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Application of Multi-Criteria Decision Analysis in Determining Suitable Waste-To-Energy Technology for Awka, Anambra State

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Abstract

This paper explored use of multi-criteria decision analysis (MCDA) to select waste-to-energy (WTE) technology for Awka, Nigeria necessary for addressing urgent urban solid waste issues. Urbanization has intensified waste generation, yet conventional waste management remains unsustainable despite government efforts. The study sought to identify suitable waste-to-energy (WtE) options through waste characterization, review of current practices, and identification of WtE choices. A survey design combining literature review data and primary data from questionnaires was used. Data was analysed through descriptive statistics and analytical hierarchy process (AHP) methodology. The AHP methodology was used to evaluate the WtE technologies and select the most appropriate technology for Awka. The WtE technologies were assessed through pairwise comparison of three main criteria and nine subcriteria assessed by 10 experts. Findings indicate that food waste is the most common waste type in Awka, followed by polyethylene/sachet water waste. The AHP-based pairwise comparison revealed that landfill gas is the most suitable WtE technology for Awka, followed by anaerobic digestion. The study portends the effectiveness of AHP for selecting sustainable waste management solutions and for resolving Awka's waste challenges while promoting urban sustainability. The study recommends implementing WtE technology, adopting improved waste management methods, enhancing public engagement, and ensuring government support and policy enforcement towards circular economy in the State.

Keywords: waste-to-energy; multi-criteria decision analysis; analytical hierarchical process

1. Introduction

Urbanization significantly increases population densities, and leads to heightened demands for resources such as food, water, technology, and energy (Jiang et al., 2021). This surge in demand results in greater solid waste generation and subsequent environmental degradation. In Nigeria cities (as seen in Awka), managing solid waste has become an urgent environmental challenge. Studies such as Ogwueleka (2009) reflected on these challenges to include route optimization issues, inefficient collection methods, inadequate collection system, improper disposal, lack of institutional arrangement, scarce financial resources, insufficient information on quantity and composition of waste, and inappropriate technology. Nigeria generates approximately 32 million tons of solid waste annually, one of the highest rates in Africa given its population of over 200 million people (Ayodele, 2022). The United Nations projects that Nigeria's population will double by 2050 (UNFPA, 2023), potentially worsening these waste management issues.

Awka, a prominent administrative and educational city in Anambra State, faces severe waste management problems. The city's current approach involves traditional waste collection using trucks, landfilling, and open incineration—methods that are increasingly unsustainable. These practices contribute to significant environmental pollution and deteriorate urban aesthetics. Moreover, indiscriminate waste disposal on streets and in drains poses serious environmental health risks, including flooding and outbreaks of waterborne diseases. Despite the evident relationship between waste generation, urbanization, population growth, and economic development, there has been limited progress in adopting more sustainable waste management solutions in Awka. The challenges in Awka highlight broader issues prevalent in many Nigerian cities: managing solid waste volumes, insufficient data on waste generation, inadequate collection systems, and difficulties in waste characterization (Nwakoby et al., 2020). The current waste management practices do not sufficiently address these issues, leading to increased environmental and public health impacts. To meet Sustainable Development Goal 11.6—aimed at reducing the adverse per capita environmental impact of cities by 2030, with a focus on improving air quality and waste management (Rodic and Wilson, 2017)—there is an urgent need to re-evaluate and enhance waste management practices in Awka.

Implementing multicriteria decision analysis (MCDA) could be pivotal in developing a sustainable waste management framework. MCDA is a tool designed to address complex environmental issues by considering both qualitative and quantitative factors (Garfi, Tondelli, and Bonoli, 2009). Its application in Awka could assist in identifying effective waste-to-energy solutions and optimal landfill siting (Qazi et al., 2018; Kurbatova and Abu-Qadis, 2020; Ukpanyang et al., 2022; Ajibade et al., 2019). By integrating various waste management strategies and supporting a circular economy, MCDA could help Awka transition to a more resilient, inclusive, and sustainable waste management system. The study aims to use multi-criteria decision analysis to select the best waste-to-energy technology for Awka, Anambra State. It assessed the characteristics of local solid waste and identified the most suitable technology for the area.

2. Materials and methods

2.1 Study area

Awka urban, located in southeastern Nigeria, covers Awka South and parts of Awka North, with coordinates between Latitudes 6°01'N and 6°17'N and Longitudes 7°21'E and 7°07'E, and spans 60.2 square kilometres. The area sits within the Anambra Basin, characterized by sedimentary rocks like Nkpolo shale and Imo shale, and features a rugged topography with elevations ranging from 60.2m to 91m. Awka experiences a tropical wet and dry climate with a seven-month rainy season and a five-month dry season, including the harmattan period, leading to frequent flooding due to inadequate drainage. Awka's vegetation has been cleared for agriculture and development, leaving behind fertile soils suitable for farming. The area's drainage is marked by rivers such as Mamu, Obibia, and Obizi. The population was projected to reach 351,176 in 2023, supports a range of economic activities including agriculture, manufacturing, and various services, all contributing to increased domestic waste generation.

