COLLECTION AND COMPOSTING OF ORGANIC WASTE: A CASE STUDY IN THE CITY OF BEIRA, MOZAMBIQUE

VALENTINA CAMINATI[1], MARCO RAGAZZI[1], SILVIA SILVESTRI[2], FEDERICO BERGHI[3], DARIO GUIRRERI[3], ADA CASTELLUCCI[1,4], ISACCO RAMA[4]

[1]University of Trento, Department of Civil, Environmental and Mechanical Engineering, Italy

[2]Fondazione Edmund Mach, Research and Innovation Centre, Italy

[3]Progettomondo NGO, Italy

[4]CAM - Consortium of Associations with Mozambique onlus, Italy

ABSTRACT

In low-income countries, the organic is the prevalent fraction of the municipal solid waste (MSW) and its decomposition can create problems with processing, odour, biogas and leachate. On the other side it is an important resource because rich in organic matter and nutrients, which can be properly recycled. Therefore, it is essential to correctly send the organic fraction to a dedicated collection and valorisation flow. Within the LimpaMOS MOÇambique project, which is taking place in the cities of Beira and Nampula, numerous Italian and Mozambican actors from the public, private and no-profit sectors are involved. The project is mainly co-financed by the Italian Agency for Development Cooperation. One of the objectives of the project is to strengthen the proper management, separation, valorisation and disposal of MSW. The composting process is a valid solution for the treatment of the organic fraction as it allows a substantial reduction in the volume of putrescible material stored in landfills, and at the same time it makes it possible to produce and sell a good quality soil conditioner. The research work carried out in this study focuses mainly on two aims: an analysis of the management of the Composting Centre (CeCom) which will be built in the city of Beira, and an investigation on the organic waste collection by local communities. In order to move the organic fraction further away from the urban context, a subsequent expansion of the input matrix of the CeCom is essential. The study wants to involve the city's second main market, some restaurants and the harbour canteen in the process of separating, collecting and managing the organic fraction. However, this expansion cannot take place without the creation of institutionalised, trained and remunerated groups of local workers.

Keywords: municipal solid waste management, mozambique, low-income country, organic waste, markets, composting, dump, leachate, biogas, dump pickers.

1 INTRODUCTION

Waste management has become one of the most complex and central environmental challenges of the 21st century. Municipal solid waste (MSW) represents a threat not only to the environment but also to people's health, especially in large cities in low-income contexts affected by uncontrolled urbanisation where the number of inhabitants is growing rapidly. MSW management and disposal practices vary significantly by income level, region and country development [1-11]. About 93% of waste is burned or dumped in lower-income countries [12-17]. Although more than 40% of the waste in the sub-Saharan Africa region is organic (OFMSW), only less of 1% is composted [18-20]. National and municipal governments often have insufficient capacity or funding to meet the growing demand for MSW management services [21-23]. Therefore, especially in big cities, dumping of OFMSW is a more common practice than separating and sending it to a dedicated collection and valorisation stream, despite the latter being the better option.

ISSN: 2398-2640 (paper format), ISSN: 2398-2659 (online), http://www.witpress.com/journals

DOI: 10.2495/EI-V5-N3-259-270

Mozambique ranks low on the human development index at 0.456, or 181 out of 189 countries [24], [25]. While the economy registered its first contraction in 2020 in nearly three decades, growth is expected to rebound over the medium-term, reaching about 4% by 2022 [26]. Since its recent independence from Portugal in 1975, agriculture as a pillar of the economy is suffering from the consequences of alternating natural events such as droughts, floods and cyclones [27].

With a population of 673,685 [28], Beira is the second main populated city of Mozambique. The city is the capital of Sofála Province in central Mozambique and has a geographically unfavourable position, due to the many tropical cyclones that attack the Mozambican coast. The situation, also due to global warming, is not likely to improve, so it is necessary to make the city as safe as possible, including in terms of MSW management [29-31]. The heavy rains in the summertime can stagnate for days on the ground, creating large swamps even where there are open dumps. As a result, the waste is more widely dispersed and the leachate generated infiltrates the soil, reaching the groundwater and contaminating it.

The OFMSW is the biggest fraction in the MSW, and its decomposition in the case of uncontrolled destination (e.g., in dumpsites) can create problems of processing, odour, biogas and leachate, leading to pollution problems and costly environmental restoration [32-35]. That is why it is essential to correctly dispose this waste fraction by directing it to a dedicated treatment: composting, anaerobic digestion, etc [36-40].

