Inter-American Development Bank

Towards the Valorization of Solid Waste in Latin America and the Caribbean

Basic Concepts, Feasibility Analysis and Public Policy Recommendations

Water and Sanitation Division

TECHNICAL NOTE Nº 2402

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January, 2022

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Cataloging-in-Publication data provided by the Inter-American Development Bank
Felipe Herrera Library

Correal, Magda Carolina.
Towards the valorization of solid waste in Latin America and the Caribbean: basic concepts, feasibility analysis and public policy recommendations / Magda Carolina Correal, Juan Alfredo Rihm; editors, Alejandra Abrodos, Claudia M. Pasquetti.
p. cm. — (IDB Technical Note ; 2402)

Includes bibliographic references.
1. Refuse and refuse disposal-Economic aspects-Latin America. 2. Refuse and refuse disposal-Economic aspects-Caribbean Area. 3. Refuse and refuse disposal-Government Policy-Latin America. 4. Refuse and refuse disposal-Government Policy-Caribbean Area. 5. Recycling (Waste, etc.)-Economic aspects-Latin America. 6. Recycling (Waste, etc.)-Economic aspects-Caribbean Area. I. Rihm, Alfredo. II. Abrodos, Alejandra, editor. III. Pasquetti, C. M. (Claudia María), editor. IV. Inter-American Development Bank. Water and Sanitation Division. V. Title. VI. Series.

IDB-TN-2402

JEL code: Q53

Keywords: Valorization, Solid Waste, Latin America and the Caribbean, Solid Waste Management, Treatment, Recycling, Plastic Waste, Best Available Techniques, Proven Technologies,

Towards the valorization of solid waste in Latin America and the Caribbean

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IDB

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To reference this document: Correal, M and Rihm, J (2022). Towards the valorization of solid waste in Latin America and the Caribbean. Interamerican Development Bank
http://dx.doi.org/10.18235/0004570

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ABOUT THIS PUBLICATION

This technical note aims to present the concepts used by countries with greater progress in the comprehensive management of municipal solid waste to evaluate the different waste segregation, treatment, and valorization techniques.[1] It also offers a feasibility analysis methodology that can guide municipalities and decision-makers in the selection of waste recovery technologies, according to their local context. Finally, it proposes a series of recommendations for the adoption of public policies and instruments that promote the introduction and use of these technologies in Latin America and the Caribbean (LAC).

In this regard, the document begins with the description in Chapter 1 of the state of comprehensive solid waste management in LAC. Next, in Chapter 2, the concepts of **best available techniques and proven technologies**, widely used by the European Union (EU), are developed. In addition, some criteria for evaluating the available technologies for the treatment and recovery of solid waste, other than landfills, are presented in the technical sheets attached to this work. Chapter 3 presents a **feasibility analysis methodology** to determine the actions that can be implemented, depending on the state of solid waste management in the local context. Chapter 4 provides a summary of the policies and instruments used by the EU to transform the waste management strategy based on the final provision of the nineteen seventies into a model based on the hierarchy of waste and the circular economy, from the nineteen nineties to the present. Likewise, some **barriers identified in the region** regarding the introduction of these technologies are pointed out and **recommendations and public policy** instruments for overcoming them are proposed. Finally, in Chapter 5 the conclusions are detailed. The study includes a **glossary** to facilitate the understanding of the concepts used in the text.

The technologies described here do not exclude the selective collection and recycling activities carried out in the region, with a high participation of waste pickers. Due to the fact that the purpose of this document is to take an in-depth look at the activities of valorization and use of waste as an alternative to final disposal, sanitary landfills are not included in the study. This is because although it is an activity that is predominant in the region, an abundant bibliography on the subject already exists. The study highlights that even though the use of sanitary landfill requires fewer financial resources compared to the other options, the costs will tend to increase over time because of the expansion of technical standards associated with risk and impact prevention and mitigation measures, the increase in the value of land, its limited availability in areas close to cities, and the acceptance of environmental and social externalities. All this underlines the need to introduce and promote the use of waste valorization techniques that, despite requiring greater capital resources, allow the transformation of waste into new resources and generate significant savings in economic and environmental terms for society over the long term, as evidenced by the positive results of the economic evaluations of many of these projects.

1 Urban or municipal solid waste (MSW) is solid or semi-solid garbage from the activities of population centers in general and includes household, commercial, non-hazardous industrial, service, market, common or non-hazardous hospital waste, the waste generated in the sweeping and cleaning of streets and public areas, and that produced by the pruning of plants in streets, squares and public gardens.

This technical study was prepared with the collaboration of María Alejandra Vásquez, Catalina García and Felipe Puentes, based on the study into alternative treatment techniques, final disposal and/or reuse of solid waste, - and the proposal to adjust to Decree 838 of 2005, financed by the Inter-American Development Bank (IDB) and drawn up by MAG Consultoría (Colombia) and DNV GL (The Netherlands).

The authors appreciate the significant contributions to the preparation of this document made by Manuel José Navarrete, Senior Specialist of the IDB's Water and Sanitation Division; Nicolás Guillermo Rezzano Tizze, Sector Specialist of the IDB's Water and Sanitation Division; Miriam Arista Alarcón, Consultant of the IDB's Water and Sanitation Division; Frans Lamers, Luis Felipe Colturato and Ricardo Orozco, specialists in the development and implementation of waste treatment and recovery projects at an international level. Likewise, the authors are grateful for the participation of those who took part in the Opportunities and Improvements Workshop designed to promote the implementation of waste treatment technologies in Latin America and the Caribbean held on October 18, 2018, in the city of Bogotá, and from which contributions and opinions were used in the elaboration of this document.

1. CONTEXT OF WASTE MANAGEMENT IN LATIN AMERICA AND THE CARIBBEAN

In Latin America and the Caribbean, it is estimated that the population reached

630 million inhabitants

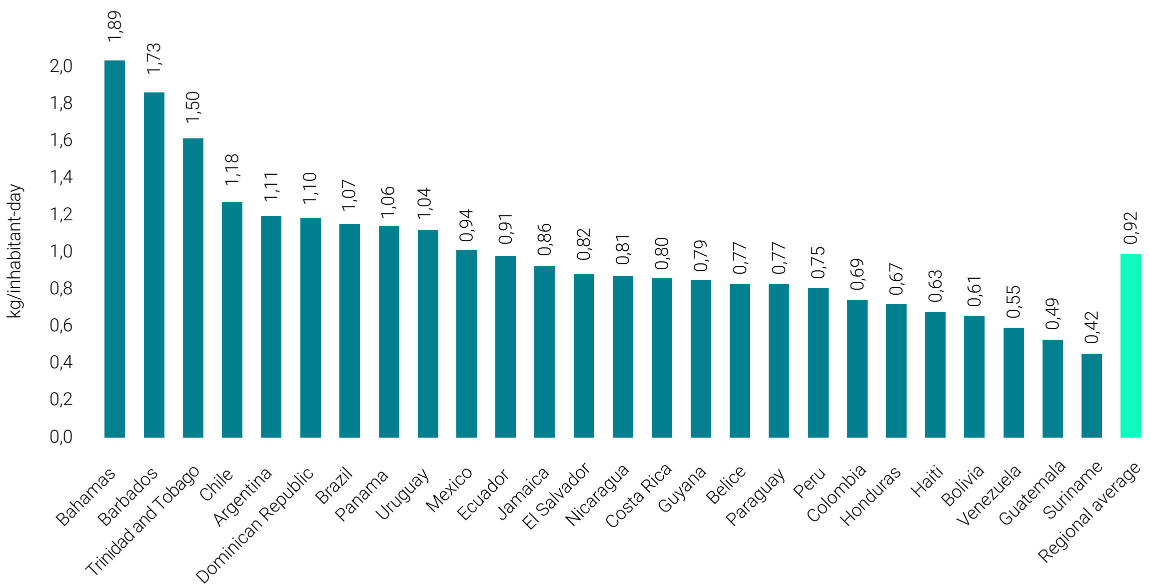
Who generated

230 million tons of solid waste

CONTEXT OF WASTE MANAGEMENT IN LATIN AMERICA AND THE CARIBBEAN

It is estimated that in Latin America and the Caribbean (LAC) the population reached 630 million (UNEP, 2016), and that nearly 231 million tons of municipal solid waste were generated in 2016 (Kaza et al., 2018), which is equivalent to an average per capita production (PPC) of 1 kilogram per inhabitant per day. The following figure shows the rate of waste generation per inhabitant or PPC in each of the LAC countries.[2]

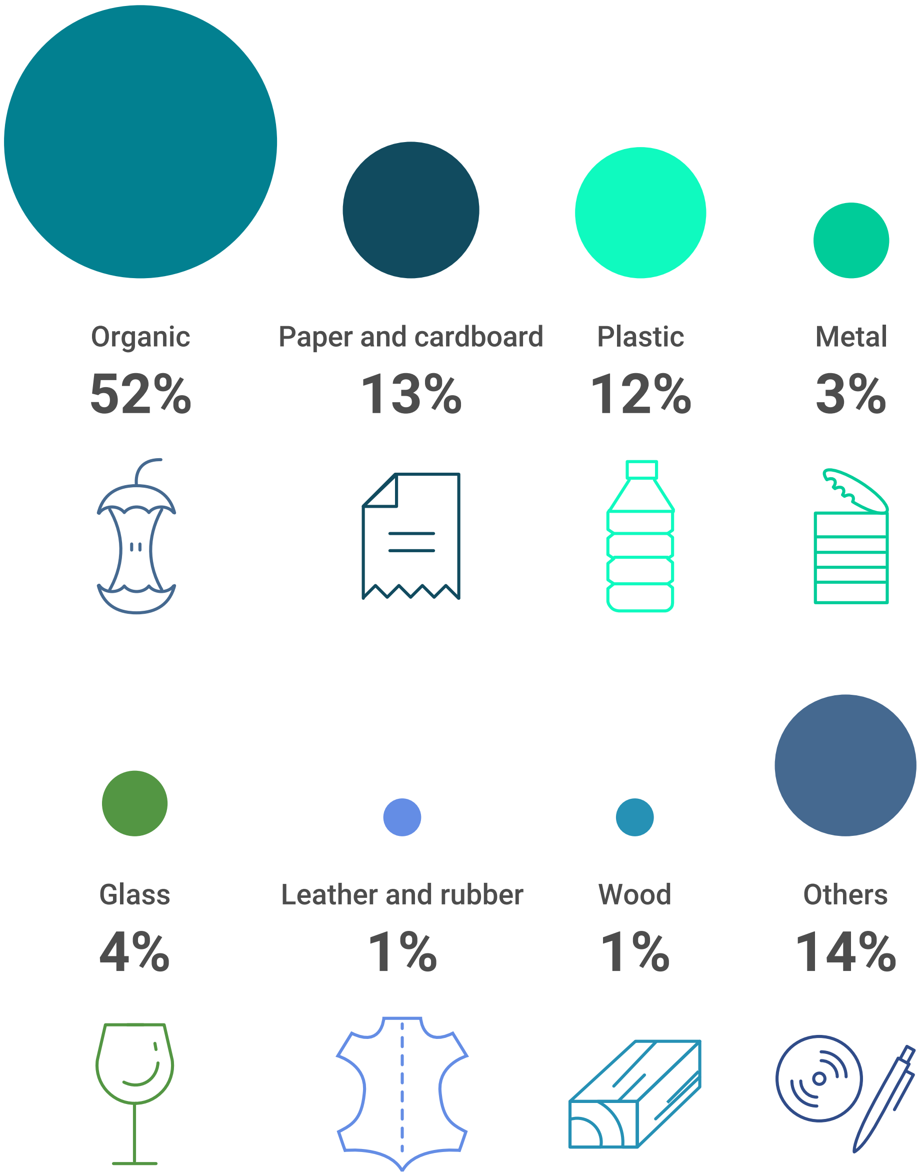
Figure 1. Generation of municipal solid waste in Latin America and the Caribbean (kg/inhab.-day)
Source: Authors' compilation based on information taken from Kaza et al. (2018).
Note: The figure considers the generation of municipal and rural solid waste.



2 Production per capita or PPC is a measure used to quantify the amount of solid waste generated by each individual in the same place within a given period of time. Its unit of measurement is usually expressed in kg/inhabitant-day.

Organic waste predominates in the physical composition of the region, while at least a third refers to recyclable waste (paper, cardboard, plastics, metals, glass), as can be seen in the following figure.[3]

Figure 2. Composition of waste in Latin America and the Caribbean



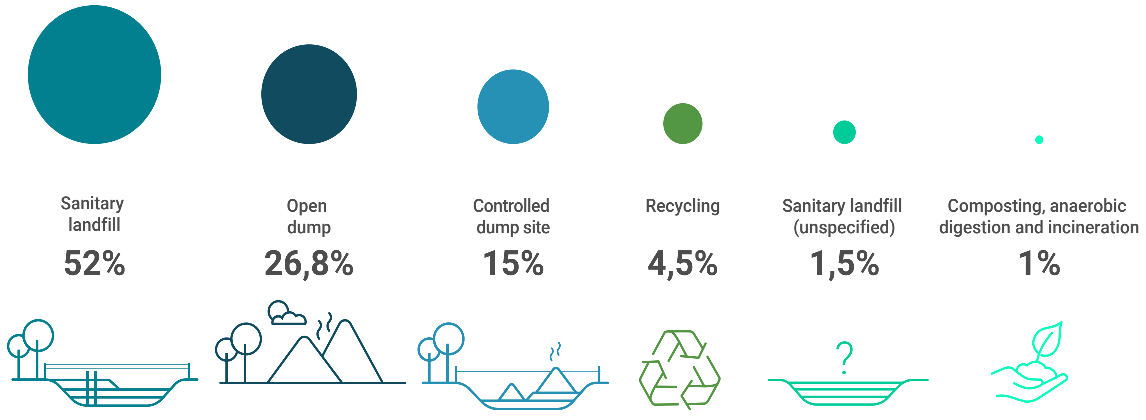
Source: Authors' compilation based on Kaza et al. (2018).

There is a high participation of waste pickers in recyclable waste recovery activities (separation, collection, transportation and classification). Waste treatment and recovery activities are still incipient in LAC; however, in Argentina, Brazil, Mexico, Uruguay, and to a lesser extent in other countries, composting systems, materials recovery facilities (MRFs), and small-scale anaerobic digestion systems have been implemented.[4]

3 Organic solid waste is understood as the fraction of solid waste that includes food waste and green waste from the pruning of plants in streets, parks and gardens.
4 Waste treatment and valorization activities are understood as those processes in which waste is transformed (physically, chemically or biologically) to optimize its management, rescue potentially reusable or recyclable materials, or recover conversion by-products (such as compost) and energy in the form of heat or combustible biogas (Tchobanoglous, Theisen and Vigil, 1994).

Regarding final disposal, about 52% of the waste generated (around 437,000 tons per day) is deposited in some type of sanitary landfill; 15% is disposed of in controlled landfill and 26.8% is disposed of in open waste dumps and other inadequate disposal sites (Kaza et al., 2018).

Figure 3. Waste management in Latin America and the Caribbean (percentage by weight)

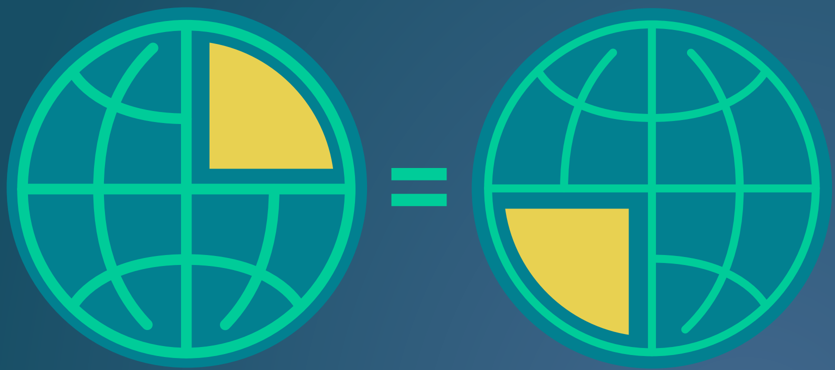


Source: Authors' compilation based on Kaza et al. (2018).

In most countries in the region, solid waste management is closely linked to the financial situation. Even though payment and collection systems have been implemented through rates (property taxes), which are mainly collected by the municipal administration, in general, the waste collection levels do not exceed 50% of the invoiced values and said value is not related to the real costs of the service, which affects the sustainability of the activity and limits the introduction of quality improvements (IDB, AIDIS, PAHO, 2010).

In Colombia, for example, a scheme is applied based on the collection of monthly fees billed and collected together with other household public services (such as electricity or water). These fees are calculated by the public sanitation service provider (public, private or mixed) based on mandatory criteria and methodologies set by the regulation commission in each public service sector (in this case, the Drinking Water and Basic Sanitation Regulation Commission). The fee system used in Colombia has made it financially possible for providers to offer services under the standards established in the regulation and has allowed fee collection levels of over 90% to be achieved in the main and intermediate cities, which encompass more than 80% of the national population. This instrument, together with the waste provision model adopted in Colombia, which is based on having public service companies separate from the municipal administration, have generated large savings in municipal budgets and significant improvements in the quality and coverage of the service.

2. BASIC CONCEPTS



Proven technology on a comparable scale

A proven technology is one that is operational anywhere else in the world at a scale comparable to that of the project in question.

The current European Union reference documents (BREF) include the following best available techniques:

1 

Biological treatment,
mechanical treatment

2 

Waste pretreatment
for incineration

3 

Co-processing
and incineration

BASIC CONCEPTS

As part of its policies of best practices for the comprehensive management of solid waste, the Organization for Economic Cooperation and Development (OECD) recommends adopting criteria that allow evaluating and selecting the best available techniques associated with the context of each population (OECD, 2007).

2.1 Best Available Techniques (BAT)

The concept of Best Available Techniques (BAT) was introduced for the first time in Directive 84/360/EEC of the European Union (EU), on the fight against pollution from industrial facilities, to be later taken up by Directive 96/61/EC for integrated pollution prevention and control (IPPC).[5] Said directive defines BAT as follows:[6]

- **Best:** The most effective techniques to achieve a high overall general level of environmental protection.
- **Techniques:** The technology used, along with the way the facility is designed, built, maintained, operated and dismantled.
- **Available:** Techniques developed on a scale that allows their application in the context of the relevant industrial sector, under economically and technically feasible conditions, taking into account costs and benefits, whether the techniques are used or produced in the Member State concerned or not, provided that the owner can access them under reasonable conditions (Council of the European Union, 1996).

Directive 96/61/EC was replaced by Directive 2010/75/EU, with which the EU seeks to avoid or, when this is not possible, to reduce emissions into the atmosphere, water and soil, to reach a high level of overall environmental protection, and to promote sustainable development.

The determination of the best available techniques is done through a procedure of exchanging information and experiences between experts from different countries, representatives of industries and environmental organizations, with the coordination of the European IPPC Office of the Institute for Prospective Technology (IPTS) (European Parliament and Council of the European Union, 2010).[7] The results are published in the so-called BAT reference documents (BREFs) (European Environmental Bureau, [n.d.]). The BREFs analyze in detail the techniques related to prevention, control, management, minimization, and recycling, which are considered the most relevant for determining the BATs.

5 BAT: Best Available Techniques.
6 "The most efficient and advanced phase of development of the activities and their modes of operation, which demonstrate the practical capacity of certain techniques to build, in principle, the basis of the emission limit values intended to avoid or, when this is not practicable, generally reduce emissions and the impact on the environment as a whole" (European Parliament, 1996).
7 The European Integrated Pollution Prevention and Control Bureau, based in Seville (Spain), is the technical body of the European Commission responsible for the preparation and periodic review of the documents on best available techniques (BREFs).

The BREFs prepared by the EU give an overview of the techniques applied in different industrial sectors, the current emissions and consumption levels, as well as the guidelines and considerations for the determination of BATs, which include both technology and how the facility is designed, built, maintained, operated, and how it will be dismantled.

There are two BREF documents for the waste management sector in the EU: **i) BREF Waste Incineration**, which includes the best techniques in the thermal treatment of waste,[8] and **ii) BREF Waste Treatment**, which refers to the best techniques in the treatment of solid waste other than thermal.[9]

The BATs constitute a dynamic tool, which involves permanent updating in accordance with the technical and technological developments in waste treatment. The OECD emphasizes that the implementation of the BATs is specific to each country or region and that it must be flexible, since their implementation depends on national regulations, technical characteristics, financial potential and local environmental conditions, and in order to avoid recovered materials not being competitive compared to their virgin counterparts.

8 Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118637_WI_Bref_2019_published_0.pdf.
9 Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC113018_WT_Bref.pdf.