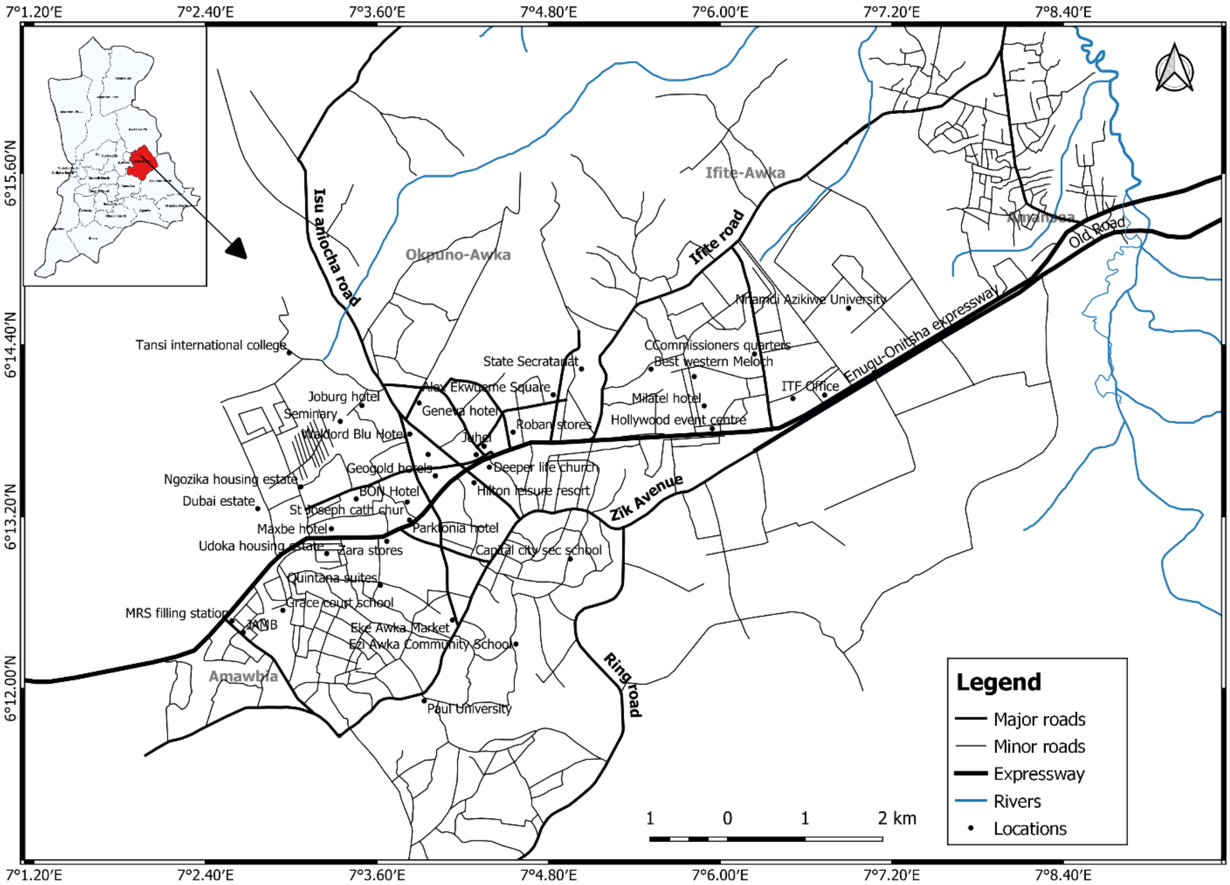

Fig 1: Map of Awka

2.2 Methodology

2.2.1 Data Collection

Survey design was adopted for this study. Primary and secondary data were generated for this study. The primary data collection tool employed in this study is questionnaire distributed to both experts and general public. Purposive sampling technique was employed in generating the required data from experts on appropriate and suitable waste-to-energy technology for Awka. Experts in the waste management sector in Anambra State were selected (Table 1).

Table 1: Consulted Experts' Categories and Profession

No	*Experts Category*	*Profession*	*Number*
1	Academics	Associate Professors and researchers in environmental management	2
2	Waste Professional	Waste collection and disposal	1
3	Graduate Researcher	PhD researchers in waste management optimization	2
4	Decision Makers	EIA experts from Environmental Agency under Ministry of Environment, Anambra State	2
5	Consultant	Principal Consultant at a Waste Management Agency	1

Simple random sampling technique was employed for the purpose of administering a general type of questionnaire for residents in Awka. This questionnaire was used in this study to determine the characteristics of solid wastes in the study area based on the perception of the respondents. Taro Yamane formula was used to determine the sample size of 399 using the population projection of 351,176persons for 2023.

2.3 Data Analysis:

2.2.1 Identification of Goal and Selection of Criteria

The major objective of this study is to decide on the appropriate waste to energy option for Awka. To determine this objective, some waste management experts in Anambra State were consulted. Given that no previous effort has been made to apply the AHP model in evaluating WtE options for Awka, a literature review was conducted on WtE options in order to identify various criteria and sub-criteria for selecting suitable WTE alternatives for the study area. The study identified 3 criteria, 9 subcriteria and 5 WtE alternatives and these were selected and applied in Awka.