2 THE LIMPAMOS MOÇAMBIQUE PROJECT

Mozambique Environment Programme started in 2018 from the collaboration between two Italian NGOs (Progettomondo and CAM) and the municipalities of the two Mozambican cities: Beira and Nampula, following previous sector studies on MSW characterisation in collaboration with University of Trento and Fondazione Edmund Mach (research, education, and consultancy in agricultural, agri-food, and environmental sectors) [36]. Accelerated growth of cities, increase in consumer goods, low diffusion of collection services, low awareness and low technical-management capacity are some of the factors that show the need for urgent and systemic interventions aimed at mitigating the impact on environment and public health.

This five-year programme includes the LimpaMOS MOÇambique project, mainly co-financed by the Italian Agency for Development Cooperation. The project aims to strengthen the public institution in its material and human components, searching for sustainable and integrated solutions for the MSW management. Among the solutions adaptable to the context of Beira, one of the many actions of the LimpaMOS project is the construction of a Composting Centre (CeCom). It continues to be carried out by the two technical and scientific main partners (University of Trento and Fondazione Edmund Mach).

Accurate knowledge of the amount and type of MSW produced is one of the basic information for MSW management. The creation of an updated database contributes substantially to define services and investments needed for collection, transport, form of treatment and final disposal of MSW. At the same time, it contributes to the formulation of strategies for the valorisation of certain fractions, such as the organic one.

The campaign of the MSW analysis made with the technical support to the Department of Urban Management, Equipment and Environment of the Municipality of Beira and was carried out during a period of 5 months, between August and December 2016. Thanks to this analysis, it was possible to elaborate the Municipal Solid Waste Integrated Management Plan of the City of Beira, a fundamental report on the composition of MSW, the current waste management and its future developments. Thirty analyses were carried out in two shifts,

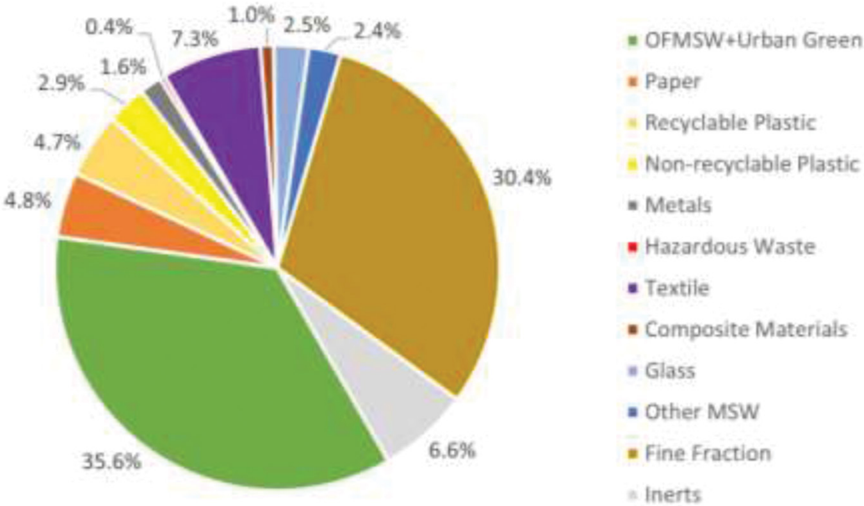

Figure 1: Results of product analysis for the city of Beira (2017).

throughout the city. MSW from road containers was analysed, as well as that collected from households living in the so-called informal part of the city, which is characterised by very precarious public or private structures and infrastructures (e.g., areas with houses built with mud and metal sheets and with pedestrian access only). In line with the literature on the composition of MSW in a low-income context, the OFMSW is the predominant one also for the considered case-study as reported in Fig. 1.

The large amount of organic matter present (more than a third of the total composition) leads to the choice of a biological treatment method for its management: one of the most popular treatments, due to its simplicity of management, is the composting process. Collection of the OFMSW at household level is not yet achievable in Beira because of the great material and management criticalities of the MSW collection and transport system. However, in addition to market activities, restaurants play an important role, as they are significant sources of OFMSW production.

In low-income contexts, most MSW is produced by market activities: 35 markets are across the city. These, between formal and informal, differ according to the nature of the products sold and are distinguished by their size and character. The amount of waste material produced in the markets has a strong impact on the collection and final disposal system. There are 16 major markets (MSW output above 100 m^3/month). Of these, half produce almost exclusively organic waste while only three produce mixed waste, half of which is organic. In Table 1 some data from five food markets are reported.

