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Environmental Technology

Assessment of the energy potential of waste destined for landfill CIGRES-RS

Avaliação do potencial energético dos resíduos destinados ao aterro sanitário CIGRES-RS

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ABSTRACT

Managing urban solid waste (MSW) is challenging throughout the Brazilian territory. Energy recovery plants that incinerate MSW can meet up to 3% of the national electricity demand, with potential for expansion. The incineration process can add value to the waste and recover large quantities of recyclable materials. This study aimed to quantify the energy potential by incineration of solid waste destined for landfills managed by the Intermunicipal Consortium for Solid Waste Management (CIGRES) for electricity generation. The potential for electrical energy, the number of homes that can be served, and the equivalent value in electrical power to be obtained with the waste transported to the CIGRES landfill were evaluated. Three possible scenarios were simulated, the first making the energy use of all waste sent to the landfill, the second recycling 16% of the suitable material, and the last recycling 30%. In the best scenario, a value of 58,774.63 kWh/day was obtained, sufficient to attend 6,603 residences, while in the scenario with 30% recycling, this number drops to 46,193.75 kWh, providing enough for 5,190 homes. The equivalent value for these numbers, using the electricity price in the region, would be R$ 25,508.19/day in the scenario with greater energy use and R$ 20,048.08/day by recycling 30% of the available material. The costs of implementing and operating this type of undertaking are still high in the country. Thus, partnerships with other consortia should be sought to make the activity viable.

Keywords: Urban solid waste; Electric power; Incineration

RESUMO

A gestão dos resíduos sólidos urbanos (RSU) é um desafio em todo o território brasileiro. As usinas de reaproveitamento energético, que realizam a incineração dos RSU, têm potencial de atender até 3%

da demanda nacional de energia elétrica, com potencial de expansão. No processo de incineração é possível agregar valor ao resíduo e recuperar grandes quantidades de materiais recicláveis. O estudo teve como objetivo quantificar o potencial energético para incineração dos resíduos sólidos destinados ao aterro sanitário administrado pelo Consórcio Intermunicipal de Gestão de Resíduos Sólidos (CIGRES) para a geração de energia elétrica. Foi avaliado o potencial de energia elétrica, a quantidade de residências que podem ser atendidas e o valor equivalente, a ser obtida em energia elétrica, através dos resíduos encaminhados ao aterro sanitário CIGRES. Foram simulados três cenários possíveis, o primeiro realizando o aproveitamento energético de todos os resíduos enviados ao aterro sanitário, o segundo reciclando 16% do material apto e o último reciclando 30% desse material. No melhor cenário foi obtido um valor de 58.774,63 kWh/dia, suficiente para atender a 6.603 residências, já no cenário com 30% de reciclagem esse número cai para 46.193,75 kWh, fornecendo o suficiente para 5.190 residências. O valor equivalente para esses números, utilizando o custo da energia elétrica na região, é de R$ 25.508,19/dia no cenário com maior aproveitamento energético e R$ 20.048,08/dia realizando a reciclagem de 30% do material disponível. Sugere-se a realização de parcerias entre consórcios para tornar a atividade viável.

Palavras-chave: Resíduos sólidos urbanos; Energia elétrica; Incineração

1 INTRODUCTION

The management and destination of solid urban waste (MSW) is a problem that has been worsening since the beginning of the industrial revolution in the XVII century when consumer goods began to be produced on a large scale. Consequently, the world's consumption pattern has increased dramatically, generating a large volume of waste. Another factor that aggravated the generation of MSW was the expansion of the world population, especially in recent decades (Hurtado, 2023).

If not managed and disposed of properly, this solid waste can cause several problems, such as soil and groundwater pollution. This occurs through the infiltration of liquids generated in the decomposition of organic waste. In addition, they can also lead to the proliferation of vectors, causing various diseases and directly impacting the health sector (Kazuva & Zhang, 2019; Florencio, Bernardo, Delia, 2023).

