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ORIGINAL ARTICLE

Effect of MBT on landfill behavior: an Italian case study

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Abstract

Bad choices in municipal waste (MW) management cause negative effects on sustainability. Evolving regulation has identified prevention and recycling as the best strategies; nevertheless, disposal in landfilling sites plays an essential role since a complete zero-waste scenario is not realistic, currently. Nowadays, policies require a preliminary waste stabilization to decrease the putrescible content. Therefore, mechanical biological treatment (MBT) has replaced the previous crushing, aimed at simple volume reduction. Literature has proved the effectiveness of MBT when MW collection system is ineffective. The present paper considered a facility in an area with a high-performance MW collection system. A long-term (1999–2019) on-site sampling allowed the comparison between two sites of the facility: the old site (before the MBT activation) and the new area, where the stabilized waste is disposed of. Monitoring of biogas, leachate (analyzed parameters: pH, BOD_5, COD, ammonia-nitrogen) and odorous emissions was performed to verify the effect of the stabilization process. The considered long period and the on-site sampling support the relevance of the results, compared to the available literature, often referred to as laboratory scale. The results proved the relatively low benefit of stabilization at the considered facility, which cannot justify the energy consumption of MBT.

Keywords Landfill · Municipal waste · Mechanical biological treatment · Leachate · Biogas · MBT (mechanical biological treatment)

Introduction

Starting from the industrial revolution, the exponential human population growth, combined with technological development, has resulted in a continuously increasing waste flow. The recent Circular Economy action plan, published by the European Commission, reports a prevision of the annual waste generation increase around 70% by 2050 [1]. The waste problem is due to both the amount and the modification of the waste type which affect the management system [2]. This topic represents a priority for the modern society, since the management choices have multiple effects: social, environmental, technical and economic [3–5]. The well-known waste hierarchy identifies prevention as the most important strategy. Nevertheless, the necessity to integrate all the available options by decision-making tools, able to involve all the stakeholders, is evident [3, 6–9]. Municipal waste (MW) covers an essential role for the whole waste management system. Many definitions of MW are used in each country, often affected by different aspects, mainly waste origin, materials and collectors [10, 11]. The Directive 99/31/EC defined MW as waste from households and other waste with similar composition and nature [12]. Furthermore, EUROSTAT includes similar wastes generated by small businesses and public institutions, excluding those from agriculture and industry [13]. The management of MW is currently one of the most serious and controversial issues, at local and regional scales, even more in developed countries [2]. The disposal in landfilling sites represents the most common strategy of MW management (also in developed countries), despite the evolving regulations [14–16]. This practice produces significant environmental impacts, if the disposed waste flow has high putrescible content and it is managed with low technical and management precautions [14]. Indeed, this fraction acts on the production of two flows: the leachate (mainly critical for aquifer) and

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greenhouse gases (GHG, which cause global warming). Leachate production is promoted by rainwater infiltrations, combined with chemical and physical phenomena, resulting in inorganic and organic contaminants, with potential effects for human and environmental health [17, 18]. Furthermore, the modern facilities include containment systems to prevent the release of pollutants [18]. GHG include a mixture of mainly carbon dioxide and methane (in comparable concentrations) with traces of H_2S, H_2, N_2O and NH_3 [19, 20]. The reduction of GHG emissions represents one of the most important priorities worldwide, currently [21, 22]. The possibility of a mechanical biological treatment (MBT), before the final disposal, could be implemented to stabilize the biologically degradable components, with the main advantages of recovery of recyclable materials, reduction of the volume of waste to dispose, and reduction of the organic matter content [20, 23]. More in detail, MBT is a simple practice able to combine mechanical separation with the biological stabilization of organic matter by aerobic/anaerobic stabilization and bio-drying [14, 20, 24–30]. The number of MBT facilities has increased in Europe (about 570 active facilities, in 2017), mainly in the last two decades to satisfy the legal obligation to both limit biodegradable waste in landfilling sites and increase recycling and energy recovery from waste [24, 27, 28, 31, 32]. The Italian scenario identified 131 MBT in 2018, since this country adopted the European Union sanitary landfill regulation by Legislative Decrees 36/2003 (implementation of Directive 1999/31/EC) and 205/2010 (transposition of European Directive 2008/98/EC), which specifies that the disposal of solid waste is possible after a ‘‘pre-treatment” (not better specified) when the limits of composition defined by the regulation are not respected [6, 12, 33–36]. Several papers summarize the benefit of an MBT implementation (as pre-treatment before landfilling) [27, 37–40]; nevertheless, some authors highlight the impact (both environmental and economic) due to MBT operations. They suggest critically assessing when the treatment is really advantageous [2, 14, 41, 42]. In this regard, some studies perform analysis (e.g., with life cycle assessment, LCA approach) to prove that the improvement of recycling systems can produce higher positive effect than MBT [28, 43]. The reason is the decrease of organic fraction in the input flow to MBT facility and the low value of the resulting product, often considered a waste to dispose of [42]. In agreement with these conclusions, Trulli et al. (2018) recommended the pre-treatment for developing regions, with low separate collection levels.

Starting from the current state of the art, the present paper considered a landfilling site for MW, located in Central Italy, where satisfying recycling levels are achieved. The facility, operating from 1999, includes an MBT from 2018, able to stabilize MW before the final disposal. The site peculiarities allowed a deepened study of the landfill behavior before and after the MBT introduction, by monitoring biogas emissions, leachate production, odors, and site settlement. The possibility of a long-time on-site detection represents a strength of the present paper.