2.2 Proven technologies

The concept of proven technology enables the establishing of the degree of preparation and the level of development or readiness of a technology to help decision-making and prevent the risks of its implementation (NCBI, 2014).

The criteria used to define a proven technology are based on the concept of technological readiness levels (TRLs), defined by the National Aeronautics and Space Administration of the United States (NASA) as a scale of merit that allows identifying and evaluating the level of readiness of one or several technologies.[10] This scale consists of nine levels, with 1 being the lowest and 9 being the highest, where the implementation of the technology guarantees successful functioning. In general terms, the concept is based on the number of years of use of a given technology, the number of facilities that operate internationally and the availability and reliability expected of its operation. This concept, even if widely used, lacks definitions or regulations for specific economic sectors, except for a few that have emerged thanks to the empirical knowledge of its application (Héder, 2017).

The EU developed this concept and has implemented it for the financing of public projects (Héder, 2017), its main representative being the program called Horizon 2020, through which several research and innovation projects are financed in various areas of knowledge (European Commission, [n.d.]). The levels of technological readiness have been adapted to the needs of the EU and respond to a general context. With them, any technology can be evaluated, as can be seen in Table 1.

Table 1. Levels of proven technologies adopted by the European Union

LEVEL	DEFINITION
1	Basic principles observed and documented.
2	Concept of the technology and/or formulated application.
3	Experimental proof of the concept demonstrated.
4	Laboratory validated technology.
5	Technology validated in an environment relevant to its application.
6	Technology demonstrated in an environment relevant to its application.
7	Demonstration of the system prototype in an operational environment.
8	Completed and qualified system.
9	Final system tested in an operational environment.

Source: Own elaboration based on the European Commission (2014).

10 TLRs: Technology Readiness Levels.

For the application of this concept in the process of preparing and evaluating solid waste segregation, treatment and recovery projects, the following **considerations are proposed in order to recognize proven technologies** (Lamers, 2019):

1. A proven technology must be available in any other part of the world on a scale comparable to the scale required, that is, on a scale like that of the project to be implemented. Project developers or potential buyers must be able to visit the site where the similar program is being implemented and directly witness the operation of these technologies, in order to observe that the waste streams to be treated are comparable to those planned.
2. A proven technology must be able to demonstrate the following:
    a. At least one operational facility of comparable scale and similar input (substrate) stream and process output that presents the desired conditions.
    b. If the technology ensures that there is power generation, this must be supported by the facility's operating records.
    c. The service provider must allow the interested party to visit the facility where the technology is operating. There must be no type of secrecy that prevents these visits.
    d. These facilities must have been operational for at least 2-3 years in order to verify that the operation can be maintained in the long term.
    e. The technology provider must exhibit the following operational aspects:
        - Quality of the input waste (physical, chemical and biological characteristics, degree of separation, calorific power, etc.).
        - Annual treatment capacity (tons/year).
        - Technology availability (number of operational hours/year).
        - Amount of atmospheric emissions released (m3/year, kg/year).
        - Pollutant discharges on land and water (m3/year and concentrations).
        - Energy output to the grid (MWh).
        - Annual averages of conversion efficiencies (tons of compost/tons of substrate; Nm3CH4/tons of substrate; MWh/tons of substrate; percentage of material segregation [PET, PP, etc.], among others).
        - Internal energy consumption (MWh).
        - General operational matters.
        - Complete balance of energy and mass, with details of internal consumption.

Correctly developing this concept in the solid waste sector is a great opportunity in LAC since it guarantees a higher level of confidence among investors and creditors, facilitates access to financing, and reduces the risks of installation, operation, and maintenance (preventive and reactive), ensures the functionality of the technologies in the medium and long term, and allows first-hand verification that the technology adapts to the required conditions.

Among the best available techniques for (non-hazardous) municipal solid waste, the current EU reference documents (BREF) include the following: i) biological treatment, physical-chemical treatment, ii) pre-treatment of waste for incineration and iii) co-processing and incineration, among others (Pinasseau et al., 2018).

For their part, the BREFs specify that alternative pyrolysis and gasification technologies for the thermal treatment of waste have been used for previously selected waste fractions and on much smaller scales than those of conventional combustion incineration systems (Neuwahl et al., 2019).[11,12]

The technical data sheets attached to this document describe the level of preparation of the technology, which is derived from the results of the consulting study, namely the Study of alternative techniques for the treatment, final disposal and/or reuse of solid waste - proposal for adjustment to Decree 838 of 2005.

11 Gasification processes require that the properties of the waste be kept within certain predefined limits, which often entails the pre-treatment of municipal solid waste.
12 Pyrolysis and gasification technologies try to separate the components of the reactions that occur in conventional waste incineration plants by way of temperature and pressure control processes in specially designed reactors. These systems are usually coupled with subsequent combustion systems for burning off the syngas (synthesis gas) generated. These processes differ from combustion in that they can be used to recover the chemical value of the waste (rather than its energy value), which can be used as raw material for other processes (Neuwahl et al., 2019).

2.3 Technologies for the valorization of solid waste

The techniques for the treatment and reuse, recycling and recovery of waste are generally grouped into **mechanical, biological and thermal/chemical treatment (thermal valorization)**, or a combination of these.

- **Mechanical treatment:** The purpose of mechanical treatment is to recover materials destined for recycling or for the production of refuse-derived fuel (RDF), as well as to prepare or make ready the waste for a subsequent treatment phase (INVENT, 2009). Normally, the mechanical treatment of waste is carried out at materials recovery facilities (MRFs), which use a certain mechanical intensity for separation, classification (garbage bag openers, rotary screens, gravity separators, 2D/3D separators, electromagnets, Foucault separators, optical sensors, among others), component or volume reduction and waste compaction. Within these facilities there may be some manual separation activities, carried out, for example, by recycling operatives.

- **Biological treatment:** Based on the stabilization of the organic fraction of municipal solid waste (MSW) after the controlled decomposition of organic material by microbial consortia, either under aerobic conditions (such as composting) or anaerobic conditions (such as anaerobic digestion), or the mechanical-biological treatment of unseparated solid waste at source. Both methods end in a reduction of organic substances, which under anaerobic digestion generates biogas that can be used as electrical, thermal, industrial energy, and/or for vehicles. It also includes biodrying.[13]

  Mechanical-Biological Treatment (MBT) is a generic concept for the **integration of several mechanical and biological processes**, which are described independently in this document. This means that the MBT integrates processes such as the separation and classification of waste with biological techniques, whether **composting or anaerobic digestion**.

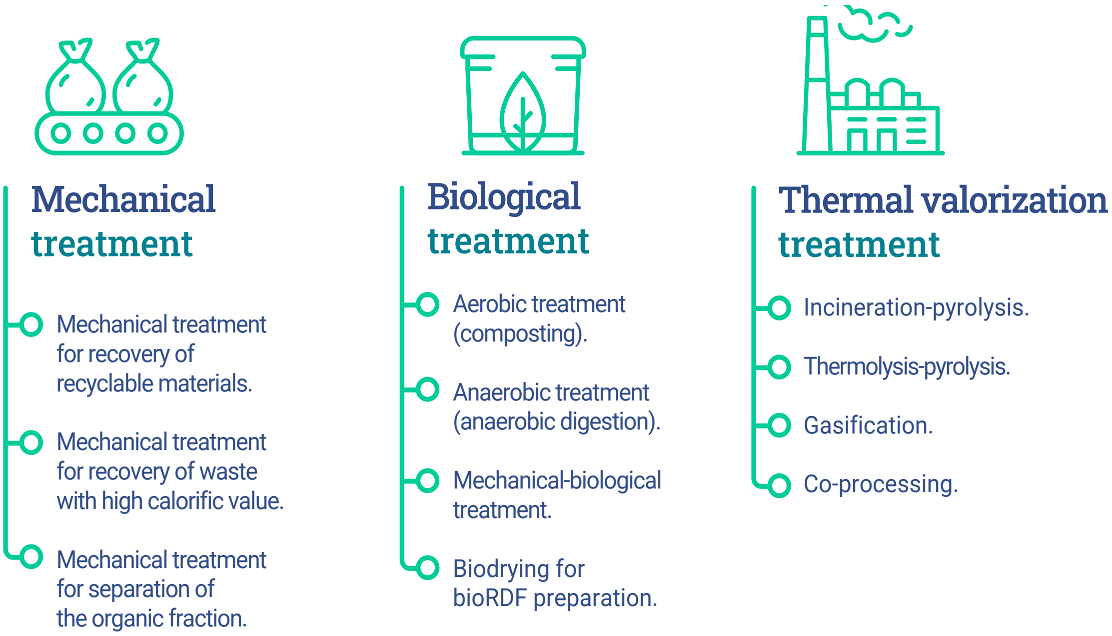
- **Heat treatment with energy recovery (thermal valorization):** It consists of the controlled chemical decomposition of waste at high temperatures in adapted facilities under controlled conditions of temperature, oxygen and time, with the purpose of reducing its volume and mass, as well as recovering energy (in the form of electricity, heat, steam) contained within the waste. The process generates fly ash (which can be used as a material for the construction of civil engineering works), ferrous and non-ferrous metal scrap (which can be reused), hydrochloric acid, gypsum and other by-products that can be used and that require additional treatment (Neuwahl et al., 2019). The thermal recovery processes include: i) combustion (thermal oxidation), whose end products include hot combustion gases (N2, CO2 and water vapor H2O), light particulate matter and ash, and the generation of electrical or caloric energy; ii) gasification (thermal oxidation in the presence of lower oxygen content), whose products are a gas rich in CO, H2 and saturated hydrocarbons (CH4) and the generation of electrical or caloric energy; iii) pyrolysis (thermal oxidation in the absence of oxygen), whose products are a gas rich in H2, CH4, CO and other gases, as well as a liquid fraction (tar or medium calorific value oil) and a solid fraction (composed of coke and inerts).

13 Biodrying consists of a series of closed containers coupled with an aeration system or a long biodrying corridor, where batches of waste are progressively moved through the corridor by means of a loading crane (Pinasseau et al., 2018).

In addition to the technologies for waste treatment, the alternative of **capturing and recovering biogas** is described, as an option for reuse of by-products derived from the decomposition of waste, either for energy generation or direct use as fuel.

> There are several alternatives for the recovery of solid waste, which are summarized in Figure 4.[14]

Figure 4. Treatments for the recovery of solid waste



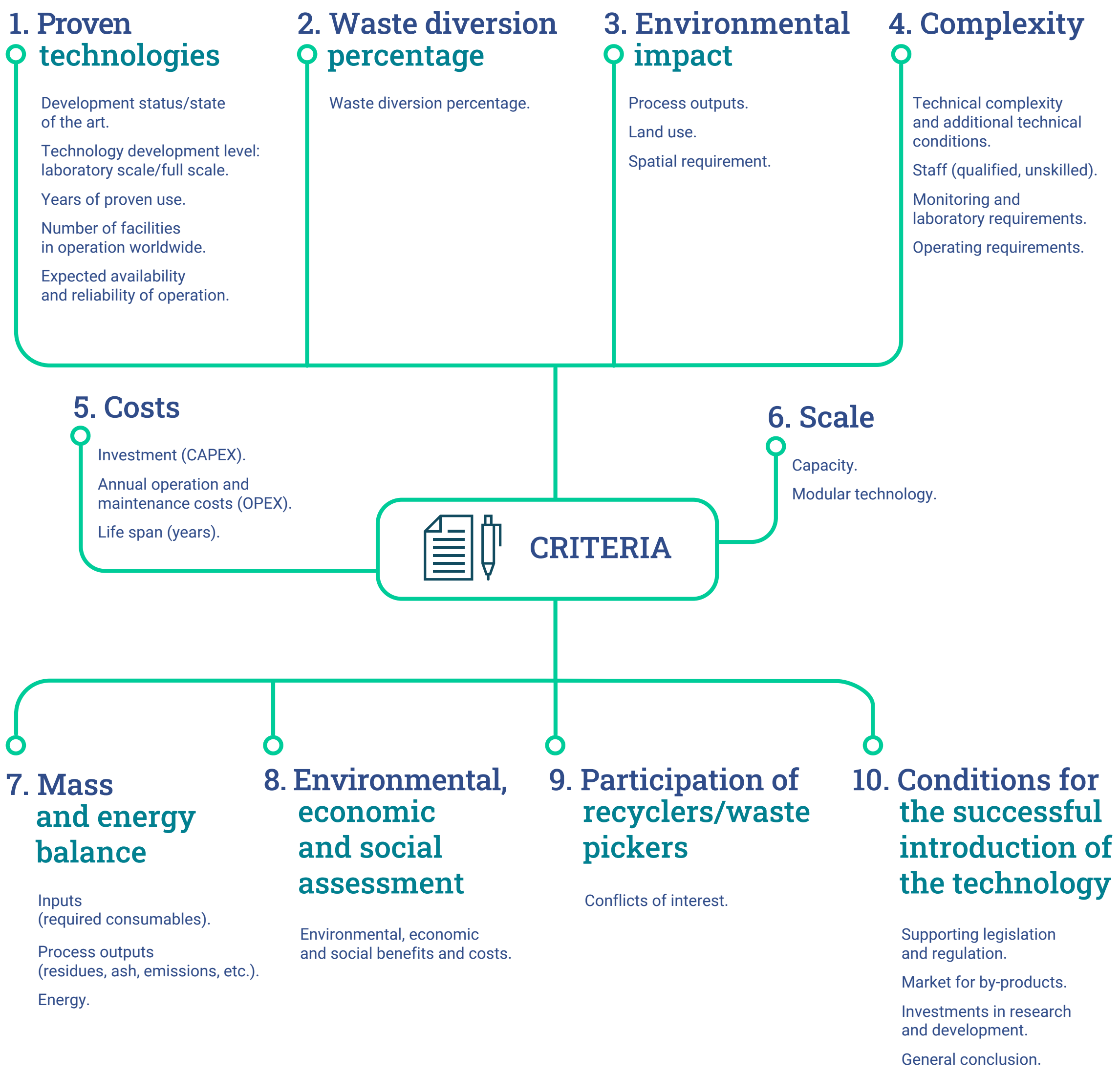
Source: Authors' compilation based on Pinasseau et al. (2018), European Commission (2017a) and European Commission (2019).

14 The European Union documents clearly state that the BATs described are not exhaustive and that there is a wide range of technologies that can improve the selected techniques.

A more detailed explanation of each of the technologies is presented in the technical data sheets attached to this document. The criteria included in the sheets take into account technical, legal, financial, economic, environmental and social aspects, which are outlined below:

- **Proven techniques:** Describes the level of development of the treatment technique, the number of years it has been used, the number of facilities in which it operates at an international level, the expected availability of service, and its operational reliability.
- **Percentage of waste diversion:** In accordance with international experiences, a percentage of solid waste diversion was established that would avoid its disposal in sanitary landfill. The deviation percentage was established for each of the study scales and for each type of treatment.
- **Environmental impact:** The environmental impact is shown, especially with regard to the output of each process (emissions), land use and the spatial requirements for the location of each treatment.
- **Complexity:** The type of personnel required (qualified or unqualified), the technical complexity of the machinery to be used, the requirements for monitoring and laboratory analysis, and some special conditions to achieve successful implementation of the treatment are described.
- **Costs:** For each scale, tentative implementation costs are presented, the approximate amount of investment, the annual costs of operation and maintenance, as well as the projected lifespan, in addition to an approximate cost per ton of waste.
- **Scale:** The operating capacity of each treatment is shown in terms of tons to treat per day, month or year.
- **Mass and energy balance:** The inputs (energy, mainly) required by each technique and the output mass of the respective process (waste, ash, emissions, etc.) are shown. In the outputs, by-products such as compost, electricity, among others, are also considered.
- **Environmental, economic and social assessment:** The environmental, economic, and social benefits and costs are presented in summarized form, as are the costs avoided by not using the sanitary landfill.
- **Participation of recyclers:** It is specified whether the technique is compatible with the participation of waste pickers.
- **Conditions for the successful introduction of the treatment:** This criterion outlines the support legislation and regulation requirements so that the treatment analyzed can work in LAC.

Figure 5. Criteria used in the technical data sheets of each treatment technology



Source: Prepared by the authors.

As an example, presented below is the technical **data sheet for the mechanical-biological treatment**, which can be used for the recovery of recyclable materials, the reduction of the volume of residues, the reduction of the organic matter content of the waste sent for final disposal, depending on the configuration of the plant (biodrying, biostabilization, biostabilization with RDF production, anaerobic digestion or composting) (Pinasseau et al., 2018). The technical data sheets of the other technologies can be consulted in the **appendices** to this document.

Table 2. Technical data sheet of the mechanical-biological treatment

TECHNOLOGY GROUP	MECHANICAL-BIOLOGICAL TREATMENT (MBT)
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology.
Level of technology development laboratory scale/full scale:	9 - full scale.
Years of proven use:	> 20 years.
Number of facilities in operation worldwide:	> 600. E.g.: Kelag (Austria), Istanbul (Turkey), FCC Wiener Neustadt (Austria), La Rioja (Spain), Botarell (Spain), Amarsul (Portugal), Montpellier (France).
Expected availability and reliability of operation (based on operating experience):	>8,000 h/year.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion:	This depends on the composition of the waste, the type of collection (selective or mixed) and the objective of the treatment. To determine the deviation values, refer to the mechanical treatment and biological treatment data sheets, respectively.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	Biogas, RDF, recyclable materials, compost, stabilized organic solid waste for sanitary landfill, leachate, atmospheric emissions, rejects, electrical and thermal energy, biomethane, CO2.
Land use:	Define the legal conditions that allow the installation of this technology.
Spatial requirement:	It depends on the type of treatment. To determine the spatial requirement values, refer to the respective mechanical treatment and biological treatment data sheets.
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Average.
Personnel (qualified, unqualified):	Qualified personnel for the operation of machinery and monitoring, and unqualified personnel for classification.
Monitoring and laboratory requirements:	Mechanical treatment: Individual and global material recovery yields. Compost: Temperature, humidity, pH, C/N ratio, porosity, unsuitable content, etc. Biogas: Yields, flow rate, composition, H2S removal, CO2 removal (biomethane), CHP emissions, methane losses in purification, etc.
Operating requirements:	Compost market, RDF market, energy market, biomethane market, recycling market.

TECHNOLOGY GROUP	MECHANICAL-BIOLOGICAL TREATMENT (MBT)
CRITERION 5: COSTS	
Investment (CAPEX):	Between US$65/TPY and US$150/TPY.
Annual operation and maintenance costs (OPEX):	Between US$32/ton and US$45/ton.
Lifespan (years):	20 years.
CRITERION 6: SCALE	
Capacity:	20,000 TPY - 500,000 TPY.
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Water: 0.14 m3/tons of waste - 0.33 m3/tons of waste.
Mass of process outputs (residues, ash, emissions, etc.): (Depends on the composition of the solid waste entering the plant.)	RDF: 0.25 tons/ton MSW - 0.35 tons/ton of MSW (including stabilized organic matter).
	Recyclables: 0.07 tons/ton of MSW - 0.1 tons/ton of MSW.
	Stabilized organic matter (for final disposal): 0.2 tons/ton of MSW - 0.25 tons/ton of MSW. 100 Nm3 of biogas/ton of organic fines.
	Leachates: 0.003 tons/ton of MSW.
	Rejects: With RDF preparation: 0.35 tons/ton of MSW - 0.55 tons/ton of RSM. Without RDF preparation: 0.5 tons/ton of MSW - 0.55 tons/ton of MSW.
Energy:	Electrical consumption: ~40 kWh/ton. - 60 kWh/ton of MSW.
	Fuel consumption: 30 kWh/ton of MSW.
	RDF calorific value: ~18 MJ/kg ==> 300 kWh/ton of RSM.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Environmental impact due to odors, visual pollution or noise. Possibility of income from the sale of by-products.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	Recyclers can be integrated into the waste sorting process.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Generate/strengthen the legislation that allows the implementation of this technique for waste treatment.
Market for by-products:	A market for RDF, compost and recyclables must be generated.
Investments in research and development:	The State and the private sector must invest.
General conclusion:	• **Advantages:** Recovery of materials and recycling, significant reduction of the volume of waste, stabilization of organic waste, production of materials that can be used as a source of energy (RDF). • **Disadvantages:** In several waste treatment processes it is possible that the product has no market; environmental effects due to offensive odors, visual pollution and noise.

Source: Prepared by the authors based on DNV GL and MAG Consultoría (2016).
MSW: municipal solid waste. TPY: tons per year.