To obtain the most realistic projection of the monthly production of MSW from the urban markets, the containers belonging to the markets were identified and it was monitored how many times per week (or per day, as for Maquinino Market) they were emptied by municipal vehicles. Each container has a capacity of 6 m^3, so, considering that emptying takes place only once it is full, the volume produced during a working month (28 days) was estimated. The density (0.49 t/m^3) assumed for the calculations of the MSW production is the maximum found in the product analysis carried out on containers from the Macurungo district that have the highest organic matter content.

Table 1: Main markets in Beira and their MSW production.

N°	Name	Character	MSW (m^3/month)	MSW (t/y)
1	Maquinino	Food market	1,152	6,773.76
2	Goto	Food market	576	3,386.88
3	Ponta Gea	Food market	144	846.72
4	Munhava Central	Food market	144	846.72
5	Nhangau	Food market	144	846.72

The Maquinino market is the one with the highest production of MSW. Maquinino was chosen as a pilot market to be used to obtain the OFMSW needed for the start-up of the composting centre CeCom. First, it has been subject to a requalification in order to improve:

(i) internal waste management through the insertion of small containers inside the market, which can be easily emptied;
(ii) the internal collection and transport with wheelbarrows;
(iii) external storage through separate collection in 6 m^3 road containers, placed on a new concrete platform adjacent to one of the market's perimeter walls on which drawings and writing have been made to identify the container for the OFMSW on one side and the one for the inorganic fraction on the other one.

The area where the CeCom will be built is about 1.5 ha and is located in Munhava district. This position was identified using essentially two basic criteria: its proximity to the city's main landfill site and the existence of a viability to allow access for trucks. CeCom's Preliminary Project was drafted in 2019 and is not yet in the implementation phase. The plant will provide two different areas for biological treatment:

- *ACT (Active Composting Time) area:* the bioxidation takes place in covered biocells made of concrete to allow easy loading/unloading operations by a tractor equipped with a shovel. This area is equipped with an air insufflation system and is kept constantly depressed by a suction system to minimise the olfactory impact of the accelerated phase. The process lasts 28 days in total.
- *Maturation zone:* here the humification processes take place, and turning operations are implemented. The area is larger than the first phase because the process takes longer (50 days).

The design of the plant is modular, based on an initial small-scale plant that can be expanded in the future to treat a larger quantity of MSW, depending on local demand. Despite the large amount of MSW and OFMSW that can be obtained from the Maquinino market, CeCom was sized considering an input quantity of 1,500 t/year, due to its being the first pilot project for the city. It has been assumed that, in addition to the flow of material from the market, the surplus generated by the screening process after maturation can be reused as an internal flow. In this way, the input matrix was considered to be 1,744 t/y. In Table 2 data regarding quantities that could be treated in the CeCom are reported.

The preliminary plant dimensioning foresees the implementation of four 50 m^3 biocells for the accelerated bioxidation process. The biocells are closed reinforced concrete structures

Table 2: Input feedstock for CeCom.

Feedstock		%		t/year
Organic matter	OFMSW	90	65	1,020.24
	Sludge	10		113.36
Structuring material	Urban green	60	35	366.24
	Excess	40		244.16
TOT				1,744

equipped with a roofing system. The four reactors are connected to a common 6.5 m wide corridor to facilitate the access (via two entrances) and the handling of the heaps. Forced ventilation is provided by the implementation of biomodules or perforated tubes disposed longitudinally. The maturation area has a surface of 1,477.53 m^2 in which the material is arranged in eight piles 16.5 m long. These are arranged horizontally, side by side, with a 3.3 m distance between each pile. A 10 m manoeuvring space was also considered.

3 CECOM POSSBILE EXPANSION

In order to have more information it was decided to analyse the contribution in terms of potential organic matter production of Goto market, the second biggest in the city. The food waste is dumped entirely on the ground and accumulated in open areas next to the stalls. The waste containers were removed because of the accumulation of waste around them, which created unfavourable and even obstructive conditions for the collection vehicles.

