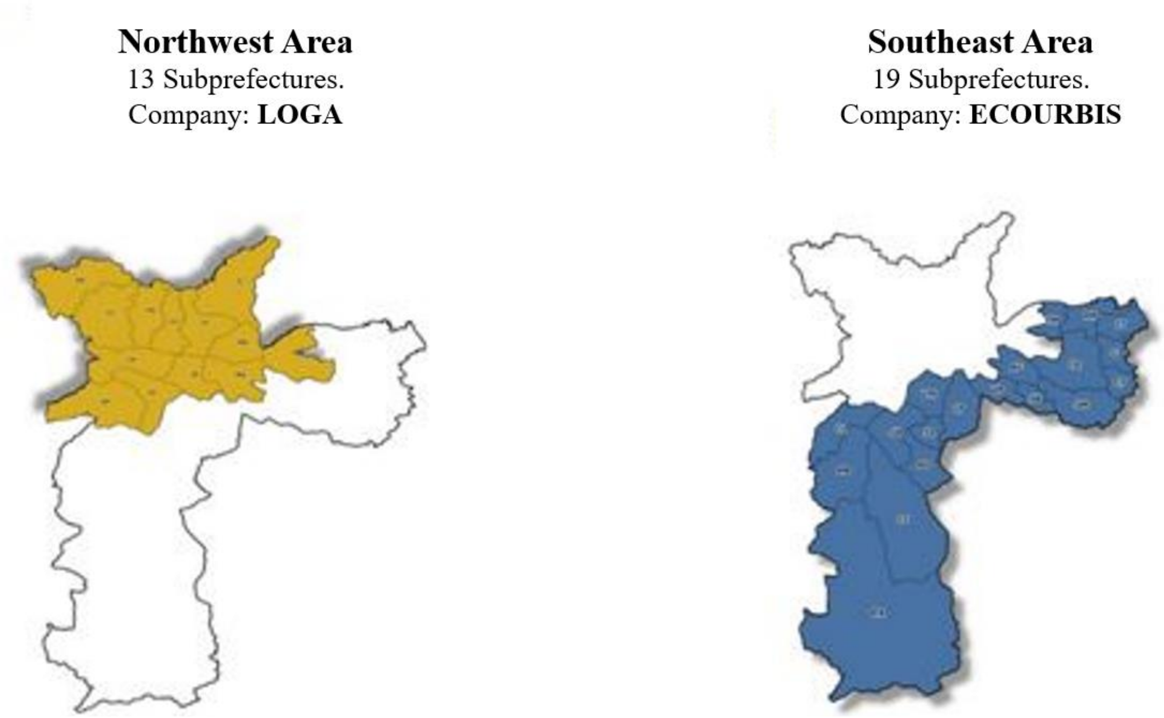

Figure 2.Map of São Paulo city divided by the two companies responsible for MSW collection. (PGIRS, 2014).

The city of São Paulo has two mechanized sorting machines with a total capacity of 500 tons of dry matter per day. The units operate around 350 tons per day, leaving them idle at around 40% of their capacity, numbers that show absorption capacity for a significant increase in the collection of dry matter.

For the general population, there is also the possibility of disposing of recyclable materials directly at the Ekopontos, or at the Voluntary Collection Points - PEVs, which are in public places such as parks, streets or in private areas such as commercial places, through agreements with private initiatives.

According to Paes & De Oliveira (2021), the MSW management system (MSWMS), is divided into two contractual parts for waste collection in São Paulo city. First, there are 2 companies that provide the services of common collection and transportation, transhipment, and final disposal in a landfill. Regarding the recyclable collection, the are other companies, which oversee the collection. The figure 3 presents the main activities of the MSW Management System - composed of the generation, collection, transportation, treatment, destination, and generation of co-products - in addition to the quantities generated and managed by the São Paulo City Hall. Therefore, the table 5 below show the amount of MSW collect from 2017 to 2022, and the table 6 shows the amount o waste collected from the storm drains.

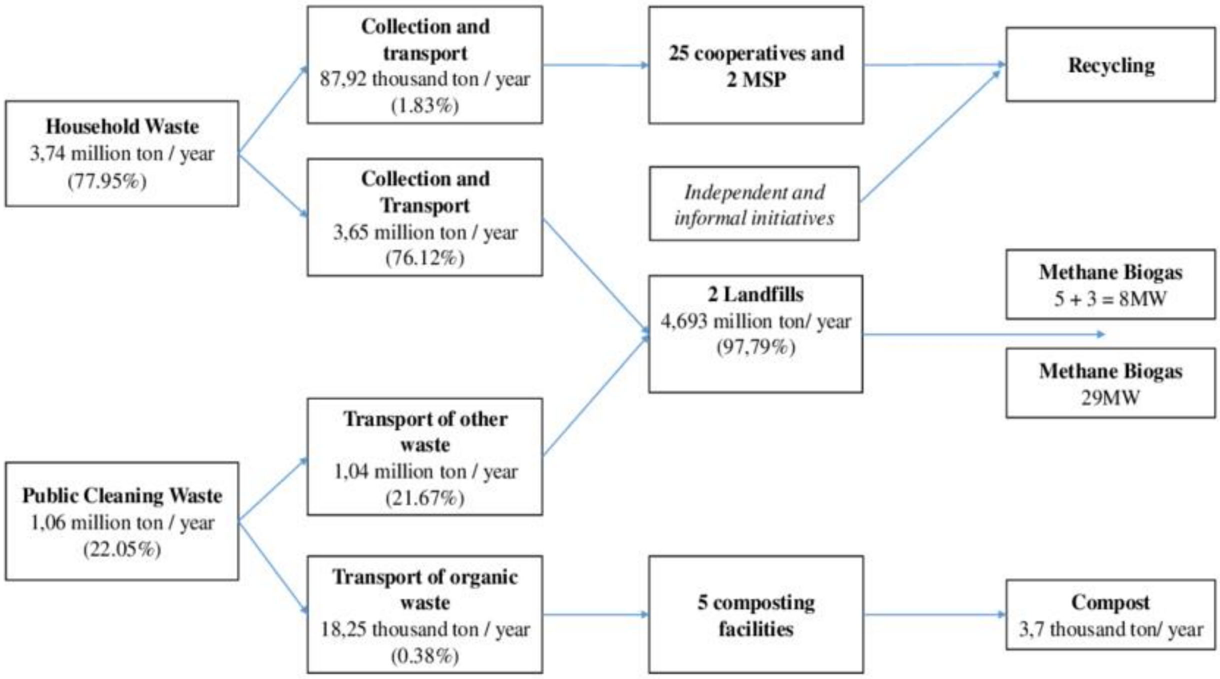

Figure 3.MSWS of São Paulo city and the quantities of MSW generated and managed in 2017. (PMSP, 2017).