Materials and methods

The landfilling site

The Corinaldo landfilling site, built in 1974, is one of the most important sites of the Ancona Province (one of the regional capitals of Central Italy), placed in a 140,300 m^2 area. The facility serves the Ancona Province, for a total population of 475,000 inhabitants, characterized by a recycling efficiency around 65% (including the main fractions of paper, plastic, metals, glass and organic, as summarized in Figure S1). It treats around 68,000 tons of unsorted MW per year, the value of which decreases following the circular economy principles. The average composition is reported in Fig. 1, and the fractions classified as “others” and “underscreening” do not include relevant percentages of putrescible materials. More in detail, the first one includes a mix of different kinds of waste, and the second one is mainly composed of inert material.

In agreement with the European regulation, the disposed waste is initially stabilized by MBT, in a facility close to the landfilling site, since 2018. During 2017, the first year of life of the operative life, the waste was pre-treated at another MBT facility, comparable to that under study, so 2017 has been included in the analysis. Thereafter, the waste flow is tipped and spread daily into the cell horizontally, with layers not higher than 30 cm, which ensures the highest waste compaction. Considering the catchment area of the landfill and the high recycling achievement of the Marche Region, the MBT facility treats the remaining unsorted waste fraction composed of mixed waste, excluding the waste from street sweeping [44]. Though 65% is a good recycling level, the unsorted fraction includes recyclable fractions and end up in the landfilling site due to incorrect collection by the regional population. The high mixing level of the flow makes impossible the hypothesis of further automatic separation and recycling before MBT as described in Fig. 2. The flowchart shows the two main fractions produced at the end of the stabilization: the overscreening and the under creening, with a further separation of the metallic residue for the inert fraction removal. Thereafter, the underscreening fraction is stabilized by biological oxidation and drying for the decrease of the dynamic respiration index. After 2 weeks of treatment, both the stabilized product (with a dynamic respiration index, DRI, lower than 1000 $mgO_2*kgSV^{-1}*h^{-1}$ [45], compared to a starting value that usually exceeds 4000 $mgO_2*kgSV^{-1}*h^{-1}$ [14]) and the overscreening fraction are

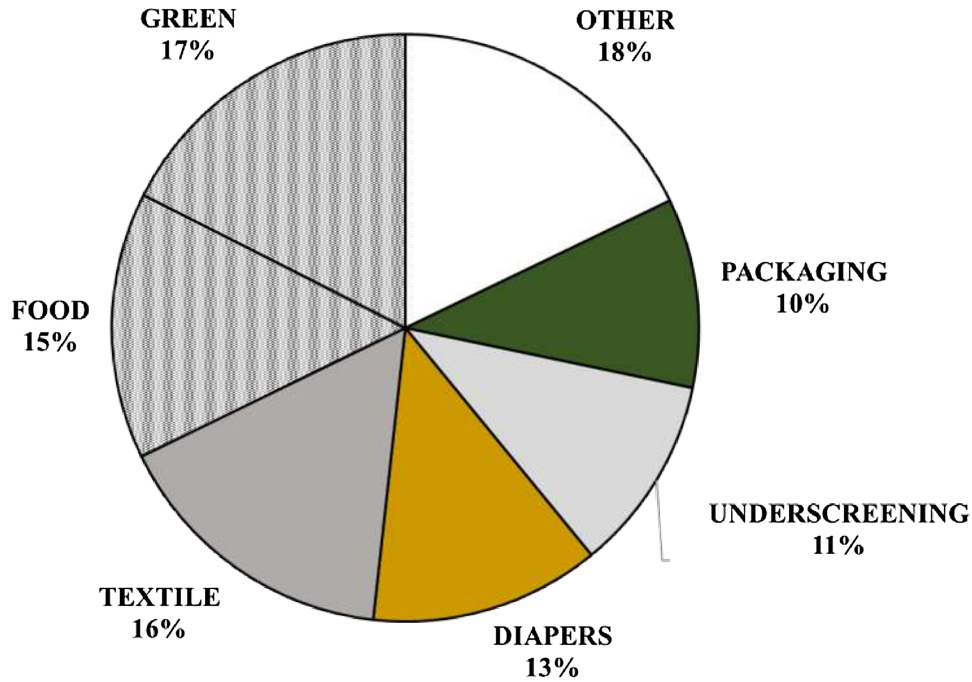

Fig. 1 Average composition of MW input to the Corinaldo facility (Excel)