According to the Thematic Diagnosis of Urban Solid Waste Management (TDUSWM) conducted by the National Sanitation Information System (SNIS) in 2020, as the final destination of MSW in Brazil, there are still 1,545 dumps, corresponding to 30.1% of the total MSW processing units in operation. Of the remainder, 12.3%

are controlled landfills, and 13% are sanitary landfills. The other 44.6% are sorting, composting, and recycling units, among other alternatives (Brasil, 2021).

One of these alternatives is treating waste by incineration. One of the objectives of the National Solid Waste Policy, instituted by Law No. 12.305/10 (Brasil, 2010) is to use technology improvements to minimize the environmental impacts inherent in waste management and disposal (art. 7, IV), one of which is technologies, energy recovery and use (art. 7, XIV). The waste suitable for sending to the Energy Reuse Unit (ERU) is urban cleaning waste, originating from street sweeping, cleaning of public streets and roads and other urban cleaning services, as well as household waste, originating from domestic activities in urban residences. In addition, waste from commercial establishments characterized as non-hazardous can be equated to household waste (Brasil, 2019).

According to the TDUSWM, in Brazil, only 16 incineration treatment units are in operation throughout the territory, corresponding to 0.3% of MSW processing units. However, they do not promote energy use (Brasil, 2021). Waste-to-Energy (WtE) incineration plays a significant role in reducing greenhouse gas emissions by avoiding landfilling of waste, thereby reducing the release of methane, a gas that is 86 times more potent than CO_2 in the short term (over 20 years) and 28 times more potent in the long term (over 100 years) (Bertone; Stabile; Buonanno, 2024; Wang; Levis; Barlaz, 2019). Furthermore, the energy generated through WtE incineration provides a sustainable alternative to energy produced from fossil fuels, further reducing its environmental footprint (Cucchiella; D'adamo; Gastaldi, 2014; Wang, et al., 2020).

In Brazil, the vast majority of MSW is not used, with a small percentage of recycling and high expenses on the part of municipalities with destinations in landfills (IPEA, 2021). Thus, studies seeking solutions to the current problem of solid waste are paramount. Thus, studies aimed at solutions to the current problem of solid waste are paramount. This work aims to quantify the energy potential for incineration of MSW sent to the Intermunicipal Consortium for Solid Waste Management (CIGRES), thus being able to obtain an estimate of the amount of energy generated by the landfill and proposing a better use of these residues.

2 METHODOLOGY

2.1 THE STUDY AREA

The Intermunicipal Solid Waste Management Consortium is located in the municipality of Seberi, northwest region of Rio Grande do Sul, on the banks of BR 386, Km 43, coordinates latitude 27º 28' 4" and longitude 53º 24' 09" west of Greenwich (Figure 1).

Figure 1 – Location of CIGRES

Source: CIGRES (2019)

The average annual rainfall is 1,900 mm (Sotério et al., 2005; Roessler et al., 2022), and the climate is Cfa (humid sub-tropical), according to Moreno (1961). The area where the sanitary landfill is located is 27.7 hectares. However, approximately 7.7 hectares are used for MSW disposal and treatment. The area was used for corn, soy, and wheat crops. In 2007, the area was acquired by the municipalities constituting the consortium to construct the landfill (Borba, 2019a).

The unit is a public consortium of 31 municipalities, serving approximately 160 thousand inhabitants, of which, according to IBGE (2010), 83,383 inhabitants live in urban areas and 69,258 in rural areas. The enterprise is responsible for sorting, composting and finally disposing of urban solid waste (RSUs). The unit receives around 1,690 tons of urban solid waste monthly (Borba, et al., 2019b; Kemerich et al., 2013).

Also, according to Borba (2019a), CIGRES is licensed under number LO 00228/2016 DL by the Henrique Luiz Roessler Environmental Protection Foundation (FEPAM), an institution in the State of Rio Grande do Sul. Considering that the activity conducted by CIGRES has a high polluting potential, a series of quarterly reports is required. These reports involve analysis of the quality of groundwater and effluent from leachate treatment ponds, flora, and landfill situations, among others (Borba, 2019a). More detailed information about each consortium municipality can be accessed in the SNIS database.