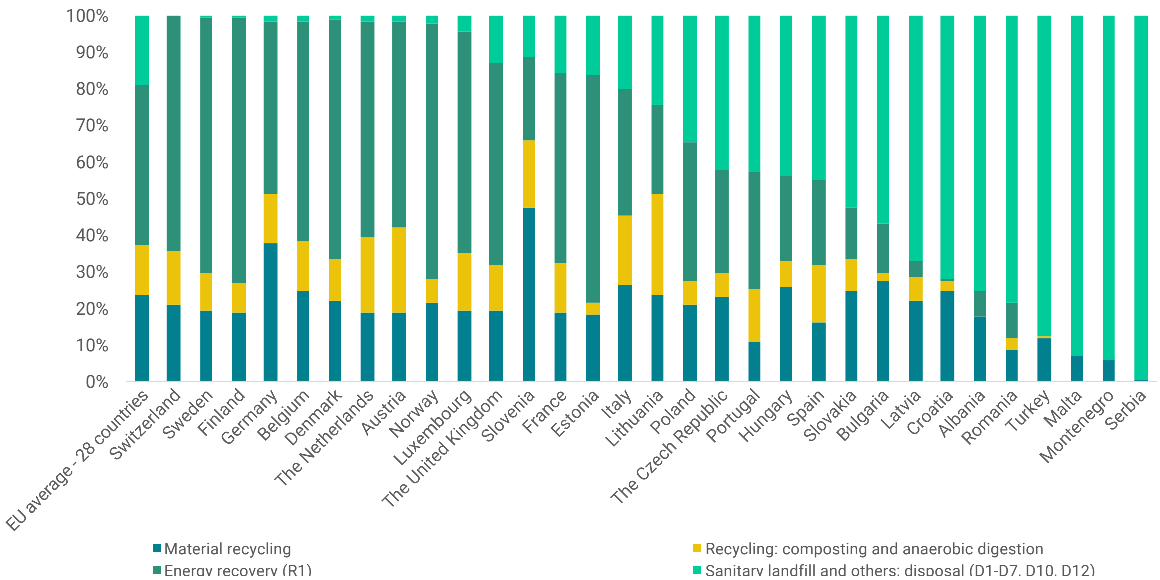
The implementation of these technologies must be accompanied by systems for treating the gas emissions produced in the operation, such as cyclones, electrostatic precipitators, factory filters, absolute filters, thermal oxidation, biofiltration, condensation and cryogenic condensation, adsorption, purification and injection of solvents (Pinasseau et al., 2018).[15] This is of vital importance for the technology to work under BAT standards and for its environmental impact to be positive.

In general, these technologies are implemented in a combined way, so that the different municipal solid waste streams generated are sent to different treatment and valorization facilities. For example, in the same city it is possible to have anaerobic digestion plants for the treatment of the organic fraction coming from marketplaces or large generators of organic waste (hotels, restaurants, food courts, etc.), solid waste recovery plants where usable materials are valorized, or plants for the preparation of RDF combined with thermal recovery plants, to which non-usable waste is taken. The selection of the combination of technologies is based on feasibility studies, which consider the composition and characteristics of the solid waste to be treated, the demand for valorized resources, and the institutional and financial capacity of the municipality or entity in charge of the project.

It is estimated that there are more than 2,700 solid waste treatment and valorization facility projects in operation in the world, distributed across more than 90 countries, with a total investment of approximately US$85 billion (Wilson et al., 2015).

15 These systems are explained in greater detail in the reference document.

Figure 6. MSW treatment in the European Union, 2018 (percentage of tons by type of treatment)



Source: Prepared by the authors based on Eurostat (2018).

In Europe, more than 470 municipal solid waste (MSW) incinerators are installed and operating, together with others for the incineration of hazardous waste and sludge from wastewater treatment plants, whose treatment capacities range between 60,000 and 500,000 tons per year (average capacity of 193,000 tons/year) (Neuwahl et al., 2019). There are also more than 6,000 biological treatment facilities for organic waste, of which nearly 3,500 are composting facilities, 150 are centralized anaerobic digestion facilities (with an average capacity of 36,800 tons per year), and more than 2,300 are anaerobic digestion facilities on farms (Pinasseau et al., 2018).

Box 1

State-of-the-art of thermal recovery at an international level

The environmental purposes behind the thermal treatment of untreated municipal solid waste (MSW) are: i) to destroy the pathogenic germs that can lead to the spread of diseases from sanitary landfill through rodents or other organisms, ii) to reduce the volume and mass of waste streams in such a way that less sanitary landfill space is required for waste fractions, iii) to recover the energy present in the waste, and iv) to prevent emissions of organic and inorganic components that can pollute the air or water.

Heat treatment has been used in Europe for more than 50 years. It is also used in the United States and has recently begun to be used in East Asia, with waste-to-energy (WTE) facilities based primarily on combustion grate incineration technology. Throughout this period of time there have been major developments that have significantly improved the operation of WTE facilities. Some of those changes are outlined below:

- While older facilities (built before 1990) were considered highly polluting and showed high levels of chemical component emissions (including dioxins and furans), the current generation of WTE plants has the lowest emissions in the entire industry due to the implementation of rigid measures for the cleaning of combustion gases. Consequently, the European BREF reference documents for waste incineration declared waste incineration on grates with proper flue gas cleaning as the **best available technology**.
- While older plants operated with a net electrical efficiency of 12-18%, which is relatively low compared to industry practices, the present generation of WTE plants can achieve 25-31% net electrical efficiency which, in practice, is greater than that which can be achieved by any technological alternative for heat treatment.

Currently, more than 1,500 WTE facilities operate in the world, which are categorized as follows:

Pyrolysis

Heat treatment without the addition of oxygen.

Gasification

Heat treatment with low addition of stoichiometric oxygen.

Incineration

Heat treatment with stoichiometric or super stoichiometric oxygen.

Incineration generates CO_2 (relative to the content of biomass in the waste) and water, while gasification and pyrolysis create an intermediate product called synthesis gas, with the presence of CO, H_2 and hydrocarbons, which are often tar-laden. Here are some experiences and observations on gasification and pyrolysis:

- **Two-stage gasification.** This is a combustion process that is basically comparable to incineration, with the difference being that it is done in two stages. These systems are tested with RDF, albeit on a smaller scale than combustion (conventional incineration), but do not offer any improved performance (rather the electrical efficiency is expected to be lower than comparable direct incineration systems and must be scrutinized to verify that their environmental performance meets the required standards). These systems are offered as "gasification", but they are really incineration systems.
- **Upstream gasification from other processes** (such as a blast furnace or cement kiln). In this case, the tar-laden synthesis gases are burned in a downward direction. It is not possible to provide proof of energy efficiency. In Japan some of these processes (like the one performed by Nippon Steel) are operational and considered proven technologies. However, they only work in combination with an upstream process and with RDF.
- **Gasification to produce a synthesis gas (or syngas) that can be burned** with high efficiency in a gas engine or gas turbine. The great challenge for these processes is the tar content present in the syngas that clogs ducts and pipes and damages the gas turbine. Several processes have been proposed for the market, developed and taken to the pilot project stage.
- **Gasification to produce a synthesis gas that can be converted** into a liquid fuel or chemical product. So far it is being developed by a few producers, one of which has been operating a pilot plant for several years and has now built a commercial facility that is in the start-up stage. Others have received commercial orders for the construction of RDF-powered plants that are currently in the financial closing stage.
- **Plasma gasification** (at very high temperatures). This has been developed by a number of vendors who have so far been unsuccessful in showing that it can operate on a commercial scale and have shared no operational data.
- **Upward pyrolysis** from another process (such as a blast furnace or cement kiln). In this case the tar-laden synthesis gases are burned off in the downstream process. It is not possible to provide proof of energy efficiency.
- **Pyrolysis** to produce a synthesis gas that can be burned off highly efficiently in a gas engine or gas turbine and, in addition, a fraction of coal or oil. The great challenges facing these processes are the tar content in the synthesis gases (see items with gasification) and the marketing, as coal, of by-products that are often presented as having a high commercial value, but in practice need to be disposed of in landfills. Several processes have been proposed in the market, developed, sent to pilot facilities and operated with RDF. The average energy obtained from the process is low.

Considering all the above, apart from combustion (and two-stage gasification, since they are systems marketed as gasification, but really involve incineration), there are no heat treatment processes available on the market that have demonstrated their commercial viability for urban solid waste treatment. Many of the alternative processes require pretreatment of the waste (with an additional energy requirement) so that it can be introduced into the facilities and transported, that is, they operate with RDF and not with MSW. It must be noted that these considerations are made for the treatment of municipal solid waste. Both gasification and pyrolysis have been individually tested and may offer possibilities for specific and highly homogeneous waste streams.

Source: DNV GL and MAG Consultoría (2016).

3. METHODOLOGY FOR THE PROJECT FEASIBILITY ANALYSIS

Proposed methodology:

1. Selection of the scenario according to the local context.
2. Selection of priorities to be addressed in waste management.
3. Selection of potentially viable treatment and valorization techniques.
4. Structuring of treatment and valorization projects.

METHODOLOGY FOR THE PROJECT FEASIBILITY ANALYSIS

At a global level, the International Solid Waste Association (ISWA) proposes the methodology called **decision trees** for project feasibility analysis. This guides the selection of a technology via questions about the context in the municipality and offers measures aimed to ensure that the conditions are adequate for the use of a certain technology (ISWA, 2013b).

For its part, the German Society for International Cooperation (the German acronym for which is GIZ) proposes a decision **matrix instrument** for the selection of the best thermal treatment and energy recovery technique, which evaluates 12 criteria and enables the technology most appropriate for local conditions to be determined (GIZ, 2017). Likewise, in recent years the use of multi-criteria analysis (MCA) has gained strength This combines a series of multidisciplinary variables, such as environmental, social, technical, financial, institutional and regulatory, and is based on the analytical hierarchy process (AHP) method proposed by Saaty (2000), which starts from the definition of a series of criteria, weights and indicators that are then combined to obtain a prioritization order.

This section presents a proposal for a feasibility analysis and evaluation methodology for the implementation of the techniques described above in LAC that considers the technical, economic, financial, social and environmental factors that determine their successful operation within the context of the region. This methodology was formulated based on the study of alternative treatment techniques, final disposal and/or reuse of solid waste - proposal for adjustment to Decree 838 of 2005, prepared by DNV GL and MAG Consultoría for the IDB in 2016. This proposal is consistent with the study undertaken by the World Bank on current and emerging technologies for the treatment of domestic solid waste (World Bank, 2011).

The methodology proposed in this document is developed in **four steps**: i) **identification of the context** in which the technology will be implemented, ii) based on the context, the **comprehensive management measures recommended to be implemented** are defined, iii) in the municipality or region that show they are prepared to apply treatment and recovery projects, the analysis of different aspects is carried out and, based on this, the recommended **type of recovery technology is established**, iv) **structuring of the projects**, with the inclusion of technical, legal and financial recommendations together with those related to risk management.

Figure 7. Methodology for the feasibility analysis of waste valorization technologies

Source: Prepared by the authors based on DNV GL and MAG Consultoría (2016).

STEP 1

Selection of the scenario according to the context

This phase includes the identification of scenarios based on the evaluation of indicators that enable the waste management situation to be known in terms of generation, collection, transportation, treatment and final disposal, as well as the potential to promote regional projects in and the institutional capacity of the municipality or region where the technology is to be implemented.

First, it is necessary to calculate the proposed indicators for waste collection and transportation, final disposal and the institutional capacity of the municipality, as per that indicated in Table 3.

It is necessary to mention that defining the institutional capacity of a municipality or a region in LAC is both complex and difficult to standardize since it depends on multiple factors such as the level of economic and social development, the municipal budget, good governance practices, the technical and professional capacity of the work teams, among others. As an example, Box 2 presents a study into the institutional capacity of municipalities carried out by the Colombian government in 2015, which provides some elements of analysis that are useful to consider.

Table 3. Indicators for the identification of scenarios

CRITERION	INDICATOR, MEASUREMENT TYPE AND UNIT	DESCRIPTION	VALUE
COLLECTION AND TRANSPORTATION	Coverage of the waste collection system (quantitative/percentage).	Population that receives the waste collection service/ Total population x 100.	• **High:** System coverage and frequency compliance above 85%. • **Medium:** System coverage and frequency compliance above 60% and one of the two criteria below 85%. • **Low:** System coverage or frequency compliance below 60%.
	Compliance with the collection frequencies established by the service provider (quantitative/percentage).	Number of effective routes carried out/Number of scheduled routes x 100.	
FINAL DISPOSAL	Remaining lifespan of the sanitary landfill (quantitative/number).	Number of years of remaining lifespan.	• **High:** Lifespan of more than 5 years and the landfill has environmental authorization. • **Medium:** Lifespan of less than 5 years and the landfill has environmental authorization. • **Low:** The landfill does not have environmental authorization; therefore, its life span is not taken into account in this case.
	Environmental authorization of the sanitary landfill (qualitative).	This shows whether the municipality disposes of its waste at a site that has environmental authorization to operate.	
INSTITUTIONAL CAPACITY	Institutional capacity of the municipality (qualitative).	Municipal development indicator that considers concepts such as economic dynamics, institutional development, quality of life of the population, environmental aspects, and security, among others.	This indicator will be adjusted according to the methodologies established by each country to assess its institutional capacity. **This document suggests the following classifications:** • **High:** High capacity for economic collection, urban development, quality of life associated with low levels of poverty, investment for environmental development and high fiscal performance. • **Medium:** Medium economic collection capacity, medium urban development, medium range poverty levels and investment for environmental development. • **Low:** Low levels of economic collection, high levels of poverty, low urban development, low or non-existent investment for environmental development and low fiscal performance.

Source: Prepared by the authors based on DNV GL and MAG Consultoría (2016).

Box 2

Case study: Evaluation of the municipal development environment in Colombia (2015)

The municipal development environment index, adopted by the Colombian government, enables municipalities to be categorized according to their characteristics and their level of municipal development using six dimensions:

- **Urban functionality:** This estimates migratory flows, population size and the distribution of the population within the territory.
- **Quality of life:** This considers the level of quality of life of the population according to their capacity to generate income and their level of poverty.
- **Economic development:** This takes into account the capacity to create added value, collection of own capital resources, internet access and disparities.
- **Environmental:** This considers the state of natural resources in terms of number of hectares of forest and environmental investment per capita.
- **Institutional:** This assesses the management capacity of the territorial administration based on fiscal performance and legal requirements.
- **Security:** This evaluates the levels of urban security and that related to the armed conflict.

According to the result of the index, each municipality is classified under one of the following three headings: Robust Development (letters A and B), Intermediate Development (letters C, D, and E), or Early/Incipient Development (letters F and G). As an example, the table below presents the results of comparing this classification for the 1,102 municipalities of Colombia and the type of final waste disposal (authorized or unauthorized) of each one. The analysis of the afore mentioned index and the determination of the type of final waste disposal of the municipalities show that there is a direct relationship between the level of municipal development and the quality of the final disposal of solid waste. This is because most of the unauthorized sites are located in municipalities with incipient/early environmental development.

Table R2.1. Results of the municipal development environment index in Colombia, 2015

DEVELOPMENT ENVIRONMENT		NUMBER OF MUNICIPALITIES BY TYPE OF FINAL DISPOSAL, 2014		TOTAL MUNICIPALITIES	
		AUTHORIZED	UNAUTHORIZED	NUMBER	PERCENTAGE
A	Robust	6		6	0.5%
B	Robust	62	2	64	5.8%
C	Intermediate	152	6	158	14.3%
D	Intermediate	239	22	261	23.7%
E	Intermediate	246	47	293	26.6%
F	Incipient	161	48	209	19.0%
G	Incipient	68	43	111	10.1%
Totals		**934**	**168**	**1,102**	**100%**

Source: Prepared by the authors based on DNP (2015) and SSPD (2016).

The results obtained make it possible to establish the scenario in which the municipality to be analyzed is located. Table 4 presents the requirements of each scenario according to the calculated indicators.

Table 4. Criteria for the selection of the scenario

SCENARIO	CRITERIA		
	COLLECTION AND TRANSPORTATION	FINAL DISPOSAL	INSTITUTIONAL CAPACITY
1	High	High	High
2	High	Medium	High
	Medium	High	High
	Medium	Medium	High
	High	High	Medium
	High	Low	High
	Low	High	High
3	High	High	Low
	High	Medium	Medium
	Medium	High	Medium
	High	Low	Medium
	Medium	Medium	Medium
	Medium	Low	High
	Low	Medium	High
4	Low	Low	Medium
	Low	Low	High
	Low	High	Medium
	Low	Medium	Medium
	Medium	Low	Medium
5	Low	High	Low
	High	Low	Low
	High	Medium	Low
	Medium	High	Low
	Medium	Low	Low
	Medium	Medium	Low
	Low	Medium	Low
	Low	Low	Low

Source: Prepared by the authors based on DNV GL and MAG Consultoría (2016).

A municipality with low institutional capacity probably does not have high collection, transportation and final disposal indicators. However, the total number of combinations that can occur in determining the scenario was acknowledged.

STEP 2

Selection of measures to implement in waste management

Selection of measures to implement in waste management

In accordance with the prioritization of waste and the lessons learned from international experiences, the measures associated with waste management must be determined bearing in mind the state of comprehensive solid waste management and the context of the project area, which were established in step 1 of this methodology.[16]

This means that **if the previously defined scenario is neither 1 nor 2, it is recommended to improve the collection, transportation and final disposal conditions before considering highly complex waste treatment and valorization systems.** The integrated waste management measures recommended for each scenario are described in Table 5.

Table 5. List of measures to implement according to the scenario assigned to the project area

SCENARIO	RECOMMENDED COMPREHENSIVE WASTE MANAGEMENT MEASURES
1	The municipality is prepared to implement or strengthen waste treatment and valorization activities.
2	Optimize the conditions of collection, transportation and/or final disposal. The implementation of complementary waste treatment and valorization systems to extend the lifespan of authorized final disposal sites is not ruled out.
3	Improve final disposal conditions based on the construction or expansion of sanitary landfill by analyzing the possibility of connecting existing or new regional schemes. If a regional system is not feasible, it is recommended to build a municipal/local system. Increase coverage rates for waste collection in both rural and urban areas.
4	Improve the quality and continuity of waste collection and transportation. Improve final disposal conditions, starting with the construction or expansion of a sanitary landfill site. Exceptionally, in case the construction of a local sanitary landfill is impossible, it is recommended to implement treatment alternatives with a low level of complexity.
5	Apply individual solutions of low complexity, such as composting systems for the biodegradable organic fraction. Implement collection routes for the non-biodegradable fraction, with low frequency and with common collection points built by the community. Transport such waste to recyclable waste manual sorting sites, regional transfer stations, or regional/local sanitary landfill sites.

Source: Prepared by the authors based on DNV GL and MAG Consultoría (2016).

16 The processes of other regions such as Europe and North America have shown that before implementing waste treatment and recovery systems, it is necessary to improve collection and transportation processes, while sanitary landfills must operate under optimal technical conditions.

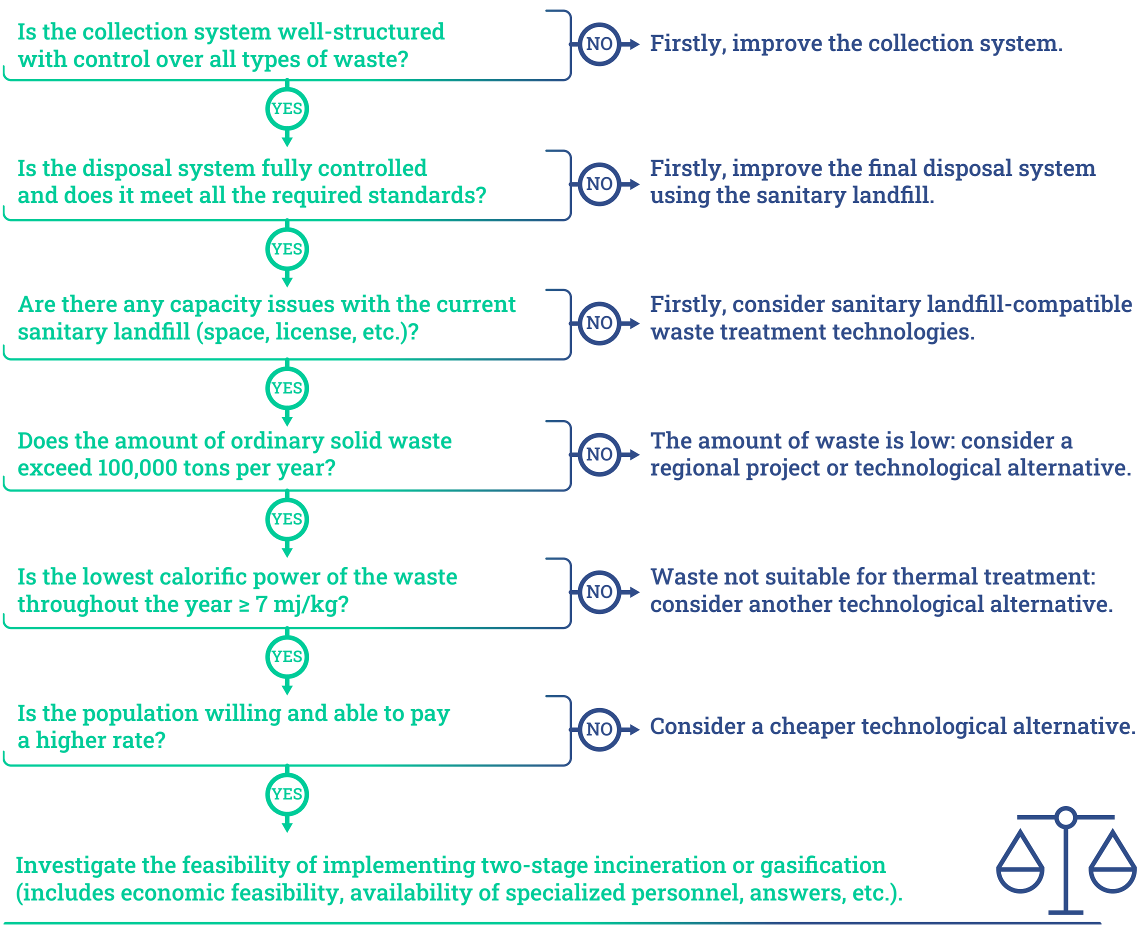
Municipalities with a robust or intermediate type of development, and which have high levels of coverage and quality in the activities of collection, transport and final disposal of waste, are prepared to advance towards other levels of comprehensive waste management that involve treatment and valorization activities. The treatment and valorization alternatives are especially recommended in areas that have achieved high standards of coverage and quality in the activities of collection, transportation, and final disposal of waste.

