Waste to Energy Technologies from Organics Fraction of Municipal Solid Waste

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Abstract— **With rapid economic growth and increased urbanization, South Africa faces the problem of municipal solid waste (MSW) disposal and pressing the need for waste to energy recovery. Nowadays, renewable energy is the key consideration in the discussion of the sustainable worldwide energy system that reduces global climate change, human health problems, and environmental degradation. Sustainable development requires the sustainable supply of clean and affordable renewable energy. The renewable energy source such as bioenergy, solar energy, wind energy, hydropower, geothermal is usually viewed as sustainable energy sources that drive economic development. Wastes are convertible to useful energy through waste to energy (WtE) technologies. In this study, renewable energy technologies from the organic fraction of municipal solid waste (OFMSW) and their relation to sustainable development are discussed. Via the application of the simple multi-attribute rating (SMART) technique of multiple-criteria decision analysis (MCDA) and analytical hierarchy process (AHP) as a decision support tool, the most preferred model option for WtE technology was selected from a list of potential alternatives available in the market base on environmental, sociocultural, technical and economical consideration. From our investigation into the City of Johannesburg Landfill, the OFMSW had the highest fraction that comprises of 34% in portion. From MCDA-AHP results, anaerobic digestion was the most preferred technology of choice, taking into consideration environmental preservation as the ultimate goal.**

Keywords— **Anaerobic, Co-digestion, Digesters, Mesophilic Temperature, MCDA.**

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I. INTRODUCTION

THE worldwide increases in population keeps on increasing the demand for food and energy supply, leading to waste generation and environmental degradation. With the fast depletion of non-renewable energy sources such as fossil fuel, coal, and petroleum which has led to global climate change, human health problems and environmental degradation. The commercial production of bioenergy and other alternative energy sources such as solar energy, wind energy, hydropower, geothermal will definitely give a drive for the development of the economy [1, 2]. Energy derived from biomass is used in the form of fuel, heat, and electricity. It is desirable to create sustainable and with zero carbon emissions worldwide energy system [3, 4].

II. ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE

The energy recovery technology from waste depends on the state of the waste, type of fuel needed and the composition of the substrate, but generally, thermal, biological and mechanical conversion processes are applied. The thermal conversion processes, which are fast include: incineration; gasification; liquefaction; and pyrolysis [5]. Biological processes which are relatively slow and mostly suitable for organic fraction of municipal solid waste (OFMSW) include; hydrolysis; fermentation; and anaerobic digestion. The mechanical process involves pressurised extraction. A short description of some of the technologies suitable for municipal solid waste (MSW) management is described below;

A. *Incineration*

The main aim of incineration is to reduce volume, toxicity and reactivity of MSW. 90% volume reduction and 75% mass reduction are possible. However, it is not an absolute environmental solution due to the nature of its by-product; ash, flue gas, and heat. The flue gas must be cleaned before they are released to the atmosphere. In the advanced system, energy recovery is implemented alongside incineration. Waste management using incineration method is now a disputable disposal option in so many countries of the world owing to the hazard it poses to human health and the environment. The primary aim of MSW management is improving human health and reducing environmental impacts, both of which cannot be guaranteed through the adoption of incineration as a waste management technique [5, 6].

B. Pyrolysis

Pyrolysis is the thermochemical decomposition of organic waste in the absence of Oxygen (O_2). This reaction takes places at operating temperature between 250-430 °C. In the course of this reaction, the organic substance is converted to gases, liquid and solid residues which contain carbon and ash. When waste is decomposed through this process, recyclable products are produced. When the process is applied as a MSW management technology, carbonaceous char, oil and combustible gases are produced. The high-temperature requirement of this process has a negative environmental impact [5, 6].