Table 5. The amount of MSW collect from 2017 to 2022 in million tons. (PMSP, 2023).

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
2017	0.319	0.287	0.316	0.283	0.320	0.300	0.293	0.308	0.302	0.314	0.308	0.333	3.682
2018	0.332	0.291	0.328	0.301	0.303	0.289	0.294	0.302	0.287	0.328	0.309	0.335	3.697
2019	0.326	0.292	0.314	0.313	0.308	0.285	0.302	0.295	0.293	0.316	0.303	0.332	3.680
2020	0.317	0.301	0.317	0.277	0.277	0.303	0.304	0.297	0.301	0.305	0.288	0.333	3.619
2021	0.309	0.279	0.314	0.275	0.278	0.277	0.275	0.281	0.273	0.275	0.286	0.300	3.421
2022	0.299	0.275	0.306	0.275	0.276	0.270	0.266	0.280	0.260	0.284	0.277	0.306	3.374

Table 6. The amount of storm drains collected from 2017 to 2022 in million tons. (PMSP, 2023).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2017	8098	6969	7538	6575	7417	6930	6826	7384	7109	7302	7440	8333	87921
2018	7736	6284	6889	6485	4849	6184	6012	6282	5844	6674	6301	7370	76910
2019	7441	6524	6724	6483	6391	5799	6510	6410	6251	6864	6787	8052	80236
2020	8423	7246	8026	8056	7459	7894	7678	7678	7811	7925	7283	8618	94097
2021	7650	6640	7058	6154	5778	5611	5537	5537	5494	5522	5665	6563	73209
2022	6224	5427	6094	5562	5565	5515	5801	5801	5396	5858	5970	7416	70629

2.4. Brazilian energy matrix

The internal energy supply (ISE), that is, the energy needed to move the economy of a region, in a period of time, that is, in 2020 in Brazil, 287.6 million tons of oil equivalent (toe) were needed, thus deforming, it shows that there was a drop of 2.2% compared to 2019, a fact related to the measures adopted to combat the COVID 19 pandemic (MME, 2020).

Thus, when analysing the rate of 2.2% presented by the ISE, can it be said that this rate was less than the rate of the gross domestic product (GDP), which for the same year in question presented a rate of -4, 1%. In short, we can point out that the service sector was severely affected by the pandemic and, thus being responsible for more than 2/3 of GDP, had strong participation in the negative indicator. However, some other sectors had positive results, such as the production of sugar, cement, grains, cellulose, and non-ferrous metals, for example. Also due to the pandemic, there was a greater permanence and activities of people in their homes, which resulted in increases of 4.1% in electricity consumption and 3.7% in consumption of cooking gas. On the other hand, energy consumption in light Otto cycle vehicles decreased by 9.3% in 2020 (MME, 2020).

Therefore, renewable energy, did not have any side effects due to the pandemic, as a surprise, those energies had an increase of 2,5%. This fact is related due to the rise in sugarcane, wind, solar and biodiesel products. The supply of hydroelectric energy was low since 2019 there was a low rainfall regime and firewood had the greatest negative contribution. To facilitate understanding, the following table 8 shows the composition of the ISE (MME, 2020).

Table 7.The composition of the ISE for 2019 and 2020, in which an increase in the share of renewable sources is observed, from 46.1% to 48.4%. (MME, 2020).

SPECIFICATION	**Thousand toe**		**20 / 19**	**Structure**	
	2019	2020	**%**	2019	2020
Non-renewable	158.316	148.518	-6.2	53.9	51.6
Oil and derivatives	100.898	95.247	-5.6	34.3	33.1
Natural gas	35.909	33.824	-5.8	12.2	11.8
Mineral coal and derivatives	15.435	14.027	-9.1	5.3	4.9
Uranium (U3O8) and derivatives	4.292	3.727	-13.2	1.5	1.3
Other non-renewable	1.780	1.693	-4.9	0.6	0.6
Renewable	135.642	139.094	2.5	46.1	48.4
Hydraulics and electricity	36.364	36.210	-0.4	12.4	12.6
Firewood and charcoal	25.725	25.710	-0.1	8.8	8.9
Derivatives from sugar cane	52.841	54.933	4.0	18.0	19.1
Other renewables	20.712	22.241	7.4	7.0	7.7
Total	293.957	287.612	-2.2	100.0	100.0
Total of which is fossils	154.023	144.791	-6.0	52.4	50.3

In 2020, the Domestic Supply of Electric Energy (DSEE) was 645.9 TWh, an amount 0.8% lower than in 2019 (it is estimated -1.2% for the world, 26,670 TWh). By observing the energy sources, solar generation had the highest growth rate in 2020, with 61.5%, and distributed generation has already contributed 45% of total generation. As solar increases its participation in the DSEE, the annual expansion rates will decrease, from 876% in 2017, to 316% in 2018 and to 92.2% in 2019). The supremacy of hydroelectric generation continues, with a slight increase in share, from 64.9% in 2019 to 65.2% in 2020, including imports (MME, 2020).

Table 8.The composition of the ISE for 2019. (MME, 2020).

SPECIFICATION	GWh		20 / 19 %	Structure	
	2019	2020		2019	2020
Hydroelectric	397.877	396.327	-0.4	61.1	61.4
Sugarcane bagasse	36.827	38.776	5.3	5.7	6.0
Wind	55.896	57.051	1.9	8.6	8.8
Solar	6.655	10.750	61.5	1.0	1.7
Other renewables	18.094	19.966	10.3	2.8	3.1
Oil	6.896	7.745	11.8	1.1	1.2
Natural gas	60.448	53.464	-11.6	9.3	8.3
Coal	15.327	11.946	-22.1	2.4	1.8
Nuclear	16.129	14.053	-12.9	2.5	2.2
other non-renewable	12.060	11.121	-7.8	1.9	1.7
Import	24.957	24.718	-1.0	3.8	3.8
Total	651.285	645.915	-0.8	100.0	100.0
Total of which is renewable	540.395	547.587	1.3	83.0	84.8

Once we look at the state of São Paulo, this in turn has a consumption of 121,707 GWh, which means that the internal states have a consumption of approximately 18.85% of the total production of Brazilian production. Thus, if we deepen our research, the city of São Paulo alone consumed 25,727 GWh, which means that the city of São Paulo alone represents 20.76% of all energy consumed by the State, or even represents approximately 4% of all the energy generated in Brazil (IMA-SP, 2020).

