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Multi-criteria Analysis of Municipal Solid Wastes Treatment Scenarios: The Case of Arusha City, Tanzania

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Abstract

Selection of the most effective municipal solid waste (MSW) treatment option is crucial for sustainable MSW management, but it remains a challenge in most cities of developing countries. More often, the decision-makers make the selection of the treatment options without economic (ECs), and environmental (ENCs) cost evaluations. Consequently, the selected technologies fail to suit the local conditions of the concerned areas and they become a high burden activity to manage. Therefore, this study aimed to use the multi-criteria analysis approach based on the ELECTRE method to analyse the most effective MSW treatment option in terms of ECs and ENCs costs in Arusha City Tanzania. A study involved the design of 54 treatment scenarios and identified six initial acceptable scenarios for ELECTRE analysis. The ELECTRE analysis results indicated that the scenario which suggests the use of composting options for organic wastes, recycling options for glass, metals, paper and plastic wastes and the use of a landfill for other wastes emerged as the dominant scenario. This scenario had the daily ECs of US$11,178 while avoiding about 124 tons of CO_2 emissions daily. A sensitivity analysis results with different criteria weights also indicated the selected scenario outranked other alternatives. The findings from this study can be applied by the decision-makers to improve MSW management in study areas and cities with similar MSW conditions.

Keywords: Municipal solid wastes; Multi-criteria; ELECTRE; Treatment option; Arusha

Introduction

Sustainable municipal solid waste (MSW) management is essential for city development, yet it remains a challenge in many cities around the world (Balasubramanian and Dhulasi Birundha 2012, Richard et al. 2019). Compared to the developed countries which practice several alternatives for MSW management, most developing countries, they do the collection of the MSW for disposal in dumpsites or landfills (Vaish et al. 2019). More often to facilitate the collection of MSW for disposal in developing countries, authorities rely on private sectors which leaves a lot of the generated MSW uncollected (Hoornweg and Bhada-Tata 2012, Lohri et al. 2015). Therefore, most of the MSW generated are dumped in non-authorized sites causing the potential risk of groundwater and surface water contaminations, food contamination and spread of infectious diseases (dos Muchangos et al. 2014, Gebrezgabher et al. 2010).

Poorly waste management is also contributing to global climate change due to increased methane generation and other greenhouse gases such as carbon dioxide gases (Menikpura et al. 2012, Papageorgiou et al. 2009). Among the strategies to mitigate greenhouse gas emissions and to operate effective waste management is through an integrated solid waste management (ISWM) system. The ISWM emphasises the consideration of several alternatives for sustainable MSW management in the order of priority i) waste reduction, ii) recycling, iii) waste processing iv) waste transformation and v) landfilling (Demirbas 2011, Palanivel and Sulaiman 2014, Van Ewijk and Stegemann 2016).

However, in most cities of developing countries, the integrated approach is rarely practised for various reasons, including limited funds for investment in waste-to-energy infrastructure, non-recognition of informal waste pickers and poor coordination between different authorities involved in waste management. Decision makers make the choice of waste treatment options based on their experience and knowledge (De Medina-Salas et al. 2017).This results in the selected waste management options not meeting the conditions of the concerned local areas (Bundhoo 2018, Guerrero et al. 2013, Mmereki et al. 2016, Sukholthaman and Shirahada 2015). Even though the MSW of most cities in developing countries comprise high organic and moisture contents, rarely, recovery of biogas and bio-fertilisers to improve waste management is made (Richard et al. 2019).

Biogas and biofertilizer recovery through anaerobic digestion (AD) or composting systems convert waste into valuable resources and reduce the amount of waste that could end up in landfills. The production of methane for energy reduces the amount of greenhouse gases released into the environment (Paolini et al. 2018, Woon et al. 2016). However, the lack of sorting programs and limited knowledge of the potential values of MSW in most developing countries present obstacles to the resources recovery from MSW (Abdel-Shafy and Mansour 2018, Lohri et al. 2014).To manage waste properly requires assessing many factors, including the economic and environmental consequences of the different waste treatment options based on the waste characteristics and their suitability to particular local environments.

A multi-criteria analysis approach “Elimination and Choice Expressing Reality (ELECTRE) is one of the most useful tools for the decision-making process for multiple criteria and can help the decision-makers to select the best treatment scenarios (Akram et al. 2019). The strength of the ELECTRE method lies in its capability to select the best alternative scenarios from several possible alternatives which are outranked by others in a selection, subject to several criteria in particular local conditions under consideration (Agrebi et al. 2017, Yu et al. 2018). With the ELECTRE method, numerous studies have been conducted to analyse appropriate MSW scenarios. Kazuva and Zhang (2019) used the ELECRE method to analyse the 108 MSW management scenarios with the lowest economic and environmental costs. According to the study's findings, organic waste should be composted, the rest should be landfilled.