The largest areas of accumulation are located inside the market in the western area. In this area, in particular, the uncontrolled dumping of waste (mainly OFMSW), together with poor accessibility and the lack of adequate vehicles for removal, has led to the creation of an open-air dump, where the accumulation of waste has been going on for more than three years. The same problem can be found in the eastern part of the market, where, right at one of the main entrances to the market, there are large heaps of mainly organic waste. The waste is collected using a combination of a tractor and a trailer two to three times a week. The waste can remain on the ground for more than a day, spilling out in putrescible and naturally degraded conditions, forming stagnations on the ground, and generating malodorous emissions. In the south-eastern part of the Goto market, near where the removal of the heap of organic matter occurs, there is a large area dedicated only to the delivery of residues from the processing and pressing of sugar cane. Bagasse (the fibrous part and bark of the cane) is produced in the first cycle of pressing and crushing. This slowly biodegradable residue could ideally be used in the composting process as a bulking agent.

Using a questionnaire, the organic waste collection methods of the 15 most popular restaurants in the city were investigated. By determining the number of containers used in each restaurant, their volume, and the frequency of emptying, it was possible to estimate the potential amount of OFMSW produced annually. For the estimation, it was considered that the percentage of OFMSW would be 90% if there is separation of the organic fractions. The week was assumed at six working days. Results are shown in Table 3.

The implementation of an organised collection of restaurant waste would involve several logistical and administrative difficulties. First, it would be necessary to guarantee the temporary storage of the waste in dedicated containers with an ideal capacity of 120 l located close to the restaurants, which is an economic expense. In addition to temporary storage, as the material is putrescible, adequate removal frequency should be ensured. Second, another critical aspect of this system is the contamination of the waste. The OFMSW that some restaurants already separate could be disposed of in dedicated external containers for restaurants only. However, it is possible that the inhabitants of the city centre will also start using the restaurants' containers to deposit their waste.

Every day, the harbour canteen offers a lunch service (11:30h-14:00h) to workers, with up to 200 covers (this data refers to the situation before the COVID-19 pandemic). The involvement of the canteen in the compost production chain will give advantages. The port area is located close to the CeCom site and is characterised by good accessibility and roads. In addition to this, the canteen is located outside the city centre and the perimeter of the port area is fenced off and access guarded, so that only workers and citizens who want to use the canteen service have access. The containers, already present within the port area to serve only the canteen, are not used for the delivery of domestic MSW. A purer organic fraction could then be obtained, which would be an optimal matrix for the composting process, and there is also the economic advantage of not having to purchase containers.

Despite Maquinino and Goto markets are considered food markets and therefore have an almost total production of organic matter, this fraction is about 85% of the total MSW in the case of the Maquinino and 95% in the case of the Goto.

The new amount of OFMSW is almost ten times higher than the one considered in the preliminary project, increasing from 1,020.24 to 10,062.42 t/year. This requires the calculation of the new CeCom layout, which will be expanded in terms of biocells and maturation area.

For the calculation of the total input matrix, two scenarios were considered, depending on the availability of sludge. This is not a strict requirement. It might not even be included in the initial matrix, thus implementing a composting process (instead of co-composting). However, the ability to also treat another problematic fraction such as sludge was considered an important requirement for the design of the CeCom. A higher amount of organic matter corresponds to a higher amount of structuring material and sludge. The incoming sludge to CeCom could be treated biologically at the ETAR water treatment plant, located in the Munhava - Matope district close to CeCom. Depending on the availability of sludge from ETAR plant, two scenarios can be considered:

- the first scenario refers to a hypothetical availability of sludge equal to 10% of the organic material (thus higher than the quantity foreseen in the preliminary design),
- the second scenario uses the same tonnes on an annual scale as initially assumed in the preliminary project.

Table 3: Potential OFMSW production of all activities.

Activity	Potential OF amount [t/y]
Maquinino market	5,757.77
Goto market	3,217.54
Restaurants	219.54
Harbour canteen	71.12
TOT	10,281.96
TOT without restaurants	10,062.42

Table 4: Input matrix amounts for two different scenarios based on sludge availability.

Scenario 1				Scenario 2			
Matrix		%	t/year	Matrix		%	t/year
Organic Matter (65%)	OFMSW	90	10,062.42	Organic Matter (65%)	OFMSW	99	10,062.42
	Sludge	10	1,118.05		Sludge	1	113.36
Structural Material (35%)	Urban green	60	3,612.15	Structural Material (35%)	Urban green	60	3,287.56
	Excess	40	2,408.1		Excess	40	2,191.71
TOT			17,200.72	TOT			15,655.05

In Table 4 the quantities assumed for the two proposed scenarios are reported.

