



LANDFILL MINING IN BRAZIL: SOME CHALLENGING ASPECTS FOR APPLICATION

*Thiago Villas Bôas Zanon¹ and Maria Eugênia Gimenez Boscov¹

¹School of Engineering, University of São Paulo, Brazil

*Corresponding Author, Received: 31 May 2025, Revised: 22 July 2026, Accepted: 25 July 2026

ABSTRACT: To address the continued global reliance on land disposal of municipal solid waste (MSW), landfill mining (LFM) has emerged as a strategy to recover resources, supporting the Circular Economy. Despite being applied since the 1950s, LFM remains an emerging approach with limited large-scale implementation. This study assesses the feasibility of LFM in Brazil by comparing the socioeconomic, environmental, and waste characteristics of international experiences with Brazilian conditions to identify the main challenges to its implementation. A narrative literature review was conducted covering LFM processes, material fractions, technological routes, economic aspects, and the current state of research and application in Brazil, followed by a comparative analysis between international studies and the Brazilian context. International experiences are predominantly limited to conceptual analyses or pilot feasibility studies, with few large- or full-scale applications. Soil-like materials generally constitute the largest fraction of mined waste, followed by combustible materials, while recyclable fractions are often limited by contamination and market constraints. In Brazil, LFM remains incipient; however, the high dependence on landfilling, low recovery rates, and large accumulated volumes indicate significant resource recovery potential. Nevertheless, its feasibility depends on site-specific technical, environmental, geotechnical, and economic conditions, including high rainfall, elevated organic matter content, increased leachate generation, steep landfill slopes, limited markets for recovered materials, and differences between engineered landfills and dumpsites. Overall, LFM represents a promising complementary strategy for Brazil, but its implementation requires pilot- and full-scale field investigations to evaluate excavation methods, material recovery routes, environmental and occupational impacts, and economic feasibility under Brazilian conditions.

Keywords: Municipal solid waste, Landfill, Mining, Energy recovery, Resource recovery.

1. INTRODUCTION

There is a global consensus that the current economic model, known as Linear Economy, should transit to Circular Economy. In the Linear Economy, the production and consumption model is characterized by a sequence of processes in series, from the extraction of raw materials from nature to the disposal of waste after consumption. In the Circular Economy, products are designed to be reused, remanufactured, recycled or recovered, and thus maintained in the economy for as long as possible, minimizing the extraction of natural resources. Also, the final disposal of waste without prior recovery is minimized, and the generation of greenhouse gas emissions are prevented or reduced, which can contribute significantly to sustainable consumption and production [1,2].

The United Nations Environment Programme defines municipal solid waste (MSW) as waste generated by householders, retailers and other small

businesses, public service providers, and other similar sources [2]. The generation of MSW is small comparatively to the enormous amounts of construction and demolition waste, industrial waste, and agricultural waste produced each year. Nonetheless, MSW totalled 2,126 billion tonnes worldwide in 2020, and is projected to reach 3,782 billion tonnes in 2050, a significant increase in waste generation, which, if not managed properly, can worsen the triple planetary crisis of climate change, biodiversity loss and pollution.

Globally 19% of MSW is recycled, 13% is used for energy recovery, 30% is landfilled, and 38% is dumped [2]. Therefore, more than half of MSW is sent for final disposal on land. In these statistics, according to United Nations Environment Programme, landfilling considers both engineered MSW landfills (also called sanitary landfills) - i.e., disposal sites with structural and environmental protection systems, such as, daily, intermediate or final cover, bottom layers, compaction, leachate and

gas drainage and treatment, geotechnical and environmental monitoring, fencing, weighbridges and security measures - and managed landfills, where there is typically only compaction, daily cover and fencing [2]. Dumping refers to places where collected waste is deposited without compaction, daily cover, and access control for people and animals. In some countries, e.g. Brazil, only engineered landfills are legally recognized as landfilling, whereas managed disposal sites and dumpsites are both considered dumpsites or inadequate deposition [3].