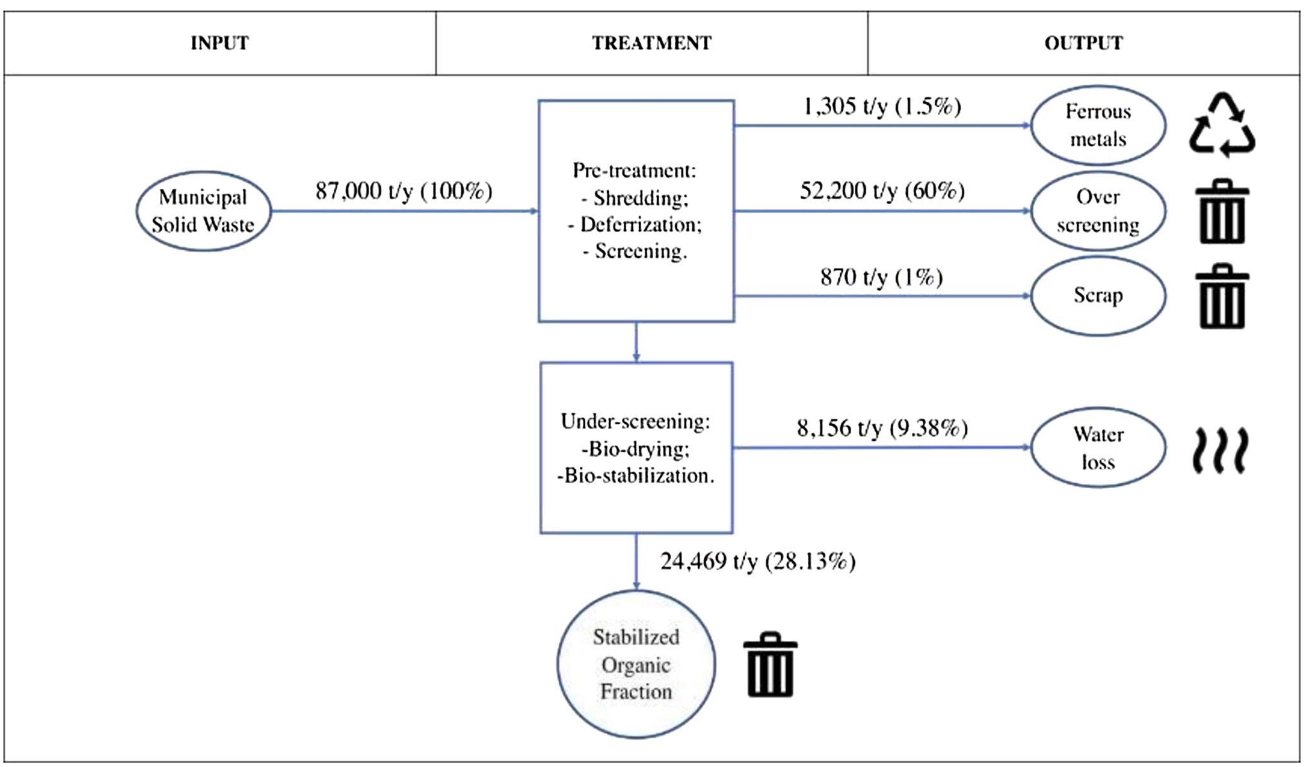

Fig. 2 Description of MBT of Cordinaldo, process design planning (Power Point)

sent to the landfilling site, similarly to that in the facility described by Calabrò et al. (2011). The water loss shown in Fig. 2 is estimated as waste weight difference before and after bio-drying and bio-stabilization. The mass balances in Fig. 2 refers to the project capacity of the facility; indeed, the MBT is currently overbuilt considering the decrease of the unsorted fraction achieved by the most recent recycling strategies. All data discussed in the present paper were supplied by ASA S.r.l., the company which currently manages the landfilling site.

Collection and analysis of samples

Biogas

Data about the biogas production were supplied by the company which manages the facility. A multigas detector (high-resolution portable fluxmeter—West System) which uses an accumulation chamber technique allowed the determination of gas composition. The system implements a static, not stationary, technique, which allows the continuous measurement of both carbon dioxide and methane within the chamber. This technique is commonly used in the agrarian field to measure the CO_2 flow and the soil respiration rate [46–49]. From the beginning of the 1990s, this technique is widely used to measure the diffuse emissions in both volcanic areas [50–52] and landfilling sites (not stationary version) [53]. The chosen method allows to obtain a quick, real-time evaluation of the gas concentration increase, avoiding the use of the empirical model depending on the soil characteristics and gas flow regime, which could increase the measurement error [50]. More in detail, the handy equipment (developed by the cooperation of the Institute of Geosciences and Georesources of Pisa, University of Perugia e West Systems srl) is composed of one chamber, two IR detectors, an analog-to-digital converter, and a handheld computer. Gases are extracted by a diaphragm pump and sent to a column for moisture removal. A fan allows to homogenize the gases within the chamber. Thereafter, the flow is sent to the spectrophotometers for gas reading. The sampling activity was carried out monthly at the suction lines activated on both the landfilling sites of interest (the old area and the operative area, Figure S2). The sampling points were referred to theoretical mesh knots of the side of 10–20 m, georeferenced by the global positioning system with a location error between 1 and 2 m.

Leachate

ASA S.r.l. supplied data of leachate production. Samples were collected monthly from the collection tank (one for each landfilling area). The analyzed parameters (considered representative of the stabilization degree) included [54–56]: pH (APAT CNR IRSA 2060 Man 29 2003 [57]), BOD_5 (APAT CNR IRSA 5120 B1 Man 29 2003 [58]), COD (ISO 15705:2002) [59], TOC (UNI EN 1484: 1999 [60]), and ammonia-nitrogen ($N\text{-}NH^{4+}$) (APAT CNR IRSA 4030 C Man 29 2003 [61]), quantified on standard basis, reported in parentheses.

Odorous emissions

Odorous emissions were determined in agreement with the European Standard (EN) EN 13,725:2003, which describes the method for the determination of odor concentration of a gaseous sample by dynamic olfactometry with human assessors and the emission rate of odors emanating from point sources, area sources with outward flow, and area sources without outward flow [62]. The monthly sampling activity involved five stations (common for both the old and the operative landfilling sites).

Results and discussion

Waste flow analysis

The data related to 2019 waste flows, supplied by the Corinaldo landfilling site manager (Fig. 3), shows fairly regular input to the MBT facility. Ancona is a seaside town and the tourism increase in summer months explains the highest values recorded in July (around 25% higher than the MBT input flow in February and 10% more than the average value of 5700 tons/month). Tourism also affects the efficiency of recycling with the lowest separated collection of the organic fraction. This is the reason for the highest effect of MBT in July, when the increase of the putrescible content is translated into the greatest gap between input and output. On the other hand, the data related to January, August and November were affected by the facility maintenance issues. It is evident that the availability of real-scale information represents a relevant advantage to assess the effect of the variables, but inevitably includes variability in process operation. Nevertheless, the long period of landfilling site observation ensured the exclusion of effects on the whole results. Overall, about 70,000 tons/year are sent to the facility for stabilization, 20% lower than the process design planning (Fig. 2). The detected output flows, ready to be sent to the landfilling sites, show an average value of 5000 tons/month. The leachate resulting from the underscreening stabilization (around 10% of input flow) is sent to the treatment (off-site), classified by the European Waste Catalogue (EWC) (19 05 99). The details of output composition identify the overscreening (dry fraction from mechanical pre-treatment) and the stabilized underscreening (from bio-drying and bio-stabilization, Fig. 2) as the most relevant fractions, with a contribution of 60% and 25%, respectively. More in detail, the stabilized underscreening is classified by the EWC as 19 05 01 (non-composted fraction of municipal and similar wastes) and 19 05 03 (off-specification compost). Overall, the treated amount is about the 86%