Given the volumes to be treated, the geometry of each biocell, and the number of days required for maturation and discharge operations, it was possible to determine the new number of cells, which is 39 (very small biocells: 5 × 5 m; height: 2 m). More data are reported in Table 5. Maintaining these dimensions (the preliminary project), it can be said that is unrealistic considering the limited availability of means and resources necessary for the construction of the biocells, leading to an increase in costs due to the necessity of equipping each biocell with a blower and relative aeration system, as well as logistical difficulties (e.g., the transfer of material to all the biocells leads to an increase in the traffic of vehicles for loading and unloading operations).

It was therefore considered to build seven biotunnels, maintaining the width of 5 m but with a length of 25 m. Biotunnels are easier to construct due to the smaller number of reactors. These, together with the initial four biocells capable of treating the preliminary design quantity of 1,744 t/year, will increase the plant's treatment capacity.

The expansion of the input matrix also entails an expansion of the maturation area for the output material. Table 6 shows the assumptions made for the design of this area, where 24 rows of 25 × 6m will be arranged. Their configuration is the same as in the preliminary project: heaps are placed side by side two by two for a total of eight heaps per column.

CeCom is a pilot project and new biocells or biotunnels could be built gradually over time. The advantage of having a modular plant means that expansion can be considered in several distinct phases, maintaining the size of the initial cells, and evaluating through subsequent studies the feasibility of building further biocells and/or biotunnels, also depending on the quality of the compost produced.

4 OTHER ASPECTS RELATED TO OFMSW MANAGEMENT

The extension of the quantities of OFMSW removed from the urban context and its proper management is fundamental for the city of Beira. In addition to the increased production of compost obtainable from the CeCom and the improvement of the hygienic conditions of the urban context, this implementation could bring other benefits.

Beira dump has a surface area of about 20 ha and is currently the only alternative for final waste deposition. MSW dumped does not receive any pre-treatment and is therefore not stabilised. Due to the high percentage of organic matter in the waste, biological degradation reactions of the putrescible fraction take place in the dump body, resulting in the production of biogas.

Table 5: Main considerations for bioreactors design.

Expansion with biocells			Expansion with biotunnels		
Biocell volume	50	m^3	Volume biotunnel	250	m^3
Mixture density	0.7	t/ m^3	Mixture density	0.7	t/ m^3
N cycles per year	13	-	N cycles per year	13	-
Input material	1,333.64	t/cycle	Input material	1,198.443	t/cycle
N biocells	39	-	N biotunnels	7	-

Table 6: Main considerations for maturation area design.

Input material	12,900.54	t/year
Mixture density	0.65	t/m^3
Material heap volume	122.5	m^3
Manoeuvring space	10	m
Distance between heaps	3.3	m
Area width	160.5	m
Area length	85	m
Total area	13,642.5	m^2

Tas and Belon [41] reported that, in 2014 in Mozambique emissions from uncontrolled landfills reached 76,546 t of carbon dioxide equivalent (CO_2-eq) and, if current conditions remained the same, this value would amount to 1,369,721 t in 2030 [31]. The anaerobic degradation of one tonne of wet MSW (60% organic matter, 40% moisture) could theoretically generate up to 200 Nm^3 of methane. However, a production of approximately 50 Nm^3 of methane per tonne of dumped MSW is considered a conservative estimate [38]. Considering a Global Warming Potential factor for methane of 28, the potential amount of CO_2-eq that will be removed from atmosphere thanks to the CeCom was estimated and is reported in Table 7: the first row of the table shows the reduction due to the start-up of the CeCom (preliminary project), while the second row shows the reduction due to the subsequent expansion of the input matrix.

In low-income contexts, such as Mozambique, waste is not always managed entirely by the municipality or by a public-private partnership. Especially in urban contexts, there is a large proportion of informal workers who contribute significantly to the management of MSW, despite not being regularly paid or subject to a contract. The informal recycling sector of some materials is based on the activities carried out by waste pickers, the so-called *catadores*, who manually separate some recyclable materials (PET, PP, HDPE and aluminium) from the mixed waste to sell them. Their earnings are based exclusively on the quantities of material brought to the collection point, where the selling price per kg is very low (7 MT for a kg of PET and 4 MT for a kg of aluminium, which are approximately equivalent to 10 eurocents and 6 eurocents). One of the most attractive workplaces for *catadores* in Beira is the city's dump, near which there is a collection point for recyclable materials. Many independent workers, families or small organised groups are permanently present at the dump. In addition

Table 7: Estimates of reduction of CH_4 and CO_2-eq produced by dumped MSW without and with the expansion of the CeCom.