According to United Nations Environment Programme, recycling includes metals, glass, paper and cardboard, some plastics, and biodegradable waste treated through composting and anaerobic digestion to make biogas [2]. Energy recovery refers to production of refuse-derived fuel (RDF) and incineration with energy recovery. This overview of MSW destination [2] indicates a poor practice of Circular Economy regarding MSW in the world. Landfill mining (LFM) is a proposal to enhance circularity for MSW. Materials disposed of in sanitary landfills and also in dumpsites may be recovered by landfill mining, a technique in which waste is excavated, sorted, separated and subsequently used as a resource, eliminating potential sources of subsoil contamination, assisting in recovering land value, reducing greenhouse gas (GHG) emissions [4-6], and reducing post-closure costs, such as leachate treatment and monitoring activities [4,7].

The LFM technique can be applied to both engineered landfills and dumpsites, however with different focus: in engineered sanitary landfills, LFM may be primarily associated with landfill capacity recovery, material and energy recovery and reduction of post-closure liabilities; in old dumpsites, LFM may be more closely related to remediation and land rehabilitation, since these sites often lack adequate containment. Old dumpsites may also present higher uncertainty regarding waste composition and risks involved.

Mined materials that are eventually not used can be again landfilled, however the goal is to minimize or even eliminate the need for returning materials to the landfill [8]. Mining can release part of the volume previously occupied by waste disposed, thereby extending landfill operation and applying the concept of a "perpetual" landfill, or freeing up areas for alternative uses [6,8]. Therefore, LFM is a technique that avoids impacting new areas for expansion or construction of new landfills and reduces the exploitation of natural resources which causes scarcity of raw materials and can thus be another valuable activity in the transition to a circular economy [7,9].

Although LFM has been the subject of an increasing number of studies in recent years, it is not a recent technique, since there are reports of its being used in Israel in the 1950s [4]. Over the last decade, several international research LFM cases have been reported with different levels of investigations; however, most reports involve conceptual analyses or pilot feasibility studies, with a limited number of large and full-scale studies [5-25].

This article aims to assess the feasibility of carrying out LFM in Brazil, comparing socioeconomic and environmental conditions, as well as MSW characteristics, of reported international experiences with those found in Brazil. Historically, almost the totality of collected MSW in Brazil has been sent for land disposal. Currently, 85.6% of MSW is sent for final disposal on land, with circa 60% of the total mass disposed of in sanitary (engineered) landfills, and 40% in managed landfills or dumpsites. Thus, there are thousands of final disposal areas (landfills and dumpsites) with potential for LFM application, either to rehabilitate the area or to recover the disposed waste.

2. RESEARCH SIGNIFICANCE

This study assesses the state of the art of Landfill Mining, discusses the main variables involved, investigates the incipient situation of LFM in Brazil, and prospects the development of LFM applications, based on international experience and on the consideration of local particularities. This article contributes with ideas for the development of research necessary to enhance LFM in Brazil by identifying issues that require more detailed studies. The final objective is to promote the circularity in waste management, present alternatives to landfill disposal, and suggest approaches for recovering dumpsites.

3. METHODOLOGY

This study was based on: (1) a narrative literature review of the state of the art of LFM, covering its main processes, material fractions, technological routes, economic aspects, and the current stage of research and application in Brazil, and (2) a comparative analysis between international LFM experiences reported in the literature and the Brazilian context.

A narrative review was the best approach to address the many aspects of LFM state-of-the-art. The review was based on Brazilian and international papers from the Scopus database, proceedings of technical and scientific conferences, U.N. and World Bank reports, and Brazilian

legislations and technical standards.

Based on this information, the main technical, environmental, economic, and geotechnical challenges for implementing LFM in Brazil were discussed, with emphasis on local conditions such as rainfall regime, high organic matter content, landfill geometry, leachate generation, market alternatives for recovered materials, and the need for future field investigations.

4. LANDFILL MINING STATE OF ART

Most LFM studies involve conceptual analyses or feasibility assessments of specific pilot projects, with a limited number of large and full-scale studies [5,10,11]. The number of studies has grown in recent decades [5].