Similarly, De Medina-Salas et al. (2017) evaluated the 36 MSW management scenarios with the lowest economic and environmental costs. The results of the study showed that the best option would be to compost organic wastes, recycle the plastic, paper, and glass and landfill the remained waste. Hanandeh and El-Zein (2010) compared ten scenarios for the biodegradable fraction in Sydney's municipal solid waste using the ELECTRE method. Anaerobic digestion and composting were determined to be the best option. Further research is needed in areas where there is a lack of studies because the studies mentioned above show that outcomes vary depending on the climate and local conditions.

This study aimed to analyse the suitable MSW treatment options for Arusha City, Tanzania, from different waste treatment scenarios using the multi-criteria analysis method (ELECTRE). The study area is the Arusha city of Tanzania, but the results can apply to any city with MSW conditions similar to this city. Arusha city has intense tourist activity and is one of the cities in Tanzania with a high MSW generation. Despite the difference in waste stream composition, a large percentage of waste is still landfilled. Therefore the selection of the several best treatment alternatives can be essential for reducing the wastes ending up in a landfill and for the sustainability of the MSW management in a city.

Materials and Methods

Applying the ELECTRE method to analyse the most desirable MSW treatment option involved two major stages; 1) Collection of the necessary data information including population, waste generation rate and quantities and compositions and 2) Waste treatment scenarios design and selection.

Collection of necessary data information

The study involved the collection of necessary data information for this study through; a field visit survey, literature reviews and the review of the relevant documents of the Arusha city council. Starting from the year 2019 the city started to utilise the newly constructed sanitary landfill which is allocated at Muriet about 6.5 km from the city centre. The completion of the Muriet sanitary landfill has also seen an improvement in the MSW collection services in the city. Currently, more than 80% of the city's household waste is collected for disposal at the Muriet landfill. The private companies and community-based organizations (CBO) handle the collection and transportation of municipal waste from 20 districts to the landfill, and the city council collects the waste in the other five districts, monitors all activities and supports the collection in other districts only when he is there is a drop-in service.

Many cities around the world they do practice the same approach of engaging private sectors in waste collection (Korai et al. 2017, Oduro-Kwarteng and Van Dijk 2013, Olukanni and Nwafor 2019, Oteng-Ababio 2010). Out of 25 Wards of the Arusha City Council, the Muriet landfill receives MSW collected from 24 wards and rarely receives the MSW from the Terrat ward which is a typical rural set-up with scattered houses and has low generation rates as per information obtained from the City Council. The per capita waste generation rate (PG) in kg/day/person for MSW of Arusha city was computed based on the population and the quantity of MSW generated daily as per Eqn (1) (Oumarou et al. 2012, Palanivel and Sulaiman 2014).

PG = (Waste generation per day /Population) (1)

Arusha city has an estimated population of 617,631 according to the National Census of the year 2022 (NBS 2022). The MSW collection capacity is approximately about 274 tons/day which is about 81% of the daily total waste generation (Arusha City Council Profile 2023). Therefore, based on this information, the resulting per capita generation rate is approximately 0.55 kg/capita/day. The per capita production rate in Arusha is slightly higher than that of sub-Saharan Africa, which is 0.46 kg/capita/day, and slightly lower than the world average production rate of 0.74 kg/capita/day (Kaza et al. 2018). The MSW compositions in Arusha city comprise 67% organic, 7% plastics, 11% paper, 4% glass, 1% metals and 10% other wastes including textiles and debris (Richard et al. 2021).

Municipal solid waste treatment scenario design

Waste compositions and characteristics are essential for the selection of treatment options (Abdel-Shafy and Mansour 2018, Yang et al. 2018). The Arusha MSW stream comprises six major waste streams (Table 1). The difference in waste streams suggests the use of different waste treatment options to manage waste. The high organic content (67%) means that apart from the landfill which currently manages the wastes other treatment options such as composting, anaerobic digestion, pyrolysis and gasification are also potential alternatives (Rada et al. 2014). Plastics and papers have low moisture contents and high calorific values and can be incinerated or recycled into other useful products (Komilis et al. 2012). Glass can be recycled, and the landfill can always receive all kinds of the waste or residues from other treatment facilities (Khandelwal et al. 2019).

For the scenarios generation, we placed the waste treatment options and compositions in precise order and options assigned with numbers: 1, 2, 3, 4 and 5 for recycling, composting, anaerobic digestion, incineration and landfilling, respectively. According to the suitability and non-suitability of the waste treatment option for the waste stream, signs (√) and (-) were assigned to indicate suitability and non-suitability. From Table 1, several scenarios with a combination of treatment options and waste streams were generated and coded with numbers for computational purposes.