The Consortium is responsible for the final disposal of waste generated by 31 cities, all in the northwest region of the State: Ametista do Sul, Barra do Guarita, Boa Vista das Missões, Caiçara, Cerro Grande, Cristal do Sul, Derrubadas, Dois Irmãos das Missões, Erval Seco, Frederico Westphalen, Iraí, Jaboticaba, Lajeado do Bugre, Liberato Salzano, Miraguaí, Novo Tiradentes, Palmitinho, Pinhal, Pinheirinho do Vale, Planalto, Redentora, Rodeo Bonito, Sagrada Familia, São José das Missões, São Pedro das Missões, Seberi, Taquaruçu do Sul, Tenente Portela, Vicente Dutra, Vista Alegre and Vista Gaúcha.

2.2 URBAN SOLID WASTE CHARACTERIZATION

All data regarding waste received by CIGRES were made available by it and refer to 2021.The total amount of MSW received by the consortium that year was 20,382.16 tons, with the municipalities with the highest contribution of shipments being Frederico Westphalen, Seberi, and Tenente Portela, with 33.34%, 7.46%, and 9.37, respectively. The cities with the lowest contribution are Novo Tiradentes, São Pedro das Missões, and São José das Missões, with 0.63%, 0.54%, and 0.64%, according to Table 1.

Table 1 – Annual contribution of each municipality

Cities	**Contribution (ton)**	**Percentage (%)**
Ametista do Sul	804.22	3.95
Barra do Guarita	306.46	1.50
Boa Vista das Missões	215.02	1.05
Caiçara	327.54	1.61
Cerro Grande	164.59	0.81
Cristal do Sul	162.04	0.80
Derrubadas	161.8	0.79
Dois Irmãos das Missões	146.12	0.72
Erval Seco	572	2.81
Frederico Westphalen	6,795.74	33.34
Irai	852.72	4.18
Jaboticaba	284.58	1.40
Lajeado Bugre	147.54	0.72
Liberato Salzano	242.8	1.19
Miraguai	404.58	1.98
Novo Tiradentes	128.86	0.63
Palmitinho	751.22	3.69
Pinhal	247.93	1.22
Pinheirinho do Vale	353.34	1.73
Planalto	1,043.68	5.12
Redentora	418.24	2.05
Rodeio Bonito	808.38	3.97
Sagrada Familia	214.04	1.05
São José das Missões	131.28	0.64
São Pedro das Missões	114.28	0.56
Seberi	1,520.89	7.46
Taquaruçu do Sul	348.58	1.71
Tenente Portela	1,910.76	9.37
Vicente Dutra	312.56	1.53
Vista Alegre	306.36	1.50
Vista Gaucha	184.01	0.90
Total	2,0382.16	100

Source: Organized by the authors (2022)

The gravimetric composition of the waste is composed mostly of organic/waste, with a total of 65.80%, followed by plastic/PET bottles, with 13.4%, and paper, with 9.07% (Table 2).

Table 2 – Gravimetric composition of waste

Waste type	**Composition (%)**
Organic/Waste	65.8
Paper/Cardboard	9.07
Plastic/PET	13.4
Aluminum	4.5
Glass	3.4
Tetra pack	2.5
Construction waste	0.9
Hospital	0.43
Total	100

Source: Adapted from Borba (2019a)

The organic waste/reject fraction consists of textile waste, diapers, organic material, styrofoam, shoes, and rubber, among other unspecified materials. CIGRES does not conduct gravimetry of the organic and waste portions. Still, in 2012, the company Ambientalis Engineering/SC surveyed this portion. At the time, this fraction of waste and organic material represented 64.5%, a value very close to the current one, so this data was used as a comparison to current values, as described in Table 3.

Table 3 – Composition of organic/waste portion

Material type	**Percentage (%)**	**In relation to the total received by CIGRES (%)**
Fabrics/leather	18.86	12.4
Organic material	68.68	45.19
Polystyrene	0.37	0.24
Shoes	7.65	5.03
Rubber	1.0	0.65
Others	3.42	2.25
Total	100	65.8

Source: Organized by the authors (2022)

All waste that arrives at CIGRES first undergoes sorting. However, the use of recyclable waste was 16% in 2018, demonstrating an inefficiency in the selective collection and segregation of solid waste; therefore, a good part of the waste that could be reused is disposed of in the landfill (CIGRES, 2019).