2.2.2. AHP Model Construction

The AHP model, developed by Saaty (1980), follows four levels of analysis (Figure 2). The first level is focused on defining clearly the objective of the study, in this case, selecting the suitable WtE option for Awka. The second level of analysis deals on the selected criteria of the WtE option. Here, the objective was decomposed into three main criteria, namely environmental and health, technical and socioeconomic. The third step is focused on the subcriteria which are under the 3 main criteria. Each of the three main criteria has three subcriteria such that there is a total of nine subcriteria providing additional information on the preferred WtE option for solid waste management in Awka. These criteria and subcriteria are shown in table 2.

Table 2: Description of Main Criteria and Sub-Criteria in the AHP Model

Main Criteria	*Sub-Criteria*	*Code*	*Description*
Environmental and Health	Pollution and production of hazardous residue	PPH	Technology with least environmental impact
	GHG emission and climate impact	GHG	Technology with reduced GHG emission
	Public and occupational health impact	POH	Capability to reduce health risks
Technical	Technical knowhow	TK	Availability of skilled personnel
	Complex nature of the technology	CNT	Technology requiring high-skilled manpower
	Potential for electricity generation	PEG	Technology with high energy potential
Socio-economic	Capital cost	CC	Technology requiring least investment cost
	Operation and maintenance cost	OMC	Technology with least running cost
	Job creation	Job	Potential to create employment opportunities

The fourth level of analysis involves evaluating the alternative WtE technologies with the criteria and subcriteria selected. The alternative WtE technologies considered in this study are shown in figure 2, which include incineration, anaerobic digestion, landfill gas, gasification and pyrolysis.

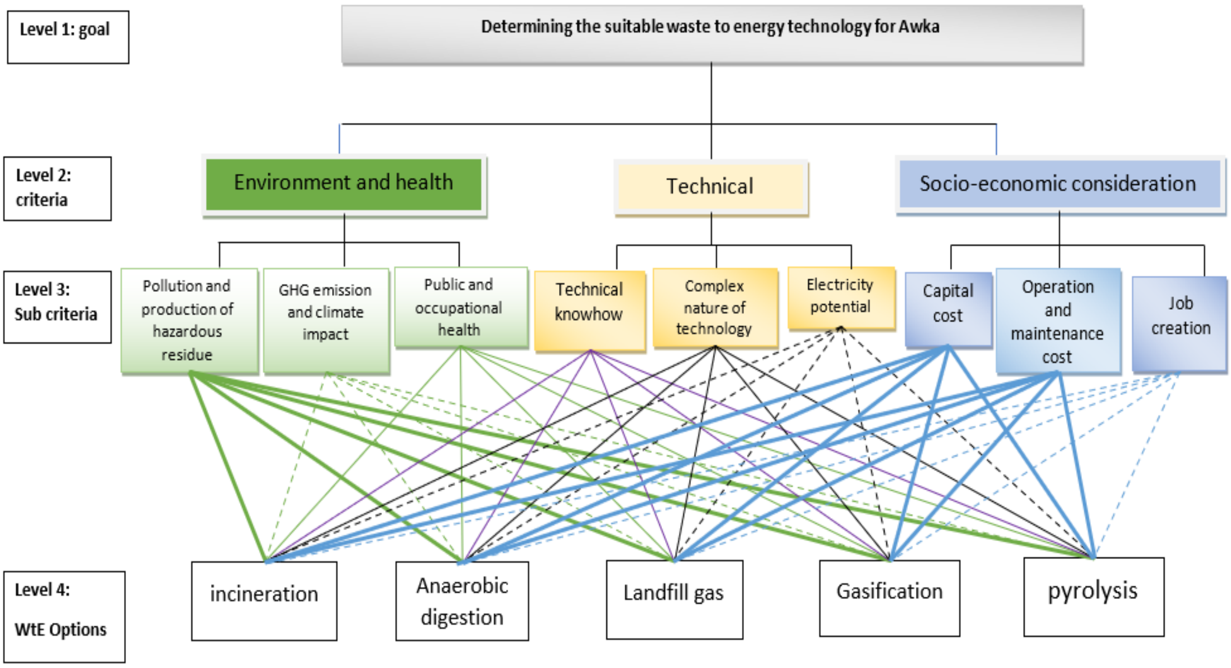

Fig 2: AHP model for the selection of optimal WtE technology

2.2.3 Pairwise Comparison

Experts ranked the technologies based on the three main criteria and nine subcriteria. To facilitate the experts in ranking their comparisons by order of importance, a nine-point scale originally proposed by Saaty (1980) was adopted (Table 3). The pairwise comparison values provided by the experts for the goal, criteria, sub-criteria, and WTE alternatives were then aggregated. These aggregated values were used to derive decision matrices for calculating the priority weights.