Before implementing highly complex waste treatment and recovery systems in a generalized manner, the collection and transportation indicators must be improved, and the final disposal sites must be modernized. However, in any of the scenarios it is necessary to promote waste prevention (reduction), minimization (reuse) and recycling campaigns, as well as to encourage the differentiated presentation of waste, which will facilitate the application of valorization projects.

It is recommended to prioritize the reuse and recycling of materials (including the recycling of the biodegradable organic fraction) before energy valorization. However, not all waste can be recycled, which is why energy treatment techniques are complementary and their use is recommended for the fraction of waste that cannot be reused or recycled.

The analysis proposed here is consistent with the **decision tree** methodology proposed by ISWA for the execution of pre-feasibility analysis of waste treatment and valorization systems, in which it is observed that before implementing a thermal treatment system, there must be good collection and final disposal systems (ISWA, 2013b).

Figure 8. Example of pre-feasibility analysis of incineration



Source: Taken from DNV GL and MAG Consultoría (2016).

Evaluation of potentially viable valorization techniques

This step applies to municipalities that are in scenarios 1 or 2 which, according to the classification and analysis carried out in the previous steps, are prepared to implement waste treatment and valorization systems. In general terms, the study of **treatment and valorization scenarios** in which different technologies are combined according to the characteristics of the solid waste to be treated is recommended.

Likewise, international experience has shown that the implementation of these projects is usually carried out in phases, that is, technologies that treat a portion of the waste are progressively incorporated until the treatment of all the waste generated is achieved. This approach requires the continuous adoption and implementation of **roadmaps or work plans**, which in most cases exceed the deadlines of the municipal administrations. For this reason, these roadmaps must be incorporated into the municipal (or regional) plans for comprehensive solid waste management, as well as into the other territorial planning instruments (for example, into the land-use, development and other similar plans).

The selection of **valorization techniques** must consider the technical, legal, financial, economic, social and environmental aspects described in Table 6 to guarantee their operational success. It is important to specify that the feasibility of implementing a certain technique must be validated with the regulations in force at the national, regional and/or municipal level.

Table 6. Feasibility analysis indicators

APPEARANCE	INDICATOR NAME	DESCRIPTION	CRITERION
Technical	Specific technical requirements of each technique.	• Amount of waste to treat (TPY). • Calorific power of the waste (kJ/Kg). • Moisture content (%). • Organic matter content (%). • Type of waste to treat. • Operational complexity. • Need for staff coaching and training.	The minimum requirements can be verified in Table 7 and in the technical data sheets attached to this document.
Environmental	Environmental benefit.	• Diversion of waste from sanitary landfill (%). • Mass and energy balance. • Environmental impact. • Generation of clean energy. • Recycling of materials. • Reduction of greenhouse gas emissions. • Soil improvers.	The minimum requirements can be verified in the technical data sheets.
Financial	Impact of paying for the waste management service on the population.	• Investment cost (CAPEX). • Operating cost (OPEX). • Amount to pay for the waste treatment service (gate fee). • Need for public budget contributions. • Existing market for the consumption of recovered products, which is evaluated through market studies. • Tax incentives.	The United Nations Environment Program (UNEP) recommends that the value to be paid for the solid waste management service be approximately equal to 1% of the gross domestic product (GDP) per monthly capita (Wilson et al., 2015).

APPEARANCE	INDICATOR NAME	DESCRIPTION	CRITERION
Legal	Regulatory requirements.	• Current regulations for treatment or valorization. • Licenses or permits necessary for construction and operation.	The regulatory requirements that govern technology and products.
Social	Participation of waste pickers in the activity and participation requirements of waste generators.	• Level of participation of recyclers/waste pickers in the activity. • Creation of direct and indirect employment. • Requires or does not require separation of waste at source (high, medium, low) and awareness raising and education programs for the population.	Both the possibility of including recyclers and the requirement of separation at source for each technology can be consulted in the technical data sheets.
Socioeconomic	Cost/benefit (C/B) ratio.	Net present value (NPV) of the flow of direct and indirect economic benefits received by private agents and society to be generated by the project after discounting the value of investments and operating costs.	If the result of the socioeconomic evaluation is greater than 1, the project has a positive benefit; otherwise, the implementation of the project may not be economically and/or socially viable. (* See Colombia example below.)

*** Example of economic evaluation, Colombia:**

TECHNIQUE	LARGE (40.000 tons/month)	MEDIUM (10.000 tons/month)	SMALL (4.000 tons/month)
Incineration	1.14	0.54	0.50
Composting	1.65	1.79	3.00
Anaerobic digestion	2.02	3.26	3.05
Biogas extraction and power generation	1.44	1.6	n/a

Source: Prepared by the authors based on Wilson et al. (2015) and DNV GL and MAG Consultoría (2016).

IN THIS STEP IT IS NECESSARY TO CONSIDER THE FOLLOWING RECOMMENDATIONS:

- Due to their medium-high complexity, thermal treatment and anaerobic digestion are recommended for municipalities classified as being a robust as long as the minimum scopes of the project are fulfilled in order to guarantee its viability.
- The participation of the recycling professionals and waste generators will depend on the level of separation at source, the degree of selective collection required, and depend on the technique selected. However, in any scenario, priority must be given to activities to recover recyclable materials at the source (equivalent to approximately 30% of the waste generated), since this is the alternative that produces the greatest net economic benefits for society. Complementary technologies will be analyzed and implemented for this activity aimed at the treatment and valorization of waste that cannot be recovered or recycled at the source, which in LAC cities is equivalent to about 70% of the waste generated.

The **technical data sheets** attached to this document are a support tool to determine the best available technique according to the characteristics of the project area, the waste, the technologies, and the level of municipal development (capacity for planning, ordering, execution and financing).

Some minimum technical criteria for each type of treatment are detailed below. For example, if a municipality classified as robust is ready to implement waste treatment systems and considers that the potentially viable treatment is thermal, it must consider (in addition to the aspects mentioned above) the specific criteria for treatment set out in Table 7. If the municipality meets the parameters described in the table, the application of the technology is viable. Otherwise, the recommendations indicated therein can be evaluated to select the best alternative that suits the technical requirements and municipal context.

Table 7. Criteria for each type of treatment

TYPE OF TREATMENT	CRITERION	PARAMETER	RECOMMENDATIONS
Mechanical	Quantity of solid waste to be treated. It can come from selective or mixed collection.	• Manual: 1,500 TPY or less. • Semi-mechanized with conveyor belt system: Between 1,500 and 40,000 TPY. • Mechanized: 40,000 TPY or more.	The qualification of the personnel will depend on the degree of mechanization used. The more mechanized, the greater the technical training of the personnel.
	There is a potential market for by-products from separation and classification.	Yes/no.	If the market does not exist, first consider a technological alternative that generates other by-products or evaluate the feasibility of opening a new market.
Biological: anaerobic digestion (AD)	Selective collection.	Separation of organic and inorganic waste.	If there is no differentiated collection system, firstly introduce one for the organic fraction of the waste or equip the facility with an in-plant mechanical pre-treatment system called mechanical biological treatment (MBT). Both options can be developed in phases and in a modular fashion. Alternatively, this technique can be used for mixed waste. In this case, the use of compost is limited to landscaping activities or the recovery of eroded areas.
	Quantity of organic solid waste to be treated.	>20,000 tons per year.	It is possible to develop small-scale projects on a larger scale.
	Moisture content of the waste.	≥ 60%.	• Wet AD: If the moisture percentage of the waste is below this value, the waste is not suitable for this technique. Consider co-digestion or combining it with other waste. • Dry or extra dry AD: The waste is suitable for this technology if the moisture content is below this value. It may even be necessary to add pruning offcuts to further reduce humidity.
	There is a market for by-products (electrical energy, biomethane, liquefied CO2, compost, liquid biofertilizer).	Yes/no.	If there is no market for the biogas (sale of electrical and thermal energy or biomethane) and compost, first consider a technological alternative that generates other possibly marketable by-products.
Biological: composting	Selective collection.	Separation of organic and inorganic waste.	If there is no collection and separation system, first introduce separation at source and differentiated waste collection. Alternatively, this technique can be used for mixed waste. In this case, the use of compost is limited to landscaping activities or the recovery of eroded areas.
	Moisture content of the waste.	Ideally, between 45 and 60%.	If the moisture percentage of the municipal waste is below than this value, the waste is not suitable for this technique. Consider another technique or combining it with other waste. If the humidity is greater than these values, and up to 75%, the technique can be used. In this case, mixing with other fractions, such as pruning waste (structuring material), will be required.
	Is there a market for by-products (compost)?	Yes/no.	If there is no market does not exist, firstly consider a technological alternative that generates other potentially salable by-products.

TYPE OF TREATMENT	CRITERION	PARAMETER	RECOMMENDATIONS
Thermal	Quantity of solid waste to be treated.	>3 tons/hour.[a]	If the amount of waste is lower, consider a regional project or another treatment technique.
	Biogas extraction	>7 MJ/kg	If the calorific value of the waste is below this value, the waste is not suitable for this type of treatment. In which case it will be necessary to consider the addition of pre-drying (bio-drying) or dehydration techniques, or the addition of other fuel sources (natural gas, etc.) to maintain temperature. Otherwise, consider another treatment technique. New facilities in China accept waste with calorific values of 5.5 MJ/kg (CNREC, 2014).
Biogas extraction and power generation	Scale.	>1 million tons accumulated in sanitary landfill.	If the value is lower, it is necessary to consider the remaining lifespan of the final disposal site to plan the capture of biogas from this operation.

Source: Prepared by the authors based on ISWA (2013b).
[a] Neuwahl et al. (2019).

Finally, although the methodology proposed here for decision-making considers, to a large extent, the financial result of the projects, the **economic evaluation** of the projects must also be considered. The result of the economic evaluation will make it possible to determine whether the project generates benefits for society are greater than its costs, in which case the contribution of public resources will be justified to achieve the financial closure of the project, if necessary. As established by Wilson et al. in the *Global Waste Management Outlook 2015*:

"Environmental pollution can be considered in economics as a 'market failure', insofar as the market does not establish prices for the limited capacity of the three environmental receiving media (air, water and soil) for the absorption of emissions, waste and discharges. The costs of environmental damage - the negative externalities of pollution and waste - are borne by society and the economy as a whole, rather than being recorded by accountants as a production cost" (Wilson et al., 2015).

Various methodologies have been developed for the economic evaluation of projects. The main direct effects and externalities associated with waste management projects are cost savings due to space savings in the sanitary landfill; revenue generated from the sale of recovered resources (energy, recyclables, RDF, compost, etc.); carbon emissions avoided as a result of better waste management; the generation of energy and the production of raw materials replaced with recyclable materials (World Bank, 2017; EEA, 2019); the reduction of emissions of air, water and soil pollutants; the positive assessment of the population, associated with the perception of having a cleaner city (for which methods of revealed or declared preferences are used, such as hedonic price methods and willingness to pay); the creation and formalization of jobs, etc. (European Commission, 2014; Wilson et al., 2015).

STEP 4

Structuring of treatment and valorization projects

Once the waste treatment and recovery technique to be implemented has been selected, and prior to the final structuring of the project, it is necessary to define the municipal or regional **administration model** (associations or groups of municipalities) based on the stakeholders forming part of the project.

For the definition of the model, it is convenient to describe and analyze different options, such as the formation of a regional public company with the shareholding of the municipalities, the association of municipalities, etc. The model must establish the benefits, commitments/obligations, requirements, contributions and shares, decision-making and administration bodies, good governance practices, staff needs and estimation of operating costs, conflict resolution mechanisms, advantages and disadvantages, among other aspects that will serve as a basis for the municipalities to make the decision. Preferably, the selected agency should have administrative and budgetary autonomy and the capacity to contract and implement the project, both in its design and construction, as well as its operation. In this regard, to select the model it will be necessary to conduct interviews and workshops with the municipal administrations to socialize the progress and results, as well as receiving their contributions and requests and attending to their queries, so that they remain fully informed. Once the administration model has been defined, the documentation for its implementation will be prepared, such as the contract drafts, statutes, and other documents that allow the municipalities to obtain authorizations and budget commitments to formalize their participation.

The next step consists of the detailed structuring of the waste treatment and recovery project at the level of feasibility or detailed design, depending on the type of contract to be used (public-private alliance or traditional public works), within which the following aspects will be taken into account.

FOR THE TECHNICAL STRUCTURING:

- *Precisely define the general aspects of the project:* its scope, the geographical location, the benefited and/or affected population, the estimated demand (for example, the tons of waste to be treated), the services that will be provided. Describe the property and topography. Carry out population and waste projections, according to their physical composition. Coordinate the relationship with the other activities of the service (such as collection, communication, education, etc.), which must be adjusted or modified.
- *Once the selection and availability of the land is confirmed:* carry out the necessary studies to determine the engineering solution, such as geotechnical studies (soil mechanics), topography, hydrogeology, hydrology, network relocation (if applicable). Describe the project, the components and auxiliary facilities, as well as the basic design, which must include: i) the design bases (treatment capacity, operating conditions, projected mass and energy balances); ii) the general specifications of the design, construction, operation and maintenance; iii) details of auxiliary facilities (accesses, perimeter fences, roads, weighing, unloading and maneuvering areas, urban planning, landscape restoration, etc.); iv) the technical specifications of each facility and component (structure and foundations, electrical installations, fire management, water management, built surfaces, etc.); v) technical conditions that will apply during the

implementation of the project (general obligations, work procedures, engineering and construction management, documentation, quality control, personnel training during construction, assembly, start-up, acceptance certificates, contingency, occupational health and safety, operation manuals, maintenance plan, environmental monitoring plans during construction and operation, waste characterization plan during operation, marketing plan and disposal of recovered waste, environmental education program, key personnel required, technical characteristics of the equipment, expected performance, service and quality indicators, measurement and reporting mechanisms to be used) (IDOM, 2020).

- *Carry out a market study to determine/confirm the demand and existing* or potential markets for the sale of by-products of treatment and valorization (such as energy, recyclable materials, compost, RDF, etc.). Carry out a sensitivity analysis according to the amount of waste, rejections or products resulting from the treatment that cannot be reused; environmental impact studies and other documents necessary to obtain the required permits, licenses and authorizations; social impact study and social inclusion plan (if applicable). Validate the socioeconomic evaluation of the project carried out previously to determine its relevance for the population, know its level of priority compared to other public investments and, in addition, assess whether the expected benefits are greater than the economic, social and environmental costs of its implementation (DNP, 2014). The structuring must establish the way in which the project will be coordinated within the municipal and/or regional land use.

FOR THE FINANCIAL STRUCTURING:

- *Its main product is the financial model,* which is a relevant tool for decision-making based on the feasibility analysis of the project. The financial model makes it possible to establish the value of the project and the sources of resources required for its viability (resources from the public budget, fees/rates for the garbage removal service, contributions to contingency funds to cover any possible risks of the project, etc.) (DNP, 2014). The financial model gathers information from all areas of the project, meaning that those responsible for its construction must have comprehensive knowledge of it and interact with the teams responsible for these areas to ensure that all the details are captured.
- *The financial model must consider previous studies* and contain, at least, the following elements: i) a detailed projection of each income item, considering the estimated income; ii) a detailed projection of annual spending; iii) a detailed projection of expenses, with the cost of capital necessary to finance the investment; iv) projected financial statements, current balances and cash flows for the entire project period; v) calculation of depreciation and amortization, with the measurement of the best combinations of investment and reinvestment scenarios, taking into account the lifespan of systems and equipment; vi) project period; vii) capital structure; viii) working capital; ix) analysis of the return on investment; x) study of payment methods/mechanisms so that the project remains sustainable; xi) sensitivity analysis to assess the impact of changes associated with input variables (for example, generation and composition of waste, duration of the construction period, investment and operating costs, gate fee, sale price of resources recovered and other income) (European Commission, 2014); and xii) scenario analysis.

- *The financial structuring must also consider the development of a detailed proposal of rates (gate fee)* that the operator (public or private) will receive. These must allow for the recovery of the investment costs as well as the operation and maintenance costs of the built systems, together with the other sources of income. Likewise, an analysis of the different modalities and the different mechanisms for collecting the proposed rates will be included.

FOR THE LEGAL STRUCTURING:

- *Within this structure, the administrative and contractual management scheme to be used is detailed.* Should the convenience of carrying out a public-private partnership (PPP) or a traditional public works contract be determined, at this stage the terms or specifications and the contract draft are designed to clearly show the obligations and responsibilities of the future public and private partners, the mechanisms for resolving conflicts between the parties, the mechanisms for the termination of the contract, the administration of resources and the form of payment, compliance with the corresponding legislation and regulations, compliance with permits and authorizations, the legal availability of the land on which the project will be located, among other elements (DNP, 2014).
- *The management process can present variations between countries:* it can be completely public, through companies, corporations, or state cooperatives; private, by means of transfers through licenses, sales or private supplies, or with the participation of both parties, through management contracts, concessions (Vives et al., 2007) or a contract for the guaranteed sale of recovered materials.[17]

FOR THE STRUCTURING OF RISK MANAGEMENT:

- *It establishes, defines, and assesses (probability and impact) the possible risks* that may arise during the different stages of the project (pre-investment, design, financial closing, construction, operation and maintenance), as well as the availability of permits and land, environmental, social, commercial, financial, macroeconomic conditions and situations of force majeure, among others.
- *In addition, prevention, management, monitoring, and mitigation strategies are defined*, as well as a proposal for the distribution or allocation of risks between the parties (including assessment, times, persons responsible, actions or measures), based on the premise that they must be awarded to whomsoever is best capable and suitable to manage and mitigate them. This step is essential to guarantee the success of the implementation of waste treatment/valorization technologies.
- *Within this framework, one of the main products of this stage is the project's risk matrix,* which summarizes the definition of the risk, its allocation, the probability of occurrence, and the assessment of its impact. Based on this risk matrix, the explicit rules on this aspect are drawn up, and these shall be included in the contract draft (DNP, 2014). Table 8 describes the types of risks that it is recommended to consider in waste treatment and valorization projects.

17 The Ministry for Regional Development of Brazil (former Ministry for Cities) is structuring contracts for the guaranteed sale of recovered products in order to reduce the value of the gate fee (an internal rate of return, IRR, is fixed), and the risk of the contract (guaranteed sale). For example, the contracting municipality assumes the acquisition, for a predetermined term and price, of biomethane, compost and/or electrical energy. Another example is the incentives for the cement companies in the use of the RDF and the need to confirm, by way of long-term contracts, the reception of said incentives. For recyclables, the "recyclables credit" is being created, with the participation of the packaging industry, within the framework of the reverse logistics program (extended producer responsibility) (Colturato, 2021).

