Municipal Solid Waste Treatment Processes: Identification and Comparison of Performance Indicators

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Abstract

Selecting the most appropriate process or a combination of them to treat municipal solid waste (MSW) is a challenge due to cultural and structural aspects of collecting segregated waste and the high investment and operational costs, since each technology has different requirements, such as typical capacity ranges, fractions of MSW that can be treated, among others. There is a gap in the literature about decision tools that simultaneously consider technical-economic, environmental, and social aspects. The main objective of this work is to propose indicators for a tool to help make decisions on how to treat MSW, encompassing the sustainability tripod. The identified economic indicators were: net present value and technology readiness level. Environmentally: global warming potential (GWP), energy and water intensity, land use, ozone depletion, photochemical smog, and acidification. On the social side: job creation, salary with the absorption of waste pickers, the population served, and the reduction in MSW sent to landfills. A database was drawn up with information collected from the literature to calculate the indicators and an analysis of the social and environmental indicators was carried out for a specific case: an MSW incineration plant with a capacity of 400 kt/year. The analysis identified the need to remove some environmental indicators: ozone layer depletion and photochemical smog, due to the lack of data available in the literature; and the social one: salary with absorption of waste pickers, since this indicator would not differentiate technologies, i.e., it is not relevant for decision-making. The result of the other indicators were job creation: 79 people; population served: 950,872 people; reduction in MSW sent to landfill: 92%; GWP: 0.45 kg CO2eq/kg MSW; energy intensity: 241.7 GWh/y; water intensity: 62 m³; land use: 15,735 m²; acidification: 53.8 t SO2eq/y. The importance of a database of plants with different capacities and compositions was also noted, so it would be possible to cover various scenarios that waste management agents might want to evaluate.

**Keywords**: waste-to-energy, sustainability, MSW incineration.

* 1. Introduction

The Brazilian National Solid Waste Policy (Brasil, 2010) defines an order of priority for waste management: non-generation, reduction, reuse, recycling, treatment of solid waste, and environmentally appropriate final disposal of waste. However, the actual scenario in Brazil is different, with around 98 % of municipal solid waste (MSW) going to landfills and dumps and only 2 % to recycling and composting (Brasil, 2021), despite the fact that there are already different treatments for MSW, such as anaerobic digestion, incineration, pyrolysis, and gasification. The inadequate disposal of waste can lead to various environmental impacts, such as water and soil contamination, air pollution, and greenhouse gas emissions (Kaza et al., 2018); and social impacts, as the proliferation of disease vectors and risk to human health (Gouveia, 2012).

The available technologies to treat MSW can convert waste into energy or other valuable products, such as biogas, synthesis gas, ethanol, among others. Anaerobic digestion uses organic matter from MSW, highlighting the need for segregation (Pinasseau, 2018). It is converted into biogas, which can generate electricity, heat, or chemicals, and digestate, which can be used as fertilizer or soil structuring material in the civil construction sector (Pinasseau, 2018). Anaerobic digestion is an established technology for MSW treatment (Neehaul et al., 2020). Incineration is the thermal process that converts MSW into thermal or electrical energy most used worldwide (Kalogirou, 2018). Other thermal processes are pyrolysis and gasification. The first one generates a 3-phases product: synthesis gas, pyrolysis oil and char (Neuwahl et al., 2019), it is still an emerging technology (Neehaul et al., 2020), and there are no large-scale plants in operation (Saveyn, 2016). Gasification generates synthesis gas and ash; synthesis gas must go through a cleaning process and can be used to generate electricity or as a raw material for other chemicals (Chan et al., 2019), and it is a technology validated in full scale (Neehaul et al., 2020).

There are some MSW treatment processes assessments in the literature. Diaz-Barriga-Fernandez et al. (2018) carried out a multi-objective optimization to support the decision-making in the MSW management, considering the financial risk involved as an objective function. Morero et al. (2017) proposed a mathematical formulation to find the optimal process design for the co-digestion of MSW and sludge, using net present value (NPV) as the objective function. Santibañez-Aguilar et al. (2014) proposed a model for optimal planning for the reuse of MSW considering economic, environmental and safety aspects, such as annual net profit, the amount of reused waste and fatalities generated, respectively. Pereira et al. (2018) presented a methodological proposal for building indicators for MSW management, encompassing the social aspect with indicators such as diseases related to environmental sanitation, the existence of collectors in dumps and on the streets.