Table 3: Scale for Pairwise Comparison for AHP

Importance Scale	***Explanation***
1	Equal importance of criteria
2	Between equal and weak importance
3	Weak importance
4	Between weak and strong importance
5	Strong importance
6	Between strong and demonstrated importance
7	Demonstrated importance
8	Between demonstrated and absolute importance
9	Absolute importance

3. Results and Discussion

3.1 Municipal Solid Waste Generation in Awka

In providing insight on the solid waste management situation in Awka, the respondents were sought to highlight the category of solid waste that dominates their waste stream. The respondents were asked to select at least two dominant solid waste type as it applies to them on daily basis. The total number of responses per each solid waste type was calculated to derive percentages. From Figure 3, 26% of the responses showed that food waste dominates solid waste generated in Awka. The food wastes consist of biodegradable wastes originating from perishable food items sellers in markets across the town, and peelings or biodegradable food wastes from households. his is followed by sachet water/polythene waste which accounts for24%, textile accounting for 12% and plastic waste occupying 11%. Another important waste type is metallic waste at 8% while other waste types which covers glass waste takes up 6%.

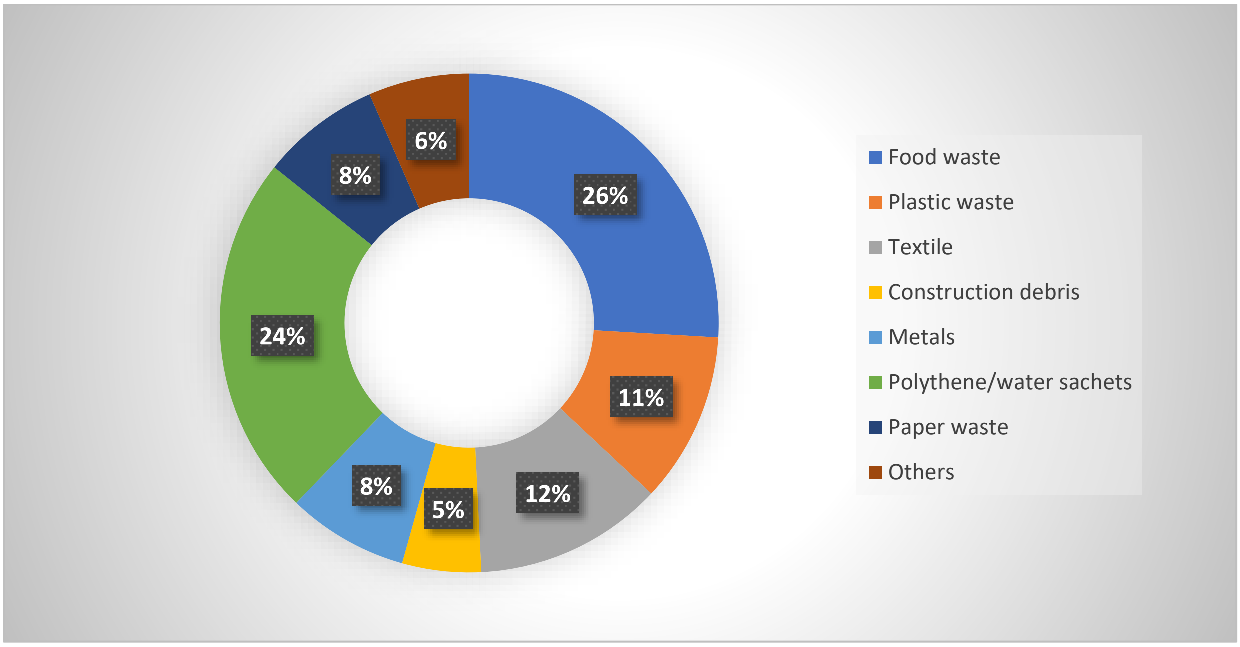

Fig 3: Perceived Composition of solid waste generated in Awka

3.2 Application of AHP

Choosing a sustainable approach to waste management in Awka is crucial for safeguarding water, land resources, and public health from the impacts of solid waste. Currently, a significant portion of municipal solid waste in Awka is disposed of improperly, with waste frequently discarded along roadsides, into rivers, and drainage systems. This contamination affects the quality of surface and groundwater, impacting both human consumption and aquatic ecosystems (Li et al., 2021). Consequently, this raises the question: "What measures can ensure solid waste is effectively managed in this area?" This study applied multi-criteria decision analysis using the AHP technique to identify an appropriate waste-to-energy (WtE) option for Awka. Data was gathered through pairwise comparison of criteria and WtE options by experts. Table 4 presents the results, indicating that environmental criteria had the highest priority weight (0.755), followed by technical and socioeconomic considerations, as determined by expert judgment. Figure 4 illustrates that experts prioritized environmental factors in selecting a WtE alternative for Awka, while socioeconomic factors ranked lowest. This may reflect the reality that solid waste in Awka is largely managed traditionally, with authorities focusing mainly on waste collection and landfill disposal. Such conventional methods have led to environmental and public health challenges that affect both the environment and the residents of Awka (Kurbatova and Ahmed Abu-Qdais, 2020).