Table 1: Potential treatment alternatives for municipal solid wastes

Waste treatment option	Organic	Plastic	Paper	Glass	Metals	Others
1:Recycling	-	√	√	√	√	-
2:Composting	√	-	-	-	-	-
3:Anaerobic digestion	√	-	-	-	-	-
4:Incineration with energy recovery	-	√	√	-	-	-
5:Landfilling	√	√	√	√	-	√

Municipal solid waste treatment scenario selection

Several factors are essential for deciding the selection process of the MSW treatment options. Some of the factors include technical, environmental, political-institutional, economic and legal aspects of the concerned locality (Zurbrügg et al. 2014). Due to insufficient data in most developing countries, the selection of the treatment option is complicated and hence few factors such as ECs and ENCs make the basis of the selection (Chen et al. 2017). Municipality managing wastes are mostly facing infrastructure investments and operation costs as two broad kinds of expenditures, of which the main challenge for the cities is operation costs for running the systems (Kaza et al. 2018). The investment costs for the treatment options include feasibility study and design, land acquisition, equipment and construction costs, and on the other hand, the operation costs include labour, fuel and equipment maintenance.

Therefore, the ECs in Table 2 are computed based on the operation costs for the treatment scenarios and ENCs based on the CO_2 emissions of the waste treatment scenarios. Due to the insufficient data in the study area, the study used the ECs and ENCs as reported by various authors to generate average costs per ton of MSW of each treatment option. From Table 2, the negative values in the treatment options cost indicate an advantage if the treatment option is adopted. For instance, the negative value in the cost of incineration of paper waste is due to the higher avoided CO_2 emissions as compared to the incineration of plastic wastes.

Similarly, the negative value in the cost of recycling paper waste indicates lower economic costs as compared to the recycling of plastic waste. With an average cost per ton, the estimates for the ECs and ENCs costs for MSW generated in Arusha city for each scenario were prepared. The cartesian coordinate system presented the ECs and ENCs and aided in selecting the few acceptable scenarios which formed the initial decision matrix during the ELECTRE method application.

Table 2: Economic cost (US$ t^{-1}) and environmental cost (CO_2 t^{-1}) of waste treatment options

Treatment option		Organic	Plastic	Paper	Glass	Metals	Others	Reference
1:Recycling	ECs	-	93.89	-45.20	20.50	18.56	-	
	ENCs		-1.30	-3.89	-0.31	-3.38	-	(De Medina-Salas et al. 2017, Kaza et al. 2018, Maalouf and El-fadel, 2019, Vasco-Correa et al. 2018)
2:Composting	ECs	47.5	-	-	-	-	-	
	ENCs	0.09	-	-	-	-	-	
3:Anaerobic digestion	ECs	85.00	-	-	-	-	-	
	ENCs	-0.56	-	-	-	-	-	
4:Incineration with energy recovery	ECs	-	34.84	34.84	-	-	-	

	ENCs	-	1.38	-0.49	-	-	-
5:Landfilling	ECs	55	72	67.25	72	70.32	68.33
	ENCs	0.47	0.04	0.44	0.44	-	0.48

Selection of scenarios using the ELECTRE method

After the identification of the initial acceptable scenarios with low ECs and ENCs, the ELECTRE method was applied to rank and identify the best alternatives (Matteo et al. 2016). The following steps were employed

Step 1: Organizing the decision matrix

The decision matrix (Eqn 1)(Akcan and Güldeş, 2019) in this study consisted of alternatives in rows which were the combinations of the few acceptable treatment options determined under section 2.2 and criteria in columns were ECs and ENCs.

$$a_{ij} = \begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ a_{21} & a_{22\dots} & a_{2n} \\ \vdots & & \vdots \\ a_{m1} & a_{m2} \dots & a_{mn} \end{bmatrix} \quad (2)$$

Where, m = number of treatment alternatives, and n = number of criteria

Step 2: Normalization of the elements of the initial decision matrix

The general ELECTRE Eqn (3) is used to determine the normalised decision matrix (X_{ij}) for the cost parameters (Çelen 2014, Gökhan Yücel and Görener 2016).

$$X_{ij} = \frac{\left(1/a_{ij}\right)}{\sqrt{\sum_{i=1}^{m}\left(1/a_{ij}^{2}\right)}} \quad (3)$$

Step 3: Formation of weighted decision matrix

The formed normalized decision matrix in step 2 was multiplied by the weighting criteria for ECs and ENCs to form the weighted decision matrix. Several methods including the analytical hierarchy process, VIKOR, and TOPSIS, can be used to compute the weighting factors for criteria, but the final decision depends on the decision-makers (Murgante et al. 2017). This study used the weighting factor of 50% each for ECs and ENCs to the assumption that both criteria are of equal importance for the sustainability of the treatment options.