OFMSW [t/y]	MSW [t]	CH_4 [Nm^3/y]	CH_4 density [kg/m^3]	CO_2-eq [t/y]
1,020	1,700	85,000	0.74	1,761.2
10,062	16,770	838,500	0.74	17,373.72

to the precariousness of their earnings, their health and safety protections at the workplace are almost inexistant.

Until separation of the organic fraction is established, CeCom will need to pre-treat the input matrix by manual sorting to remove residual fractions. This process could be implemented through the work of the *catadores*, who would then be regularised, trained and paid regularly, allowing them to work in a safe and controlled environment. The quality of compost obtained will be assessed in test fields, refining management practice over time. The first objective is to obtain a soil conditioner with good characteristics that can be used in agriculture.

In all cases, because of the primary need to bio-stabilise the MSW, it is advisable to consider the implementation of alternative treatment plants to CeCom that can produce a suitable material for landfill or energy recovery. Biodrying and biostabilisation are potentially applicable technologies for this purpose [42-44]. It is important to note that these are proposals for forms of treatment whose output has smaller margins of applicability than composting.

Further evaluations of these technologies must always be made considering the context of the city of Beira. In fact, the biodried material requires a facility suitable for its use (e.g., cement works) and cannot be stored in landfills due to the high concentration of volatile solids in it. Stabilised material, on the other hand, can be safely landfilled but the process is more complex to control (water must be added during treatment) and costs are different.

5 FINAL REMARKS

Training and support for public institutions, municipal or private companies for the management of MSW, and for all citizens are aspects that must necessarily accompany project proposals to improve the entire waste management chain. In Beira there is a requirement that all non-domestic MSW producers (such as restaurant owners) must ensure that their waste is managed by transporting it in their own vehicles or those of the Beira City Council (e.g., by signing a contract that ensures daily service). However, this is not happening regularly, contributing to an increase in the amount of waste deposited in containers for public domestic collection.

Starting a collection of the organic fractions with the markets is a good prospect, both because of the great abundance of it and because of the existence of a collection and transport system which, although it has many criticalities, has been operating for years and can be more easily upgraded. Efficiency requires money, which in the future could also come from the sale of good quality compost.

ACKNOWLEDGEMENTS

This paper was written within the project 'Limpamos Moçambique' (AID code 011891), implemented with the contribution of the Italian Agency for Development Cooperation (AICS). The responsibility for the content of this publication lies with the authors and the project partners and does not necessarily represent the views of the AICS funding body.

REFERENCES

[1] Xu, J., Li, R., Shi, Y. & Deng, Y., Life cycle assessment-based optimization approaches for sustainable disposal of municipal solid waste. *Sustainable Cities and Society,* **79,** p. 103665, 2022.

[2] Khan, A.H., López-Maldonado, E.A., Khan, N.A., Villarreal-Gomez, L.J., Munshi, F.M., Alsabhan, A.H. & Perveen, K., Current solid waste management strategies and energy recovery in developing countries - State of art review. *Chemosphere,* **291**, p. 133088, 2022.

[3] Kundariya, N., Mohanty, S.S., Varjani, S., Hao, Ngo, H., W.C., Wong, J., Taherzadeh, M.J., Chang, J.S., Yong, Ng. H., Kim, S.-H. & Bui, X.-T., A review on integrated approaches for municipal solid waste for environmental and economical relevance: Monitoring tools, technologies, and strategic innovations. *Bioresource Technology*, **342,** p. 125982, 2021.

[4] Gautam, M. & Agrawal, M, Greenhouse gas emissions from municipal solid waste management: A review of global scenario. *Environmental Footprints and Eco-Design of Products and Processes*, pp. 123–160, 2021.

[5] Priti, M.K., Review on evolution of municipal solid waste management in India: practices, challenges and policy implications. *Journal of Material Cycles and Waste Management*, **21(6)**, pp. 1263–1279, 2019.

[6] Ferronato, N., Torretta, V., Ragazzi, M. & Rada, E.C., Waste mismanagement in developing countries: A case study of environmental contamination. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, **79(3)**, pp. 185–196, 2017

[7] Friedrich, E. & Trois, C., Current and future greenhouse gas (GHG) emissions from the management of municipal solid waste in the eThekwini Municipality - South Africa. *Journal of Cleaner Production*, **112,** pp. 4071–4083, 2016.