2.5. Waste-to-Energy

According to Gupta et al. (2015) and De Souza Melaré et al. (2017), the Management of municipal solid waste (MMSW) is a global problem in terms of environmental pollution, social inclusion, and economic sustainability. Thus, the authors Bing et al. (2016), reports in their research, which that issues requires integrated assessments and holistic approaches to address it. Special attention should be paid to developing and emerging countries where unsustainable management of MSW is widespread. Differences should be highlighted between developing large cities and rural areas, where management problems are different, especially in terms of the amount of waste generated and the available MSW management facilities

(TORRETTA et al., 2019). However, both suffer from negative economic, political, technical, and operational constraints (IMAM et al., 2008).

To Liu et al. (2020), the issue of municipal solid waste management is one of the key drivers for countries around the world to achieve the goals of the Paris Agreement and the 2030 Agenda for Sustainable Development. The Paris Agreement allows for nations' national contributions to incorporate waste management initiatives as part of an attempt to decrease emissions of greenhouse gases, utilise waste as a source of energy, recycle and repurpose waste, and recover methane from landfills. The Sustainable Development Goals (SDGs) include target 11.6, which is focused on reducing the negative per capita environmental impacts of cities, including through special attention to air quality and the management of municipal solid waste and other wastes. Goal 11, which focuses on sustainable cities and communities, is one of the 17 goals that make up the Sustainable Development Goals (SDGs). Targets 12.4 and 12.5 of Sustainable Development Goal 12 (responsible consumption and production) are cantered on the ecologically responsible management of all waste via waste avoidance, reduction, recycling, and reuse. Target 12.3 of the same goal focuses on the reduction of food waste. However, the annual waste generation across the globe is expected to increase from 2.01 billion tonnes in 2016 to 3.40 billion tonnes in the next 30 years, as stated by the World Bank (2018). This trend is especially true for developing countries in Asia and Africa. This suggests that there has not been much progress in reversing the trend of increasing the output of municipal waste, which indicates that the world is still on the road to becoming a "throwaway society." Incineration of municipal waste is one of the greatest alternatives for lowering waste volumes and recovering energy; nonetheless, only a circular economy can assure a drop in waste creation on a per capita basis and offer a long-term solution to the issue of global waste.

2.3.4. WtE by Incineration

The process of incineration involves immediately combusting waste in the presence of oxygen temperatures of at least 800 °C. This results in the release of heat energy, gases, and inert ash. The amount of energy that can be recovered depends on the density and composition of the waste. The relative quantity of moisture and inert components that contribute to heat loss; the ignition temperature; the size and shape of the elements; the design of the combustion system, and so on are all factors that are taken into consideration. Anything from 65 to 80% of the energy content of organic matter may be recovered as heat energy. This heat energy can be put to direct thermal use, or it can be used in conjunction with steam turbine generators to produce electricity (VARADI et al., 2007).

Traditional incinerators that burn waste reach temperatures of over 760°C in the furnace and well over 870°C in the secondary combustion chamber throughout the combustion process. These temperatures are necessary for preventing smells brought on by incomplete combustion; nevertheless, they are not high enough to burn or even melt some of the inorganic materials, such as glass. This is a requirement. Some modern incinerators make use of auxiliary fuel at temperatures that may reach up to 1,650 °C to get around the drawbacks of regular incinerators. These reduce the amount of garbage by more than 97% and convert inorganic components like metal and glass to inert ash (ABBASI et al., 2022).

Waste that is burned only for the purpose of volume reduction may not need any further fuel beyond the first start-up phase. When the objective is the production of steam, supplementary fuel may have to be used in conjunction with the pulverized refuse since the energy content of the trash might vary from time to time or because there may not be enough waste available (ABBASI et al., 2022).

Although incineration is extensively used as a necessary method for waste disposal, it is related with several toxic outputs that are of concern to the environment, although to varying degrees. The good news is that they may be effectively controlled via the installation of suitable pollution control systems, as well as through the construction of an adequate furnace and the regulation of the combustion process.

According to Youcai (2017), MSW incineration is a combustion process, typically involving heat and mass transfer categories such as thermal decomposition, dissolving, evaporation, and chemical reactions. The incineration of municipal solid waste is an integrated process of evaporation combustion, decomposition combustion, and surface combustion. Therefore, municipal solid waste incineration can be divided into three processes: drying, thermal decomposition, and combustion.

- 1st Drying. The drying step of MSW is a process in which the heat in the combustion chamber vaporizes the connected water and inherent water. Drying is classified as conduction, convective, or radiation drying based on heat transmission. The greater the water content of the MSW, the longer the drying phase and the more thermal energy needed, lowering the temperature at the surface, and so impacting the whole incineration process.

- 2nd thermal decomposition. Because of the extremely high temperatures, the decomposition and volatilization of combustible chemicals in MSW produce a range of volatile hydrocarbons and carbon sequestration products. Endothermic and exothermic processes are involved in thermal breakdown. The rate of thermal decomposition is proportional to the content of combustible components, the rate of heat and mass transmission, and the particle size of organic materials.
- 3rd Combustion. Drying and thermal degradation create gaseous and solid combustible compounds that, insufficiently exposed to air in the incinerator, ignite at high temperatures. Thus, MSW incineration involves gas-phase and heterogeneous combustion and is more difficult than gaseous and liquid fuel combustion.

However, according to Liu et al. (2020), in they researcher they gave an overview of the advantages, downsides, and requirements of waste-to-energy incineration, which is shown in the table 9 below.

Table 9. Main advantages, disadvantages, and requirements of WtE incineration. Adapted by Liu et al. 2020).