Step 4: Determination of concordance and discordance sets

To obtain the concordance and discordance sets, matrix Y is used to compare the pairs of the different alternatives of the weighted normalized matrix. The alternatives having a higher score or equal to the other element of the pair their criteria weights were considered under the concordance sets defined by C (a, b) as per Eqn 4 (Akcan and Güldeş 2019). For the discordance sets defined by D (a, b) as per Eqn 5, the alternatives considered were the ones with lower scores than the other elements of the comparison pair.

$$C(a,b) = \{j, Y_{aj} \geq Y_{bj}, \text{for } j = 1, 2\dots n \quad (4)$$

$$D(a,b) = \{j, Y_{aj} < Y_{bj}, \text{for } j = 1, 2\dots n \quad (5)$$

Where a and b indices should be a ≠b and j = number of criteria

Step 5: Formation of matrices of concordance and discordance

The concordance matrix was generated from the sum of the criteria weights (w_j) contained in the concordance sets generated in step 4 as per Eqn. (6), and does not consider any indices value for a = b. On the other hand, the discordance matrix was computed by dividing the maximum difference value of the comparison pair in the discordance set by the maximum difference value of the comparison pair in both concordance and discordance sets (Eqn.7) (Doumpos and Figueira 2019).

$$C(a,b) = \sum_{j=\in Cab} w_j \quad (6)$$

$$D(a,b) = \frac{Max\ j \in D_{ab}\left|Y_{aj} - Y_{bj}\right|}{Max\ j\ \left|Y_{aj} - Y_{bj}\right|} \quad (7)$$

Step 6: Determination of the concordance and discordance thresholds

At this step, the concordance and discordance thresholds which are indicated as (C* and D*) were calculated as per the formula in Eqn 8 and 9 (Murgante et al. 2017).

$$C^* = \frac{1}{m\ (m-1)} \sum_{i=1, i\neq j}^{m} \sum_{j=1, j\neq i}^{m} C_{ij} \quad (8)$$

$$D^* = \frac{1}{m\ (m-1)} \sum_{i=1, i\neq j}^{m} \sum_{j=1, j\neq i}^{m} D_{ij} \quad (9)$$

Where m presents a matrix dimension (m × m), C_{ij} and D_{ij} represent values under the concordance and discordance sets.

Step 7: Formation of concordance and discordance dominance matrices

The concordance and discordance matrices F_{ij} and G_{ij} were determined as per Eqn (10) and (11). For the concordance dominant matrix construction, the values in the concordance matrix (C_{ab}) computed in step 5 greater or equal to the concordance threshold (C*) were assigned one, otherwise zero. Similarly, for the discordance dominant matrix any values in the discordance matrix (step 5) less or equal to the discordance threshold (D*) were assigned one, otherwise assigned zero (Akram et al. 2019).

$$F_{ij} = \begin{cases} 1, C_{ab} \geq C^* \\ 0, C_{ab} < C^* \end{cases} \quad (10)$$

$$G_{ij} = \begin{cases} 1, D_{ab} \leq D^* \\ 0, D_{ab} > D^* \end{cases} \quad (11)$$

Step 8: Constructing a matrix of aggregate dominance

To obtain a matrix of aggregate dominance (E_{ij}), the elements of the dominance concordance matrix were multiplied by the elements of the dominance discordance matrix as per Eqn 12.

$$E_{ij} = F_{ij} * G_{ij}\ \ldots (12)$$

Step 9: Elimination of the less favourable alternatives

From the aggregate dominance matrix formed, the number of the dominance of each treatment scenario was computed as per Eqn (13).

$A_{ij} = 1$, then A_i was preferred to A_j (13)

The more the alternative was preferred among the alternatives, the better it was among the ranks.

Results and Discussion

Municipal solid waste generation of Arusha City

Figure 1 shows the estimates of Arusha City's waste generation from 2019 to 2030, as forecast by Arusha City Council (Source: Data obtained from Arusha City Councils office) By 2030, MSW generation in the city is expected to reach over 430 tons. Therefore, municipal waste is likely to pose a continuous risk of contaminating the environment and endangering human health and therefore requires proper management.