However, although there are the assessments mentioned above, they are of specific scenarios, and many consider only one or two aspects. There is, therefore, a gap in the literature regarding decision-making tools that simultaneously consider technical-economic, environmental, and social aspects, and that can be applied to different scenarios. The main objective of this work is to propose indicators for a tool to help make decisions on how to treat MSW, encompassing the sustainability tripod.

* 1. Methodology
		1. Technical-economic aspects

This work considers that economic development is related to technical aspects (Sikdar, 2003). The NPV is a widely used technical-economic indicator, such as in the analysis of the potential economic viability of implementing MSW incineration plants in Brazil (Silva et al., 2020) and economic analysis of MSW gasification and incineration with generation of energy (Rodrigues et al., 2020).

To calculate the NPV, it is possible to account for a premium received from the public authorities for treating MSW as revenue, the costs of land use, and revenue for the CO2 mitigation, based on carbon credits (Araya, 2019). It is also important to consider the technology readiness level (TRL), related to data availability and the risk linked to technology (Klar et al., 2016).

* + 1. Environmental aspects

The indicators were identified in line with the main environmental impacts of the MSW treatment sector: leaching, air pollution, and greenhouse gas emissions (Kaza et al., 2018), and are presented in Table 1.

Table 1 – Environmental indicators

|  |  |  |
| --- | --- | --- |
| Indicator | Calculation form | Unit |
| GWP | Ratio between the total mass of CO2eq and the amount of MSW treated. | kg CO2eq/ kg MSW  |
| Ozone depletion | Ratio between the total mass of CFC-11eq and the amount of MSW treated. | kg CFC-11eq/ kg MSW  |
| Energy intensity | Ratio between net energy (difference between produced and consumed) and the amount of MSW treated. | MJ/ kg MSW |
| Water intensity | Ratio between the mass of water consumed and the amount of MSW treated. | kg water/ kg MSW |
| Land use | Ratio between the area used and the amount of MSW treated. | m²/ kg MSW |
| Photochemical smog | Ratio between the total mass of ethyleneeq and the amount of MSW treated. | kg ethyleneeq/ kg MSW  |
| Acidification | Ratio between the total mass of SO2eq and the amount of MSW treated. | kg SO2eq/ kg MSW  |

* + 1. Social aspects

This aspect is sometimes neglected due to its subjectivity, and it is not yet consolidated (Interlenghi et al., 2017). Critical points for identifying the indicators, presented in Table 2, were the generation of employment and income, and reduction in the amount of MSW sent to landfill, which reduces the population's potential exposure to disease vectors (Gouveia, 2012). The authors emphasize the existence of waste pickers in South America who informally collect, separate, classify and market recyclable wastes.

Table 2 – Social indicators

|  |  |  |
| --- | --- | --- |
| Indicator | Calculation form | Unit |
| Job creation | Number of jobs generated with the implementation of the process | People |
| Salary with the absorption of waste pickers | Difference between the average received by the waste pickers and the average paid by companies | USD |
| Population served | Population served | People |
| Reduction in MSW sent to landfill | Quantity of MSW treated / quantity of MSW generated | % |

* + 1. Analysis of the social and environmental indicators

A database was drawn up with information collected from the literature to calculate the indicators and an analysis of the social and environmental indicators was carried out for a specific case: an MSW incineration plant with a 400 kt/year capacity. The MSW composition was assumed as: 53.03 % of organic matter; 19.69 % of plastic; 16.57 % of paper and cardboard; 2.95 % of glass; 1.49 % of metal; and 6.27 % other recyclables as presented for the Rio de Janeiro State Solid Waste Plan Report (Rio de Janeiro, 2013) for medium-sized cities, between 100,001 and 1,000,000 inhabitants. Since a plant with the studied capacity serves cities of this size, considering the per capita generation of 1.1 kg/day also presented in the report (Rio de Janeiro, 2013).

This database – a compilation developed by the authors based on data from different plants – contains the necessary information to calculate the indicators, such as the number of employees, average emission of CO2eq and SO2eq per ton of MSW, water and energy consumption, and the area occupied by the plant. In this database, the averages of each indicator will be identified for plants similar to the one studied, and this value is identified as the result of that indicator.