Table 8. Types of risk

TYPE OF RISK	DESCRIPTION
Land acquisition	Variation in the availability of the land necessary for the development of the project.
	Variation of costs for the acquisition of land and eventual socioeconomic compensations required by the affected community.
Social and environmental	Variation in the times or requirements for obtaining, amending and/or transferring environmental permits/licenses.
	Environmental constraints such as loss of biodiversity, reuse and exploitation of natural resources, and relocation of communities.
	Requirements by the environmental authority, which are not part of the obligations contained in the environmental permit and/or license, in accordance with the regulations.
	Community resistance or opposition to the implementation of the project.
Equipment	Variations in the costs of importing equipment due to changes in the market, in tariffs and in the exchange rate.
	Variations in equipment performance.
Design	Variation in costs derived from changes in studies and designs.
	Selection of an inadequate technology.
	Variation in costs due to adjustments in designs requested by the authorities.
Construction	Variation in the cost of the project caused by changes in the quantities of work, problems in designs, construction methodology, execution schedule or related to the capacity of the builder.
	Variation in the prices of consumables, materials, labor and other construction elements and associated indirect costs.
Operation and maintenance	Variation in operation and maintenance costs, due to macroeconomic variables (inflation and exchange rate) or maintenance and repair costs greater than those projected or accumulation of technical shutdowns/suspensions.
	Quantity and/or composition of waste different from those projected or variation in yields (percentage of recovery of recyclables, Nm3 biogas/ton; compost quality, MWh/ton, among others).
	Variation in the prices of consumables for operation and maintenance activities.
Commercial	Waste generation less or greater than projected or insufficient control in the destination of the waste flow.
	Variation in income derived from the modification of the rates/fees for the solid waste management service.
	Favorable or unfavorable effects derived from the market and the sale of the by-products of the treatment and reuse of waste.
	The variation in the sale prices of energy and recovered products may proportionally affect the participation in the total income of the project.[18]
	The outputs of the process do not meet the expected quality targets.
	Failure to comply with emission limits (to air or water).
	Favorable or unfavorable effects derived from the fundraising operations and collection of charges/rates or gate fees.[19]
Financial	Not obtaining the financial closure of the project, which will depend on the available financing mechanisms, potential investors and financiers, market conditions, as well as macroeconomic aspects, the reduction in credit supply, etc.
	Negative effects due to the application of locally established gate fees.
	Variations in interest rates and exchange rates due to financial market effects.

18 In general, the demand for RDF in the region is very low and does not have a developed market, despite it being an imperfect substitute for coal. In the event of not achieving its sale, a fee must be paid for its final disposal and the associated transportation costs.
19 Fee charged on a specified amount of solid waste received at a waste processing facility..

TYPE OF RISK	DESCRIPTION
Regulatory	Variation in income caused by changes in the calculation of charges/rates.
	Legislative and regulatory changes (changes in the environmental and/or economic requirements, or in the regulatory instruments; for example, introduction of taxes on sanitary landfills, prohibitions, or restrictions on final disposal, among others) or the decisions of the contracting party ("sovereign act") that affect the waste treatment and recovery process, different from the regulation of charges/rates.
Force majeure	Force majeure in the acquisition of property caused by events exempting liability, which depends on the existing mechanisms for the purchase of properties in each country.
	Force majeure due to significant variation of the maximum established time applicable for the issuance of environmental permits/licenses and other permits required by the project.
	Non-catastrophic insurable events, such as weather events, heavy rains, winds, or unpredictable earthquakes.
	Insurable catastrophic events, generally associated with return periods greater than 50 years, for phenomena such as earthquakes and landslides and other weather events such as heavy rains and hailstorms that may be frequent throughout the year.
	Non-insurable events, such as the occurrence of archaeological finds within the project area or similar events that generate delays in the works or higher costs in the execution of the project.
	Political discontinuity that limits the implementation of the project.

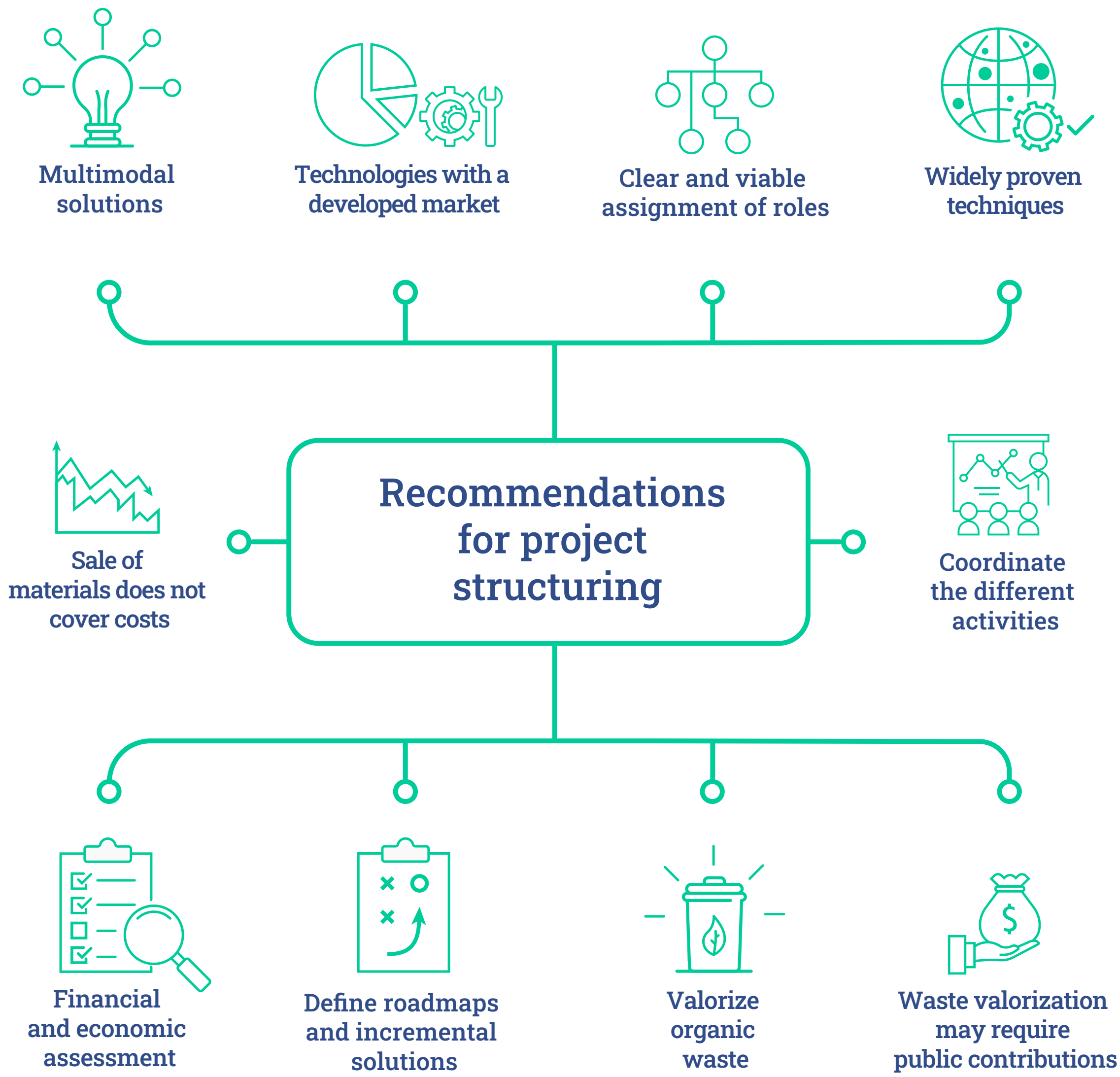
Source: Prepared by the authors based on CONPES (2001) and European Commission (2014).

When there are favorable local conditions for the development and implementation of projects, private participation and investment is usually greater because the risks of conflict or expropriation are lower for investors. Also, better risk management strategies generate greater confidence among investors to agree to get involved in the project. In this regard, the local conditions must be evaluated to establish if the minimum favorability for the execution of the project is met. If the balance of comparing the favorability of each of the local conditions against the risk that investors are willing to accept is positive, the development of a waste treatment and valorization project can be considered (Vives et al., 2007).

Some final recommendations for the structuring and evaluation of solid waste treatment and recovery projects are presented below in summary form:

- Choose multimodal solutions, that is, define scenarios in which different treatment techniques are combined, depending on the characteristics of the waste and the existence of a market that demands the recovered products, which can be implemented progressively through phases or modules; and that these scenarios are articulated with municipal planning and a vision of comprehensive management of urban solid waste in the medium and long term.
- Choose technologies whose recovered products have a widely developed market, where there is a high level of certainty that the resources will be in demand and the expected income will be generated. Similarly, it is necessary to encourage the creation of markets that ensure demand, improve prices and reduce the risks of marketing recovered materials or resources.
- Choose widely proven techniques. Especially in LAC, where the resources available for investment are limited, it is necessary to prefer technologies that have already been used on a commercial scale, of a similar size to the one of the project that is expected to be implemented, that are in operation and whose results are proven and thoroughly documented. It must not be forgotten that innovation and the development of new techniques require larger budgets, as well as the technical and political availability to accept that not all projects are successful.
- It is essential to carry out both the financial and economic evaluation of the projects since the former will determine whether the expected income is sufficient to ensure the viability and sustainability of the project and public contributions are not required. The economic evaluation will establish whether the benefits generated by the project, apart from the financial income, are greater than its costs, in which case public contributions will be justified to ensure the financial closure of the project, if necessary.
- The structuring of the project must define the business or transaction model for the implementation of the project, as well as the roles, rights and obligations of the different players and the instruments to ensure its compliance.
- Treatment and recovery techniques must preferably be implemented progressively, in phases, since, according to international experience, no city in the world has solved the problem of waste management with a single project and in a single moment. Due to the above, the structuring of projects must include roadmaps or work plans that ensure the continuous implementation of the project above and beyond the municipal administration periods. This progressive roadmap will make it possible to incorporate the technological advances that arise periodically, avoid excess capacity that generates idle work sites, and improve the financial viability of the projects by distributing the investments over time.

Figure 9. Recommendations for the structuring of solid waste treatment and valorization projects



Source: Prepared by the authors.

4. PUBLIC POLICY RECOMMENDATIONS TO PROMOTE THE VALORIZATION OF SOLID WASTE

Regulatory system

Promote the development of technologies for the valorization of solid waste.

Having a regulatory system that encourages the development of technologies for the valorization of solid waste is a starting point for strengthening waste management and moving towards techniques that promote its reuse and prevent its final disposal.

Adopt targets, actions, and instruments.

It is necessary to adopt targets, actions and instruments that discourage final disposal and promote the valorization of solid waste.

PUBLIC POLICY RECOMMENDATIONS TO PROMOTE THE VALORIZATION OF SOLID WASTE

Public policies are decisions and actions of governments through which they seek to solve the different problems of society and overcome the barriers that limit or affect the development of activities and services, in this case, the comprehensive management of solid waste.

As an example, and frame of reference, the experience of the European Union in the adoption of public policies and the choice of instruments used is presented. Then, some of the barriers that, in the opinion of the authors, limit the implementation of waste treatment and valorization projects in LAC are described. Finally, some public policy recommendations for the region are proposed.

4.1 Public policies and instruments used in the European Union

Since 1975, and especially since 1994, the countries of the European Union (EU) have aimed to reduce the amount of waste generated and reverse the positive relationship between economic growth and the growth of waste generation (European Commission, 2017a; European Commission, 2019b). To achieve this, the EU has gradually assumed different goals and strategies, which are summarized below, in order to ensure the elimination of waste and, instead, treat it as a raw material (detailed in the appendices are the directives, decisions and regulations adopted by the EU to encourage the valorization of solid waste).

Table 9. Mandatory reuse targets within the European Union (Directive 94/62/EC)

DEADLINE	ACTION	PERCENTAGE
06.30.2001	Valorize or incinerate in waste incineration facilities with energy recovery.	Minimum: 50%. Maximum: 65%. Average based on the weight of packaging waste.
12.31.2008	Valorize or incinerate in waste incineration facilities with energy recovery.	Minimum: 60% of the waste.
06.30.2001	Recycle.	Minimum: 25%. Maximum: 45%. From the weight of all the packaging materials contained in packaging waste, with a minimum of 15% by weight for each packaging material.
12.31.2008	Recycle.	Minimum: 55%. Maximum: 80%. From the weight of packaging waste. Minimum: 60% glass, paper and cardboard; 50% of metals; 22.5% of plastics; 15% of wood.

Source: European Parliament and Council of the European Union (2008).

Table 10. Reduction targets for biodegradable municipal waste in sanitary landfill in the European Union (Directive 99/31/EC)

PERCENTAGE ALLOWED TO ENTER SANITARY LANDFILL (in weight of biodegradable municipal waste produced in 1995 or the immediately preceding year)	**DEADLINE AFTER THE ENTRY INTO FORCE OF THE STANDARD**
Up to 75% of the total amount.	5 years
Up to 50% of the total amount.	8 years
Up to 35% of the total amount.	15 years

Source: Council of the European Union (1999).

On the other hand, in various European countries taxes or prohibitions have been implemented on sanitary landfills so that waste is disposed of through alternative forms of treatment. Table 11 shows the measures taken by some European countries in relation to the prohibition of sanitary landfills or the establishment of a tax, as well as the percentage variation of final disposal between 2005 and 2012.

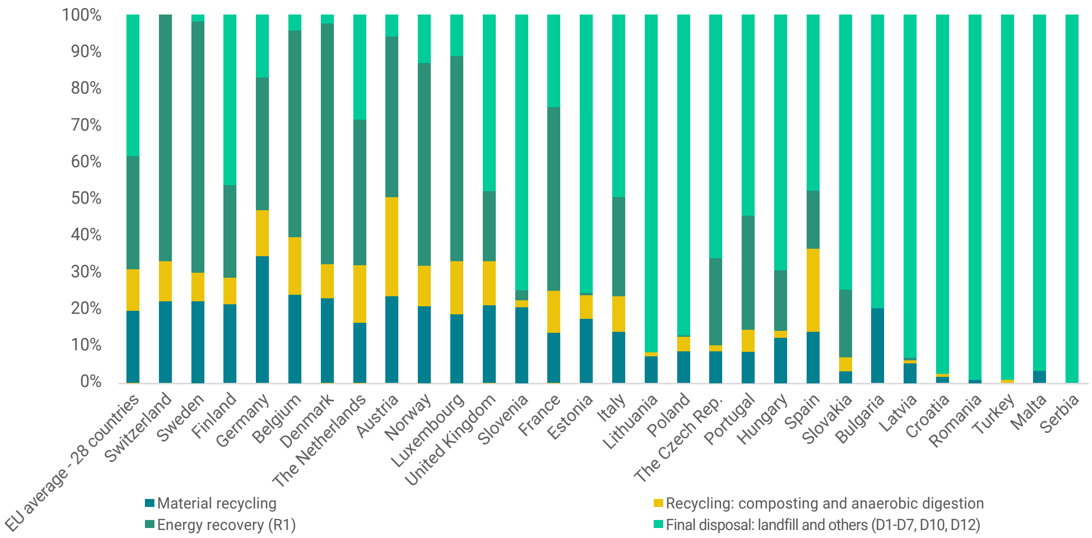
Table 11. Taxes and prohibitions on sanitary landfill established by some member countries of the European Union from Directive 99/31/EC and percentage variation of final disposal 2005-12

COUNTRY	**PROHIBITION**	**TAX ON FINAL DISPOSAL[a]** (euros/ton.)	**VARIATION IN FINAL DISPOSAL BETWEEN 2005 AND 2012**
Germany	Since 2005, final disposal in sanitary landfill has been prohibited.		-94%
Belgium, Flanders	Since 2006, the prohibition has been in force for combustible household waste and commercial and industrial waste.	€31.70-€84.89 (depending on whether it is public or private and whether it is combustible or non-combustible waste).	-91%
Norway	Since 2009, a ban has been in force for all waste with TOC>10%.	€37.40	-88%
Sweden	Since 2002, a ban has been in force for separated combustible waste and since 2005, for organic waste.	€43	-87%
Austria	Since 2008, there has been a ban on waste with TOC>5%.	€87	-72%
Denmark	Since 1997, there has been a ban on waste suitable for incineration.	€63	-55%
United Kingdom		€2.50-€72	-54%
France	Since 2002 the country has been governed according to the directive.	€100 (unauthorized final disposal sites). €30 (authorized final disposal sites). €20 (authorized final disposal sites with ISO 14000). €15 (landfill that reuses at least 75% as energy). The values increase every January 1.	-16%

Source: Eurostat (2018).
[a] Additional value to the gate fee that seeks to discourage final disposal in sanitary landfill. The funds are used to finance solid waste recovery projects.
TOC: total organic carbon.

The measures adopted by Switzerland, The Netherlands, Sweden, and Germany allowed the final disposal to decrease by more than 80% between 1994 and 2005.[20]

Figure 10. MSW treatment in the European Union, 2008 (percentage of tons by type of treatment)



Source: Eurostat (2008).

Based on the review of these experiences, the Organization for Economic Cooperation and Development (OECD) has formulated a guide to best practices for solid waste management (OECD, 2016), which are summarized in Table 12.

Table 12. Guide to best practices for solid waste management

LESSON	DESCRIPTION
1	Define the **regulatory and compliance body at an appropriate government level** for waste treatment and valorization facilities, consisting of legal requirements (authorizations, licenses, permits or standards), which consider the context of the country in which they are developed and the minimum standards that must be met in economic, social, and environmental matters.
2	Develop and implement **practices and instruments** that allow the authorities to carry out monitoring, surveillance, and control of compliance with norms and national and international regulations, as well as the application of best practices in the waste sector. In this way, the authorities will be able to take prompt, adequate and effective action in the event of non-compliance.
3	Define the **best available techniques (BATs)** for waste management processes and ensure that waste treatment and recovery facilities work in accordance with the BATs, taking into account technical, operational and economic feasibility.
4	Promote the **exchange of information and lessons learned** between producers, waste generators, waste managers and authorities, to promote waste prevention, optimize operations and minimize the amounts of waste disposed of and improperly treated.
5	Integrate **performance elements** into the waste management policy, such as indicators, goals and deadlines, to guarantee sound economic, social and environmental management.
6	Introduce **incentives and/or support measures** for waste treatment and valorization facilities that comply with the established performance elements.
7	Implement the **technical recommendations** for solid waste management developed by the OECD.
8	Advance in the **internalization of environmental and human health costs** in waste management by differentiating between hazardous and non-hazardous waste, adopting instruments and methodologies that enable them to be valorized and included within the costs of final disposal, treatment, and/or valorization of waste.
9	Create and implement **incentives** to participate in recycling schemes.
10	Implement an **environmental responsibility and compliance regime** for the facilities in order to prevent environmental damage.
11	Ensure that the implementation of the performance elements does not discourage recycling or the inclusion of waste pickers.
12	Guarantee the **predictability of the sale of products** (biomethane, electricity, compost, recyclables, RDF) in order to reduce the risks for investors.
13	Create alternatives to **maximize the market value of the products** of the MSW treatment facilities to reduce the gate fee that the public authority must pay.

Source: Prepared by the authors.

20 Countries are listed in order of decrease in waste disposal.

4.2 Barriers and recommendations in Latin America and the Caribbean

The main aspects identified as impediments to encourage the use of solid waste treatment or valorization techniques in LAC were classified as legal, technical, financial, and socioeconomic barriers. They are summarized below.

4.2.1 Legal barriers

There is a **lack of consistency in the terms and definitions** of the concepts related to the integral management of solid waste used in the standards that regulate said activities in the LAC countries. In addition, the legislative bodies mainly **regulate final disposal activities** and exclude waste treatment and recovery from the standard, which generates legal uncertainty about the technical scope of said activities and the legal and financial instruments required for their implementation.

On the other hand, **there is a need of better coordination between government entities** related to waste management, which limits the issuance of comprehensive policies that effectively introduce the concept of circular economy and that facilitate the demand for materials and by-products obtained from the treatment and valorization of the waste generated. In addition, from the legal point of view, **land use or territorial planning instruments do not always require the incorporation of areas** where waste treatment projects can be implemented.

Likewise, some countries have adopted measures that, although they seek to apply the concept of prioritization of solid waste management widely developed in Europe, in some cases do not adjust to the economic and social context of the country or region in question, which leads to the projects not being viable or the development of projects that could be feasible being discouraged in the long run.

To overcome these barriers, it is recommended to **establish clear and unique definitions**, based on the concepts used at the international level. Similarly, it is essential to **regulate treatment and valorization activities and strengthen the definitions and obligations for final disposal**. It is highly recommended to **set up a multisectoral group that enables the coordination of policies and initiatives** in comprehensive waste management, made up of representatives of the public service sectors of sanitation, environment, health, energy, industry, and commerce, among others. It is important to **set conditions and requirements on the location, construction and operation** of waste treatment and valorization systems and determine **specific guidelines regarding environmental requirements** (licenses and types of permits) for each type of solid waste treatment, valorization and/or final disposal technique.