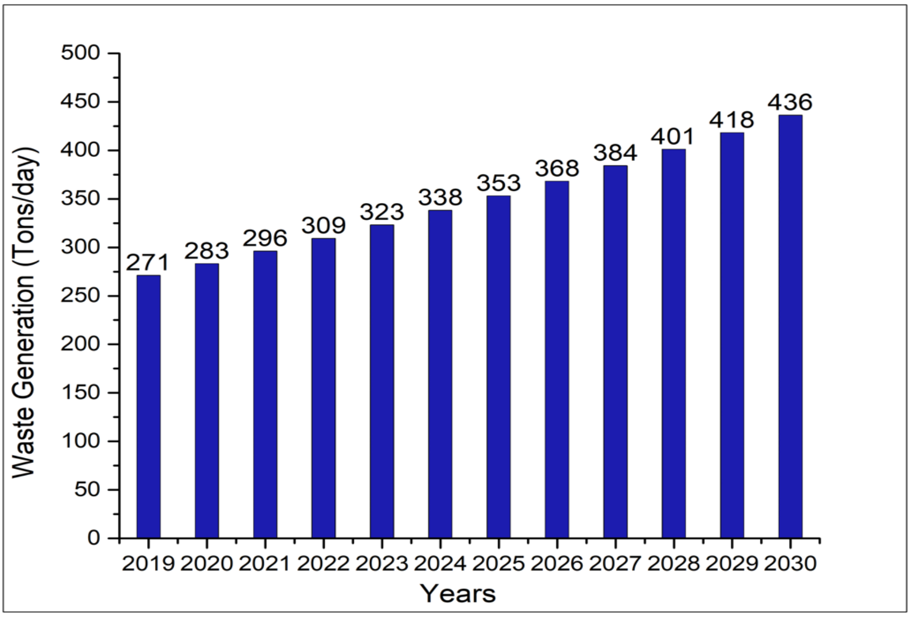

Figure 1: Arusha waste generation forecast

Municipal solid waste treatment scenarios and their associated costs

Table 3 depicts 54 treatment scenarios generated for MSW treatment for all waste streams in Arusha city. Each of the treatment scenarios combined each of the waste streams by type of treatment and their associated ECs and ENCs. The ECs and ENCs for each scenario resulted from multiplying the unit cost of each type of treatment (section 2.3) by the percentage composition of each waste stream of Arusha city. The first and last scenarios generated in this study were A1 and A54 composed of the numbers 211115 and 555515, respectively. The first scenario indicates the use of composting options for organic waste; therefore, the first digit code was two. The second, third, fourth and fifth digits of the code were assigned one and indicated the use of recycling options for glass, metals, paper and plastic wastes. The sixth digit code for the first scenario was five, indicating the use of a landfill for other wastes.

On the other hand, the last scenario indicates the use of a landfill for organic, plastic, paper and other wastes; hence the first, second, third, fourth and sixth digits of the code were 5. The fifth digit code for the last scenario was one indicating that metals must be recycled. The daily minimum ECs and ENCs were US$ 10,058 and -242 tons of CO_2 emissions which represent scenarios A2 (241115) and A19 (311115), respectively. Scenario A2 indicate the use of composting options for organic waste, incineration options for plastic wastes, recycling options for paper, glass and metals and the use of a landfill for other wastes. Scenario A19, on the other hand, suggests the use of an anaerobic digestion treatment option for the organic waste, a recycling option for plastic, paper, glass and metals and a landfill for other wastes. Therefore, the ideal scenario would either be A2 or A19 If the selections are made based on either ECs or ENCs.

However, scenario A2 despite having the lowest ECs has high daily ENCs of -73 tons of CO_2 emissions as compared to some other scenarios, and therefore this scenario indicates less advantage to the environment as compared with some other scenarios. Similarly, scenario A19 despite having the lowest ENCs has high daily ECs of US$17,987 as compared to some other scenarios. Therefore, to reach the ideal scenario with reasonable ECs and ENCs, the ELECTRE analysis was applied.

Table 3 Scenarios formed and their associated daily economic and environmental costs

Scenario	Code	ECs (US$)	ENCs (CO_2)	Scenario	Code	ECs US$	ENCs (CO_2)
A1	211115	11,178	-124	A28	311515	18,550	-234
A2	241115	10,058	-73	A29	341515	17,429	-183
A3	251115	10,763	-98	A30	351515	18,134	-208
A4	214115	13,564	-22	A31	314515	20,936	-132
A5	244115	12,444	28	A32	344515	19,815	-81
A6	254115	13,149	3	A33	354115	19,958	-115
A7	215115	14,531	5	A34	315515	21,902	-105
A8	245115	13,410	56	A35	345515	20,782	-54
A9	255115	14,115	31	A36	355515	21,487	-79
A10	211515	11,741	-116	A37	511115	12,540	-55
A11	241515	10,621	-65	A38	541115	11,420	-4
A12	251515	11,326	-90	A39	551115	12,125	-29
A13	214515	14,127	-14	A40	514115	14,926	47
A14	244515	13,007	37	A41	544115	13,806	97
A15	254115	13,149	3	A42	554115	14,511	72
A16	215515	15,093	13	A43	515115	15,892	74
A17	245515	13,973	64	A44	545115	14,772	125
A18	255515	14,678	39	A45	555115	15,477	100
A19	311115	17,987	-242	A46	511515	13,103	-47
A20	341115	16,867	-191	A47	541515	11,982	4
A21	351115	17,572	-216	A48	551515	12,687	-21
A22	314115	20,373	-140	A49	514515	15,489	55
A23	344115	19,253	-90	A50	544515	14,368	106
A24	354115	19,958	-115	A51	554115	14,511	72
A25	315115	21,339	-113	A52	515515	16,455	82
A26	345115	20,219	-62	A53	545515	15,335	133
A27	355115	20,924	-87	A54	555515	16,039	108