The mining process of waste disposal sites involves not only the extraction of the landfilled materials, but also the separation of the materials into groups (or fractions) with properties of interest. LFM feasibility is highly dependent on the correct selection of processes and equipment [5].

Two methods are reported in literature for extracting waste to be mined: drilling and excavation, both using conventional equipment [5,10,11]. Drilling is used in scientific pilot projects and allows greater depths to be reached but reduces the size of the mined material and involves high operational costs; excavation by hydraulic excavators or similar is used in large or full-scale projects, has low operational costs, but it does not reach great depths.

Following extraction, materials must be separated and screened for efficient material recovery. Pre-drying is recommended to improve sorting (separation) processes and for end-use of mined materials [10-14].

Sorting equipment is always necessary to separate mined materials into different groups, because MSW is composed of many different constituents. To select the sorting equipment, it is necessary to identify and quantify the materials to be mined and groups or subgroups into which materials can be divided. Such division typically is based on the potential uses as resources such as Waste-to-Material or Waste-to-Energy (WtE) [5,11,15]: (i) combustible fraction (paper, cardboard, textiles, wood, foams, plastics, leather and rubber); (ii) inert fraction (stones, ceramics, glass and metals); (iii) soil-like materials; and (iv) remaining fractions.

The combustible fraction includes materials with high calorific potential that can be used as fuel (in biomass industrial boilers, clinker production furnaces, in pyrolysis, gasification or incineration). Here the main critical parameters are calorific value, moisture content, metals, ash content and chlorine

content.

Many components of landfilled waste are potentially but not effectively recyclable. Only ferrous and non-ferrous metals can effectively be recycled, while other materials which are conceptually recyclable (mainly paper, cardboard and plastics) generally do not have the minimum necessary quality due to the presence of impregnated contaminants (for example, organic matter and soil). This makes them more attractive to use as fuels; even so, prior treatments could be necessary, such as separation, cleaning and drying [10,11].

Soil-like materials involve soils and materials with a granulometry similar to soils (such as partially or fully decomposed organic matter) and can be used in the following applications: (i) at final disposal sites as waste cover or biocovers (layers constructed in active or closed landfills for methane oxidation, reducing fugitive emissions); (ii) composting; or (iii) in other applications as construction material. Soil present in mined material mainly originates from daily, intermediate and final covers of the waste landfill; i.e., soil is used in large quantities during landfill operations. Composting is also a possibility for this fraction (if uncontaminated), but evaluation of the percentage of remaining organic matter and concentration of metals is necessary, since these constituents can limit or make composting unfeasible, even in non-food crops [5]. For the reuse of soil-like materials, their chemical composition and potential contamination should first be assessed in relation to the intended use. Although the advanced degree of decomposition typically observed in these excavated materials is expected to limit nutrient release, composting may still provide beneficial improvements when applied to agricultural soils, including enhanced aeration, increased porosity, and greater particle aggregation. Furthermore, for the reuse as landfill cover and construction material, facility of spreading and compacting, as well as resulting permeability and shear strength, which depend on geotechnical properties, should also be investigated.

The composition of materials mined from MSW landfills varies significantly among different landfills, depending on original waste composition, waste age, location, climate and hydrological conditions [5,9]. Original waste composition of MSW varies according to population income level [2,26], whereas composition of disposed waste varies depending on prior treatments before final disposal. Table 1 presents waste composition and values ranges found in two review papers that present cases on landfill mining in different countries. The percentage of the combustible fraction in both studies is in the same

order of magnitude in both studies, while soil-like materials are relatively close.