The high content of organic matter in the waste within the region has a significant impact on emissions into the atmosphere and the generation of leachate at final disposal sites. It is therefore necessary to **prioritize and specify the cases in which organic waste must be treated before its final disposal**, in order to reduce the environmental impacts caused by this type of waste.

The success of the operation of waste treatment and valorization techniques depends on the composition and quantities of the waste generated in the context where its implementation is evaluated. For this reason, it is essential to **know the technical and operational status of the current waste management system in terms of collection, transportation, and final disposal, as well as the roles of the monitoring and control entities** in charge of inspection and information systems and monitoring that allow traceability of said system.

If the municipality cannot meet the requirements to adopt a waste treatment technology, it should focus on solving the deficiencies of its collection and transportation system and strengthening its coverage, as well as the conditions under which final disposal of the waste is carried out.

4.2.2 Technical barriers

Waste separation at source is carried out in few households and sometimes with low quality levels. This situation makes it difficult to implement some treatment and valorization techniques, which is why it is necessary to implement programs that promote a change in the behavior of the population. Also, **ignorance of the use of different techniques affects decision-making.** For their part, **those in charge of regulating and supervising the use of waste treatment and valorization methods tend to be unaware of the state-of-the-art of the technologies**, which means that the regulations consider only traditional technologies or those with lower efficiencies and greater economic, social, and environmental impacts. In addition, the number of **technical personnel specialized in the use of the different technologies is very limited within the region**. At the same time, **most LAC countries do not have information reporting systems**, or they are ineffective, which makes it difficult to monitor compliance with regulations.

Consistent with the lessons learned from the European process, it is essential to **differentiate waste streams**. In this regard, it is essential to educate the urban and rural population, the commercial sector and the industry so that they can carry out separation at source. Likewise, it is necessary to **strengthen regulations and the application of the law** in terms of separation at source and **include waste valorization goals**, with certain compliance deadlines, taking into account the characteristics of the municipalities and the current recycling rates.

Investing in the training and education of suitable human capital for the development of regulation and application of the law in the sector, as well as **developing and/or improving monitoring and traceability systems** that facilitate compliance with the functions of waste management are fundamental actions. Similarly, it is advisable to implement training programs through companies that wish to execute the different techniques, educational centers or job training centers. Governments and companies can **promote technical visits to countries where treatment and valorization technologies** are produced and used in order to collect information on their installation and operation so they can establish better criteria for assessing the feasibility of implementing such techniques in the local context. This knowledge must be disseminated and multiplied in the parts of the value chain of the integral management of solid waste. Likewise, the execution of local pilot projects enables the gaining of knowledge and experience, identifying functional aspects and accelerating the learning curve. In the same way, it is necessary to promote effective control and the use of digitization and innovation.

Finally, it is necessary to work towards the **standardization and technical certification of urban solid waste treatment units** in order to homogenize terms and definitions, guarantee procedures and minimum necessary requirements, assist designers and investors in decision-making and in the consistency of the facility, reduce technical risks for obtaining environmental licenses and the construction and operation of facilities, and establish minimum quality standards to be met by the products generated.[21]

4.2.3 Financial barriers

In general, waste treatment and valorization techniques require additional income to that of the sale of the valorized resources or the by-products of the treatment to make the projects financially viable.

This barrier is affected by the prioritization of other problems and other sectors when distributing resources, which leaves investments in the development of infrastructure for this activity behind; meanwhile, some projects to which resources have been allocated have not been successful due to lack of technical knowledge or lack of follow-up once the initial investments have been made.

Due to the above, it is recommended to **create incentives to promote the development of markets for valorized products or treatment by-products**. In the same way, it is suggested to **establish guidelines so that public resources are allocated** only to techniques that are **feasible from the economic, financial, social and environmental point of view;** adopt rules that oblige municipalities and districts to allocate a greater part of their resources to financing this type of project; include measures to promote regional projects for the location of this type of infrastructure and incorporate regulations such as the **establishment of long-term contracts** to guarantee that the waste is taken to these projects, which will reduce the service rate (gate fee) and optimize its financial viability.

This is affirmed by the results obtained in regions with greater progress in regulation, technology, and knowledge of the population, where the regulatory guidelines show that **it is necessary to develop financial and economic incentives to make the use of alternative techniques viable**, since it is recognized that the resources obtained from these processes (raw materials, energy, etc.) do not generate enough income to pay for their implementation and operation.

In this regard, it is recommended to **develop and strengthen the following financing mechanisms:**

- **Rate** that recognizes the real costs of these techniques.
- **Landfill tax and incentives for reuse** to discourage final disposal and improve the financial viability of these techniques.
- **Extended responsibility of the producer** to strengthen the responsibility of the industry in the generation of waste after the consumption of goods or products sold on the market, either through monetary mechanisms that help finance techniques for the treatment of solid waste derived from each industry or that guarantee the demand for the materials, or by improving the design of its products and packaging to reduce the generation of waste or optimize its recyclability.
- **Development of markets and business models** for recovered resources or materials in order to facilitate and guarantee their demand and sale.

21 La Asociación Brasileña de Normas Técnicas (ABNT) está preparando normas sobre ecoparques, entendidos como sistemas donde se realizan diferentes actividades de gestión y valorización de residuos sólidos, como en el caso de las plantas mecánico-biológicas (Colturato, 2021).

- **State financing for investments in infrastructure and land,** taking into account that capital investment is the most expensive component of these techniques, for which co-financing mechanisms could be developed, for example, through PPPs or non-refundable contributions by national or municipal governments.

All these instruments must be oriented and coordinated so that the **user pays based on the amount of waste generated,** namely in accordance with the principles of "polluter pays" and "pay as you throw". Based on the experience of European countries and some cities in Canada and the United States, it is recommended that the rate include a fixed component that ensures permanent availability of the service and discourages inadequate disposal, plus a variable component that promotes separation at source and waste reduction. The application of this strategy requires effective scrutiny and education of the population.

4.2.4 Socioeconomic barriers

It is likely that the main socioeconomic barrier in LAC is the inequality of geographic, social, and economic conditions both at local and regional level which makes it difficult to establish one-size-fits-all measures that are at the same time appropriate to the specific context. On the other hand, the low participation of waste generators from the residential, commercial and industrial sectors significantly affects the effectiveness of the solutions. In LAC a great many people make a living from recycling, and they must be taken into account within the waste treatment and valorization strategies and business models.

To overcome these barriers, it is recommended that governments prioritize activities that favor the recycling of the dry fraction of waste, which requires the selective collection of the recyclable fraction, destined for preparation activities for reuse or recycling. Measures must also be established that, in differing ways, indicate the actions that municipalities and regions must implement according to their size and characteristics. Finally, one of the main instruments to improve waste management in LAC is to carry out informative and educational campaigns for users related to their obligations, including those related to paying for the service, and the negative effects on human health and the environment that can caused by improper management.

4.3 Final recommendations

Public policy instruments can be classified into four main categories: 1command and control (direct regulation), administrative, economic and market, and information and education. Some public policy instruments that could be applied in LAC to eliminate barriers and encourage the use of better techniques for waste management, through treatment and valorization, are proposed below.

Table 13. Public policy instruments for solid waste management

INSTRUMENT	DESCRIPTION	EXAMPLES
Direct regulation	Rules, standards, prohibitions, restrictions, sanctions.	• Appoint an effective regulation and inspection authority. • Adopt and/or strengthen the technical, legal and financial regulation of waste management activities. • Implement control actions for waste management. • Establish progressive goals for waste valorization. • Implement extended producer responsibility measures to encourage demand for recovered materials and generate resources to finance valorization programs. • Establish progressive and mandatory goals to reduce the amount of biodegradable waste that is allowed to be disposed of in sanitary landfill without prior treatment and implement selective collection programs for organic waste. • Establish progressive and obligatory goals for the use of RDF by cement companies.
Administrative	Permits, licenses, management plans.	• Adopt and implement a national plan for comprehensive solid waste management that establishes progressive goals and deadlines for waste valorization.
Economic and market	Taxes, fees/rates, tax benefits, subsidies, deposit/reimbursement, tradable permits.	• Charge the population for the provision of the solid waste management service using effective collection mechanisms and ensuring that the charge allows costs to be recovered. • Introduce economic instruments (extended producer responsibility, incentives and guaranteed demand for recovered resources, landfill tax, incentives for separation at source) that progressively discourage final disposal and make waste treatment and valorization viable.
Information and education	Information systems, educational campaigns, publicity and image, and environmental certifications and marks.	• Implement a national information system that allows the collection, validation and publication of information and indicators that describe the status of waste management and its development.

Source: Prepared by the authors based on Rodríguez-Becerra and Espinoza (2002).

Having a regulatory system that encourages the development of waste treatment technologies is a starting point for strengthening waste management and moving towards techniques that promote reuse and prevent final disposal. However, there are few cases in which municipal waste treatment and valorization projects reach their financial closure through the sale of recovered resources, for which it is necessary to adopt incentives and instruments that discourage final disposal and encourage valorization of the waste. Economic instruments for transforming the behavior of both consumers and producers are highlighted, as are those for correcting market failures, including external environmental or social costs.

Even though several LAC countries have implemented collection systems for waste management, it is recommended that the following aspects be taken into account to guarantee the financial sustainability of waste management, as well as of the treatment and valorization systems:

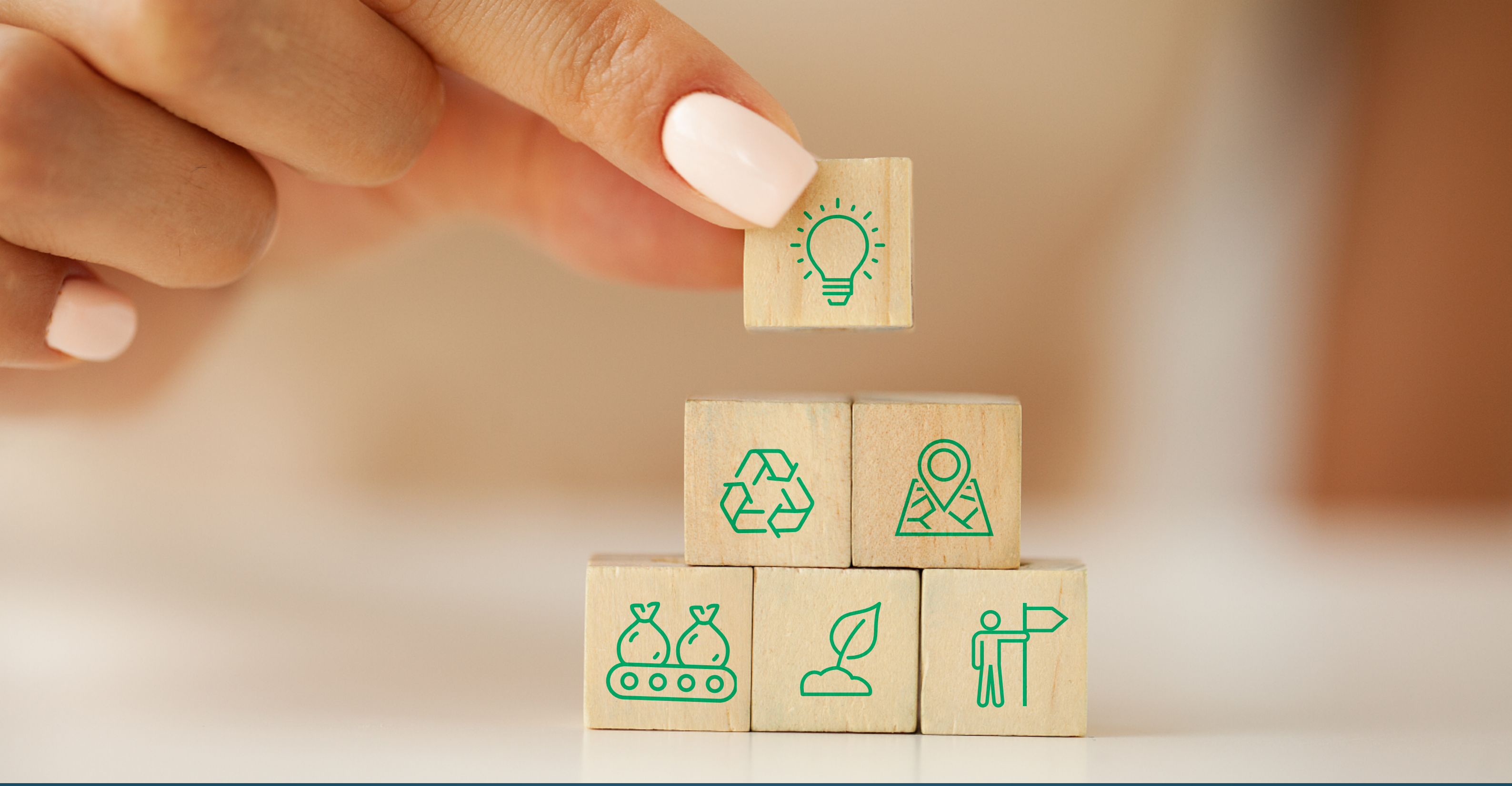
- **Cost recovery:** Despite generating income from the sale of by-products, such as energy, compost, RDF or recyclable materials, in general, waste treatment and valorization techniques will be more expensive than sanitary landfill, making it necessary to charge the population for the provision of waste management services, including valorization. Governments have the power to define the basis for charging for this service, which can be done through methodologies that establish the basis for calculating the amount to be charged and the guidelines for estimating costs, as well as the criteria for evaluating the collection alternatives.

- **Adoption of economic instruments:** Some economic instruments make it possible to generate income for waste management and, at the same time, discourage generation or final disposal (for example, landfill tax or tax on final disposal without prior treatment). However, implementing this type of economic instrument requires very effective control systems, which, in turn, require information systems to monitor compliance with standards and goals.

- **Ensure the demand for by-products:** Even if waste treatment can generate different by-products, these may not have a market and, consequently, cannot generate a source of income to cover the costs of the activity. For this, it is necessary to promote the creation of markets that ensure the demand for these by-products through instruments such as tax benefits, extended producer responsibility schemes, reuse incentives and normative instruments that regulate and promote markets such as the transition to renewable energies generated from waste, the demand for recyclable materials, the use of RDF, among others.

Finally, just as organizations and groups of experts have been created in Europe for the evaluation of available techniques and technologies, it is recommended that a similar regional body be established in LAC that contemplates the same functions and takes into account the local context, both in generation and composition of waste, as well as accessibility, financing and other pertinent considerations to establish the BATs specifically applicable to the countries of the region. This body must include the participation of technical experts who have first-hand knowledge of the socioeconomic, technical, legal and financial situation of the LAC countries. The results generated here will serve as a benchmark for implementing technologies that guarantee high reliability, operate in accordance with local characteristics and are effective solutions to the region's waste valorization deficit.

In a similar way to that developed by the EU, these technical references must be subject to constant evaluation and feedback and consider a broader diversification of the waste streams traditionally used in LAC, specifying their levels of applicability in relation to each productive sector and establishing recommendations for their optimal development.



5. CONCLUSIONS

1 The best available techniques serve to impact different issues on the public policy agenda

The best available techniques (BATs) serve as a benchmark to determine the actions with the best performance in different industrial sectors, which, directly or indirectly, have an impact on different issues on the public policy agenda that have been developed over recent years, such as compliance with the Sustainable Development Goals (SDGs) promoted by the United Nations (especially Goals 11.6, 12.3, 12.4, 12.5 and 14.1 [UN, 2015), the commitments to reduce carbon emissions of the Paris Agreement on Climate Change, the implementation of technologies for the generation of renewable energy, and the promotion of a circular economy with the aim of achieving sustainable development.

LAC must prepare its own reference documents adjusted to the regional and local context

2

It is desirable in LAC for countries to work together to prepare reference documents on the best available techniques, adjusted to the regional and local context, which serve as a basis to encourage the incorporation of the principles of the circular economy, compliance with the SDGs and investor confidence in solid waste valorization systems.

3

The valorization of solid waste provides important environmental, social, and economic benefits

The valorization of solid waste provides major benefits, such as the reduction of carbon emissions generated by the waste decomposition processes, as well as by the production processes of raw materials that can be replaced with recovered materials (recyclables, compost, fertilizers, etc.). In addition, it allows the recovery of the energy potential present in the waste (biogas, RDF, steam, heat), which can be used to generate electricity. The diversion of solid waste to valorization systems extends the lifespan of sanitary landfills, which are an alternative to the closure of open dumps and other unsuitable sites. Consequently, the implementation of these projects constitutes a mechanism for creating "green" jobs and sustainable economic development.

4

The region must develop and apply a regional statistics and information system to permanently monitor its progress

It is recommended to develop and apply a regional statistics and information system that enables continuous monitoring of the status and progress of waste management in LAC, similar to the experience of the European Union (Eurostat system), and to jointly define, among the countries of the region, the best available techniques and prepare the respective reference documents that guide governments in the selection and structuring of the projects that best fit the local context.[22]

5

The implementation of waste treatment and valorization techniques requires the execution of pre-feasibility studies

The implementation of waste treatment and valorization techniques requires the execution of pre-feasibility studies to evaluate the possible treatment scenarios and select the most appropriate combination of technologies, according to the characteristics of the local context, for which the feasibility analysis methodology proposed in this document can be used. Whatever the case, the legal, economic, financial, technical, social, and environmental aspects must be analyzed, among which we can highlight the composition of the waste, the institutional capacity to manage and finance the project, and the existence of markets that demand the recovered resources and materials.

22 Data from the European Statistical Office, better known as Eurostat, are available at: https://ec.europa.eu/eurostat/home?.

6

Before implementing a valorization system, it is necessary to have an adequate collection, transportation, and final disposal strategy

Before starting up waste treatment and valorization systems, the municipality or organization behind the project must ensure that there is a well-developed collection, transportation, and final disposal strategy. If not, it is recommended to focus on strengthening these activities and, in parallel, gradually incorporating recycling tasks and low-complexity valorization techniques.

In LAC, the implementation of waste valorization projects is still incipient

7

In LAC there is a tendency to eliminate waste through the technique of final disposal in sanitary landfill and open dumps. Some cities in the region have developed waste valorization projects; however, the implementation of these technologies is still incipient due to the lack of mechanisms that ensure their financial viability, the low level of knowledge and experience, the absence of oversight and authority to demand better waste management practices from municipalities and operators, the low levels of payment and collection of resources for the service, and the lack of public policies that guide municipal governments towards the progressive incorporation of better techniques through the definition of goals, prohibitions, restrictions, incentives, and economic instruments, among others.

8

The region is required to adopt financial instruments that guarantee the sustainability of investments in the sector

Finally, it is necessary for the region to adopt economic instruments that maximize income for waste management and guarantee the demand for by-products, in order to reduce the risks to the facility and to investors. Likewise, LAC must establish business models that take into account specific local features and achieve a reduction in treatment costs (gate fee) for the population.

GLOSSARY

- **Mass and energy balance:** The balance between the amount of materials and energy entering and leaving a process or system (ISWA, 1992).
- **Biodigester:** Industrial plant for the treatment of organic waste through an anaerobic process. Its end products are biogas and digest.
- **Open dump:** Place where waste is dumped in the open in an uncontrolled manner without receiving any type of sanitary treatment.
- **Elimination:** Any operation that is not valorization, even when the secondary consequence of the operation involves the reuse of substances or energy (European Parliament and Council of the European Union, 2008).
- **Emission:** The release, into the atmosphere, water or soil, of substances, vibrations, heat or noise coming directly or indirectly from occasional or diffuse sources at a facility (European Parliament and Council of the European Union, 2010).
- **OFMSW:** Organic fraction of municipal solid waste obtained through a mechanical separation pretreatment system.
- **Gate fee:** The waste treatment fee received by the operator of a treatment facility per ton of waste that comes in.
- **Waste combustion or incineration facility:** Any technical unit or equipment, fixed or mobile, dedicated to the thermal treatment of waste with recovery of the heat produced by combustion or without recovery, through incineration by oxidation of waste, as well as other thermal treatment processes, such as pyrolysis, gasification and plasma process if the substances resulting from the treatment are subsequently incinerated (European Parliament and Council of the European Union, 2010).
- **Calorific power:** The amount of heat produced when a mass quantity of a material (usually a fuel) undergoes complete combustion under certain specified conditions. It is usually presented in terms of kilojoules per kilogram (kJ/kg) for liquid and solid fuels, and kilojoules per cubic meter (kJ/m3) for gases (ISWA, 1992).
- **Waste producer or generator:** Any person whose activity produces waste (initial waste producer) or any person who carries out pre-treatment, mixing, or other operations that cause a change in the nature or composition of said waste (European Parliament and Council of the European Union, 2008).
- **Recycling:** The reuse of materials, not necessarily in their original form; re-entry onto a production line, where the waste is processed as a raw material for the mainstream of the process (direct recycling). Composting or anaerobic digestion is a way of recycling the organic fraction. The transformation of waste into energy (indirect recycling); the separation of materials at source, and their collection and transportation, where applicable, are activities considered to be part of the recycling process (ISWA, 1992).
- **Recyclers/Waste pickers:** Worker who performs the trade of collecting, selecting, and recovering solid waste, and generates an income from the sale of the recovered material (LACRE network, 2013).
- **Recovery:** For the purposes of this document, synonymous with valorization.