2.3 ENERGY POTENTIAL OF WASTE SENT TO CIGRES

The energy potential of MSW disposed of in CIGRES was calculated using the lower calorific value, amount of waste received daily, and electromechanical efficiency of the system, which were obtained from Equations 1 and 2, where the first specifies the total theoretical energy and the second the total theoretical potential, thus ascertaining the population that this generation can serve. The data in Table 4 were used as reference.

Table 4 – Poder Calorífico dos Materiais

Material	Kcal/kg
Plastics	6.300
Rubber	6.780
Leather	3.630
Textiles	3.480
Wood	2.520
Food	1.310
Paper	4.030

Source: EPE (2014)

According to EPE (2014), for PCI < 1,675 kcal/kg, incineration is not technically viable, for values between 1,675 and 2,000 kcal/kg, technical measures depend on some pre-treatment that increases the calorific value, while for values above 2,000 kcal/kg, gross combustion is technically viable.

The number of people that the system can serve was calculated from data from the Laboratory of Energy Efficiency in Buildings (LabEEE, 2022). According to LabEEE (2022), the average electricity consumption in Brazilian residences is 152.2 kWh. However, this value is very variable in the region. While the north region has a lower average, which is 88.25 kWh, the south region has the highest, with 273.1 kWh/month in summer and 261.3 kWh/month in winter, thus calculating the total of households served by energy generation from MSW, the regional average value for winter and summer was used, which was 267.2 kWh.

There are several empirical models available for determining the Lower Calorific Power (PCI) of MSW (Liu et al., 1996; Abu-Qudais; Abu-Qdais, 2000; Thipkhunthod et al. 2005; Chang et al., 2007, Ogwueleka; Ogwueleka, 2010). The calculation of PCI of MSW is quite complex and subject to large variations, due to the heterogeneity of the materials, with the representativeness of the samples being a critical factor (Pavan, 2010). Regarding the empirical mathematical models, three models are used to estimate the lower calorific value of MSW: those based on physical composition, those based on centesimal analysis and those based on elemental chemical analysis. The analysis of the physical composition (gravimetric) is based on the mass fractions of plastics, paper, moisture, various organics, textiles, leather and rubber and other combustible materials present in the MSW (Silva et al., 2014). The calculation of the PCI for each fraction of the MSW is given by the PCI of the material multiplied by its percentage by mass, about the whole, as described in Equation 1 (Borges, 2018).

$$PCI = PCIpl\,.\%pl + PCIpp\,.\%pp + PCIb\,.\%b + PCImo\,.\%mo \qquad (1)$$

Where:

PCI = lower calorific power (kcal/kg);

PCIpl = lower calorific value of plastic (kcal/kg);

%pl = percentage of plastic in the sample (%);

PCIpp = lower calorific value of paper and cardboard (kcal/kg);

%pp = percentage of paper and cardboard in the sample (%);

PCIpl = lower calorific value of rubber (kcal/kg);

%pl = percentage of rubber in the sample (%);

PCImo = lower calorific value of organic matter (kcal/kg);

%mo = percentage of organic matter in the sample (%).

According to Poletto (2008) and Silva (1998), with the defined PCI value, it is possible to determine the theoretical total of energy generated per day (kWh) using Equation 2.

$$Tte = PCI * K * \eta * mRSU \quad (2)$$

Where:

Tte = total theoretical energy (kWh);

Qt = amount of MSW available (kg/day);

PCI = internal calorific power (kcal/kg);

K = conversion factor from kcal to kWh (0.001163);

Nh = number of hours in the year (8,760 h);

η= system yield (28%).

To calculate the total theoretical power (MW), Equation 3 (Rossi, 2014) was used, which considers the total energy and hours of operation of the plant. ERUs with current technology can operate 8,000 hours per year, the national average PCI is 1,792 kcal/kg, and the system efficiency for electrical conversion is 25% to 35% (ABREN, 2020).

$$Pt = \frac{Et}{h} \quad (3)$$

Where:

Pt = total theoretical power (MW);

Et = total theoretical energy (mWh);

h = hours of operation per day of the plant (h).