Formed scenarios for the initial decision matrix

The ECs and ENCs were presented in the Cartesian graph for better visualization and selection. Figure 2 shows the graphical presentations for ECs and ENCs for all 54 scenarios. To obtain acceptable scenarios for ELECTRE analysis, the daily ECs ≤ US$ 12,000 and ENCs ≤ -50 tons of CO_2 emissions were set. Following these conditions set, the six scenarios (A1, A2, A3, A10, A11 and A12) as presented in Table 4 were selected for ELECTRE analysis. Scenarios A38 (541115) and A47 (541515) were also within acceptable ranges for ECs but outside the ENCs range, hence were not selected for ELECTRE analysis. Similarly, scenarios A19 (311115) to A37 (511115), were within acceptable ranges for ENCs but outside the acceptable ranges for ECs and hence not selected for the initial decision matrix as well.

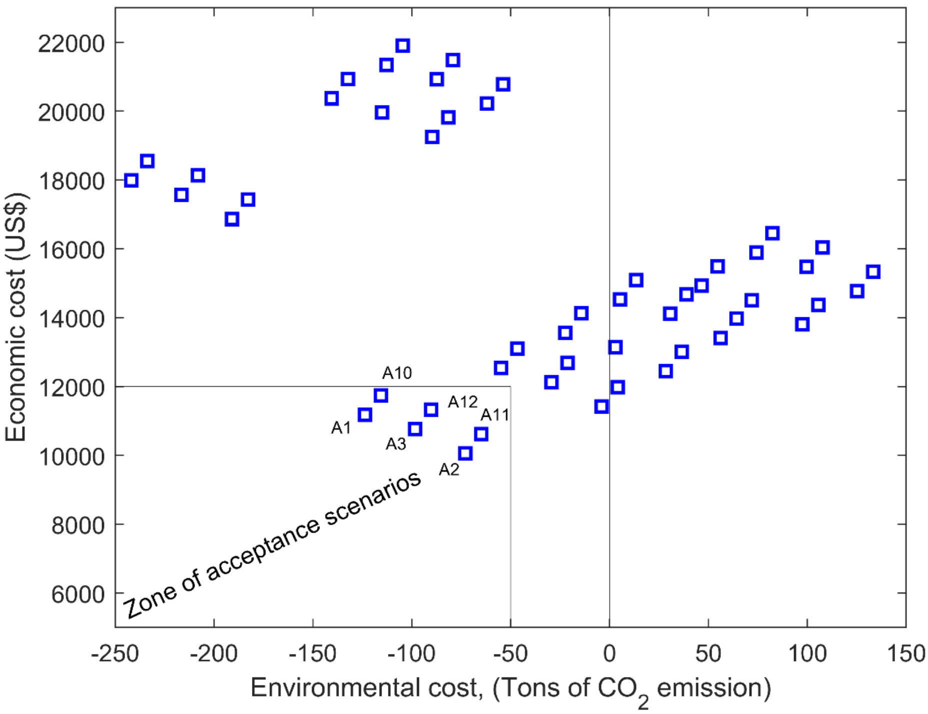

Figure 2: Economic and environmental costs for Arusha treatment scenarios presented in Cartesian coordinates for the better visualization of acceptance scenarios

Table 4: Selected scenario for the initial decision matrix

Scenario	Code	ECs (US$)	ENCs (CO_2)	Scenario	Code	ECs (US$)	ENCs (CO_2)
A1	211115	11,178	-124	A10	211515	11,741	-116
A2	241115	10,058	-73	A11	241515	10,621	-65
A3	251115	10,763	-98	A12	251515	11,326	-90

ELECTRE analysis results for the favourable treatment alternatives

Table 5 shows the summary of the results from ELECTRE analysis which were computed based on steps 1-9 in section 2.4. As seen in Figure 3, scenario A1 has five outgoing arrows (number of dominance =5) and zero incoming arrows and therefore ranked the first alternative amongst the others. The second-ranked scenarios were both A3 and A10 which have both three outgoing arrows (number of dominance =3) and one incoming arrow. The fourth, fifth and sixth-ranked scenarios were A12, A2 and A11 with two, one and zero outgoing arrows (number of dominance =2, 1, 0) and three, four, and five incoming arrows, respectively. Therefore, the most favoured scenario is A1 (211115) which has ECs and ENCs per day of US$11,178 and -124 tons of CO_2 emissions. This scenario suggests the use of composting options for organic wastes, recycling options for glass, metals, paper and plastic wastes and the use of a landfill for other wastes. Composting of organic wastes in comparison to the landfilling of wastes (the current option in use) as the favourable scenario suggests represents more benefits in economic and environmental costs and environmentally and therefore, can contribute to the waste management sustainability.