C. Gasification

Gasification is a thermochemical decomposition of MSW using a fraction of an oxidizing agent. It could be described as the incomplete decomposition of carbon-based feedstock to generate synthesis gas. This process is close to pyrolysis; the only difference is that oxygen is included to keep a reducing atmosphere, where the amount of oxygen that is available is less than the stoichiometric ratio for complete combustion. Gasification produces syngas which is primarily carbon monoxide, hydrogen, and sometimes methane. They can be used for heat, power, fuels, fertilizers or chemical products and may produce char, inert slag, brine, bio-oils and steam. The residual char and slag may require landfilling. A Gasification facility often produces greenhouse gas, contaminants, and toxins. Gasification equipment will require large quantities of residuals as feedstock which is about 75-330 tons per day [5, 6].

D. Composting

Composting is a good alternative to transporting organic waste to the landfill, as it could be done on-site with minimal investment. The process produces fertilizer and heat. Also produced is carbon dioxide, a greenhouse gas, which is released into the atmosphere. There are high possibilities of contaminants such as glass in the waste to be composted which will render the produce product worthless [5, 6].

E. Anaerobic digestion

Anaerobic digestion (AD) is the biological degradation of organic matter such as industrial waste, agricultural wastes, animal wastes and domestic wastes in the absence of oxygen [7]. The process is suitable for energy recovery from different organic feedstock with biogas and digestate as the main product of the process [8, 9]. The biogas consists of mainly methane, a combustible gas, and carbon dioxide. The digestate can be utilised for different purposes. Depending on its characteristics, polymer products can be made from digestate aside it utilization as fertilizer. Anaerobic digestion stabilizes, disinfect and deodorise waste. It provides flexibility of use of fuel produced by this process [5, 6].

III. Technology Selection Methods

Several methods have been developed to give unbiased results when it comes to decision-making on a particular choice of technology. In principle, all methods are based on the steps summarized below [10];

- Identification of the problem,
- Identification of stakeholders,
- Seeking the unbiased opinions of the stakeholders in the form of solutions to the identified problem. The identified solutions are treated as alternatives and the key performance indicators of the chosen options become the selection criteria,
- Modelling the obtained solutions so as to obtain impartial results through detailed analyses. At the modelling stage is when the decision maker decides on which particular selection method to employ basing on the nature of the problem at hand.

In modern times, technology designs are probabilistic in nature and the evaluation criterion is multi-dimensional. This calls for complex tools that can capture all the dimensions of a decision problem. The existing technology selection methods include;

A. Multi-criteria decision analysis (MCDA)

MCDA is an approach employed by decision makers to make recommendations from a set of finite seemingly similar options basing on how well they score against a pre-defined set of criteria. MCDA techniques aim to achieve a decision goal from a set of alternatives using pre-set selection factors herein referred to as the criteria [11]. The selection criteria are assigned weights by the decision maker basing on their level of importance. Then using appropriate techniques the alternatives are awarded scores depending on how well they perform with regard to particular criteria. Finally, ranks of alternatives are computed as an aggregate sum of products of the alternatives with corresponding criteria. From the ranking, a decision is then made [12].

There are several variations in MCDA techniques used currently employing mathematics and psychology. These include; analytic hierarchy process (AHP), Simple multi-attribute rating technique (SMART) and Case-based reasoning (CBR).

AHP aims at organizing and analyzing complex decisions basing on their relative importance independent of each other. [13, 14]. Saaty [13] developed a scale of 1-9 to score alternatives basing on their relative importance as shown in Table I. However, the major drawback of the AHP is the alteration of ranks in cases where new alternatives are introduced into an already analyzed problem [13, 14].

By applying the SMART technique, alternatives are ranked basing on ratings that are assigned directly from their natural scales [15, 16]. The advantage of the SMART technique over AHP is the fact that the decision-making model is developed independently of the alternatives.

Therefore, the scoring of the alternatives is not relative and therefore introduction of new alternatives doesn't affect the ratings of the original ones making it a more flexible and simpler technique [16].

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TABLE I
SAATY'S SCALE INTENSITY 1-9

Scale Intensity	Definition	Explanation
1	Equal Importance	Two elements equally contribute to the intended objective.
3	Moderate importance	Basing on judgement and experience one element is favoured over the other.
5	Strong Importance	Basing on judgement and experience one element is strongly favoured over the other.
7	Very Strong Importance	One element is very strongly favoured over the other and its dominance can be demonstrated in practice.
9	Extreme Importance	The evidence favouring one element over another is of the highest order of affirmation.