Three scenarios were analyzed, the first performing the energy use of all the waste destined for the CIGRES sanitary landfill, the second performing the recycling of the percentage equivalent to what the consortium manages to sort today, which is 16%. The third scenario simulated recycling 30% of the suitable materials.

With the energy conversion efficiency, defined PCI, operating hours, and amount of waste available, it is possible to calculate the power and total theoretical energy according to equations 2 and 3.

3 RESULTS AND DISCUSSION

3.1 ENERGY POTENTIAL OF WASTE SENT TO CIGRES

For the three scenarios to be evaluated, the PCI of each fraction of the waste in the landfill MSW was first calculated, according to Table 5. The PCI values used for each material were researched in the literature using the data available from EPE (2014), an agency linked to the Ministry of Mines and Energy.

Table 5 – PCI values for the different projected scenarios

Material type	Scnarios		
	Without recycling (Kcal/Kg)	16% recycling (Kcal/Kg)	30% recycling (Kcal/Kg)
Textiles	440	440	440
Organic Material	591.98	591.98	591.98
Others	56.7	56.7	56.7
shoes	142	142	142
Rubber	44.07	44.07	44.07
tetra pack	131.34	84.66	74.21
Paper	365.52	306.28	255.5
Plastic	844.2	709.38	590.31
PCI	2,585.74	2,375.07	2,194.76

Source: Organized by the authors (2022)

The identification of the amount of energy generated per day, the number of homes supplied, and the equivalent economic value is shown in Table 6.

Table 6 – Evaluation of the proposed scenarios regarding theoretical power and energy, population served and equivalent value

Scenarios	Theoretical total power (MW)	Theoretical total energy (kWh/day)	Residences served (un)	Equivalent value in energy (R$)
Total recycling	2.93	58,774.63	6,603	25,508.19
16% recycling	2.58	51,702.07	5,809	22,438.69
30% recycling	2.3	46,193.75	5,190	20,048.08

Source: Organized by the authors (2022)

According to the values obtained, the best energy potential was found in the proposed scenario where all the material was used, with a difference of 12,580.88 kWh, for the scenario with 30% recycling. This generation difference impacted the number of people that can be served, reaching the number of 1,413 homes between this and the scenario with most of the recycled material.

As evaluated, all scenarios have a lower calorific value sufficient to burn mass. According to Barja (2006), energy losses occur in the system in the conversion of thermal energy to electricity, generally in plants of up to 20 MW, and the efficiency is around 35%.

The equivalent amount of electricity in the best scenario was R$25,508.19, a value of R$5,460.11 higher compared to the scenario where a smaller amount of MSW was used to generate electricity. The kWh value used was informed by Empresa Rio Grande Energia (RGE, 2022), responsible for the electricity distribution in the northwest region of the State; according to RGE, the average kWh value is R$0.434.

Also, with the energy generated, it is possible to meet the consumption of 6,602 homes. According to IBGE estimates (2010), in 2022, the Municipality of Seberi will have a population of approximately 10,678 inhabitants. Assuming three people live per residence, this generated electricity would be enough to serve the entire population.

However, according to ABREN (2021), for the investment to implement a WtE plant to be viable, the plants must have a daily receipt of at least 150 tons, as construction and operation expenses are high, mainly because it has a rigorous gas treatment system, requiring state-of-the-art technologies. In addition, there is a need to adapt the energy generated by the WtE plants; currently, the value to make the projects viable must be R$670.00/mWh. According to studies by the Energy Research Company (2008), for economic viability, WtE power plants must have a capacity of at least 2MW and a scale of 150 t/d.

This amount is 54% higher than the amount currently charged by the company RGE, responsible for a large part of the electricity distribution in the region of the CIGRES landfill. However, there is a prediction of a reduction in the cost of the average tariff for energy generated from the ERUs, reaching a value of R$ 250.00/mWh in 2040; thus, the average value from 2024 to 2040 would be R$ 329.00/mWh (ABREN, 2021).

An alternative to try to facilitate the implementation of an ERU in the region would be the union between consortia responsible for the management and disposal of solid waste, such as the Intermunicipal Consortium for Cooperation in Public Management (CONIGEPU) and the Intermunicipal Consortium for Multifunctional Management (CITEGEM), as they also manage MSW in the region, thus increasing the amount of waste received per day and consequently the electricity production.