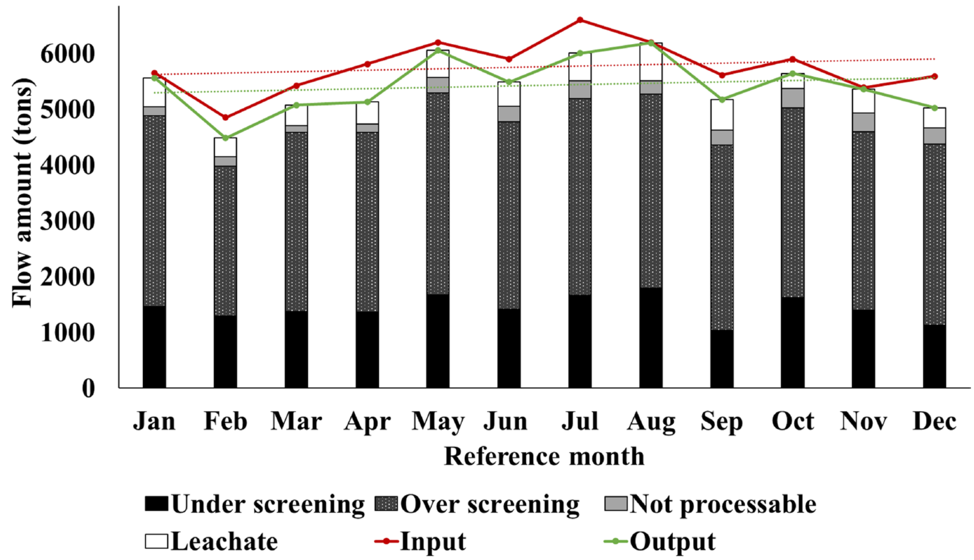

Fig. 3 Monthly input and output flows at Corinaldo MBT facility (reference year: 2019) (Excel)

of the starting waste, which grows up to 94% considering the leachate from the stabilizations cell. A further percentage, lower than 1%, is composed of ferrous metals to send to recycling. From an economic point of view, a weight loss of about 6% causes a relevant cost increase from 79.20 €/ton for the waste management at the landfilling site to € 113.0 €/ton, which includes both the MBT and the final disposal. The economic considerations were based on the real price list of the facilities. Therefore, the evolution from a simple mechanical pre-treatment to the most innovative stabilization has caused an economic cost growth of 30%. Following the APAT guidelines, this cost increase should allow the removal of pollutants and undesired materials and the decrease of volume to dispose of (thanks to both the recovery of valuable fractions and the organic component degradation), emissions (both biogas and leachate), odors, compaction costs and settlement phenomena [36].

The biogas analysis

The study of the biogas trend was essential to prove the effect of MBT on waste stabilization. With this aim, a deepened analysis was carried out to compare the biogas production in the old area (only mechanical pre-treatment, January 2005–January 2006) with that in the operative section (disposal after a preliminary MBT, January 2019–April 2020). The availability of huge quantities of information, referred to different times of landfilling, allowed to exclude the effect of waste degradation phenomena. The details of the collected data are reported in Table S1. Two factors can affect the produced biogas amounts: the quantity of the disposed waste and the age of the landfilling site. To include both factors in the assessment, two performance indexes were evaluated as follows:

$$\text{Index 1} = \frac{\text{total extracted biogas (m}^3\text{)}}{\text{total disposed waste quantity (tons)}}, \quad (1)$$

$$\text{Index 2} = \frac{\text{monthly extracted biogas (m}^3\text{)}}{\text{landfilling site age (months)}}. \quad (2)$$

Each value of Index 1 correlates the whole biogas produced within the considered period with the disposed waste amount. On the other hand, Index 2 correlates the monthly collected biogas with the age of the site.

As reported in Fig. 4a, the two areas showed comparable increasing trends of Index 1 with the highest slope value in the old area case. This difference is mainly due to the highest putrescible content in the old waste, because the separated collection of organic fractions, on Ancona Province territory, was started in 2006. The results include a data variability connected to the seasonal variation of biogas production, irrespective of the reference area, since the degradation is promoted by rains, at not too cold temperature [63, 64].

Figure 4b shows the trend of Index 2 in the old landfill (January 2005–January 2006, corresponding to a site age between 61 and 73 months) and the operative area (January 2019–April 2020, corresponding to an age between 22 and 37 months). Overall, the values of Index 2 are comparable, except for the date recorded in July 2019 (age: 28 months) of the new landfill. Nevertheless, the old site shows the highest stability with an Index between 4.0×10^3 and 4.8×10^3 m^3month^{-1}. Data related to the operative landfilling area in April 2020 show a biogas extraction around 2.000.000 di m^3, resulting from a total disposed of 223.000 tons, at 37 months