- **Sanitary landfill:** Infrastructure/engineering technique for the confinement of solid waste. It includes the spreading, arrangement and compaction of waste on an impermeable bed with drainage channels, its coverage with soil or another inert material at least daily, to control the proliferation of vectors and the proper management of gases and leachates, in order to avoid contamination of the environment and protect the health of the population. Sanitary landfill involves an engineering project design plan and entry control. There are no waste pickers at the site.

- **Municipal solid waste (MSW):** Urban or municipal solid waste (MSW) is solid or semi-solid garbage from the activities of population centers in general and includes household, commercial, non-hazardous industrial, service, market, common or non-hazardous hospital waste, the waste generated in the sweeping and cleaning of streets and public areas, and that produced by the pruning of plants in streets, squares and public gardens.

- **Extended producer responsibility:** This an instrument that obliges manufacturers and importers of certain mass consumption products to organize, develop, and/or finance the comprehensive management of waste derived from their products, once the end consumer discards them.

- **Reuse:** The direct use of a material more than once for the same purpose for which it was originally designed or the use of a material in its original form for a purpose other than that for which it was designed.

- **Emerging technique:** A new technique for an industrial activity that, if developed commercially, can provide an equal or greater level of environmental protection than that which would be obtained with the current best available techniques and even generate higher cost savings (European Parliament and Council of the European Union, 2010).

- **Proven technology:** A concept that defines the degree of readiness of a technology. Its main purpose is to help decision-making regarding the development of different technologies, as well as the transition to them, and prevent the risks of their implementation (NCBI, 2014).

- **Treatment:** Any method, technique or process designed to change the physical, chemical and biological characteristics or composition of a waste in order to neutralize it, to recover energy or materials from the waste, to bring the waste to a less hazardous or non-hazardous state and to make it safer to transport, store or dispose of; to make it more manageable for material recovery, storage or volume reduction (ISWA, 1992).

- **Emission limit values:** The concentration of certain specific parameters, whose value must not be exceeded within one or several established periods (European Parliament and Council of the European Union, 2010).

- **Valorization:** This includes the recycling, new use, recovery of waste, or any other action aimed at obtaining secondary raw materials, or the use of waste as an energy source.

- **Controlled landfill:** Place for the final disposal of solid waste that, while it does not have the infrastructure of a sanitary landfill, has some control measures.

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APPENDICES

Technical data sheet 1: Mechanical treatment

The separation and classification of waste can be carried out both manually and in materials recovery facilities (MRFs).[23] **Manual separation** takes place in facilities where operators carry out selective control, which enables the quality of the separated materials to be increased.

For their part, the **MRFs** are facilities that use high mechanical intensity through the use of different units for the separation, processing and transformation of materials. Each of the units takes advantage of the physical (diameter, density, color, etc.) or chemical characteristics of the materials to classify them by type, taking into account the type of material to be recovered and the desired quality, the materials that enter and come out during the process and the required characteristics after the process is finished. One of the main advantages of this technique is the efficiency in the recovery of materials. Currently, separation plants are used in some cases for mixed waste not separated at source, as well as for the separation of packaging, organic fractions and other fractions separated at source.

TECHNOLOGY GROUP	MECHANICAL TREATMENT
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	> 20 years.
Number of facilities in operation worldwide:	>600 (for example: Bollegraf MRF New York City: 70 - 200 tons/hour).
Expected availability and reliability of operation (based on operating experience):	>8,500 h/year.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	This depends on the composition of the waste and whether it has been separated at source. If RDF is manufactured, the deviation can be up to 70%.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	Recyclable materials, RDF, organic fraction intended for biological treatment. Rejected waste that must go to final disposal or treatment.
Land use:	Define the legal conditions for land use that allow the installation of this technology.
Spatial requirement:	0.30m2/TPY.

23 In some LAC cities, manual separation is carried out by waste pickers/recyclers, who recover the waste, mainly domestic, at source, at the point of generation. Once classified, the materials are collected and transported to collection centers where they are commercialized.

TECHNOLOGY GROUP	MECHANICAL TREATMENT
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Medium.
Personnel (qualified, unqualified):	Qualified and trained personnel for the management of machinery and the classification of waste.
Monitoring and laboratory requirements:	None.
Operating requirements:	Collection system of waste separated at source to guarantee the quality of recyclables, market for recyclables.
CRITERION 5: COSTS	
Investment (CAPEX):	US$70/TPY - US$75/TPY.
Annual operation and maintenance costs (OPEX):	US$35/ton - US$38/ton.
Lifespan (years):	20 years.
CRITERION 6: SCALE	
Capacity:	Manual: 1,500 TPY or less. Semi-mechanized (mainly with conveyor belts and weighing and compaction equipment): Between 1,500 TPY and 40,000 TPY. Mechanized (with conveyor belts, weighing, separation and packaging equipment): 40,000 TPY or more.
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Waste to treat.
Mass of process outputs (residues, ash, emissions, etc.):	It depends on the composition of the waste that enters the plant and whether it has been separated at source.
	Rejects: 0.4 tons/ton of separated inorganic waste.
Energy:	Electrical consumption: 15 kWh/ton - 20 kWh/ton of waste.
	Fuel consumption: 8 kWh/ton - 10 kWh/ton of waste.
	Generation: n/a.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Environmental impact due to odors, noise or visual pollution.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	Recyclers can be integrated into the waste characterization process.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THETECHNOLOGY	
Supporting legislation and regulation:	Legislation that authorizes and regulates the implementation of mechanized waste separation systems.
Market for by-products:	The market for classified materials may be created or strengthened.
Investments in research and development:	The State and the private sector must make investments.
General conclusion:	• **Advantages:** Recovery of materials and recycling, high diversion of waste that favors the economic value of reusable materials. • **Disadvantages:** Various waste treatment processes, the products may not have a market.

Source: DNV GL and MAG Consultoría (2016).

Technical data sheet 2:
Biological treatment - Anaerobic digestion

Anaerobic digestion, also known as **methanation, biodigestion or biogas production**, is a controlled process of waste decomposition in conditions in which there is no presence of oxygen, at temperatures suitable for the mesophilic (40°C) or thermophilic anaerobic phase (55°C) of natural origin and with facultative bacteria species that convert degradable organic matter into biogas and sludge (digest). Digestion can be dry when the digester contains between 15% and 40% dry material, and wet when the dry content is less than 15% (Pinasseau et al., 2018).

TECHNOLOGY GROUP	ANAEROBIC DIGESTION
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	>25 years.
Number of facilities in operation worldwide:	>120 centralized facilities for the organic fraction of municipal waste. There are also more than 2,500 individual installations at farms or similar sites (Pinasseau et al., 2018).
Expected availability and reliability of operation (based on operating experience):	>8,000 h/year.
Key performance indicators (if available):	25 - 30 days (residence time of the organic material for its decomposition).
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	If the solid fraction of the digest is used as compost, the waste that goes to the sanitary landfill is reduced between 50 and 60%; otherwise, it decreases between 33 and 38% (Colturato, 2021).
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	Digest, wastewater and biogas.
	Rejects/non-compostable material: approx. 0.2 tons/ton. MSW treated.
Land use:	Define the legal conditions that allow the installation of this technology.
Spatial requirement:	0.10 m2/TPY - 0.25 m2/TPY.

TECHNOLOGY GROUP	ANAEROBIC DIGESTION
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Complexity: Medium-high. Technical conditions: Collection requires waste separation at source, stable temperature for optimal decomposition conditions, and biogas generation. Plug-flow dry-way digesters can treat the OFMSW obtained from the separation of the organic fraction contained in the MSW without selection at source. Obtaining OFMSW from MSW is carried out with a pre-treatment line that is made up of a booth for manual selection of bulky objects, bag-opening equipment, a trommel screen with a 80 m/m sieve and a magnetic separator. In some cases, a ballistic separator for heavy debris is also included. The fraction that is obtained is the OFMSW with feeds the dry process digesters that admit up to 7%-8% of heavy waste (glass, ceramic, sand, etc.).
Personnel (qualified, unqualified):	Qualified personnel for the operation of the machinery and monitoring, and unqualified staff for processing the raw material.
Monitoring and laboratory requirements:	Biogas production rate, raw material temperature, pH, C/N ratio, biogas composition (CH4, CO2, H2, O2, H2S), continuously measured NH3- NH4 content and fatty acids.
Conditions for the successful implementation of technology:	High enough rate for electricity generated from biogas. Incorporation of biogas as a non-conventional energy source within the energy market. Incentive for the use of biomethane.
CRITERION 5: COSTS	
Investment (CAPEX):	Between US$140/TPY - US$250/TPY, depending on project scale.
Annual operation and maintenance costs (OPEX):	Between US$20/ton - US$60/ton (Kaza et al., 2018).
Lifespan (years):	25 years (with proper maintenance).
CRITERION 6: SCALE	
Capacity:	20,000 TPY - 240,000 TPY (World Bank, 2011).
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Water: ~0.1 tons/ton of organic waste separated at source.
Process outputs:	Biogas: 80 Nm3/ton. - 120 Nm3/ton of organic waste entered (Pinasseau et al., 2018).
	Digest: 0.4 ton/ton of organic waste.
	Wastewater: between 0.1 tons/ton of organic waste and 0.5 tons/ton of organic waste, according to technology.
	CH4 Fugitive Emissions: ~0-411g/ton of organic waste separated at source.
Energy:	Thermal energy consumption: 20 kWh/ton - 120 kWh/ton of organic waste.
	Electric power consumption: 20 kWh/ton - 55 kWh/ton organic waste, approximately 15% of the energy produced.
	Electricity generation: 200 kWh/ton - 250 kWh/ton of organic waste.
	Heat generation: 200 kWh/ton - 250 kWh/ton of organic waste.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Odor impact. The process itself does not generate odors, these are produced in the reception and feeding area, as well as in the digest dehydration warehouse, for which an air treatment system must always be included in these two areas complete with a backstop biofilter. Positive environmental impact due to emission reduction.

TECHNOLOGY GROUP	ANAEROBIC DIGESTION
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	Complementary activity and not a substitute for treatment of the inorganic fraction.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Generate/strengthen the legislation that allows the implementation of this technique for waste treatment.
Market for by-products:	Participation of biogas in the energy market as an alternative source of energy.
Investments in research and development:	The State and the private sector must invest.
General conclusion:	• **Advantages:** A 25% reduction in the amount of waste that reaches the sanitary landfill; generation of ~100-200 kWh/ton net of electricity. • **Disadvantages:** Complex technology; separation and pretreatment of the organic fraction is required; waste post-treatment (water separation, waste stabilization); high investment and operating costs.

Source: DNV GL and MAG Consultoría (2016).
OFMSW: Organic fraction of urban solid waste.

Technical data sheet 3: Biological treatment - Composting

The waste intended for composting is preferably **food matter or offcuts generated by pruning, lawn mowing or gardening activities**, which are mainly composed of organic material. In addition, they must have low contaminant concentrations or a low presence of materials with other characteristics. This technique is also used to **stabilize sludge from anaerobic digestion**, reduce the presence of pathogens, odors, or its potential for decomposition.

Closed (in vessel) or bioreactor composting systems are installed in facilities where organic matter is disposed of in a closed environment, with aeration and/or mixing techniques and temperature and humidity control. A good mixture is guaranteed by grinding the waste prior to its treatment and moving the pile manually or mechanically. Aeration is achieved by blowers and/or air suction through a perforated grid floor or special aeration channels in the tunnel floor. The moisture content must be balanced by feeding the piles with sawdust or other dry elements that prevent the generation of anaerobic conditions and the proliferation of bad odors (Pinasseau et al., 2018). Currently composting with semi-permeable membranes is used as a form of in-vessel composting.

TECHNOLOGY GROUP	COMPOSTING
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	>25 years.
Number of facilities in operation worldwide:	There are more than 3,500 composting facilities in operation for garden waste (green) or household organic waste (Pinasseau et al., 2018). Examples: Wilp, the Netherlands (225,000 TPY); CEAMSE, Argentina (25,000 TPY); GS Brothers, United States (220,000 TPY); Sutton Courtenay Compost Facility, United Kingdom (190,000 TPY).
Expected availability and reliability of operation (based on operating experience):	>8.500 h/year.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	If compost is used, the amount of waste sent to sanitary landfill is reduced by between 25 and 40%.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	Compost, leachate, emissions (CH4, NH3, N2O, VOC, CO2).
	Rejects/non-compostable material: approx. 0.2 tons/ton - 0.5 tons/ton that enters.
Land use:	Land use planning: rural land.
Spatial requirement:	Closed: 0.1-0.4 m2/TPY of organic waste. With forced aeration: 0.4-0.5 m2/TPY of organic waste. Static Piles: 0.6-1.0 m2/TPY of organic waste. Tchobanoglous, Theisen, and Vigil (1994).

TECHNOLOGY GROUP	COMPOSTING
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Complexity: Low-medium. Technical conditions: Separation and pretreatment of the organic fraction. The moisture content of the waste must be between 45 and 60%.
Personnel (qualified, unqualified):	Qualified personnel for the operation of the machinery and temperature and humidity monitoring.
Monitoring and laboratory requirements:	Temperature, humidity, pH, C/N ratio, porosity (particle size).
Conditions for the successful implementation of technology:	Market for compost/possibilities for certifying the compost.
CRITERION 5: COSTS	
Investment (CAPEX):	Between US$75/TPY - US$80/TPY.
Annual operation and maintenance costs (OPEX):	Between US$40/ton and US$45/ton.
Lifespan (years):	20 years.
CRITERION 6: SCALE	
Capacity:	1,000 TPY - 200,000 TPY.
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Water: 0.14 m3/ton. - 0.33 m3/ton of organic waste.
Mass of process outputs (residues, ash, emissions, etc.):	Emissions: 816 g - 1,132 g of CH4/ton of organic waste; 371 g NH3/ton of organic waste; 0.150 kg N2O/ton of organic waste.
	Compost: 0.2 ton/ton of organic waste - 0.5 ton/ton of organic waste.
	Leachate: ~0.03 m3/ton of waste - 0.1 m3/ton of waste.
	Rejects/non-compostable material: approx. 0.1 tons/ton organic waste separated at source.
Fuel:	Fuel consumption: 20.6 kWh/ton of organic waste separated at source.
Energy:	Electrical consumption: 8.4 kWh/ton organic waste separated at its source.
	Generation: n/a.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Environmental impact due to odors, visual pollution or noise.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	Complementary activity and not a substitute for its activities; possibility of using recyclers directly at the treatment plant for waste classification.

TECHNOLOGY GROUP	COMPOSTING
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Generate/strengthen the legislation that allows the implementation of this technique for the treatment of waste and sale of compost.
Market for by-products:	Incipient market for by-products.
Investments in research and development:	State and private investments must be made.
General conclusion:	• **Advantages:** Relatively simple and robust process; significant reduction in the volume of waste; shorter process time and less space requirements compared to open-air composting; better control over the process; less emissions. • **Disadvantages:** Higher treatment costs compared to open-air composting; the market for compost must be developed.

Source: DNV GL and MAG Consultoría (2016).
CEAMSE: State Company for Ecological Coordination in the Metropolitan Area.

Technical data sheet 4: Biological treatment - Intensive heat treatment

Patented technology for the treatment of organic matter, whose operation is based on the dehydration of the waste to be treated through the application of microwaves that dry and reduce the volume of the material introduced by up to 90%. This treatment has advantages such as the following: i) treatment times do not exceed 24 hours, ii) the space occupied by the reactor is minimal, iii) it does not generate odors, iv) it does not release methane and v) its products can be used as organic fertilizer.

TECHNOLOGY GROUP	ACCELERATED HEAT TREATMENT
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Emerging technology.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	5 years.
Number of facilities in operation worldwide:	There are around 100 teams operating in Europe and there are others operating in Australia, the United States, Honduras, Ireland, Japan, Norway and the Republic of Korea.
Expected availability and reliability of operation (based on operating experience):	8,400 h/year.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	If the compost is used, the amount of waste sent to sanitary landfill is reduced by around 52% due to the complete use of the organic fraction.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	Compost.
	Clean water for reuse in irrigation, washing or related activities.
Spatial requirement:	2 m2/unit.
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Complexity: Low to zero. Technical conditions: Prior separation of the organic fraction.
Personnel (qualified, unqualified):	Trained personnel for the operation of the equipment.
Monitoring and laboratory requirements:	None. The technology operates automatically.
CRITERION 5: COSTS	
Investment (CAPEX):	US$282.50/TPY.
Annual operation and maintenance costs (OPEX):	US$1,000 - US$2,500 per year for equipment that treats 500 kg of waste per cycle.
Lifespan (years):	15 years.

TECHNOLOGY GROUP	ACCELERATED HEAT TREATMENT
CRITERION 6: SCALE	
Capacity:	36 TPY - 602 TPY.
Modular technology:	No.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Organic waste.
Mass of process outputs (residues, ash, emissions, etc.):	Water: 1,200 liters/ton of organic waste.
	Compost: 0.1 tons/ton of organic waste.
	Rejects: 0 tons/ton of organic waste separated at source.
Fuel:	Fuel consumption: 20.6 kWh/ton of organic waste separated at source.
Energy:	Electrical consumption: 11 kWh/ton of organic waste separated at source.
	Generation: n/a.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Total use of the organic fraction.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	Complementary activity of the comprehensive management of solid waste; possibility of hiring recyclers directly at the treatment plant for waste classification.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Generate/reinforce the legislation that allows and regulates the sale of compost.
Market for by-products:	Incipient market for by-products.
Investments in research and development:	Not necessary.
General conclusion:	• **Advantages:** Relatively simple and complete process; significant reduction in the volume of waste; shorter process time compared to other composting techniques and less space requirements compared to other open-air composting techniques; fully automatic process control. • **Disadvantages:** Higher treatment costs, both in investment and operation, compared to other composting techniques.

Sources: DNV GL and MAG Consultoría (2016) and Hevron Group (2018).

Technical data sheet 5: Thermal treatment - Incineration with or without power generation

The combustible materials found in the waste burn upon reaching the necessary ignition temperature and upon contact with oxygen, meaning they undergo an oxidation reaction. The reaction temperature is between 850°C and 1,450°C, and the combustion process occurs in the gas and solid phase, simultaneously releasing thermal energy.

A minimum calorific power of the waste is required to allow the thermal chain reaction and self-sustaining combustion (called autothermal combustion), that is, there is no need to add other fuels. Within the incineration technique, rotary kilns, fluidized bed and grate incineration technologies are used, the latter being the most used for the treatment of mixed municipal solid waste (in Europe, about 90% of installations are of the grill type). Fluidized bed technology is used for the combustion of RDF, which is prepared through pretreatment techniques consisting of classification, grinding (to achieve 50 mm diameter particles), and removal of ferrous and non-ferrous materials (Neuwahl et al., 2019).

TECHNOLOGY GROUP	THERMAL TREATMENT OF INCINERATION
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	>25 years.
Number of facilities in operation worldwide:	> 500 Examples: Amsterdam, The Netherlands, 5 lines, 1.55 million TPY entering the facility for treatment; Rotterdam, the Netherlands, 7 lines, 1.25 million TPY; London Lakeside, England, 0.4 million TPY; Palm Beach, Florida, USA, 1 million TPY; Sysav, Malmo, Sweden, 3 lines, 400,000 TPY; Martinique, 2 lines, 112,000 TPY.
Expected availability and reliability of operation (based on operating experience):	>8,000 h/year.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	75%, if the bottom ash is not recycled for the manufacture of construction materials and the recovered metals are used. 98%, if the bottom ash is recycled.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs (recycled products, waste, ash, emissions, etc.):	Bottom ash, which is normal waste and which - depending on local regulations - can be used as a special embankment material and as a road sub-base material. Fly ash, which should be considered as hazardous waste due to the content of heavy metals and leaching. Flue gas treatment waste, which is the result of flue gas treatment and can be hazardous depending on the type of flue gas treatment (dry or wet).
Air Emissions:	The gases must meet the most stringent requirements of the standard. The treatment must always be equipped with control and cleaning systems for emissions and combustion gases.
Reuse of water and wastewater:	The water is used for flue gas cleaning (semi-dry or wet) and for cooling both the ash and the installation itself. If cooling water is used, the discharge temperature may be limited and may lead to exceeding the allowable values on very hot days.
Land use:	Industrial.
Spatial requirement:	0.1 m2/TPY - 1.5 m2/TPY, depending on project scale.