	Advantage	Disadvantage	Requirement
Technology	1. WtE incineration is beneficial in terms of lowering the amount of waste for landfilling, disease management, and energy recovery (heat and electricity).	2.The facility's technologies (building and operation) are complex.	1.WtE combustion necessitates waste with an adequate LCV (Lower Calorific Value). 2. The composition of waste should be thoroughly investigated.
Environment	2.Incineration is an effective method for reducing the volume of waste destined for landfills, thereby allowing landfills to be utilized more efficiently.	1.APC residue (fly ash) and solid residue (bottom ash) must be treated appropriately due to the health dangers they pose.	1.Air pollution, waste disposal, and water pollution regulations are necessary environmental standards. 2. Bottom and fly ash must be disposed of securely in a landfill.
Social aspects, other	1.Incineration of WtE is effective in preventing infections from viruses and microorganisms and controlling the spread of infections related to waste. 2. In the event of a power outage caused by a natural calamity, WtE incineration facilities can function as an alternative source of backup power. 3. Incineration facilities for WtE contribute to the circular economy.	1. People who live nearby often don't want incinerators built because they are worried about how they will affect their health, how they will pollute the environment, how they will smell, and how they will cause land prices to go down. They are also unhappy because they don't understand why the sites were chosen or because they don't understand why they were chosen.	1.Nearby residents must approve the construction, and the facility must be approachable for their observation. 2. Neighbors' participation in the source-separation of waste is required for WtE incineration.

2.3.5. WtE by Gasification

The Gasification of MSW is a more recent discovery due to the wide variance in MSW characteristics, even though mature gasification technology for coal and petroleum coke can be traced back to the 1800s. Due to advantages including material recovery, decreased landfill disposal, and hazardous gas emission management, the use of waste gasification has increased dramatically during the past two decades (CONSONNI & VIGANÒ, 2012).

Although gasification and combustion are two thermochemical processes that are very similar to one another, they differ significantly. Gasification stores energy in the chemical bonds of the resultant gas; burning releases that energy by rupturing those chemical bonds. Whereas combustion oxidizes the hydrogen and carbon into water and carbon dioxide, respectively, the gasification process adds hydrogen and removes carbon from the fuel to generate gases with a greater hydrogen-to-carbon (H/C) ratio (BASU, 2010).

According to Arena (2012), waste gasification is a complicated process because it includes a great number of phases. These phases can be described as physical and chemical interactions that take place at temperatures that are typically higher than 600 degrees Celsius. The precise temperature is determined by the type of reactor as well as the characteristics of the waste, particularly the temperatures at which the ash softens and melts.

It is possible to define gasification as a partial oxidation of waste in the presence of an amount of oxidant that is less than what is required for stoichiometric combustion. In other words, the gasification process refers to the transformation of waste into energy or synthesis-gases through gas-forming reactions. During the gasification process, the fuel (waste) is what provides the system with the necessary amount of heat to gasify. This kind of gasification is referred to as autothermal gasification. According to Knoef (2005), the author explains that the result of the gasification process is not a hot flue gas, as is the case with the conventional direct combustion of wastes, but rather a hot fuel gas (also known as a "producer gas" or a "syngas"), which contains significant quantities of products that have not been completely oxidized and have a calorific value. This gas can be used in separate processing equipment, even at different times or locations.

To Consonni & Viganò (2012), syngas is basically a mixture of CO, H2, CO2 and H2O, related to the term ‘‘gasification plant” is generally used to name the whole system that converts the primary feedstock into useful energy carriers. To illustrate the gasification plant, the figure 4 illustrates the basic process options and the possible outputs.

The primary feedstock could theoretically be any hydrocarbon; however, because the chemistry and fluid dynamics of gasification are extremely sensitive to variations in feedstock composition, moisture, ash content, particle size, density, reactivity, etc., the admissible range of feedstock properties for a given gasifier is rather limited (much more so than for a combustor). In contrast to combustion plants, where the useful output is power and perhaps heat, a gasification plant's output can range over a wide spectrum, including chemicals, liquid fuels, or hydrogen in addition to power and heat. The process for producing chemicals, liquid fuels, or hydrogen has (usually extremely strict) standards that must be met, and syngas must be correctly processed to do this. The high efficiency, internally fired cycles (gas turbines, internal combustion engines) that cannot operate with the acid gases, particulates, tar, and other contaminants in the raw syngas produced by the gasifier require proper syngas treatment (FIGUERAS et al., 2023).

The nature and potential of the gasification plant are fundamentally different depending on whether syngas is adequately processed to suit the requirements of an internally fired cycle or a synthesis process. The gasification plant is quite similar to a combustion plant if raw syngas is burned in a boiler to fuel an externally fired cycle, with the exception that full oxidation occurs in two steps: first feedstock gasification, then syngas combustion. One advantage of such a "two-step oxidation" plant is that it is significantly simpler and less complicated to run than a plant that includes syngas clean-up plus one of the systems shown in the lower part of figure 4. In contrast, the mere separation of oxidation into two stages enables the capture of only a small number of the potential benefits of gasification. Consequently, a plant designed according to the "two-step oxidation" concept depicted in the upper portion of figure 4 is a type of combustion plant and not a gasification plant (CONSONNI & VIGANÒ, 2012).

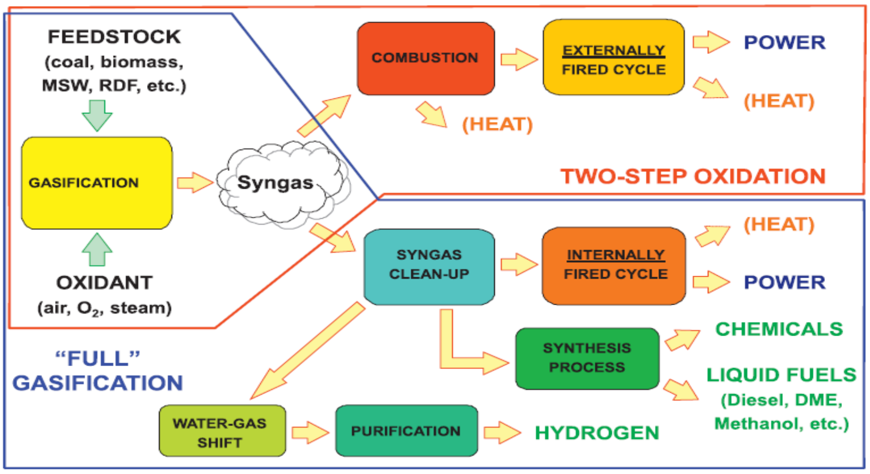

Figure 4. Schematic representation of the basic processes of a gasification plant. If raw syngas is combusted into a boiler (path in upper part) the plant is very similar to a combustion plant, with the difference that oxidation is broken down into two steps. The potential benefits of gasification can be fully captured only by following the ‘‘full’’ gasification path in the lower part, where syngas is properly treated ahead of being fed to an internally fired cycle, a synthesis process, or a system to generate hydrogen. (CONSONNI & VIGANÒ, 2012).