Table 1 Percentage of material recovered in different LFM cases

Fractions	Krook et al. [11]	Jain et al. [5]
Soil-like material	50% to 60%	48.6%
Combustible fraction	20% to 30%	24.5%
Inert fraction	10%	21.3%
Others	-	5.6%

Time factor, represented by waste age, is a key variable of mined materials composition over time, since degradation processes of organic-putrescible materials (mainly food remains, wood, paper and cardboard) occur, reducing the participation of this fraction. Thus, over time, soil-like materials fraction increases, combustible fraction decreases, and the inert fraction remains constant [5,6]. This occurs because the combustible mass degrades over time and converts to soil-like materials fraction, while the inert materials remain constant. There are also changes in characteristics, such as reduction of materials size in waste mass [6,16,17]. Granulometry is an information of interest, since one of the most conventional processes for separating MSW is sieving, allowing the separation of smaller fractions (soil and food waste) from larger fractions, which generally have a higher calorific value.

Since most of mined waste composition is soil-like materials, as shown in Table 1, the first process recurrently applied after waste extraction is granulometric separation. This fraction is distinguished from the others mainly by size, therefore sieving sets soil-like materials apart. For screening, trommels or vibrating screens are mainly used, with no standard size for screen openings (screen sizes between 1 and 40 mm are described in the literature), which impairs the comparison of percentage soil-like materials fraction among different LFM studies [5,10,11]. The grain diameter for coarse sands, the thickest fraction of soils, is defined as 4.8 mm in geotechnics. Many mining studies use much larger opening sizes, probably due to the mined soils forming clods and being agglutinated.

To separate the other groups and subgroups of materials, the following equipment is also found in mining studies: crushers, ferrous metal separators, non-ferrous metal separators, air separation technologies and conveyor equipment [5,10,11].

Krook et al. conducted an extensive literature review on landfill mining, covering the main trends, objectives, topics and findings in 39 research articles

published during the period 1988-2008 [11], whose geographical distribution is shown in Fig. 1. The main topics of the articles are presented in Fig. 2.

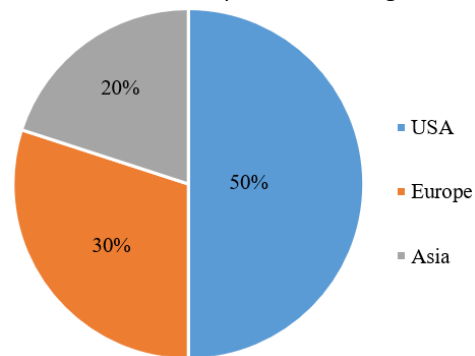


Fig. 1 Krook et al. [11] geographical distribution of LFM cases

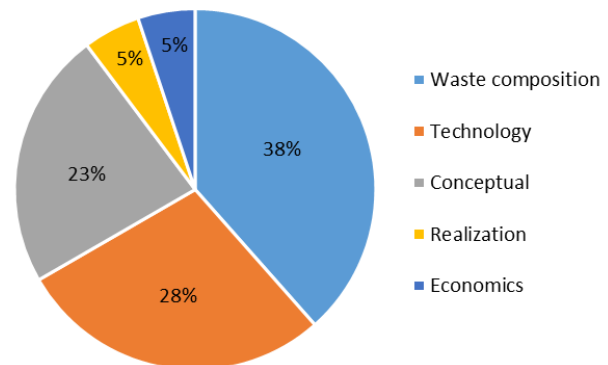


Fig. 2 Krook et al. [11] categorization of 39 reviewed papers regarding main topics

Jain et al. found 108 publications related to LFM distributed in different regions [5] as seen in Fig. 3. In both review papers there are no publications from Latin America, Caribbean, and Sub-Saharan Africa.

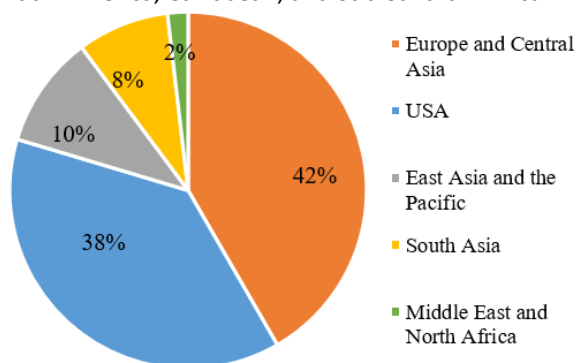


Fig. 3 Jain et al. [5] geographical distribution of LFM cases

One of the fundamental topics to be evaluated in LFM is economic viability. There are articles in the literature that explore this topic, addressing the need for generating gains and revenues - avoided post-closure costs of the landfill, externalities, added value due to landfill space gain, land value, materials