From the ECs and ENCs comparison table (Section 2.3), composting of the current 182 tons of organic waste may cost up to daily US$ 8625, while landfilling could cost up to US$ 9986 per day. Similarly, concerning environmental protection, the composting of organic wastes could lead to up to 16 tons of CO_2 emissions in comparison to 85 tons of CO_2 emissions by the landfill. Recycling of recyclable materials also has higher contributions in avoiding CO_2 emissions and has an added advantage to the local community due to employment opportunities. In the city of Arusha, the recycling rate of recyclable materials is 18% and the sector employs around 400 landfill waste pickers. Most commonly recovered are materials related to plastics such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC). Other materials include metals, cans and cardboard boxes. The waste pickers recover recyclable materials and sell them to local transfer and processing centres in Arusha City Council. Not only do the waste pickers do an excellent job of sorting the recycled waste, but they also receive lower wages due to additional transportation costs for the pre-processed recycled waste to the processing centres abroad. Therefore, one area that needs to be improved is the establishment of local processing centres and this would help create favorable local markets for the waste collectors. Table 6 shows the purchase of recyclable materials and the selling price of pre-processing materials in pre-processing centres in Arusha city.

Table 5: Summary of concordance and discordance sets, indexes and dominance

Concordance sets		Index	Discordance sets		Index	Aggregate sets and dominance		Dominance number	Rank
C(1,2)	(2)	0.5	D(1,2)	(1)	0.222	A1→A2	1		
C(1,3)	(2)	0.5	D(1,3)	(1)	0.207	A1→A3	1		
C(1,4)	(1,2)	1.0	D(1,4)	(-)	0.000	A1→A10	1	A1 = 5	1
C(1,5)	(2)	0.5	D(1,5)	(1)	0.080	A1→A11	1		
C(1,6)	(1,2)	1.0	D(1,6)	(-)	0.000	A1→A12	1		
C(2,1)	(1)	0.5	D(2,1)	(2)	1.000	A2→A1	0		
C(2,3)	(1)	0.5	D(2,3)	(2)	1.000	A2→A3	0		
C(2,4)	(1)	0.5	D(2,4)	(2)	1.000	A2→A10	0	A2 = 1	5
C(2,5)	(1,2)	1.0	D(2,5)	(-)	0.000	A2→A11	1		
C(2,6)	(1)	0.5	D(2,6)	(2)	1.000	A2→A12	0		
C(3,1)	(1)	0.5	D(3,1)	(2)	1.000	A3→A1	0		
C(3,2	(2)	0.5	D(3,2	(1)	0.230	A3→A2	1		
C(3,4)	(1)	0.5	D(3,4)	(2)	1.000	A3→A10	0	A3 = 3	2
C(3,5)	(2)	0.5	D(3,5)	(1)	0.030	A3→A11	1		
C(3,6)	(1,2)	1.0	D(3,6)	(-)	0.000	A3→A12	1		
C(4,1)	(-)	0.0	D(4,1)	(1,2)	1.000	A10→A1	0		
C(4,2	(2)	0.5	D(4,2	(1)	0.353	A10→A2	1		
C(4,3)	(2)	0.5	D(4,3)	(1)	0.638	A10→A3	0	A10 = 3	2
C(4,5)	(2)	0.5	D(4,5)	(1)	0.166	A10→A11	1		

C(4,6)	(2)	0.5	D(4,6)	(1)	0.161	A10→A12	1		
C(5,1)	(1)	0.5	D(5,1)	(2)	1.000	A11→A1	0		
C(5,2	(-)	0.0	D(5,2	(1,2)	1.000	A11→A2	0		
C(5,3)	(1)	0.5	D(5,3)	(2)	1.000	A11→A3	0	A11= 0	6
C(5,4)	(1)	0.5	D(5,4)	(2)	1.000	A11→A10	0		
C(5,6)	(1)	0.5	D(5,6)	(2)	1.000	A11→A12	0		
C(6,1)	(-)	0.0	D(6,1)	(1,2)	1.000	A12→A1	0		
C(6,2	(2)	0.5	D(6,2	(1)	0.531	A12→A2	1		
C(6,3)	(-)	0.0	D(6,3)	(1,2)	1.000	A12→A3	0	A12= 2	4
C(6,4)	(1)	0.5	D(6,4)	(2)	1.000	A12→A10	0		
C(6,5)	(2)	0.5	D(6,5)	(1)	0.169	A12→A11	1		
TOTAL C		15	TOTAL D		17.79				
C threshold		0.5	D threshold		0.593				