2.3.6. WtE by Landfill Gas

For the survival of the human species, energy in its many manifestations is indispensable. Humans have always sought to evolve, discovering alternative sources and methods for adapting to their living environment and satisfying their requirements. In this manner, the depletion, scarcity, or inconvenience of one resource is typically offset by the emergence of another. Electricity has become one of the most versatile and convenient forms of energy in terms of energy supply, making it an indispensable and strategic resource for the socioeconomic development of many nations and regions (PIÑAS et al., 2016).

This economic development and the rising consumption of energy sources have contributed to a global environmental imbalance. If global efforts to redirect our productive activities are not made, the quality of life of future generations and the survival of our species will be jeopardized.

In this context, the use of alternative energy sources, particularly biogas, appears as an opportunity of particular importance to contribute to the energy supply of the interconnected system, in the form of decentralized generation and close to the points of consumption, using national equipment and fuel (e.g., process residues). These advantages, combined with the well-known environmental benefits, make biogas a strategic option for the country, depending on the country's energy needs (BARROS et al., 2014).

According to Sauve & Van Passel (2020), Landfill Gas (LFG) is regarded as an important source of renewable energy and has the potential to be exploited in the generation of electric power. LFG may be collected using a system of wells and pipelines that are established before the closing of a specific cell in a landfill. This allows for the most efficient collection possible.

The composition of municipal solid waste (MSW), the pace at which trash is deposited, and several other factors (such as temperature, moisture content, and the presence of harmful compounds) all affect how much LFG is produced. In addition, the LFG production rate is a function of time, reaching a maximum approximately one year after deposition and then progressively declining (RAJESH et al., 2020).

Biogas, in turn, has positive effects on the environment, with an emphasis on the mitigation of carbon emissions from the atmosphere, resulting in a carbon-neutral electricity production process that contributes to the reduction of the effect of the furnace. This occurs because all the carbon dioxide produced by the process is ingested by plants and re-used in the process, maintaining the concentration of carbon dioxide in the atmosphere (BRANCO, 2010).

LFG is made up of around half methane (the major component of natural gas), half carbon dioxide (CO2), and a trace of non-methane chemical substances. According to recent research, methane is a strong greenhouse gas that is 28 to 36 times more efficient than CO2 in trapping heat in the atmosphere over a 100-year period (US EPA, 2023).

2.6. Quality standards related to incineration

The most significant environmental effect of MSW incineration is due to atmospheric emissions. Carbon dioxide (CO_2), sulfur oxides (SOx), nitrogen oxides (NOx), nitrogen (N_2), and particulate matter are the most common. At lower concentrations, hydrochloric acid (HCl) and hydrofluoric acid (HF) gases may be emitted. There is also the generation of carbon monoxide (CO), hydrocarbons, dioxins, and furans as a result of incomplete combustion, as well as the release of heavy metals as a result of particulate matter (MACHADO, 2015).

Concentrations of pollutants released by facilities that incinerate municipal solid waste are often greater than those released by facilities that burn fossil fuels. This is because municipal solid waste has a lower calorific value, and the process itself is less efficient. These vary depending on the type of incineration technology that is utilized as well as the composition of the mass of waste that is being burned (SCHRAMM, 2015).

The burning of municipal solid waste may result in the emission of heavy metals, most notably cadmium, mercury, and lead, as well as, to a lesser degree, arsenic, beryllium, and chromium. In the process of thermal conversion of municipal solid waste, organic micropollutants such as polycyclic aromatic hydrocarbons (PAHs), formaldehyde, and polychlorinated biphenyls (PCBs) are also released into the environment. Both classes of pollutants respond very slowly to degradation in the environment, and in addition to this, the compounds they create in people have the potential to cause cancer (CAIXETA, 2005).

The organochlorine compounds known as dioxins and furans may either be found in (MSW) or can be produced during the gas cooling step of the incineration process at temperatures around 300 degrees Celsius. They are known as Persistent Organic Pollutants (POPs), and they pose a significant risk to human health due to their high potential for toxicity. The largest danger of dioxin contamination occurs owing to its deposition and dilution in water. Most of the dioxin contamination occurs as a result of ingestion (98%), rather than inhalation (2%), which poses the least amount of risk (MACHADO, 2015).

In Brazil, incineration facilities are subject to the rules of national environmental council (CONAMA) Resolution No. 316/2002, which controls waste thermal treatment techniques and provides operating processes, emission limits, performance criteria, control, treatment, and disposal end of effluents. This resolution also establishes operational procedures, emission limits, and performance criteria for the treatment of waste thermal effluents. In addition, it is essential to make notice of many additional normative and regulatory tools that are used in Brazil for the purpose of controlling thermal processes.

- CONAMA Resolution No. 05/89 (BRAZIL, 1989), and Resolution No. 491/19 (BRAZIL, 2018), defines national air quality standards, established the National Air Quality Program (PRONAR), and provides rules for monitoring and inventorying emitting sources and atmospheric contaminants.
- The fundamental and secondary criteria for SO_2 (sulphur dioxide), CO (carbon monoxide), O_3 (ozone), NO_2 (nitrogen dioxide), inhalable particles, suspended particles, and smoke were specified in CONAMA Resolution No. 491/19 (BRAZIL, 2018).
- CONAMA Resolution No. 264/99, which authorizes the licensing of rotary kilns for the production of clinker for the co-processing of leftovers in the cement manufacturing process (BRAZIL, 2000).
- CONAMA Resolution No. 283/01, which addresses the treatment and eventual disposal of waste generated by health-care facilities (BRAZIL, 2001).