Table 4: Pairwise comparison matrix for main criteria relative to the main goal

Criteria	Environmental and health	Technical	Socio-economic	Priority
Environmental and health	1.00	9.00	9.00	0.755
Technical	0.111	1.00	6.00	0.188
Socio-economic	0.111	0.167	1.00	0.057

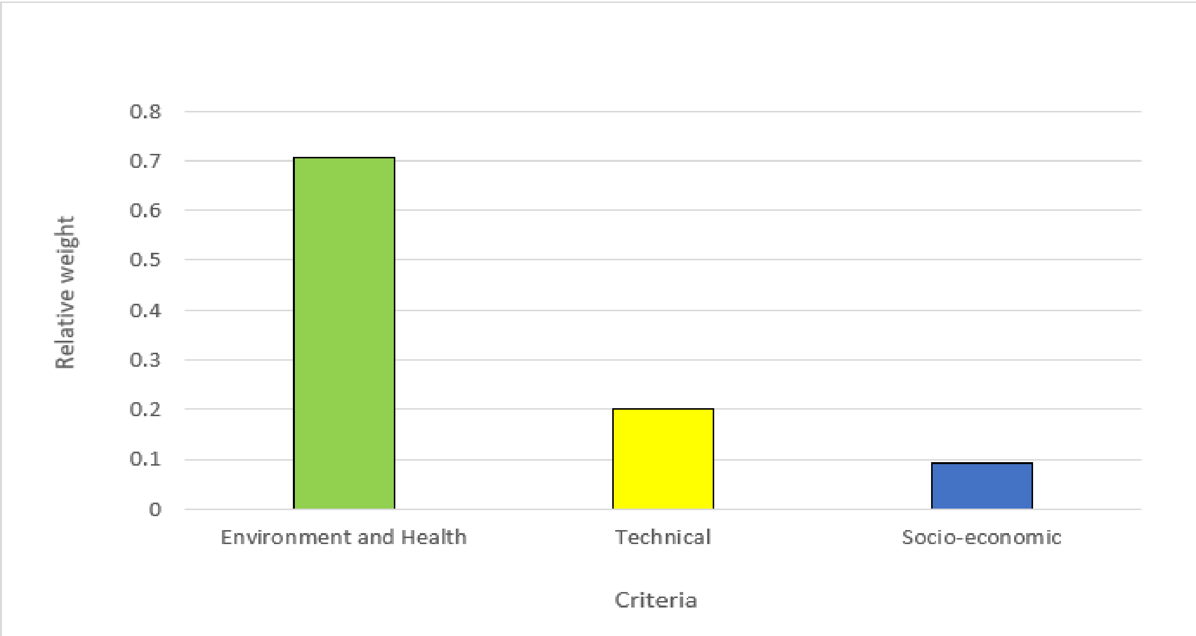

Fig 4: Priorities of the main criteria with respect to the goal of selecting a suitable WTE for Awka

The pairwise comparisons of the nine sub-criteria were conducted within each main criterion, resulting in three comparison matrices based on expert opinion. In Table 5, it is evident that under the "Environment and Health" criterion, public and occupational health impact (weight = 0.679) and GHG emissions (weight = 0.241) were prioritized, while pollution and hazardous residue production held the lowest priority. This finding aligns with that of Qazi, et al. (2018), where GHG emissions were highly prioritized as key sub-criteria for WTE selection under Environment and Health considerations. The high priority for these sub-criteria may stem from the evident air quality issues in Awka; which mainly arises due to poor management of landfill and open dumps (which are mostly burnt in the evenings), and which equally affects residents' health.

Within the sub-criteria of technical criteria, potential for energy production held the highest priority (0.597), followed by the complexity of selected technology (weight = 0.282), with technical know-how given the least priority. This ranking suggests that, according to experts, energy production potential is the primary factor for WTE selection in Awka, with the complexity of technology as a secondary concern, and technical know-how deemed less critical. This result likely reflects inadequate power supply from power-generating (Gencos) and distribution companies (Discos), government limitations in providing sufficient power, poor infrastructure in the energy sector, and a weak grid system.

Table 5: Pairwise comparison of the subcriteria with respect to main criteria

Criteria	Environment and Health			Technical			Socio-economic			Priority Vector
Subcriteria	**PPH**	**GHG**	**POH**	**TK**	**CNT**	**PEG**	**CC**	**OMC**	**Job**	
PPH	1	0.2	0.167	-	-	-	-	-	-	0.079
GHG	5	1	0.2	-	-	-	-	-	-	0.241
POH	6	5	1	-	-	-	-	-	-	0.679
TK	-	-	-	1	0.2	0.333	-	-	-	0.120
CNT	-	-	-	5	1	0.2	-	-	-	0.282
PEG	-	-	-	3	5	1	-	-	-	0.597
CC	-	-	-	-	-	-	1	0.2	0.25	0.101
OMC	-	-	-	-	-	-	5	1	0.111	0.227
Job	-	-	-	-	-	-	4	9	1	0.672

In the socioeconomic sub-criteria, job creation ranked highest with a priority weight of 0.672, followed by operation and maintenance cost at 0.227, while capital cost held the lowest priority at 0.101. In Qazi et al. (2018), operation and maintenance cost were identified as a key component of the socioeconomic criteria when evaluating WTE technologies. However, contrasting findings from Agbejule et al. (2021), Kurbatova and Ahmed Abu-Qdais (2020), and Rahman, Azeem, and Ahammed (2017) highlighted capital cost as central to assessing the socioeconomic aspects of WTE technology selection and implementation.