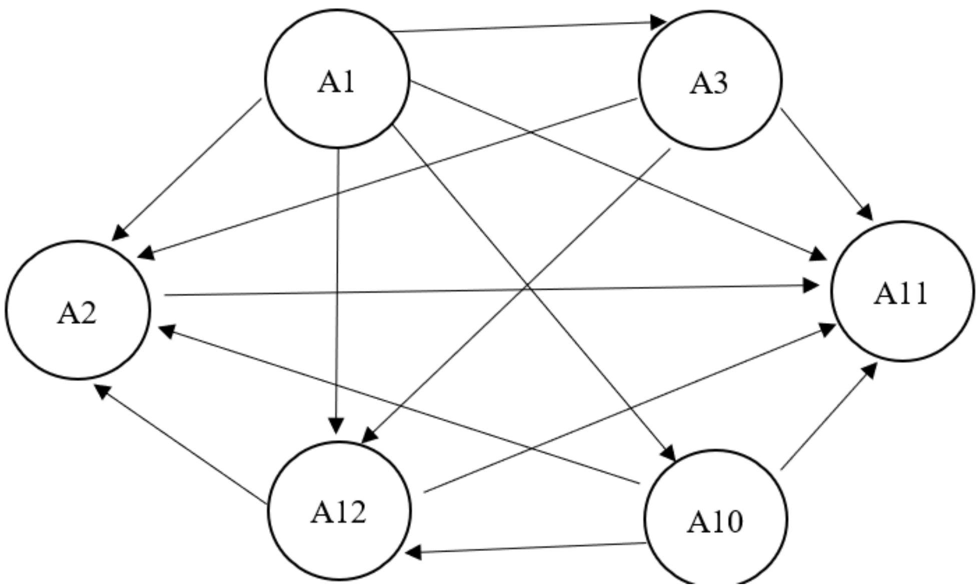

Figure 3: Graphical representation of treatment scenarios outranking relationship. The out outgoing arrows from the scenarios indicate the number of dominance.

Table 5: Purchasing of the recyclable materials and the selling price of the pre-processed materials in Arusha City, Tanzania

Materials	Purchasing price (US$ per kg)	The selling price of pre-processed materials (US$ per kg)	Expected final products after processing
Plastic bottles	0.09	0.26	Fibres for carpets, apparel, bottles, textiles and sheets

			products, washbowls, buckets, shampoo bottles, shopping bags
Hard plastics	0.17	0.39	Woven mat, plastic buckets, rollers
Cardboard boxes	0.02	0.10	Tissue papers, new cardboard
Metals	0.22	0.26	Appliances and building materials

Sensitivity Analysis

Table 6 details the sensitivity analysis results for eight experiments conducted using the multi-criteria approach based on ELECTRE with varying ECs and ENCs criteria. In these experiments, the total weights criteria for both ECs and ENCs was one and was set to vary from 0.1 to 0.9 for ECs and from 0.9 to 0.1 for ENCs criteria. Among the eight experiments conducted, scenario A1 has outranked all other alternatives in six experiments (1, 2, 3, 4, 5 and 6). In experiment seven, both scenarios A1, A2 and A3 emerged as the best treatment scenarios. Only, in the last experiment, scenario A2 emerged as the best scenario followed by scenario A1. Generally, we can see that, scenario A1 was the best alternative in different weights criteria and only insensitive and outranked by scenario A2 at the highest ECs criterion weight.

Table 6: Sensitivity analysis results with varying criteria weights

Experiment number	Descriptions for the weight criteria		Selected scenario
1	Economic cost	0.1	A1
	Environmental cost	0.9	
2	Economic cost	0.2	A1
	Environmental cost	0.8	
3	Economic cost	0.3	A1
	Environmental cost	0.7	
4	Economic cost	0.4	A1
	Environmental cost	0.6	
5	Economic cost	0.6	A1
	Environmental cost	0.4	
6	Economic cost	0.7	A1
	Environmental cost	0.3	
7	Economic cost	0.8	A1 or A2 or A3
	Environmental cost	0.2	
8	Economic cost	0.9	A2
	Environmental cost	0.1	

Conclusions

In this study, a multi-criteria decision approach based on the ELECTRE method was applied to evaluate the most favourable treatment scenario for MSW management of Arusha City Tanzania. The ELECTRE analysis results showed that of all the 54 treatment scenarios, the scenario which suggests the use of composting option for organic wastes, recycling option for glass, metals, paper and plastic wastes and the use of a landfill for other wastes emerged as the dominant scenario. In comparison to the current use of the landfill, composting and recycling are more beneficial economically and environmentally. Further evaluation of the real situation in the country also reveals this alternative to be feasible. In Arusha city, in particular, the recycling of MSW has employed approximately about 400 waste pickers at the landfill. Markets for composts from organic waste treatment are also feasible due to the presence of horticulture activities in the city and most of the country. Thus, the findings of this study can be applied by the decision-makers involved in managing waste to improve the MSW management in the study area and cities with similar MSW conditions.

Data Availability

The data used to support the findings of this study are included in the article

Conflicts of Interest

The authors declare they have no competing interests

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