3. Method

As this thesis is based on a theoretical model, therefore, the methodology adopted for the development of this thesis was the deep search in with the information available online, whether through journal articles, or master and doctoral dissertations.

3.1. Study area

This thesis has as the area of study on São Paulo city, which is exposed in the figure 5, whose area extends for 21.521,202km² and is situated in the southeast of Brazil. It is the most populous state, with approximately 12.40 million inhabitants, (IBGE, 2021). It is worth noting that the city of São Paulo was selected as the study sample area since, according to Romero (2022), it is the biggest city in Brazil in terms of population. Furthermore, according to the worldometer (2015), São Paulo is the eleventh largest city in the world.

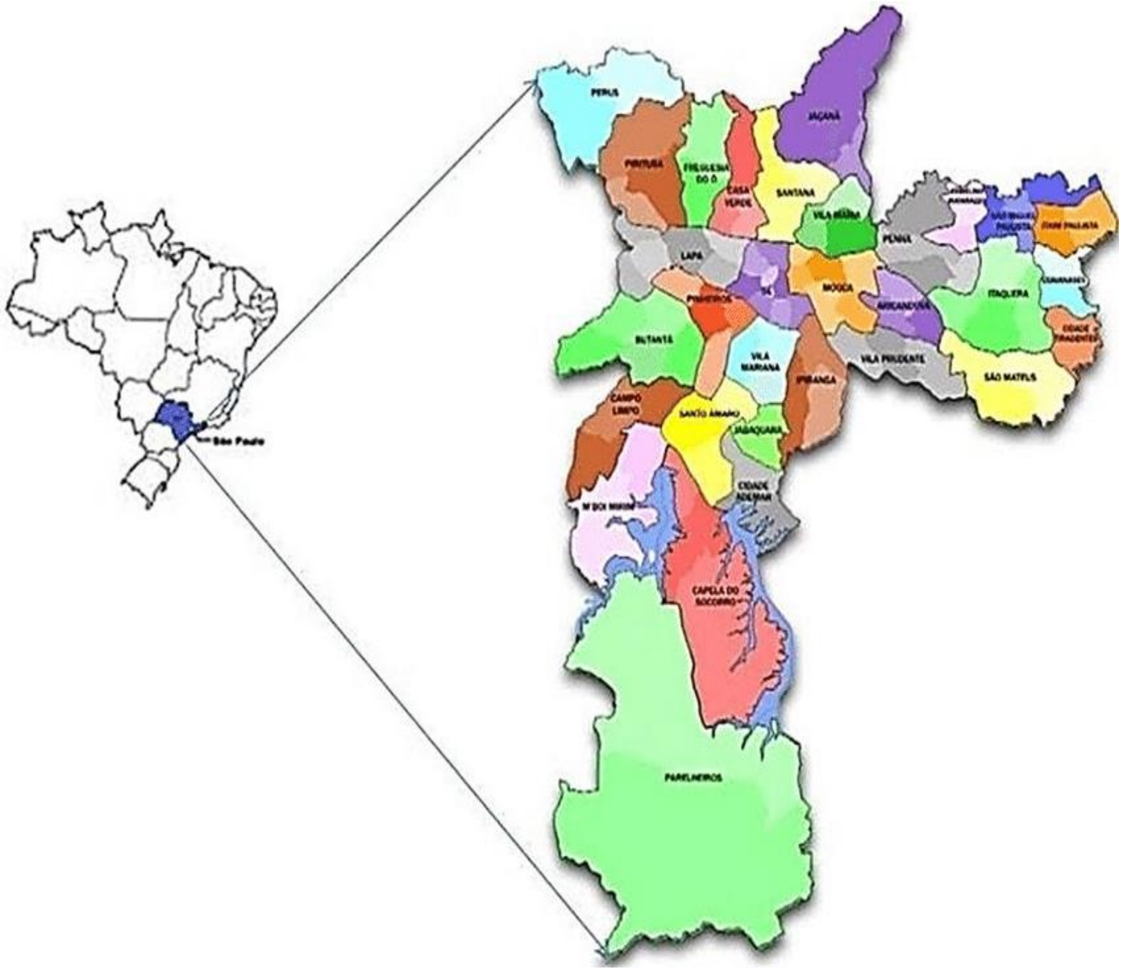

Figure 5. Map of Brazil highlighting the State of São Paulo and the city of São Paulo with its subdivisions. (NASCIMENTO & BENCHIMOL, 2015).

4. Results and discussion

4.1. Results

In this section, the advantages, and disadvantages of the three forms of energy production from solid waste presented in items 2.5.1, 2.5.2 and 2.5.3 will be presented as a result. It is worth noting that this result will be done theoretically, that is, as explained in item 3 of this thesis. In addition, it will be presented as a theoretical result how much energy could be generated if a WtE plant is implemented in the city of São Paulo, and how much percentage this reduces the energy use of the general matrix of energy used in the city of São Paulo.

4.1.1. WtE by Incineration

The hot flue gas generated in an incineration facility may be used to generate steam by cooling it in a high-pressure feed-water boiler. The supersaturated steam generated may be used to power a condensing steam turbine for power alone, a back-pressure steam turbine, or an extraction-condensing steam turbine for combined heat and power (CHP) subsequent generations through the typical steam Rankine cycle. The generated steam may also be collected for use as thermal energy in district heating systems or industrial operations. Up to 80-90% of the waste's energy may be recovered as heat in the boiler (DEFRA, 2013).

It has been stated that when 1 metric ton of MSW is combusted in a modern incineration plant, about 80% of the contained energy can be recovered as heat to generate steam in a steam turbine, producing 500-600 kWh of electricity and 1000 kWh of Thermal energy (AWASTHi et al., 2019, KAZA & BHADA-TATA, 2018, ALAO et al., 2022).

Based on this assumption and in relation to the data presented in tables 5 and 7, we can theoretically have the following amount of energy generated, which is presented in table 10 in relation to the MSW collected from householders and table 11 with the waste collected from storm drains.

Table 10.Amount of energy that could be generated by incineration from the total MSW collected from households in the city of São Paulo from 2017 to 2022. (OWN AUTHORSHIP, 2023).