Additionally, a pairwise comparison was conducted for WTE options based on the nine sub-criteria (Figures5 and 6). Experts' responses produced nine matrices showing that for the pollution and

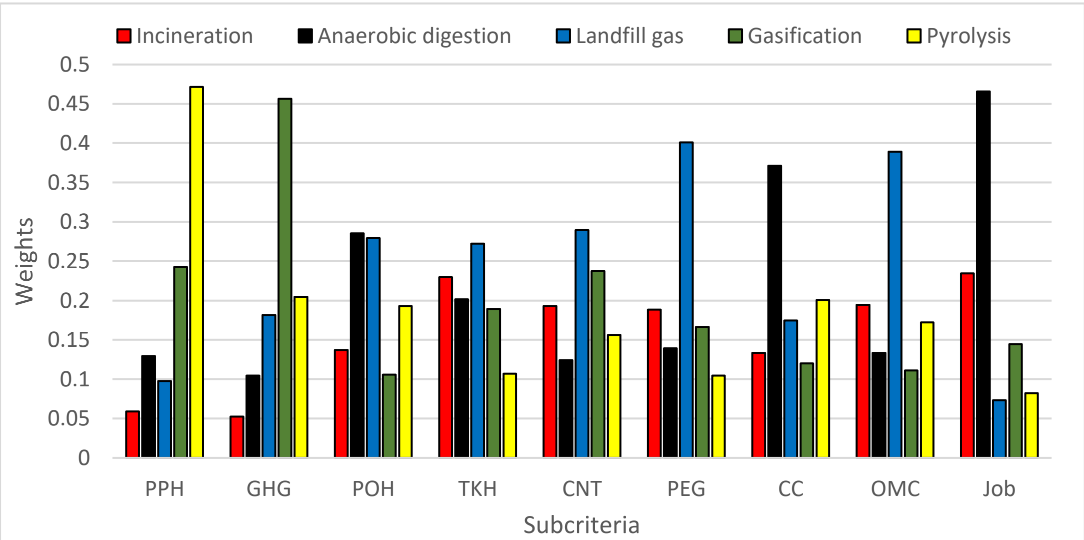

Fig 5: Priority of waste-to-energy technology based on sub-criteria

production of hazardous residue (PPH) sub-criteria, incineration performed worst regarding environmental pollution, closely followed by landfill gas digestion. Gasification, pyrolysis, and anaerobic digestion received the highest weights, making them the preferred technologies concerning pollution potential. This result aligns with the findings of Kubartova and Abu-Qdais (2020), where anaerobic digestion was reported as the best alternative due to its low pollution potential. Similar result was reported in Agbejule et al. (2021).