[8] Li, P., Li, Y.P., Huang, G.H. & Zhang, J.L., Modeling for waste management associated with environmental-impact abatement under uncertainty. *Environmental Science and Pollution Research*, **22**(7), pp. 5003–5019, 2015.

[9] Ionescu, G., Zardi, D., Tirler, W., Rada, E.C. & Ragazzi, M., A critical analysis of emissions and atmospheric dispersion of pollutants from plants for the treatment of residual municipal solid waste. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, **74(4)**, pp. 227–240, 2012.

[10] Kathiravale, S. & Muhd Yunus, M.N., Waste to wealth. *Asia Europe Journal*, **6(2)**, pp. 359–371, 2008.

[11] Cocarta, D.M., Rada, E.C., Ragazzi, M., Badea, A. & Apostol, T., A contribution for a correct vision of health impact from municipal solid waste treatments. *Environmental Technology*, **30(9)**, pp. 963–968, 2009.

[12] Suthar, S. & Singh, P. Household solid waste generation and composition in different family size and socio-economic groups: A case study. *Sustainable Cities and Society*, **14(1)**, pp. 56–63, 2015.

[13] Salvia, G., Zimmermann, N., Willan, C., Hale, J., Gitau, H., Muindi, K., Gichana, E. & Davies, M., The wicked problem of waste management: An attention-based analysis of stakeholder behaviours. *Journal of Cleaner Production,* **326,** p. 129200, 2021.

[14] da Silva, C.L., Weins, N. & Potinkara, M., Formalizing the informal? A perspective on informal waste management in the BRICS through the lens of institutional economics. *Waste Management*, **99,** pp. 79–89, 2019.

[15] Idowu, I.A., Atherton, W., Hashim, K., Kot, P., Alkhaddar, R., Alo, B.I. & Shaw, A., An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences. *Waste Management,* **87,** pp. 761–771, 2019.

[16] Aparcana, S. Approaches to formalization of the informal waste sector into municipal solid waste management systems in low- and middle-income countries: Review of barriers and success factors. *Waste Management*, **61**, pp. 593–607, 2017.

[17] Guerrero, L.A., Maas, G. & Hogland, W. Solid waste management challenges for cities in developing countries. *Waste Management*, **33(1)**, pp. 220–232, 2013.

[18] Mupara, S.W., Nkuba, M.R. & Gwebu, T.D., Intra-urban patterns of domestic solid waste recycling in sub-Saharan Africa: towards an exploratory search for insights in Gaborone, Botswana. *Geo Journal,* **83(5)**, pp. 967–982, 2018.

[19] Kubanza, N.S. & Simatele, D., Social and environmental injustices in solid waste management in sub-Saharan Africa: a study of Kinshasa, the Democratic Republic of Congo. *Local Environment,* **21**(7), pp. 866–882, 2016.

[20] Couth, R. & Trois, C., Effective waste management through composting in Africa, Waste Management, **32**(12), pp. 2518–2525, 2012.

[21] Kaza, S., Yao, L.C, Bhada-Tata, P., Van Woerden, F., *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*, World Bank: Washington, pp. 1–295, 2018.

[22] Gorelick, J., Supporting the future of municipal bonds in sub-Saharan Africa: the centrality of enabling environments and regulatory frameworks. *Environment and Urbanization*, **30(1)**, pp. 103–122, 2018.

[23] Lodi, J., A critical analysis of regional planning in South Africa in the 21st century, *WIT Transactions on Ecology and the Environment*, **93**, pp. 251–260, 2006.

[24] IIED, *Urbanization, Gender and Urban Poverty: Paid work and Unpaid Carework in the City*, International Institute for Environment and Development: United Nations Population Fund, 2012.

[25] Human Development Index (HDI). United Nations Development Programme, http://hdr.undp.org/en/indicators/137506. Accessed on: 14 Dec. 2021.

[26] The World Bank in Mozambique. The World Bank, https://www.worldbank.org/en/country/mozambique/overview#1. Accessed on: 14 Dec. 2021.

[27] Data Bank, World Development Indicators. The World Bank, https://databank.worldbank.org/reports.aspx?source=2&country=MOZ. Accessed on: 14 Dec. 2021.