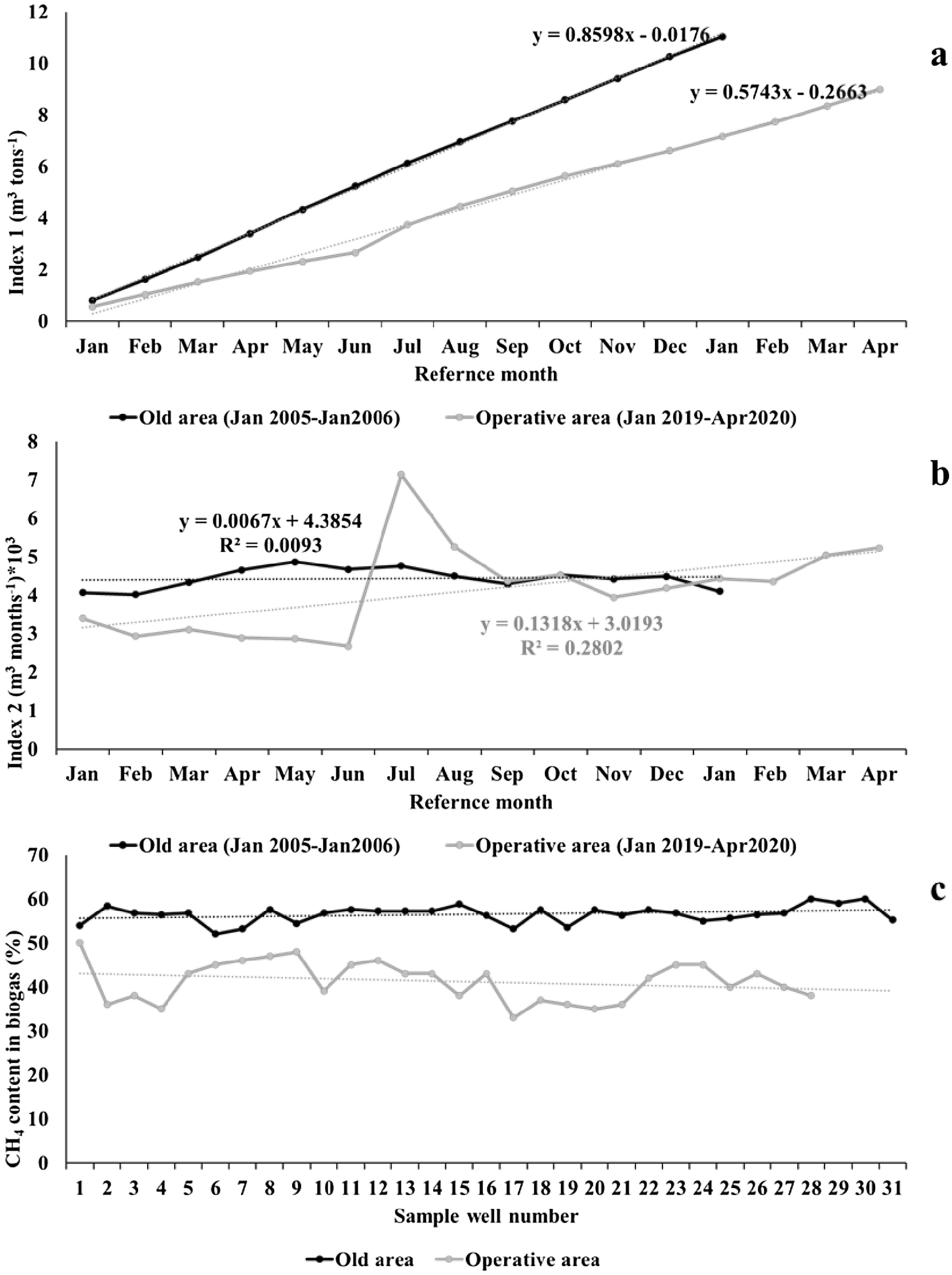

Fig. 4 Biogas production: trend of **a** Index 1 **b** Index 2, old site (sampling time: January 2005–January 2006) vs operative landfilling area (sampling time: January 2019–April 2020). **c** CH_4 content, comparison between the old site (only waste grinding before the disposal) and the new area (MBT for the preliminary stabilization) (Excel)

of landfill age (Index 2 = 5.2×10^3 $m^3 month^{-1}$). The same biogas quantity results from a total disposed of 328.000 tons at 67 months of landfill age (Index 2 = 4.7×10^3 $m^3 month^{-1}$). The results suggest that the MBT implementation did not produce a drastic effect on biogas production. The two areas are characterized by the same management conditions and comparable physical/environmental peculiarities; therefore, the possible effect of these factors on the biogas production has been excluded. 30 samples from each area (1 for each sample wells), related to one month of 2005 and 2020 for the old and operative sites, respectively, were collected for the gas characterization. The high number of measurements (between 20 and 30) ensures a good interpretation of the overall gas emissions from landfill [65]. The average composition of samples of the old site (Fig. 4c) showed a content of 56% ± 2 of CH_4 and almost total absence of O_2. On the other hand, contents of 40% ± 5 of CH_4 and 2% ± 1 of O_2 were detected in the biogas extracted from the operative site. On the qualitative characterization basis, the new biogas has a lower calorific value with a consequent decrease of energy production around 20%, compared to the old site. Different hypothesis could be linked to variation of biogas composition: the reduction of organic fraction composition (for the improvement of the waste collection system in Ancona Province) and the effect of MBT. This aspect represents a criticality, since the possibility of biogas exploitation for energy recovery could make the landfilling more sustainable than MBT, as proved by literature [66–68]. Indeed, considering the MBT energy request and the resulting emissions, relevant environmental loads are estimated, mainly in the categories of global warming potential and ozone layer depletion [66].

The leachate analysis

Leachate production is the second factor chosen to compare the two management scenarios (only waste grinding before the disposal vs MBT for the preliminary stabilization). As confirmed by the literature, there is a close connection between the leachate production and rainfall, which significantly increases the production [38, 69–71]. Figure 5 correlates the annual rainfall with the annual leachate production at the landfill to confirm the consistency with the literature data. With this aim, a range between 12.4 and 50.0% of rainfall converted into leachate was considered in agreement with both Linde et al. (1995), which reported 15–50%, and Baucom and Ruhl (2013), which considered a range between 12.4 and 27.2% [71, 72]. The results, estimated considering the exposed surface, the rainfall quantities and the produced leachate, are included within the estimated range in all the selected years (2005–2018) proving the representativeness of the assessed data.