* 1. Results

The TRL 9 was identified for incineration technology, since there are several MSW incineration plants in the world (Kalogirou, 2018). For reference purpose, anaerobic digestion (Neehaul et al., 2020) and sanitary landfill (Kaza et al., 2018) also have TRL 9, gasification presents TRL 8, since it is also validated in full scale, but not as long as incineration and anaerobic digestion (Neehaul et al., 2020), and pyrolysis is validated in pilot facilities, presenting TRL 6 (Saveyn et al., 2016). The social and environmental indicators were evaluated for the proposed scenario as presented in Table 3.

Table 3 – Result of social and environmental indicators

|  |  |  |  |
| --- | --- | --- | --- |
| Indicator | Result | Unit | Validated |
| Job creation | 79 | People | Yes |
| Salary with the absorption of waste pickers | 94.03 | USD | No |
| Population served | 950,872 | People | Yes |
| Reduction in MSW sent to landfill | 92% | - | Yes |
| GWP | 0.45 | kg CO2eq /kg MSW | Yes |
| Ozone depletion | - | - | No |
| Energy intensity | 241.7 | GWh/y | Yes |
| Water intensity | 62 | m³ | Yes |
| Land use | 15,735 | m² | Yes |
| Photochemical smog | - | - | No |
| Acidification | 53.8 | t SO2eq/y | Yes |

The social indicators job creation, population served and reduction in MSW sent to landfill were validated, as there is data available for their calculations, and each technology will present different values, making it possible to differentiate the technologies through these indicators. On the other hand, the salary with the absorption of waste pickers indicator did not prove to be effective, since the average value received by collectors and that paid to operators by companies do not vary from technology to technology, so this indicator does not differentiate between technologies, and is not relevant for the decision-making tool.

Two of the environmental indicators were not validated for use in the decision-making tool. They are ozone depletion and photochemical smog. This occurred because there is no data available in the literature to calculate these indicators, leading to the need to remove them from the tool. The ozone depletion indicator is not relevant in the decision-making as its impact is important in the case of a landfill, but there is little variation among treatment alternatives (Arafat et al., 2015).

On the other hand, photochemical smog is an interesting indicator for decision-making, since it is a local measure of environmental impact, unlike other indicators such as GWP which is a global one. Therefore, the possibility of compensating for the lack of data with a calculation proposal must be assessed. For example, the maximum emission allowed by regulatory agencies for emission plants, such as incineration and gasification plants, can be used, as emission occurs in high-temperature exhaust systems (Rani et al., 2011).

All other environmental indicators were validated, since there is data available for their calculations, and the technologies can be differentiated between them, for example: anaerobic digestion will not have the same CO2eq emission as incineration, therefore, this indicator helps in the decision-making between technologies.

* 1. Conclusions

This work identified the main technologies used to treat MSW, and the indicators that make it possible to compare them to select the most appropriate process (or a combination of them) in different scenarios, considering the sustainability tripod. With the TRL analysis it was found that pyrolysis is the only one of the technologies analyzed that is not globally consolidated. Although all the other technologies are already in operation on a large scale, gasification is the most recent one, with fewer plants in operation.

The analysis identified the need to remove some environmental indicators: ozone layer depletion and photochemical smog, due to the lack of data available in the literature; and the social one: salary with absorption of waste pickers, since this indicator would not differentiate technologies, i.e., it is not relevant for decision-making. The importance of a database of plants with different capacities and compositions was also noted, so that it would be possible to cover various scenarios that waste management agents might want to evaluate.

References

H. A. Arafat, K. Jijakli, A. Ahsan, 2015, Environmental performance and energy recovery potential of five processes for municipal solid waste treatment, Journal of Cleaner Production, 105, 233–240.

V. A. Araya, 2019, Should the chilean government encourage waste-to-energy facilities for municipal solid waste? Columbia University, USA.

Brasil, 2010, Lei No 12.305, de 2 de agosto de 2010. Presidência da República, Brasil.

Brasil, 2021, Diagnóstico temático: manejo de resíduos sólidos urbanos – visão geral – ano de referência 2020, Ministério do Desenvolvimento Regional, Brasil.

W. P. Chan, A. Veksha, J. Lei, W. D. Oh, X. Dou, A. Giannis, G. Lisak, and T.T. Lim, 2019, A novel real-time monitoring and control system for waste-to-energy gasification process employing differential temperature profiling of a downdraft gasifier, J. Environ. Manage., 234, 65-74.