In CBR, problem solving is done basing judgement on similar past problems and experiences. Basically, the decision is made basing on what has happened before. [17].

IV. METHODOLOGY

A. *Waste quantification*

Waste generated in this study was quantified at the City of Johannesburg landfill A, Gauteng Province, South Africa. This involved measurement of the waste at the point of generation to obtain the total amount of waste generated. Waste quantification was done in accordance with the standard methods of ASTM D 5231-92 [18].

B. *Screening Waste to Energy (WtE) Technologies*

An Analytic Hierarchy Process (AHP) was used in the decision-making process for the most appropriate technology. The goal of the decision was to select the WtE technology with the lowest negative impact on the environment. Four key criteria were considered, they are; environmental; sociocultural; technical; and economic criteria. Each of the criteria has their sub-criteria that was used to conduct a pairwise comparison. Four WtE technology options were considered namely; anaerobic digestion, composting, incineration and landfill. A nine-point scale pairwise comparison was used in developing a comparison matrix table. The confidence level of the result was checked using consistency index (CI) and consistency ratio (CR). A CR < 0.1 indicates that the analysis was reliable.

V. RESULTS AND DISCUSSION

The feasibility study for waste quantification was conducted on site, at the City of Johannesburg landfill A. A total of 5.5 ton of waste was weighed, sorted and categorised at both sites. The fractional composition of the waste from the three sources are presented. Historical data for the landfills were used to assess the daily tonnages of waste discharged. Based on historical data, an average total of 1,444,772 ton per annum of domestic waste was generated in the City of Johannesburg, South Africa. Of this total, 562,028 ton/annum was discharged at landfill site A (Pikitup 2015) [19]. From our investigation, the landfill fractional composition comprised of 34% OFMSW portion made up of food waste (Fig. 1). Of the total waste generated, 3%, 1%, 5%, 17% were the textile/fabric, special care waste, metals, and others general waste respectively. Organic waste was the most abundant component of the MSW, accounting for 34%. Recyclables (plastics, glass and paper/paperboards) was the second-largest component 19%, 9% and 12% respectively.

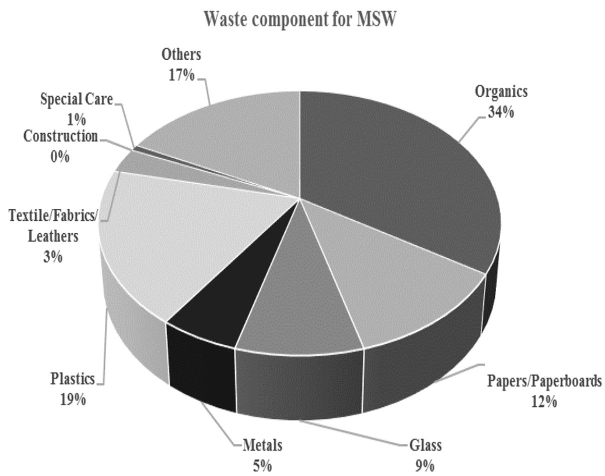

Fig. 1. Municipal solid waste quantification results, municipal landfill at City of Johannesburg

Seasonal variation contributes to the difference in the organic waste. However, general waste is influenced by the city population. In particular, seasonal variation affects the moisture content of the waste and hence the density of waste requiring disposal. Considering Fig. 2, OFMSW and compost were the main ingredients for waste to energy technologies.

In this study, a pairwise comparison of the criteria was conducted with a subjective approach based on the overall goal of the analysis, which is environmental preservation. The weighted factor for the four criteria was as presented in Table II.

TABLE II
PRIORITY VECTOR OF THE CRITERIA

	Environmental	Sociocultural	Technical	Economical
Weighted factor	0.55	0.26	0.05	0.13

Pairwise comparison of each technology was conducted against each criteria and a priority matrix was developed. The performance of each WtE technology presented as a

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priority vector against the four criteria was summarised in Fig. 2.