Further evaluations focused on the assessment of Index 3 Eq. (3) to quantify the real production at the landfilling site, considering both the disposed waste and the site age, in agreement with the previous assessment of biogas production.

$$\text{Index 3} = \frac{\text{collected leachate } (m^3)}{\text{total disposed waste quantity (tons)} * \text{ landfilling site age (month)}}, \quad (3)$$

where the collected leachate is the volume produced during the reference year and the total disposed waste included the whole quantity in the period of interest. Two annual ranges were chosen to compare the two areas: 1999–2002 for the old site (750 mm average rainfall) and 2017–2019 for the new area (670 mm average rainfall). In both cases, a total disposed waste quantity of 200,000 tons was selected and the

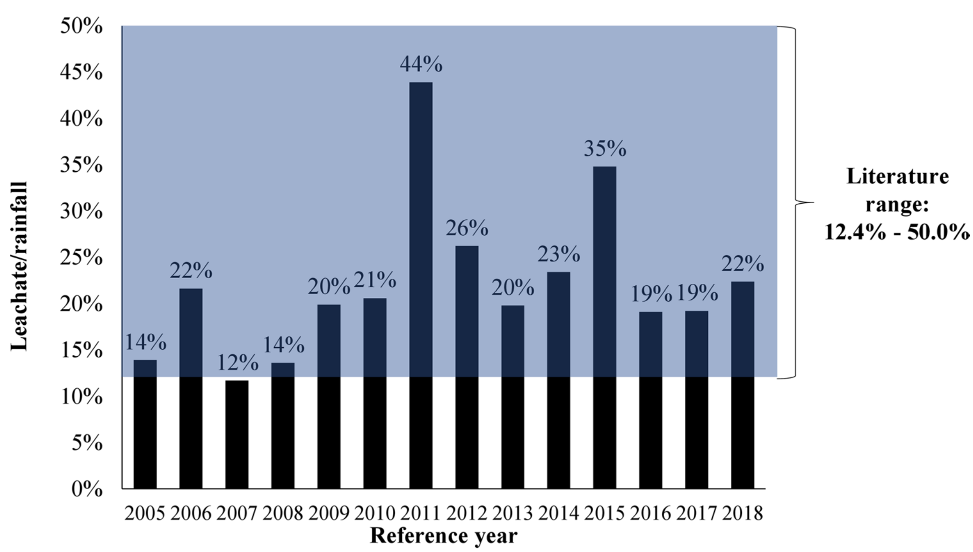

Fig. 5 Rainfall and leachate production: (a) assessment of the water conversion into leachate, comparison with the literature (Excel)

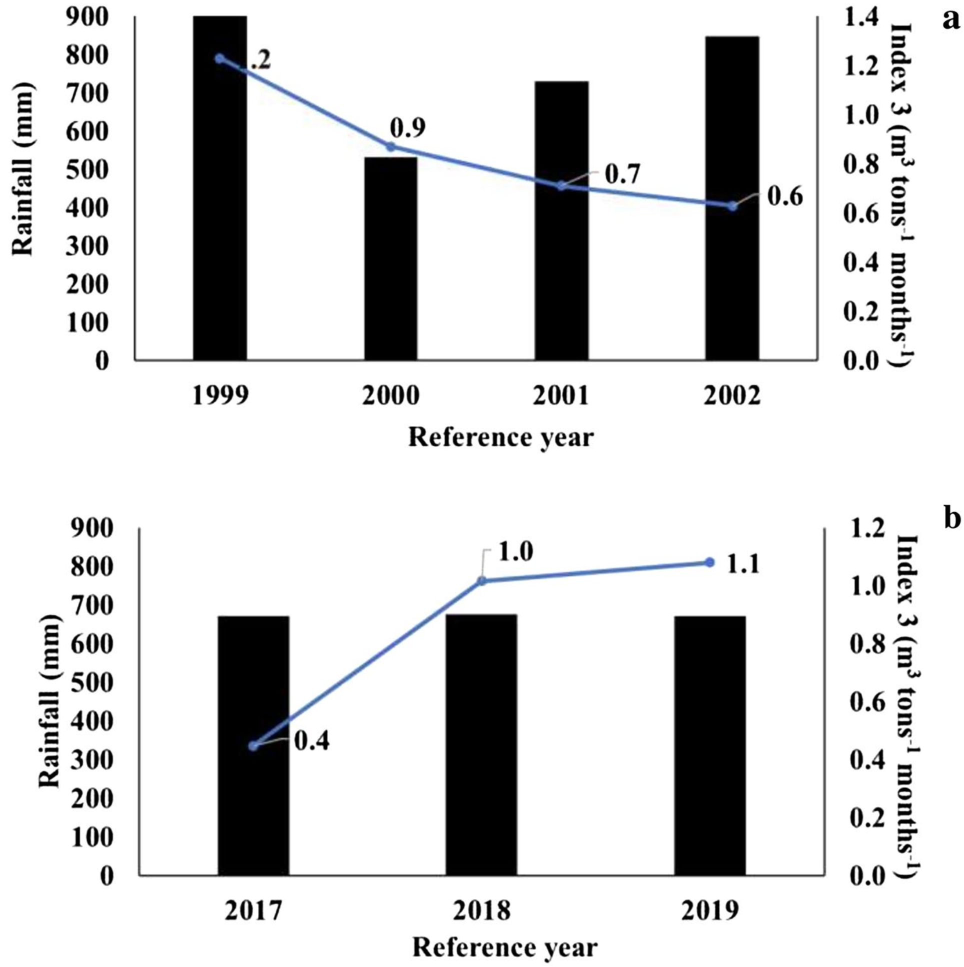

Fig. 6 Trend of Index 3 on the rainfall and landfilling site age in the cases of **a** the old and **b** the new area (total disposed waste quantity of 200,000 tons) (Excel)