[28] Anuário Estatístico 2020 Província de Sofala. Instituto Nacional de Estatística, Delegação Provincial de Sofala, www.ine.gov.mz/estatisticas/publicacoes/anuario/anuario-provincia-de-sofala/ae-sofala-2020.pdf/view. Accessed on: 15 Dec. 2021

[29] Gani, A.H.A., Aderoju, O.M., Dias, A.G., Monjane, A.A.R. Improving the attitude and reaction towards municipal solid waste management in Mozambique, *WIT Transactions on Ecology and the Environment,* **247,** pp. 47-56, 2020.

[30] Gani, A.H.A., Dias, A.G., Monjane, A.A.R. Impact of gross domestic product change on municipal solid waste generation in Maputo, Mozambique, *WIT Transactions on Ecology and the Environment,* **247**, pp. 15-24, 2020.

[31] Sallwey, J., Hettiarachchi, H., Hülsmann, S. Challenges and opportunities in municipal solid waste management in Mozambique: A review in the light of nexus thinking, *AIMS Environmental Science,* **4**(5), pp. 621-639, 2017.

[32] Zhang, Y., Ning, X., Li, Y., Wang, J., Cui, H., Meng, J., Teng, C., Wang, G., Shang, X. Impact assessment of odor nuisance, health risk and variation originating from the landfill surface, *Waste Management,* **126,** pp. 771-780, 2021.

[33] Ali, Q.H., Sugihen, S.R., Munawar, E., Adisalamun The Effect of Leachate Recirculation on the Greenhouse Gases Emission from Municipal Solid Waste (MSW) Landfill in Tropical Climate Region, *Proceedings of the IOP Conference Series: Materials Science and Engineering,* **778**(1),012138, 2020.

[34] Chen, Y.M., Zhan, L.T., Xu, X.B., Liu, H.L. Geo-environmental problems in landfills of MSW with high organic content. *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering: Challenges and Innovations in Geotechnics,* pp. 3009-3012, 2013.

[35] Yang, N., Zhang, H., Shao, L.-M., Lü, F., He, P.-J. Greenhouse gas emissions during MSW landfilling in China: Influence of waste characteristics and LFG treatment measures, *Journal of Environmental Management,* **129,** pp. 510-521, 2013

[36] Guirreri, D., Silvestri, S., Cristoforetti, A., Rama, I., Giurea, R., Magaril, E., Rada, E.C. Composting strategy for developing cities: A case study of Beira, Mozambique,. *WIT Transactions on Ecology and the Environment*, **247**, pp. 69-79, 2020

[37] Sarmento dos Muchangos, L., Tokai, A., & Hanashima, A., Greenhouse gas emissions and cost assessments of municipal solid waste treatment and final disposal in Maputo City, Environment, *Development and Sustainability,* **21**, 145–163, 2019.

[38] Scarlat, N., Motola, V., Dallemand, J. F., Monforti-Ferrario, F., & Mofor, L., Evaluation of energy potential of municipal solid waste from African urban areas, *Renewable and Sustainable Energy Reviews,* **50,** 1269-1286, 2015

[39] Ragazzi, M., Maniscalco, M., Torretta, V., Ferronato, N., Rada, E.C. Anaerobic digestion as sustainable source of energy: A dynamic approach for improving the recovery of organic waste. *Energy Procedia,* **119,** pp. 602-614, 2017.

[40] Andreottola, G., Ragazzi, M., Foladori, P., Villa, R., Langone, M., Rada, E.C. The unit integrated approach for OFMSW treatment. *UPB Scientific Bulletin*, Series C: Electrical Engineering, **74**(1), pp. 19-26, 2012.

[41] Tas, A. and Belon, A. A Comprehensive Review of the Municipal Solid Waste Sector in Mozambique, Carbon Africa Limited, Nairobi, pp. 1-80, 2014.

[42] Dziedzic, K., Łapczynska-Kordon, B., Malinowski, M., Niemiec, M., Sikora, J. Impact of aerobic biostabilisation and biodrying process of municipal solid waste on minimisation of waste deposited in landfills. *Chemical and Process Engineering*, **36**(4), pp. 381-394, 2015.

[43] Stan, C., Apostol, T., Paraschiv, G., Pásztai, Z. Two solutions for MSW treatment in view of landfill minimization and energy recovery maximization. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, **76**(4), pp. 247-256, 2014.

[44] Rada, E.C., Ragazzi, M., Badea, A. MSW Bio-drying: Design criteria from A 10 years research. *UPB Scientific Bulletin, Series D: Mechanical Engineering*, **4**(3), pp. 209-216, 2012.