A. D. Diaz-Barriga-Fernandez, J. E. Santibañez-Aguilar, J. B. González-Campos, F. Nápoles-Rivera, J. M. Ponce-Ortega, M. M. El-Halwagi, 2018, Strategic planning for managing municipal solid wastes with consideration of multiple stakeholders, Computer Aided Chemical Engineering, 44, 1597-1602.

N. Gouveia, 2012, Resíduos sólidos urbanos: impactos socioambientais e perspectiva de manejo sustentável com inclusão social, Ciên. Saúde Coletiva, 17, 6, 1503-1510.

S. F. Interlenghi, P. A. Bruno, O. Araujo, J. L. Medeiros, 2017, Social and environmental impacts of replacing transesterification agent in soybean biodiesel production: multi-criteria and principal component analyses, J. Clean. Prod., 168, 3, 149-162.

E. N. Kalogirou, 2018, Waste-to-Energy technologies and global applications, CRC Press, USA.

S. Kaza, L. C. Yao, P. Bhada-Tata, and F. van Woerden, 2018, What a waste 2.0: a global snapshot of solid waste management to 2050, World Bank, USA.

D. Klar, J. Frishammar, V. Roman, and D. Hallberg, 2016, A technology readiness level scale for iron and steel industries, Ironmak. Steelmak., 43, 7, 494-499.

B. Morero, A. F. Montagna, E. A. Campanella, D. C. Cafaro, 2017, Integrated Process Design Optimization Accounting for Co-Digestion of Sludge and Municipal Solid Waste, Computer Aided Chemical Engineering, 40, 853-858.

N. Neehaul, P. Khadoo-Jeetah, and P. Deenapanray, 2020, Energy recovery from municipal solid waste in Mauritius: opportunities and challenges, Environ. Dev., 33, 100489.

F. Neuwahl, G. Cusano, J. G. Benavides, S. Holbrook, and S. Roudier, 2019, Best Available Techniques (BAT) reference document for waste incineration: industrial emissions directive 2010/75/EU (Integrated Pollution Prevention and Control), Joint Research Centre – European Commission, Luxembourg.

S. S. Pereira, R. C. Curi, W. F. Curi, 2018, Use of indicators in urban solid waste management: a methodological proposal of construction and analysis for cities and regions, Engenharia Sanitaria e Ambiental, 23, 3, 471–483.

A. Pinasseau, B. Zerger, J. Roth, M. Canova, and S. Roudier, 2018, Best Available Techniques (BAT) reference document for waste treatment: industrial emissions directive 2010/75/EU (Integrated Pollution Prevention and Control), Joint Research Centre – European Commission, Luxembourg.

B. Rani, U. Singh, A. K. Chuhan, D. Sharma, R. Maheshwari, 2011, Photochemical Smog Pollution and Its Mitigation Measures, Journal of Advanced Scientific Research, 2, 4, 28-33.

Rio de Janeiro, 2013, Plano estadual de resíduos sólidos do Rio de Janeiro (PERS): relatório síntese, Secretaria de Estado do Ambiente (SEA) – Rio de Janeiro, Brasil.

L. F. Rodrigues, I. F. S. Santos, T. I. S. Santos, R. M. Barros, and G. L. Tiago Filho, 2022, Energy and economic evaluation of MSW incineration and gasification in Brazil, Renew. Energy, 188, 933-944.

J. E. Santibañez-Aguilar, J. Martínez-Gómez, J. M. Ponce-Ortega, F. Nápoles-Rivera, M. Serna-González, M.M. El-Halwagi, 2014, An Optimal Planning for the Reuse of Municipal Solid Waste Considering Economic, Environmental and Safety Objectives, Computer Aided Chemical Engineering, 33, 1027-1032.

H. Saveyn, P. Eder, M. Ramsay, G. Thonier, K. Warren, and M. Hestin, 2016, Towards a better exploitation of the technical potential of waste-to-energy, Joint Research Centre – European Commission, Luxembourg.

S. K. Sikdar, 2003, Sustainable development and sustainability metrics, AIChE J., 49, 8, 1928-1932.

L. J. V. B. Silva, I. F. S. Santos, J. H. R. Mensah, A. T. T. Gonçalves, and R. M. Barros, 2020, Incineration of municipal solid waste in Brazil: an analysis of the economically viable energy potential, Renew. Energy, 149, 1386-1394.