sales (including rare materials) - to fund activities related to LFM (extraction, separation, transportation, heat treatment and final disposal of materials) [18-21]. Esguerra et al. conducted a review of studies that assessed LFM economic potential, selecting 15 that met certain criteria (full article in English, quantitative analysis, among others) [18]. These studies mostly comprised an economic analysis focused on decision-making about a specific landfill and concluded that mining has low economic potential; only 2 proved to be profitable [18]. However, the authors call attention to the need for expanding scenarios and improving scientific prospective analyses.

Rosendal [7] points out that LFM operations have generally been performed by municipal landfill owners and directed to solving landfill problems rather than to recovering resources. According to the author, a change of perspective, qualifying LFM as equivalent to a remediation or mining activity, would result in more favorable institutional conditions and better access to the market for mined materials.

The difficulty of implementing the reuse of recovery materials is an important issue in LFM. Even in Europe - one of the most environmentally, legally, socially, and economically favorable global regions for LFM implementation - secondary resources are frequently prejudiced through strict requirements for marketability, while primary resources are supported through subsidies [7].

4.1 State of the Art of LFM in Brazil

There are few studies on the application of landfill mining in Brazil [6,15,22,24,25], and no cases of pilot, large and full-scale application have been identified.

Regarding recovery potential, data analyses from tropical landfills, comparing new waste and mined waste aged 4 to 6 years, show that there is a tendency for components with high calorific potential to concentrate along the disposal time, and at the same time there is a reduction in the moisture content (from 100% on a dry basis to 20% to 60%). These are indications that 4 to 6 years are sufficient for most microbial processes to occur, conditions that can favor LFM and energy recovery from waste due to the moisture reduction [6]. This expected behavior can be observed in Fig. 4, where the higher calorific value (HCV) of waste in an engineered landfill in the city of Salvador was measured for 2.5 years: after 0.5 years HCV reaches a high-level range and remains in the range of 23 to 27 MJ/dry kg for circa 2.5 years (investigated time). Kasam et al. also studied the effect of age on MSW composition

collected in an Indonesian landfill [27]. However, samples from 0 to 2 years were collected from a well-managed part of the landfill, whereas samples older than 3 years were collected from an open dumping site, what makes the comparison more difficult.

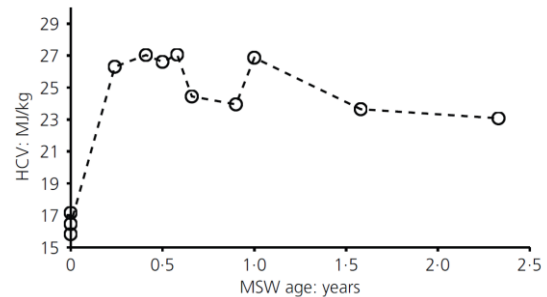


Fig. 4 High Calorific Value obtained in a Brazilian MSW landfill [6]

In a landfill located near the city of São Paulo, waste aged between 10 and 16 years was sampled with the aim of evaluating combustible fraction. The study concluded that the fraction with diameter higher than 40 mm, which corresponded to 27% of the mined materials, had potential for energy recovery (due to the high presence of plastics and paper), presenting average calorific value that would meet the criteria for refuse derived fuel according to the applicable state legislation [15].

A closed landfill located in the city of Campinas, Brazil, was also subject of characterization based on waste age, in addition to assessing the potential use of the landfilled materials. Data analysis from mined waste aged 8 years revealed that a significant potential for biogas generation remained at the landfill even after 8 years of disposal, showing that the mineralization of organic matter was not completed [25]. Also, the soil-like fraction offered potential benefits for agriculture, once it exhibited higher levels of calcium (Ca), iron (Fe), manganese (Mn), boron (B), and cation exchange capacity (CEC) compared to traditional organic fertilizers, at the same time presenting low levels of potentially toxic elements [28]. Mined waste aged 24 years presented 71% of soil-like materials, what lead the authors to conclude that LFM in Brazil will be mainly driven by the recycling of this fraction [28].