Finally, within these three scenarios approached, a final analysis was conducted, where it was identified among them that had the best monthly financial return, whether using all the material for incineration or selling part of the recyclable material used, such as plastic and paper. The data generated are shown in Table 7.

The values used to calculate the revenue from the sale of recyclable materials were obtained through data from the Company CICLO, which recycles materials. The company is headquartered in Cachoeirinha, Rio Grande do Sul. Paper and Tetra Pak packages cost R$0.15, cardboard R$0.30, plastic R$0.50 and PET bottles R$1.50.

Table 7 – Value obtained in the three analyzed scenarios

Material	Scenarios (value in R$)		
	Without recycling	16% recycling	30% recycling
Plastic	0	1,190	2,240
Paper/Cardboard	0	120	226.5
tetra pack	0	33	61.5
Energy generated	25,508.19	22,438.69	20,048.08
Total	25,508.19	23,781.69	22,578.08

Source: Organized by the authors (2022)

Economically, the most profitable option was the scenario where all the waste was used to generate electricity. However, this should not be the only factor to be considered to recycle or not the materials. According to ABREN (2021), the hierarchy in the treatment and disposal of solid waste must prioritize the following order: non-generation, reduction, and reuse.

Therefore, public and private institutions should encourage and promote awareness practices for the entire population to obey this proposed hierarchy, prioritizing non-generation and, when this is not possible, reduction.

If non-generation is not feasible, using as many recyclable materials as possible should be promoted to increase that material's useful life and preserve natural resources.

4 FINAL CONSIDERATIONS

Regarding the treatment of solid waste, Brazil still has a long way to go, as 73.8% of all waste generated is disposed of in landfills, which have a very low sorting rate of recyclable materials, and very few do the same energetic use, not even the burning of gases. Another 26.2% go to controlled landfills or dumps; the two alternatives are at the bottom of the solid waste treatment hierarchy line, demonstrating the country's inefficiency in working on the issue of MSW treatment.

However, new milestones regarding this issue have emerged, such as the consolidation of the National Solid Waste Plan (PLANARES) in 2022, where goals and guidelines were defined to modernize urban solid waste management. One of these goals is to increase energy use from MSW, develop partnerships with the private sector, and promote technical, environmental, and economic feasibility studies to implement ERUs.

WtE plants are a consolidated technology in developed countries, proving an effective and safe alternative if well controlled, adding value to MSW, and generating energy and income. The experiences of these countries in using this technology show that it is possible to conduct efficient management of MSW, combining the best practices of the hierarchy of the treatment of urban solid waste, promoting recycling and energy use.

For these practices to be disseminated in Brazil, some obstacles must be overcome, such as the lack of funding and financial structuring of the enterprise. This way, the country can use its full potential to build approximately 120 WtE plants, enough to supply 3% of the national electricity demand.

In the three scenarios, The CIGRES landfill showed viability for energy use in terms of its PCI, being between 2,585.74 kcal/kg and 2,194.78 kcal/kg. In the three proposed scenarios, the energy generated reached 58,774.63 kWh/day in the best case, an amount that can supply 6,603 homes, an amount that is sufficient to cover the demand of the inhabitants of the municipality of Seberi, where the landfill operates.

However, these numbers do not demonstrate the feasibility of implementing an ERU from solid waste sent to CIGRES, as the construction and operation of this type of plant still demands a very high financial contribution, a large amount of solid waste is required to make the enterprise viable. Even so, the possibility of joining consortia in the region to centralize a greater amount of MSW and enable energy use should be evaluated.

In the current model and size, the best option for MSW management is to increase the consortium sorting rate, which is currently 16%, thus extending the useful life of materials and preserving natural resources. For the best use of recyclable materials, actions should be carried out with the population in all consortium municipalities to promote selective collection, the correct segregation of MSW, and actions for the decentralized treatment of organic waste, such as composting. Thus reducing the amount of waste sent to the landfill, facilitating the sorting of these materials, extending their useful life, and even generating more revenue with the materials sold.

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