TECHNOLOGY GROUP	THERMAL TREATMENT OF INCINERATION
CRITERION 4: COMPLEXITY	
Complexity and additional technical conditions:	Medium-high.
Personnel (qualified, unqualified):	Staff must be trained to operate incineration plants. Operators must have a higher technical education in different areas of knowledge, such as electrical engineering, mechanical engineering and chemical engineering, preferably.
Monitoring and laboratory requirements:	Continuous measurement of total dust emissions, TOC, HCl, HF, SO2, NOx, CO; sampling and measurement of air content for PCDD/F (polychlorinated dibenzo-p-dioxins and furans) and heavy metals (Cd, Tl, Hg, Sb, As, Pb, Co, Cu, Mn, Ni). Periodic control of levels of dioxins and furans in the stack outlet.
Operating requirements:	Pre-homogenization of the waste in the waste pit; homogenization of air in the oven; calorific value of waste greater than or equal to 7 MJ/kg; lower values require pre-drying systems.
CRITERION 5: COSTS	
Scale:	Average scales from 60,000 TPY - 500,000 TPY; effective scales per line from 80,000 TPY - 220,000 TPY. A small scale of < 60,000 TPY is considered.
Investment (CAPEX):	From US$500/TPY to US$700/TPY.
Lifespan (years):	20 years of economic life; the technical life can reach 40 years.
Annual operation and maintenance costs (OPEX):	Between US$65/ton and US$90/ton.
Key performance indicators (if available):	Costs: Chemical use, maintenance costs/ton, ash treatment costs, internal energy use costs. Income: Total electrical energy production, total heat production, total output (availability), operating costs, gate fee.
CRITERION 6: SCALE	
Capacity:	50,000 TPY/line to 350,000 TPY/line.
Modular technology:	Modular, on larger scales (for an installation of at least 300,000 tons).
CRITERION 7: MASS AND ENERGY BALANCE	
Process outputs (net production of electricity and/or heat [kWh/ton], recycled products, waste, ash, emissions, etc.):	Depending on the composition of the waste, 1 ton of MSW can generate 250 kg of bottom ash, between 15 and 30 kg of fly ash, around 40 kg of dry weight of waste flue gas treatment, 20 kg of scrap and 2 kg of ferrous metals, depending on the quality of the input and the choice of technology.
Combustion gases:	1 ton of MSW generates 5,500 m3 - 6,500 m3 of dry combustion gases.
Used water and wastewater:	1 ton of MSW in wet flue gas treatment generates 0.15 tons - 0.3 tons of effluents.
Inputs (required consumables: energy, chemical or biological consumables, etc.):	In general, the chemical products used per ton are: 22 kg of lime (flue gas dry cleaning service); 0.3 kg/ton of active carbon (Hg and dioxin removal); 5 l/ton ammonia solution (NOx for selective non-catalytic reduction - SNCR). Potable water use: about 0.4 m3/ton of waste.
Energy:	Energy consumption. Use of electrical appliances: 10 - 15% of production (0.06 MWh/tons -0.12 MWh/ton of waste incinerated at a normal calorific value of 10 MJ/kg). Average fossil fuel use of 2 l/ton.
	Generation. Output electrical network of 0.5 MWh/ton - 0.9 MWh/ton of waste incinerated at a normal calorific value of 10 MJ/kg.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Reduction of final disposal in sanitary landfill; reduction of greenhouse gas emissions from waste decomposition; alternative source of energy.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	Complementary technique and not a substitute for their activities.

TECHNOLOGY GROUP	THERMAL TREATMENT OF INCINERATION
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Requirement of regulatory instruments to control emissions, land use permitted for this type of facility and sale/use of by-products.
Market for by-products:	Creation of a market for the sale of ash for the construction industry. Sale of energy from non-conventional sources within the energy market.
Investments in research and development:	The State and private companies must invest to develop this type of technology.
General conclusion:	• **Advantages:** Energy recovery with the possible substitution of fossil fuels; metal recovery; ash recycling; significant reduction in the volume of waste; complete removal of organic waste; greenhouse gas emission reduction source; the greatest possible diversion of waste to dispose of in sanitary landfill. • **Disadvantages:** Relatively high costs; a great effort to manage public acceptance; requirement of specialized personnel.

Source: DNV GL and MAG Consultoría (2016).

Technical data sheet 6: Thermal treatment - Gasification

Gasification is the partial combustion of organic substances that produces gases that serve as raw material or as fuel (Neuwahl et al., 2019).

In Europe the treatment is used with a previous preparation of the RDF, especially in two-stage combustion systems (gasification and subsequent combustion of the gases produced). However, this technology tends to offer lower efficiencies than direct combustion and requires a greater number of steps that may result in a higher volume of emissions and may increase the risk of operation failure. On the other hand, said waste must have a high homogenization that allows its treatment, since variations in its composition drastically alter the gases produced. Next, the technical data sheet that summarizes the information of this technology is presented. The gasification reactors used are fluidized bed, current flow, cyclone and packed bed (Neuwahl et al., 2019).

TECHNOLOGY GROUP	GASIFICATION
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology when combined with incineration or when its by-products are used as raw material and there is prior waste preparation such as RDF.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	>40 years.
Number of facilities in operation worldwide:	Most of the installations that use gasification are considered incineration, since they use this technique for the treatment of syngas. It is known that there is a facility solely for gasification in Finland.
Expected availability and reliability of operation (based on operating experience):	85%.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	Assuming a reuse of the organic fraction, the deviation can be in the order of 52%. But incineration or reuse of the gases generated must be used.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	600 m3 - 7,000 m3 syngas/ton of treated waste.
Land use:	Land-use planning, preferably in rural areas, so as to mitigate the impact of the installation at the urban level.
Spatial requirement:	Variable. It depends on the system with which the technology is combined.
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Medium complexity.
Personnel (qualified, unqualified):	Qualified personnel for the operation of the machinery and the performance of monitoring procedures.
Monitoring and laboratory requirements:	Concentrations of CO, CO2, CH4, N2, H2O.
Conditions for the successful implementation of technology:	The waste must have 20% humidity and be completely homogenized.

TECHNOLOGY GROUP	GASIFICATION
CRITERION 5: COSTS	
Investment (CAPEX):	US$500/TPY - US$700/TPY.
Annual operation and maintenance costs (OPEX):	US$45/ton - US$180/ton.
Life span (years):	There is no information.
CRITERION 6: SCALE	
Capacity:	250 tons/day - 500 tons/day.
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Energy, water, organic waste.
Mass of process outputs (residues, ash, emissions, etc.):	CO2, H2, CO, CH4 emissions.
Fuel:	n/a.
Energy:	942 MWh/year - 7,971 MWh/year.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Reduction of final disposal in sanitary landfill; reduction of greenhouse gas emissions from waste decomposition; alternative source of energy; high investments.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	No participation.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Requirement of regulatory instruments to control emissions and sale of by-products.
Market for by-products:	Sale of energy from non-conventional sources within the energy market, as well as for the gases generated that can be used taking advantage of their chemical value.
Investments in research and development:	The State and private companies must invest to develop this type of technology.
General conclusion:	• **Advantages:** Energy recovery, with the possible substitution of fossil fuels; the significant reduction in the volume of waste after thermal treatment; the complete elimination of organic waste; the strong reduction of greenhouse gas emissions. • **Disadvantages:** Need to combine the technique with incineration. Problems of acceptance by the communities.

Source: DNV GL and MAG Consultoría (2016).

Technical data sheet 7: Co-processing in cement kilns

Co-processing in cement kilns is the procedure by which fossil fuels or mineral resources are replaced by solid waste derivatives for energy recovery (GIZ, 2017).

It requires waste streams that are relatively homogeneous (RDF) to ensure that combustion is controlled and that the product output has the expected quality, since waste can be part of the raw material for industrial production (as in the case of cement). Below is the technical data sheet that summarizes the information on this technology.

TECHNOLOGY GROUP	CO-PROCESSING IN CEMENT KILNS
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology when combined with incineration or when its by-products are used as raw materials.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	Technology used since the 20th century.
Number of installations in global operation:	Used by several cement companies worldwide. A number is unknown approx. No. of facilities.
Expected availability and reliability of operation (based on operating experience):	100%.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	48%, depending on the composition of the treated waste.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	NOx, CO, SOx, HCl and HF emissions.
Land use:	Land-use planning, preferably in rural areas, so as to mitigate the impact of the installation at the urban level.
Spatial requirement:	It depends on the system with which the technology is combined.
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Medium/high complexity.
Personnel (qualified, unqualified):	Qualified personnel for the operation of the machinery and the performance of monitoring procedures.
Monitoring and laboratory requirements:	NOx, CO, SOx, HCl and HF concentrations.
Conditions for the successful implementation of technology:	The waste must be homogenized in order to guarantee the continuity of combustion and the quality of the end product.

TECHNOLOGY GROUP	CO-PROCESSING IN CEMENT KILNS
CRITERION 5: COSTS	
Investment (CAPEX):	US$10/TPY - US$30/TPY. (Depending on the purpose this cost may vary).
Annual operation and maintenance costs (OPEX):	US$10/ton - US$25/ton.
Lifespan (years):	There is no information.
CRITERION 6: SCALE	
Capacity:	50,000 TPY approx.
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Waste.
Mass of process outputs (residues, ash, emissions, etc.):	NOx, CO, SOx, HCl and HF emissions.
Fuel:	n/a.
Energy:	n/a.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Reduction of final disposal in sanitary landfill; reduction of greenhouse gas emissions from waste decomposition; alternative source of energy; high investments.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	No participation.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Requirement of regulatory instruments to control emissions and sale of by-products.
Market for by-products:	Not necessary.
Investments in research and development:	Improvement of systems to prevent emission leaks.
General conclusion:	• **Advantages:** Energy recovery, with the possible substitution of fossil fuels; the significant reduction in the volume of waste after thermal treatment; the complete elimination of the waste entered into the system; the heavy reduction of greenhouse gas emissions. • **Disadvantages:** Problems of acceptance by the communities. High investments required. Emission leaks.

Source: European Commission (2017) and GIZ (2017).

Technical data sheet 8: Capture and valorization of biogas

The methane generated by the decomposition of waste in sanitary landfill is produced under anaerobic conditions. Uncontrolled release of methane from sanitary landfill contributes to greenhouse gas emissions.

The migration and accumulation of methane pose a risk of explosion that can affect neighboring populations. Biogas extraction systems are part of the controlled operation of sanitary landfill. Biogas can be used to generate power or heat, and, after cleaning, it can be used to increase pressure for injection into a natural gas network or for direct use as transportation fuel.

TECHNOLOGY GROUP	CAPTURE AND VALORIZATION OF BIOGAS
CRITERION 1: PROVEN TECHNOLOGIES	
Development status/state of the art:	Proven technology.
Technology development level, laboratory scale/full scale:	9 - full scale.
Years of proven use:	>25 years.
Number of facilities in operation worldwide:	>300.
Expected availability and reliability of operation (based on operating experience):	85%.
CRITERION 2: WASTE DIVERSION PERCENTAGE	
Waste diversion percentage:	n/a.
CRITERION 3: ENVIRONMENTAL IMPACT	
Process outputs:	100 kWh/ton - 120 kWh/ton of MSW.
Land use:	It depends on the use of the land destined for the operation of the sanitary landfill.
Spatial requirement:	0.8 m2/TPY - 1.5 m2/TPY.
CRITERION 4: COMPLEXITY	
Technical complexity and additional technical conditions:	Medium complexity. It requires adaptation of the landfill infrastructure for the implementation or restructuring of biogas extraction systems.
Personnel (qualified, unqualified):	Qualified personnel for the operation of the machinery and the performance of monitoring procedures.
Monitoring and laboratory requirements:	CO_2, CH_4, N_2, N, H_2, O_2 concentrations.
Conditions for the successful implementation of technology:	Feasible for large capacity sanitary landfill sites.
CRITERION 5: COSTS	
Investment (CAPEX):	US$400,000 for every 300 kW installed.
Annual operation and maintenance costs (OPEX):	Information not available.
Lifespan (years):	20 years.

TECHNOLOGY GROUP	CAPTURE AND VALORIZATION OF BIOGAS
CRITERION 6: SCALE	
Capacity:	Ideal for sanitary landfill with more than 500,000 tons of waste disposed of.
Modular technology:	Yes.
CRITERION 7: MASS AND ENERGY BALANCE	
Inputs (required consumables):	Energy, water (0.1 m3/ton of waste).
Mass of process outputs (residues, ash, emissions, etc.):	Fugitive emissions of CO_2, H_2, CO, CH_4.
Fuel:	n/a.
Energy:	942 MWh/year - 7,971 MWh/year.
CRITERION 8: ENVIRONMENTAL, ECONOMIC AND SOCIAL ASSESSMENT	
Environmental, economic and social benefits and costs:	Significant reduction of greenhouse gases. Access to unconventional sources of energy.
CRITERION 9: PARTICIPATION OF RECYCLERS/WASTE PICKERS	
Conflicts of interest:	n/a.
CRITERION 10: CONDITIONS FOR THE SUCCESSFUL INTRODUCTION OF THE TECHNOLOGY	
Supporting legislation and regulation:	Regulation that requires capture and active treatment of biogas in sanitary landfill and final disposal sites. Regulation of gas emissions.
Market for by-products:	Generate/strengthen the market for non-conventional energy sources.
Investments in research and development:	The State and the private sector must invest.
General conclusion:	• **Advantages:** Reduces the risk of explosion at sanitary landfill sites due to accumulation of biogas. The sale of biogas can be a source of income for the sustainability of the system. • **Disadvantages:** Suitable for sanitary landfill with a capacity greater than 9,000 tons per year.

Source: Conestoga-Rovers and Associates (2004) and IDB (2017).

Decisions and directives of the European Union for solid waste management

YEAR	DIRECTIVE	MEASURES TAKEN
1975	75/442/EEC	• It requires the adoption of measures for the prevention and use of waste so that it does not endanger human health or the environment. • It also requires the creation or designation of an authority in charge of the management and supervision of waste management. • It establishes the preparation and implementation of a national plan for comprehensive waste management. • It assigns responsibilities to waste generators and managers. • It requires the preparation of a report on the situation of waste every three years.
1994	94/62/EC Container and packaging regu-lations	• Relating to packaging and packaging waste. • It establishes mandatory goals (percentage) for recycling.
1999	99/31/EC Final disposal	• It establishes the tax on sanitary landfill in order to reduce the environmental impacts generated by final disposal. • It establishes mandatory goals to reduce the amount of biodegradable waste disposed of in sanitary landfill. • It prohibits the admission of liquid, explosive, corrosive, oxidizing, easily flammable or flammable, hospital, tires and other hazardous waste to sanitary landfill. • It orders measures to be taken to ensure that the design, construction, operation, closure, decommissioning, and post-closure costs of at least 30 years are reflected in the prices that will be charged for the use of sanitary landfill.
2000	2000/532/EC	• It establishes a detailed classification of the types of waste according to their hazard level and origin.
2003	Decision 2003/33/EC	• It establishes the criteria and procedures for admitting waste to landfill.
2005	22005/20/EC Thematic strategy for the prevention and recycling of waste	• Amends Directives 94/62/EC and 2004/12/EC. • Application and control of current waste legislation through socialization and awareness measures, publication of directives and guides, surveillance and monitoring of cross-bor-der movement, financing of projects to improve final disposal and promotion of selective collection. • Simplification of waste transfer control processes and updating of regulations in accor-dance with technical standards. • Introduction of the life cycle concept in waste policy and adoption of the hierarchy for waste treatment. • Promotion of waste prevention plans and issuance of regulations related to the manage-ment of waste from extractive industries, ecological design, among others. • Improvement of the knowledge base through mechanisms to collect information related to waste with the collaboration of Eurostat and the European Environment Agency. • Publication of a document on best available techniques applicable to waste treatment industries, in which the pros and cons of more than 900 waste treatment techniques are analyzed. • More precise development of the recycling policy of the European Union and definition of new recycling objectives.

2006	2006/12/EC	• Defines the measures to be adopted by member states in the field of waste. These are the following:
		  ◦ The prevention or reduction of the production of waste and its harmfulness through the technical development and sale of products and the development of appropriate tech-niques for the elimination of dangerous substances contained in the waste destined for valorization.
		  ◦ The valorization of waste through recycling, new use, recovery or any other action aimed at obtaining secondary raw materials.
		  ◦ The use of waste as a source of energy.

2006	2006/66/EC	• • Relating to batteries and accumulators, and their waste.

YEAR	DIRECTIVE	MEASURES TAKEN
2008	2008/98/EC Waste Framework Directive	• Legal framework for the treatment of waste, which establishes the obligation to adopt measures to reduce it, prepare it for reuse, recycle it, or to give it another value (for example, energy) and eliminate waste. • It establishes that waste management is the obligation of whoever produces or owns it and that the State cooperates, but the task is not its responsibility. • It extends the responsibility of the producer. • It determines that all waste must undergo valorization processes. • It promotes the reuse and recycling of products. It establishes that before 2020, the preparation for reuse and recycling (paper, metals, plastic and glass) of household waste must be increased to at least 50% by weight and up to 70% overall by weight of construction and demolition waste (C&DW). • Compliance must be reported every three years to the Commission. • It requires the disposal of waste according to technical provisions. • It requires ensuring that waste management does not endanger human health or the environment. • It establishes the selective collection of organic waste. • It requires the development of a waste management plan. • It requires the development of a waste prevention program. • It requires the delivery of a progress report in relation to waste prevention in Europe. • It establishes the implementation of an action plan to improve consumption habits. • It orders the creation of an information exchange system on best practices in prevention. • It establishes ecological design requirements.
2009	2009/28/EC	• Promotes the use of energy from renewable sources.
2010	2010/75/EU	• On industrial emissions.
2011	Decision 2011/753/EU	• Establishes standards and calculation methods for verifying compliance with the objectives set forth in Article 11, section 2, of the Waste Framework Directive (WFD).
2012	Regulation 1179/2012	• Establishes criteria to determine when the recovered glass ceases to be waste in accordance with the WFD.
2012	Regulation 493/2012	• Establishes detailed standards for calculating the efficiency levels of the recycling processes for waste batteries and accumulators.
2012	2012/19/EU	• About waste electrical and electronic equipment.
2013	2013/2/EU	• Amends Directives 94/62/EC, 2004/12/EC and 2005/20/EC relating to packaging and packaging waste.
2013	2013/56/EU	• Amends Directive 2006/66/EC regarding the placing on the market of portable batteries and accumulators containing cadmium, intended for use in cordless power tools, and button cell batteries with a low mercury content.
2013	Regulation 715/2013	• Establishes criteria to determine when copper scrap ceases to be waste in accordance with the WFD.
2014	COM/2014/0398 Towards a circular economy: a zero waste program in Europe	• Maintain the added value of the products for as long as possible and exclude waste. • Reduce waste and decrease dependency on virgin raw materials. • Promote a strategic axis of design and innovation by supporting R&D policies, the directive on ecological design, among other measures. • Promote a strategic axis of financing through the clarification of the obligations of financial entities in relation to sustainability, the preparation of the methodology of "resistance tests of resources", the guide of ecological public contracting and the prioritization of projects of circular economy in financing plans. • Promote a strategic axis of accompaniment to companies and consumers through the measurement of the environmental impact on the design of products, processes, and the supply and financial support.
2015	Directive (EU) 2015/720	• Amends Directive 94/62/EC regarding the reduction of the consumption of light plastic bags.
2015	Directive (EU) 2015/1127	• Amends Annex II of Directive 2008/98/EC on waste and which repeals certain directives.
2018	Directive (EU) 2018/851	• Amends Directive 2008/98/EC on waste.
2018	Directive (EU) 2018/850	• Amends Directive 1999/31/EC on the dumping of waste, introduces goals for the selective collection of organics and incorporates all the concepts of circular economy.
2018	Directive (EU) 2018/852	• Amends Directive 94/62/EC on packaging and packaging waste.

YEAR	DIRECTIVE	MEASURES TAKEN
2019	Communication on the European Green Deal (EC)	• Establishes the European Green Deal.
2020		• Investment plan of the European Green Deal and the Just Transition Mechanism (JTM).
2020	EC proposal	• Proposal for a European Climate Law to guarantee climate neutrality in the European Union by 2050.
2020		• Action plan for a circular economy focused on the sustainable use of resources.

Source: Prepared by the authors based on European Commission (2019a).

Towards the valorization of solid waste in Latin America and the Caribbean

Basic concepts, feasibility analysis and public policy recommendations

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