Guimarães et al. assessed the mining potential from old closed dumpsites that operated between 1989 and 2015 [22], providing relevant data on waste composition (Fig. 5): high percentage of plastics and soil-like materials, and low percentage of organics (probably because much of the organic matter had degraded). The potential for LFM apparently is 42% combustible fraction (plastics and textiles) and 3% recyclable materials (metals). The reuse of the soil-like fraction (organics and soil)

should be further investigated.

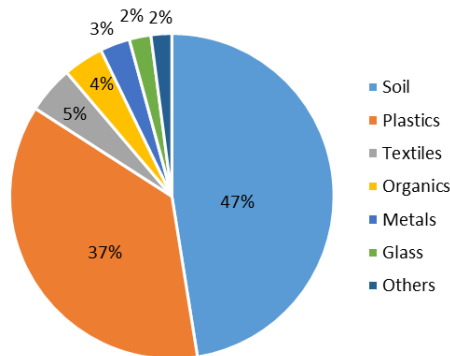


Fig. 5 Average composition of samples collected in 9 dumpsites [22]

5. DISCUSSIONS

In Brazil, practically all MSW is disposed of in landfills and dumpsites, accounting for 85.5% of the total MSW generated, while waste recovery remains very low, below 10%, including recycling and waste-to-energy, as shown in Fig. 6. Considering this disposal pattern and the estimated average gravimetric composition of Brazilian MSW presented in Fig. 7, both the quantity and proportion of recoverable waste accumulated in final disposal sites are likely to be significant. There is a large presence of organic waste, corresponding to 45.3% of MSW, and waste with energy recovery potential, which represents more than 35% of MSW (plastics, textiles, paper and cardboard, leather and rubber, and multilayer packaging).

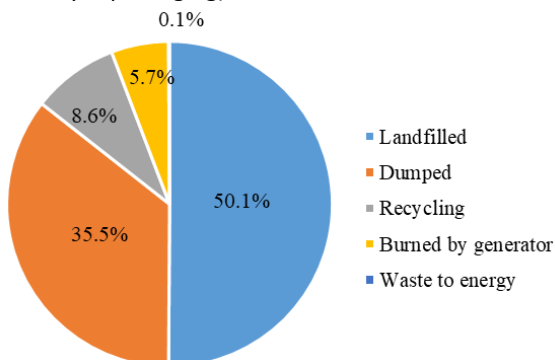


Fig. 6 Brazilian MSW destination in 2023 [29]

In the case of LFM, the amount of organic matter is expected to decrease quickly compared to the amount of generated MSW; amount of soil, stones, ceramics, glass, plastics and metals will remain the same; paper, cardboard, textiles, leather and rubber will degrade slowly, and their quantity should decrease slightly. In percentage terms, a lower percentage of organic matter is expected for the excavated material; and energy use is probably the best use for plastics, paper, cardboard, textiles,

wood, foams, plastics, leather and rubber, since they are contaminated and can hardly be recycled.

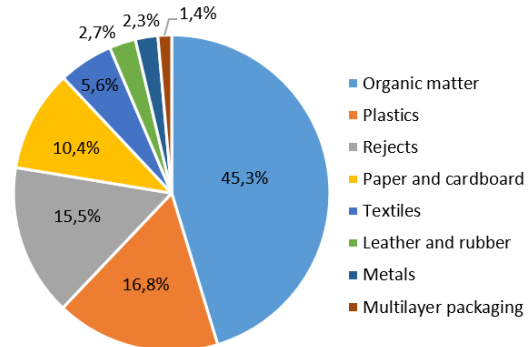


Fig. 7 Brazilian MSW composition in 2020 [30]

Despite the difficulty to recycle materials from landfill mining, research has been conducted in Brazil to characterize the fractions of municipal solid waste focusing on the energy or material recovery to minimize final disposal [31-33].