	MSW (million ton)	**GWh**
2017	3.682	1836.896
2018	3.697	1844.322
2019	3.680	1835.790
2020	3.619	1805.473
2021	3.421	1706.808
2022	3.374	1683.106

Table 11. Amount of energy that could be generated by incineration from the total MSW collected from storm drains in the city of São Paulo from 2017 to 2022. (OWN AUTHORSHIP, 2023).

	MSW (million ton)	**GWh**
2017	0.0124	6.201
2018	0.0089	4.454
2019	0.0178	8.883
2020	0.0153	7.652
2021	0.0150	7.488
2022	0.0113	5.641

Thus, when analysing tables 10 and 11, specifically in the year 2020, as in item 2.4 of this thesis, the city of São Paulo in the year 2020 consumes approximately 121,707 GWh, in this way if a WtE pant were applied, in the year 2020, 1813.125 GWh could have been produced, this follows approximately 1.48% of all energy consumed in the city of São Paulo.

4.1.2. WtE by Gasification

Main components of a municipal solid waste incinerator include a furnace, an afterburning chamber, a heat recovery steam generator, and emission control equipment. Incinerators are used to dispose of MSW. The exhaust gas then travels via the post-combustion chamber and into the heat recovery boiler, which is where the steam is created. Steam has a variety of applications, including district heating, industrial use, and the generation of electricity in a steam turbine. The most advanced methods now available may reach net electric efficiency of around 22–25% (PANEPINTO et al., 2015).

Syngas is a combustible gas product that provides a more versatile kind of energy than hot combustion gas. Syngas may be used in a wide variety of applications. Additionally, syngas can be burned in a boiler to produce steam and electricity, or it can be used as a fuel in reciprocating engines and combined cycle turbines. Syngas can be used immediately adjacent to the location where it is produced, or it can be piped to a location that is located some distance away from the location where it is produced (PANEPINTO et al., 2015).

As a result, while conducting a survey to determine the amount of electricity that can be created from each ton of MSW, it was feasible to achieve the following result: Using gasification technology, one ton of municipal solid waste may be utilized to produce up to one 1000 KWh of electricity. (Global Syngas Technologies Council, 2021; FOUTS, 2020).

Based on this assumption and in relation to the data presented in tables 5 and 7, we can theoretically have the following amount of energy generated, which is presented in table 12 in relation to the MSW collected from householders and table 13 with the waste collected from storm drains.

Table 12. Amount of energy that could be generated by gasification from the total MSW collected from households in the city of São Paulo from 2017 to 2022. (OWN AUTHORSHIP, 2023).

	MSW (million ton)	**GWh**
2017	3.682	3682.261
2018	3.697	3697.148
2019	3.680	3680.045
2020	3.619	3619.270
2021	3.421	3421.485
2022	3.374	3373.973

Table 13. Amount of energy that could be generated by gasification from the total MSW collected from storm drains in the city of São Paulo from 2017 to 2022. (OWN AUTHORSHIP, 2023).

	MSW (million ton	**GWh**
2017	0.0124	12.431
2018	0.0089	8.929
2019	0.0178	17.807
2020	0.0153	15.339
2021	0.0150	15.011
2022	0.0113	11.309

Thus, when analysing tables 12 and 13, specifically in the year 2020, as in item 2.4 of this thesis, the city of São Paulo in the year 2020 consumes approximately 121,707 GWh, in this way if a WtE pant were applied, in the year 2020, 3634.609 GWh could have been produced, this follows approximately 2.99% of all energy consumed in the city of São Paulo.

4.1.3. WtE by Landfill Gas

Landfill gas (LFG) could be a big source of energy, and it should be taken out and used when it's best for the environment, the economy, and the technology. Over a time of about 15–20 years, about 60–80 m³ of LFG can be used per tonne of wet municipal solid waste (MSW). Most of the time, when LFG storage systems are put in place, the LFG is used to make energy, but there are also times when huge amounts of gas are burned. Most of the time, this is because the price of energy in these countries is cheap, which makes it not worth it to invest in and run a gas usage plant. Also because of this, gas extraction and burning are sometimes only done with the help of money from a carbon credit program. This happens a lot in countries that are still growing economically. It is hard to understand how energy can be lost when it is needed so much (COSSU & STEGMANN, 2018).

According to the EPA (2022), one million tons of municipal solid waste generates about 300 cubic feet per minute (cfm) of landfill gas (LFG), which means 509.703 cubic meter per hour (m³/h) and it continues to generate LFG for as much as 20 to 30 years after it has been buried in a landfill. Based on the studies carried out by the authors Chandra and Ganguly (2023), it was possible to establish that every 1 ton of MSW disposed of in landfills can produce approximately 6.908×10^{-6} GWh.

Based on this assumption and in relation to the data presented in tables 5 and 7, we can theoretically have the following amount of energy generated, which is presented in table 14 in relation to the MSW collected from householders and table 15 with the waste collected from storm drains.

Table 14. Amount of energy that could be generated by landfill gas from the total MSW collected from households in the city of São Paulo from 2017 to 2022. (OWN AUTHORSHIP, 2023).

	MSW (ton)	**GWh**
2017	3682261	25.437
2018	3697148	25.540
2019	3680045	25.422
2020	3619270	25.002
2021	3421485	23.636
2022	3373973	23.307

Table 15. Amount of energy that could be generated by landfill gas from the total MSW collected from storm drains in the city of São Paulo from 2017 to 2022. (OWN AUTHORSHIP, 2023).

	MSW (ton)	**GWh**
2017	12431	0.086
2018	8929	0.062
2019	17807	0.123
2020	15339	0.106
2021	15011	0.104
2022	11309	0.078

Thus, when analysing tables 14 and 15, specifically in the year 2020, as in item 2.4 of this thesis, the city of São Paulo in the year 2020 consumes approximately 121,707 GWh, in this way if a WtE pant were applied, in the year 2020, 25.108 GWh could have been produced, this follows approximately 0,021 % of all energy consumed in the city of São Paulo.

4.2. Discussion

After examining all the aforementioned data, it is evident that WtE by gasification produced the greatest results, with an average production of 3579,030 GWh for MSW collected from households and 13.41 GWh for waste collected in storm drains.