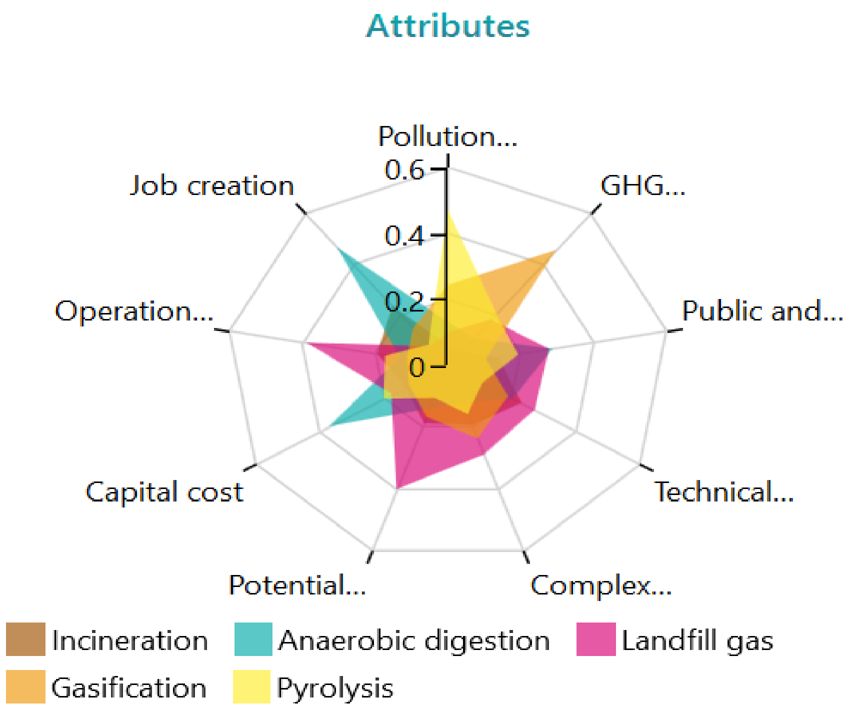

Fig 6: Attribute diagram of waste-to-energy technology

Under the GHG emissions sub-criteria, experts favoured gasification as the most suitable WTE option for Awka due to its low greenhouse gas emissions, followed by pyrolysis and landfill gas, with anaerobic digestion and incineration as the least preferred. For public and occupational health sub-criteria, anaerobic digestion and landfill gas had the least potential for health impacts, followed by pyrolysis, while gasification and incineration were the least preferred.

For the technical criterion and its first sub-criterion, technical know-how, results indicated that landfill gas was the top choice among experts due to the availability of skilled personnel for WTE technology, followed by incineration and anaerobic digestion, which shared high priority weights. Gasification and pyrolysis were the least preferred. The preference for landfill gas aligns with findings by Farooq, Haputta, Silalertruksa, and Gheewala (2021), Agbejule et al. (2021), and Kurbatov and Abu-Qdais (2020). Regarding the complex nature (CNT) of WTE technology, landfill gas was again rated highest, followed by gasification. This suggests landfill gas is favoured for its low requirement for skilled labour, especially in a developing city like Nigeria, as noted by Farooq et al. (2021). Gasification and incineration followed, while anaerobic digestion and pyrolysis, which require high-skilled labour due to their complex processes, were least preferred under CNT.

For energy generation potential, landfill gas ranked highest based on expert judgment, followed by incineration and gasification, with anaerobic digestion and pyrolysis rated lowest for electricity generation potential. Regarding capital cost, anaerobic digestion emerged as the preferred choice due to its lowest cost, followed by pyrolysis and landfill gas, with gasification being least favoured. Experts also ranked landfill gas highest for its low operational and maintenance costs, followed by incineration and pyrolysis. Agbejule et al. (2021) noted that experts considered incineration second due to labour costs and lack of waste sorting requirements. For job creation potential, anaerobic digestion was identified as having the highest job creation potential, followed by incineration, with landfill gas and pyrolysis ranked lowest.

The final AHP step requires determining the overall WTE alternative priority by combining the weights of all criteria, sub-criteria, and alternatives. As shown in Figure 7, landfill gas and anaerobic digestion were the top choices, with global weights of 0.258 and 0.222, respectively. Gasification ranked third with a global weight of 0.195, while gasification and incineration were least preferred for waste management in Awka. The AHP findings for selecting a suitable WTE technology in Onitsha align with Kurbatova and Abu-Qdais (2020) in Moscow, where landfill biogas ranked highest, followed by anaerobic digestion, and with Qazi et al. (2018) in Oman, where anaerobic digestion was the top choice.