Recyclable waste from household selective collection in the city of São Paulo/Brazil sent to two automatic sorting facilities and one manual sorting facility were characterized [33]. The rejects of these facilities after the sorting operations were also characterized. Gravimetric, geotechnical (water content, grading curve, compaction and direct shear) and environmental (organic matter content, ash content, pH, electrical conductivity and various metals) characterization tests were conducted. The authors observed that some recyclable/reusable were discarded to be deposited as rejects in landfills (e.g., glass, some specific types of plastics - PVC, LDPE, PP, and PS). This can be explained because, despite being recyclable, not all materials have economic viability for recycling. A considerable percentage of recyclable material in the rejects from those three sorting facilities was observed, and it was estimated that the lower heating value (LHV) of the analyzed samples results in values higher than that required for the technical feasibility of incineration.

However, there are few Brazilian studies on LFM. In many countries where LFM cases have been reported, the value of land is a significant factor in economic viability, which can be as significant as the revenue from materials that can be valued. In Brazil, a country of continental dimensions, the land freed up by LFM would not have such a great relevance in the economic viability. This is possibly the main reason for the lack of interest in this topic in the country.

Also, the circularity of the economy is still a new concept for Brazilian public managers, entrepreneurs in the sanitation sector, and the citizens in general. Since 2010, the year of publication of the National Policy for Solid Waste, a

federal law, a legal and institutional framework has been slowly developing to meet the law's requirements. The first step was the improvement of land disposal and the need for municipalities to formulate and implement a plan for solid waste management. Recycling, reverse logistics, composting, and circularity are steps that are being implanted at different paces.

One of the potential ways to seek circularity of LFM is the use of the combustible fraction, the second largest typical fraction among mined waste as presented in Table 1. There is a Brazilian law to regulate waste characteristics to be applied as refuse-derived fuel (RDF) for the cement industry, an important economic activity in Brazil. This use is very strong in Brazil and started in the 1990s due to industrial waste with high calorific potential. Cement Brazilian plants typically seek RDF with a calorific value exceeding 2,775 kcal/kg (dry basis), a small particle size (up to 50 mm), and a maximum chlorine content of 1% (dry basis). In Brazil, there are currently 60 cements plants with licensed furnaces for co-processing waste [34]; 2% of productive energy demand for cements plants came from MSW in 2020, while the sector has set a goal to reach 17% by 2050 focusing on the reduction of GHG emissions [34], so LFM has the potential to be a source of resource for cement sector. The study cited by Bernardes Jr [15] may indicate the possibility, in some cases, that the combustible fraction of the mined waste can meet the requirements without the need for extensive drying and sorting. Also, Machado et al. observed that in large tropical sanitary landfills, waste biodegradation and compression are responsible for reducing the initial water content from about 100% to about 50% 4-5 years after disposal [35]. This suggests that extensive drying of the mined waste may not be always necessary for RDF production; however, this should be analyzed case by case.

A framework to analyze the fractions of landfilled material according to the possible applications, including energy recovery, composting, geotechnical use of soil-like fraction and metals recycling was proposed by [24,25,28].

Analyzing the circularity potential of the organic matter in final waste disposal sites, there is a Brazilian law for composting and there are some practical experiences, but mostly from agrobusiness waste.

Additionally, there are geotechnical challenges that may make this solution less attractive: there are regions with high rainfall, limiting operation time along the year and increasing leachate generation; MSW has a high percentage of organic matter; landfills can be very high (Bandeirantes and São João

Landfills reached height of, respectively, 100 m and 130 m, while the Caieiras Landfill will reach 140 m) and with steep slopes (typically 1V:2H [36]), a combination that brings greater difficulty to excavation and may generate additional costs. The excavation plan must account for geotechnical stability throughout the process. It should be pointed out that, as the excavation proceeds, the cover is removed, MSW is exposed, and infiltration of stormwater may increase, rising pore pressure and reducing stability. On the other hand, there is an already know-how developed in Brazil for the design and operation of tropical sanitary landfills [37], which allows overcoming these challenges.