same executive of the two areas ensured the same management conditions. Furthermore, considering the comparable quantity of rainfall in the two periods, this aspect cannot affect the results. Figure 6 shows comparable results in both scenarios, with an average value of Index 3 around 0.8. This result suggests that the implementation of a preliminary MBT did not significantly reduce the leachate production in the new landfilling area. The comparable results allow to exclude the possible effect of moisture content (due to waste age, pre-treatment, permeability, compaction, particle size and density) on leachate production [54, 73]. The comparable moisture content of the waste in the two sites is justified by the water evaporation during the crushing operations of the waste disposed between 1999 and 2002 and the current highest separation of the organic fraction in the operative site. Considering the young age of the operative site in 2017, the increasing trend of Index 3 from 2017 and 2018 is justified by the activation time, necessary to stabilize the conditions for leachate production (e.g., temperature).

The additional leachate characterization is an essential step to study the landfill behavior, as explained in Table S2. Indeed, biodegradation processes are carried out by three groups of bacteria: hydrolytic and fermentative bacteria (polymer hydrolyzation and fermentation of monosaccharides to carboxylic acids and alcohols), acetogenic bacteria (conversion of carboxylic acids and alcohols to acetate, hydrogen, and carbon dioxide), and methanogens (conversion of end products to methane and carbon dioxide). Variation of pH value is linked to the specific biodegradation phase; the neutral pH decreases for the carboxylic acids accumulation and increases for their consumption during the methanogenic phase (range: 7.5–9 [74]). In addition to pH, BOD/COD is a parameter representative of the landfill state, since a high ratio indicates the presence of biodegradable compounds still present in the leachate [15, 75, 76]. This ratio decreases during the biodegradation phase, with values around 0.6 which are reduced up to 0.1 in the methanogenic phase [17, 76–78]. The trend of both pH and BOD/COD was analyzed during the 3-year periods 2004–2006 for the old site and 2017–2019 for the new site. The choice was due to an analytical issue, since the sample collection and analysis were carried out by the same certified laboratory. The results in Fig. 7a prove the achievement of methanogenic phase, with stationary pH (around 8.5) and BOD/COD values (between

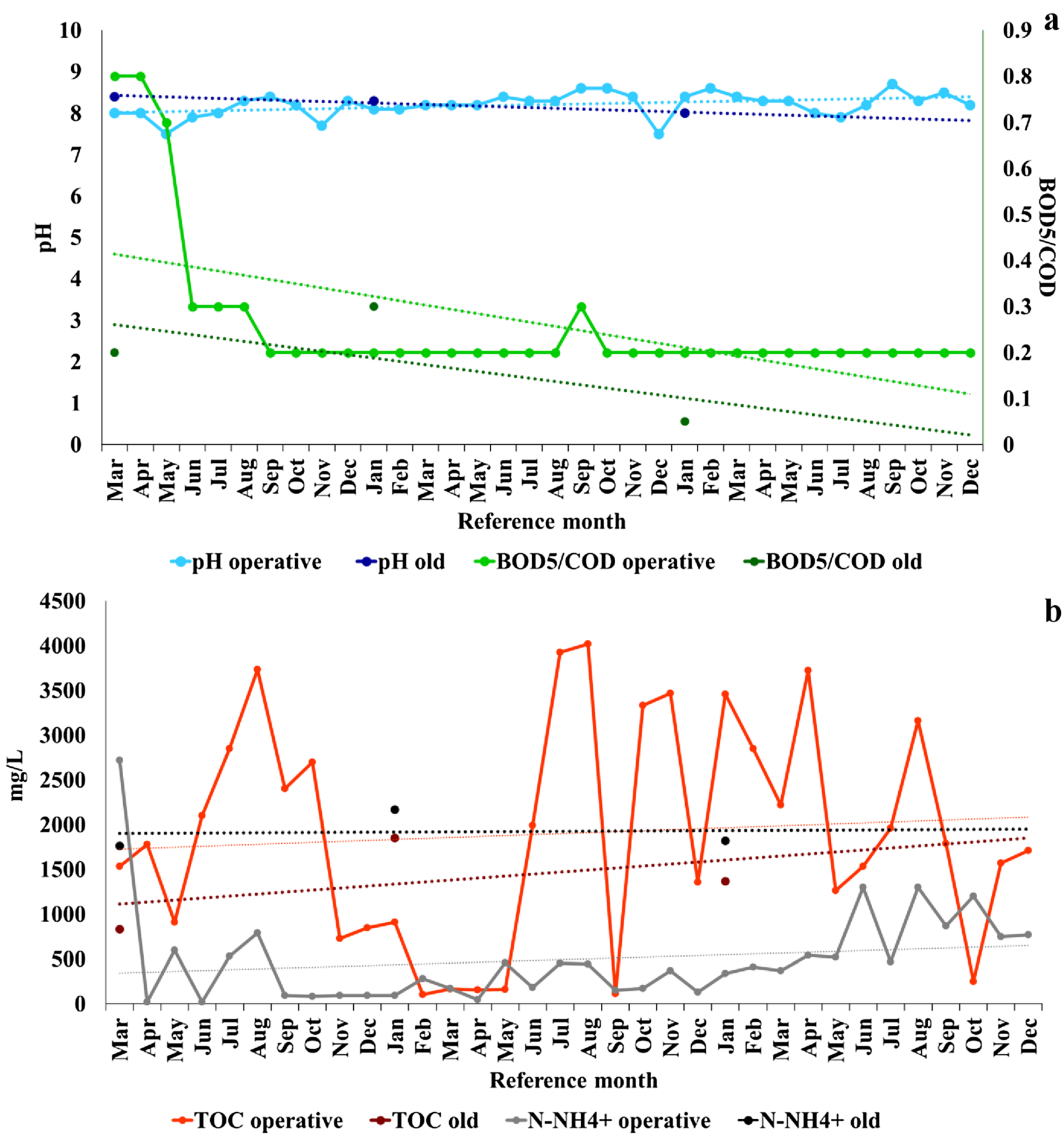

Fig. 7 Trend of **a** pH and BOD_5/COD, **b** TOC and N-NH^{4+} parameters detected at the two analyzed landfilling areas: 3-year periods 2004–2006 for the old site and 2017–2019 for the new site (Excel)