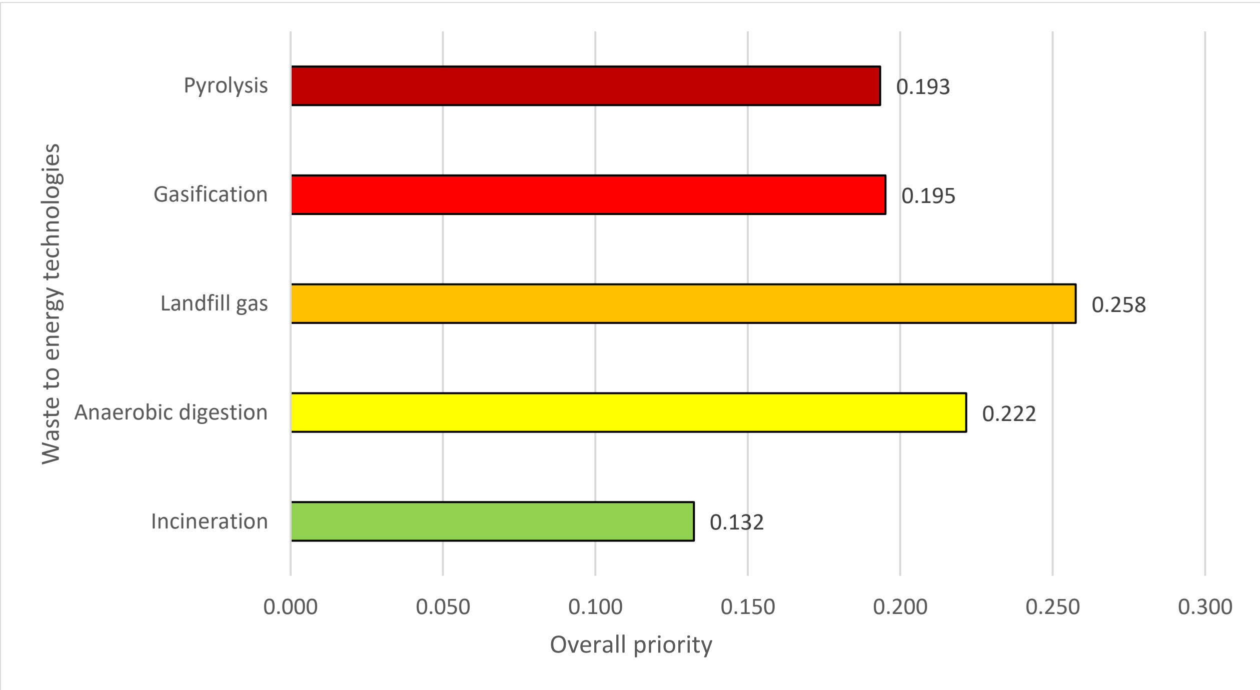

Fig 7: Global ranking of waste-to-energy technologies for Awka

4. Conclusion

The application of multi-criteria decision analysis using the AHP technique in this study sought to identify a suitable waste-to-energy option for Awka. This was achieved through the data generated based on pairwise comparison of the criteria and WtE options available to the experts. Our conclusions are that solid wastes pose a threat to human health if not properly disposed. The application of multi-criterial decision analysis will serve as a veritable tool to manage waste in order to clamp down on its negative effects on the environment and promote energy technology in Awka. Based on the different criteria and subcriteria, the WtE technologies were ranked and landfill gas is the most preferred WtE technology followed by anaerobic digestion. In view of this, the study recommends that the waste management agency should adopt improved waste management methods by implementing a WtE technology. This will support the drive towards circular economy. The Ministry of Environment through its waste management agency should enhance public engagement, and ensuring government continued support and policy enforcement towards achieving and maintaining a viable waste-to-energy economy.

References

Agbejule, A, Shamsuzzoha, A., Lotchi, K., and Rutledge, K. (2021). Application of Multi-Criteria Decision-Making Process to Select Waste-to-Energy Technology in Developing Countries: The Case of Ghana. *Sustainability*, 13, 12863. https://doi.org/10.3390/su132212863

Ajibade F.O., Olajire O.O., Ajibade T.F., Nwogwu N.A., Lasisi K.H., Alo A.B., Owolabi T.A., and Adewumi J.R. (2019) Combining multicriteria decision analysis with GIS for suitably siting landfills in a Nigerian state. Environmental and Sustainability Indicators 3 (4), 1 – 14.

Ayodele M (2022, March 23) Nigeria's waste management policy yields little gains. Business Day Newspaper. Retrieved from https://www.google.com/amp/s/businessday,ng/amp/big-read/article/nigerias-waste-management-policy-yields-little-gains/

Farooq A, Haputta P, Silalertruksa T and Gheewala SH (2021) A Framework for the Selection of Suitable Waste to Energy Technologies for a Sustainable Municipal Solid Waste Management System. *Front. Sustain.* 2, 1-17. https://doi:10.3389/frsus.2021.681690

Garfi M., Tondelli S., and Bonoli A. (2009). Multi-criteria decision analysis for waste management in Saharawi refugee camp. *Waste Management* 29, 2729–2739

Jiang T-B, Deng Z-W, Zhi Y-P, Cheng H and Gao Q (2021). The effect of urbanisation on population health: Evidence from China. *Front. Public Health* 9:706982.

Kurbatova A. and Abu-QdaisH.A. (2020). Using Multi-Criteria Decision Analysis to Select Waste to Energy Technology for a Mega City: The Case of Moscow. *Sustainability*, 12, 9828; doi:10.3390/su12239828

Li P., Karunanidhi, D., Subramani T., and Srinivasamorrthy K. (2021). Sources and Consequences of groundwater contamination. Arch Environ ContamToxicol., 80(1), 1-10.

NwakobyN.K, Okoye N.J., Chukwurah D.C (2020). Waste Disposal and Management in Awka Capital Territory, Telescoping the Roles of Anambra State Environmental Protection Agency (ANSEPA) 2012 – 2019. World Journal of Innovative Research (WJIR), 9 (5), 147-152

Qazi W.A., Abushammala M.FM and Azam M-H (2018). Multi-criteria decision analysis of waste-to-energy technologies for municipal solid waste management in Sultanate of Oman. *Waste Management and Research*, Vol. 36(7) 594–605

Rahman, S.S., Azeem, A., and Ahammed, F. (2017). Selection of an appropriate waste-to-energy conversion technology for Dhaka City, Bangladesh. *International Journal of Sustainable Engineering, 10*, 104 - 99.

Rodic L. and Wilson D.C. (2017). Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries. *Sustainability*, 9, 404, 1 – 18.

Saaty T.L. (1980). The Analytical Hierarchy Process. McGraw-Hill, New York.

Ukpanyang, D., Terrados-Cepeda, J. and Hermoso-Orzaez, M.J. (2022**)** Multi-Criteria Selection of Waste-to-Energy Technologies for Slum/Informal Settlements Using the PROMETHEE Technique: A Case Study of the Greater Karu Urban Area in Nigeria. Energies, 15, 3481. https://doi.org/10.3390/en15103481