LFM can also cause discomfort to neighborhoods, due to odor, noise and emission of particulate matter [7] and entails other potential risks - such as occupational safety issues (e.g., landfill gas exposure, fire risk, biological hazards, sharp materials, and unstable waste mass) - which can be mitigated through appropriate plans and programs. However, in the long term, it could bring benefits such as increasing the value of the surrounding area, recovering urban areas of considerable dimensions, and reducing potential risks to public health and environmental pollution. This challenge of acceptance by the surrounding community requires communication and dialogue with society.

It is important to consider the lessons learned and recommendations related to existing international studies. Therefore, in Brazil, field investigations should be carried out to assess the behavior of the waste composition and changes in the characteristics of the waste as a function of its age. Executing these investigations can subsequently allow planning, specifying and dimensioning appropriate processes for conducting pilot, large and full-scale studies, allowing the assessment of the performance and economic viability of LFM [23]. Local particularities should also be considered in the LFM assessment, such as local rainfall regime, since significant areas of Brazilian territory have locations with high rainfall index, which may interfere with waste extraction activities, waste processing and LFM feasibility.

In future studies to evaluate LFM, it is also important to consider different scenarios of separation, valorization, market issues for recycled materials - a vital issue in Brazil, where public policies for use of recycled material are incipient - and market for the fuel fraction. Guerreiro analyzed the production of RDF in Brazil [38]. The annual RDF production is 176,000 tons, but just one plant utilizes MSW, with a yearly production of 30,000 tons (while 89 million tons MSW are collected yearly in Brazil). Another plant co-processes RDF from MSW, waste

tires, biomass (wood chips), and paints and solvents, achieving a blend with high calorific power.

The technological route of waste excavation processes must be addressed by incorporating the know-how developed in landfilling operations. Last but not least, the inclusion of waste pickers cooperatives in the sorting processes with capacitation for the different scenarios must also be considered, because they represent a significant percentage of the non-specialized labor force in Brazil.

Finally, landfill mining should not be regarded as a justification for the continued reliance on landfilling as a primary municipal solid waste management strategy. Waste prevention, along with reduction, reuse, recycling, and other resource recovery measures, should remain the priority within the waste management hierarchy.

6. CONCLUSIONS

Although a significant number of scientific publications address LFM, the number of full-scale cases remains limited. The identified studies mostly involve conceptual analyses and pilot studies, with few reports of large and full-scale cases.

For Brazil, the analysis indicates significant potential for the implementation of LFM due to the historical predominance of land disposal as the dominant MSW management strategy and the limited recovery of recyclable material prior to final disposal. Consequently, significant quantities of potentially recoverable materials are expected to remain stored in landfill sites. The most promising recovery opportunities include the extraction of combustible fractions for energy recovery, the reuse of soil-like materials where technically and environmentally feasible, and the reclamation of landfill capacity or the rehabilitation of degraded areas.

However, the feasibility of LFM in Brazil depends on local technical, environmental, economic, and geotechnical conditions. High rainfall, high organic matter content, increased leachate generation, steep and high landfill slopes, limited markets for recovered materials, and the distinction between engineered landfills and dumpsites are key factors that must be considered. Therefore, future research should prioritize field investigations at pilot, large, and full scale to evaluate waste composition, excavation methods, sorting routes, recovery alternatives, environmental, social and occupational risks, and economic viability under Brazilian conditions.

7. ABBREVIATIONS

B = boron
Ca = calcium
CEC = cation exchange capacity
Fe = iron
GHG = greenhouse gas
HCV = higher calorific value
LDPE = low density polyethylene
LFM = landfill mining
LHV = lower heating value
Mn = manganese
MSW = municipal solid waste
PS = polystyrene
PP = polypropylene
PVC = polyvinyl chloride
RDF = refuse-derived fuel
U.N. = United Nations
WtE = waste-to-energy

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