Therefore, WtE by incineration ranked second, with an average generation of 1,785,399 GWh for municipal solid waste collected from household's sources and 6,720 GWh for for waste collected in storm drains. Third place was occupied by WtE by Landfill Gas, which presented the lowest yields compared to the other methods of energy production presented above. Observing the average values produced, 24,724 GWh were obtained for MSW collected from households and 0.0931 GWh for waste collected in storm drains.

It is also noted that when evaluating the amount in percentage that would reduce the electricity demand of the central Brazilian matrix of energy supply, it does not present a large reduction in terms of percentage, so if we look at the average electricity consumption per person in the city of So Paulo in the year 2020, which was approximately $9{,}851\text{x}10^{-3}$ GWh, it is important to note that this estimate is based on the population of the capital of São Paulo in the year 2020. Consequently, if a WtE plant by gasification were implemented, as it demonstrated the greatest performance in terms of energy production, the quantity of energy produced would be sufficient to support approximately 370 308 persons.

However, if we observe that the number of people who would be subsidized with the energy from gasification is small, it would be possible to sustain the capital of the State of Espirito Santo for 1 year, along with several other cities with a smaller population or population equal to 370 308 people. Due to Brazil's extreme inequality, this quantity of energy produced could be incorporated into a social initiative for low-income families.

Another factor to consider when implementing a WtE by incineration or gasification is the act of reducing the area demand for landfills, given that all the landfills have a finite lifespan and that the companies responsible for this landfill site will eventually need to provide a new site for a new landfill. According to Moya et al. (2017) and Beyene et al. (2018), when implementing a WtE plant by incineration or gasification, the volume reduction for municipal solid waste can range from 70 to 95%, whereas for landfills it is 45 to 50%.

Referring to the bias of the new MSW management law, which was described in item 2.2 of this thesis, the implementation of a WtE plant reinforces the concept of shared MSW management, as partnerships can be developed with various small cities in order to construct a WtE plant that can serve as many cities as possible, with the primary goal of properly disposing of MSW and increasing the amount of energy to be produced. Additionally, it can increase the diversity of Brazil's primary energy sources.

5. Conclusion and Suggestions

5.1. Conclusion

This study sought to estimate the theoretical potential of the following systems to generate electricity. (1) generation of electricity from incineration; (2) generation of electricity from gasification; and (3) generation of electricity from landfill methane. Considering the presented objectives, it can be concluded that the generation of energy by gasification presented the highest average yield, being 3,579,030 GWh for the MSW collected from the houses and 13.41 GWh for the residues collected from the drainage networks of the rains, and that it can supply the energy needs of approximately 370,308 people, as well as the capital of the state of Espiríto Santo, for instance.

5.2. Suggestions

The following topics are suggested for future research.

- Economic study to verify the feasibility of implementing a WtE plant.
- Study of the composition of MSW generated in the city of São Paulo.
- Evaluation of the efficiency of small-scale electricity generation, considering the climatic characteristics of the city of São Paulo, seeing if climate variation will have any interference in efficiency.
- Study of an alternative way to increase the efficiency of electricity generation, since this process generates heat, and such thermal energy can be converted into electricity.

Summary

The population has been reached 7.8 billion in 2020, in this way, studies carried out revealed that the population is estimated to reach 8.8 billion by 2030. because of this population growth the MSW generation around the world was estimated to be 1.3 billion tons, with an annual growth projection reaching 2.7 billion in 2050. Specifically in Brazil, daily generation was 224.000 tons/day in 2022 with a projection of 331.232 tons. day[1] for 2050, and a population of 214.3 and 233 million inhabitants respectively. The management of Municipal Solid Waste (MMSW), according to Khan et al. (2022) is a fundamental and indispensable public service for humanity, for the MSW there are 3 ways to be disposal thermal route (gasification, pyrolysis, incineration), bio-conversion route (anaerobic digestion, composting), and landfilling. The main objective of this thesis is to theoretically present, based on the available literature, an overview of the potential for the energy use of MSW in São Paul - Brazil. Showing the data found in studies already carried out, thus exemplifying the estimates of the theoretical potentials of electric energy generation by the following systems. (1) generation of electricity from incineration; (2) electricity generation from gasification; (3) electricity generation from landfill gas. The methodology adopted for the development of this thesis was the deep search in with the information available online, whether through journal articles, or master and doctoral dissertations. After examining all the data, it is evident that WtE by gasification produced the greatest results, with an average production of 3579,030 GWh for MSW collected from households and 13.41 GWh for waste collected in storm drains. The amount of electricize generated can supply the energy needs of approximately 370,308 people, as well as the capital of the state of Espiríto Santo, for instance.

Keywords: MSW generation, public service; Electric energy generation.

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Appendix 4 – Declaration

STUDENT DECLARATION

Signed below, Da Silva Paula Luis Guilherme, student of the Szent István Campus of the Hungarian University of Agriculture and Life Science, at the BSc/MSc Course of Bsc. Environmental Engineering declare that the present Thesis is my own work and I have used the cited and quoted literature in accordance with the relevant legal and ethicalrules. I understand that the one-page-summary of my thesis will be uploaded on the website of the Campus/Institute/Course and my Thesis will be available at the Host Department/Institute and in the repository of the University in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes **no***

Date: Gödöllő, 2023. May 03rd.

Student

SUPERVISOR'S DECLARATION

As primary supervisor of the author of this thesis, I hereby declare that review of the thesis was done thoroughly; student was informed and guided on the method of citing literature sources in the dissertation, attention was drawn on the importance of using literature data in accordance with the relevant legal and ethical rules.

Confidential data are presented in the thesis: yes **no** *

Approval of thesis for oral defense on Final Examination: **approved** not approved *

Date: Gödöllő, 2023. May 03th.

Dr. Csegődi Tibor László
Dr. Csegődi Tibor László, tanársegéd
signature

***Please, underline the correct choice!**

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Da Silva Paula Luis Guilherme (Student's YTXM9Y), I here declare that the final essay/**thesis**/master's thesis/portfolio[1] has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I **recommend**/don't recommend[2] the final essay/thesis/master's thesis/portfolio to be defendedin a final exam.

The document contains state secrets or professional secrets: yes **no***[3]

Gödöllő, 2023, May 3rd.

Dr. Csegődi Tibor László
Dr. Csegődi Tibor László, tanársegéd
Internal supervisor

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[1] Please select applicable and delete non-applicable.
[2] Please underline applicable.
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