0.05 and 0.2) in both the sites of interest [74]. The period between March and May marks the transition from acetic to methanogenic phases (BOD/COD > 0.4) [74]. The identification of methanogenic phase is further supported by the TOC results, lower than the limit of 4500 mg/L, in spite of the data variability (Fig. 7b). Overall, the characterization shows comparable results, without relevant advantage in the case of stabilized waste. Figure 7b shows a significant difference of N-NH^{4+} concentration in the leachate from the two areas. This aspect could be connected to the landfill age (around 90 months of the old site vs 36 months of the operative one), since ammonia often represents a long-term pollutant in leachate [17]. For this reason, a longer observation of the operative site would be necessary to make conclusions about this aspect.

Odorous emissions

The decrease of odorous emissions from landfilling site is included in the list of APAT guideline targets [36]; therefore, the inclusion of this aspect in the present study was considered important. With this aim, five sampling stations were chosen to compare the landfilling site impact, before and after the MBT implementation. The time periods selected for the sampling activities were March 2008–March 2009 and April 2017–December 2019. This choice ensured the same sampling stations. Data collected between 2009 and 2016 were not taken into account for the entry into operation of a composting facility close to the landfilling site that could negatively affect odor detection. The same facility was converted into the MBT, currently operating, in 2017. Results in Table 1 report the average values detected at each sampling station during the reference period, without relevant improvement after the stabilization start-up. On the other hand, the odors measured between 2004 and 2006 (when the separated collection of organic fraction was not activated) showed an average value of 48 ± 10, suggesting the significant effect of the high-efficiency collection system.

Soil settling assessment

The waste settlement can be described by three steps, similarly to the soil phenomena. The first phase is the immediate waste settlement due to the gas and particle expulsion or compression. The second stage, named consolidation stage, is time dependent and due to the dissipation of pore pressure excess. The third step is connected to the biodegradation processes [79]. While it is an interesting aspect to analyze, the assessment of MBT effect on soil settling phenomena is complicated in the present experimentation, since it is mainly affected by the method used for waste disposal at the landfilling site. In this regard, the increase of compactor capacity from 35 tons of the old area to 57 tons of that used in the operative one is translated into an increase of compaction level around 35%. This technical improvement allowed an economic advantage for the company around 20%, compared to the old practices (considering the machinery rent). Waste grinding level is another essential variable of the soil settling effects, as confirmed by the literature [79]. Considering these aspects, the comparison between the two sites was not reliable, since the new landfill area uses higher-performance equipment for both the compactor and grinding operations.

Table 1 Odor emissions at five sampling stations before and after MBT

Sampling station	S1	S2	S3	S4	S5
Old landfilling site					
Average value (o.u./m^3)	23	23	24	22	21
St. dev	6	11	9	9	15
New landfilling site (MBT)					
Average value (o.u./m^3)	29	28	28	33	25
St. dev	9	9	8	31	7

Discussion and conclusions

Waste management is a debated critical topic, since it is affected by several variables, including the waste composition and the local peculiarity. Wrong choices can be translated into negative effect for all the spheres: environmental, economic, and social. Therefore, the extensive large-scale scientific research is necessary to support the decisions of the stakeholders involved. Many studies were carried out in regions with critical waste management situation, proving the relevance of MBT [2, 14, 24, 80]. Nevertheless, the present paper proved the relatively low benefit achieved by an MBT implementation in an area with satisfactory collection and recycling levels. In this regard, literature has already proved the key role of the preliminary management steps for the creation of a sustainable system, able to avoid MBT use [25, 43].

As explained in the present work, the use of an MBT as preliminary treatment, before the disposal, produced low performance, without decrease of emissions (leachate, biogas, odors), in an area where the organic content (mainly from food and green) in the residual waste fraction does not exceed the 30%. Furthermore, it should consider that this value will reduce with the growing strategies of circular economy and the increase of people awareness of the subject of organic fraction collection. The only difference detected by the showed analysis was a change in the biogas composition. This aspect, partially attributable to the improvement of organic fraction collection in Italy (from 40 kg/(inhabitant*year) of 2004 to 120 kg/(inhabitant*year) of 2020 [81, 82]), represents a weakness of the waste management chain, because the possibility of biogas exploitation partially balances the environmental burdens of landfill. The energetic aspect is further aggravated by the energetic demand of stabilization facility with the consequent growth of the waste management costs, as proved by the present analysis. Many authors quantified the negative environmental impacts due to electricity demand of MBT in several impact categories, at the expense of the final low process efficiency [2, 28, 66]. Some consideration should be done about the possibility to give value to the stabilized product, as an alternative to the current disposal [8, 83]. In this regard, literature reports the possible energetic enhancement of this flow [3, 58, 84]. The results showed in the present paper analyze many aspects of the life of landfilling site, considering different periods of time and waste management systems (with or without a high-performance collection and recycling system). Additional studies should be performed at the end of the life of the second area, to assess the possible differences in the behavior of the two sites.

Considering the achieved results, the present work aims to provide a support for the development of new policies focused on the improvement of waste collection strategies, able to produce high-quality separated fractions, both from qualitative and quantitative point of views (e.g., door-to-door collection). Further actions should be addressed at the improvement of downstream management.

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