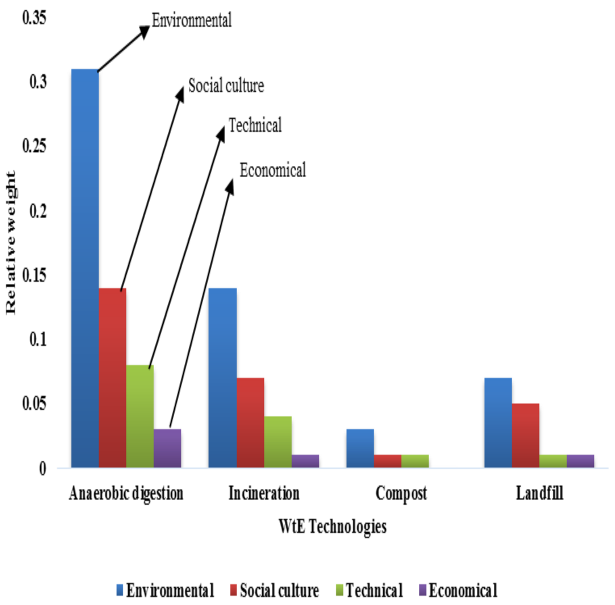

Fig. 2. WtE technology ranking against each criteria

The synthesis of all matrices was done. Synthesis was the process of multiplying each criterion ranking by the priority vector and adding the resulting weights to get the overall priority vector. From Fig. 3, there was a 54% acceptance of anaerobic digestion towards meeting the four criteria stated to achieve the goal of environmental preservation while landfill had the least acceptance of 5%. Incineration and compost had acceptance of 27% and 14% respectively.

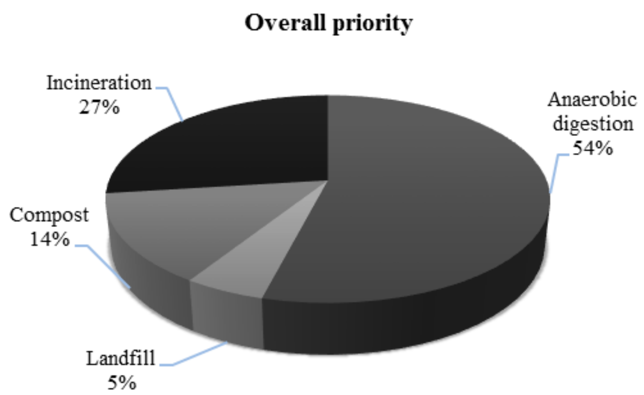

Fig. 3. Overall priority of each technology towards the goal of environmental preservation

From Table III, anaerobic digestion has the largest outcome. Idealizing the largest outcome and proportioning other technologies against anaerobic digestion, implies that incineration has a 49.42% of the appeal of anaerobic digestion, composting has 25.24% of the appeal of anaerobic digestion and landfill has the least appeal of 9.29% to anaerobic digestion.

TABLE III
OVERALL PRIORITY AND IDEALIZED PRIORITY OF EACH WtE TECHNOLOGY

WtE	A	B	C	D	Overall Priority	Idealized Priority
Anaerobic Digestion	0.31	0.14	0.03	0.07	0.54	1.00
Incineration	0.14	0.07	0.01	0.05	0.27	0.49
Compost	0.08	0.04	0.01	0.01	0.14	0.25
Landfill	0.03	0.01	0.00	0.01	0.05	0.09

Where: A –Environmental, B- Socialculture, C-Technical, D- Economical.

The overall CI (consistency index), RI (random consistency index) and CR (consistency ratio) indicated the analysis was reliable as overall CR<0.1 as shown in Table IV.

TABLE IV
CONFIDENCE CHECK OF ANALYSIS

Overall CI	Overall RI	Overall CR
0.1478	1.8	0.0821

From the MCDA-AHP results, anaerobic digestion was the most preferred technology, taking into consideration environmental preservation as the ultimate goal. Anaerobic digestion (AD) was only suitable for organic waste hence, it has become very paramount to quantify the percentage of organic wastes that go into the waste streams which mostly end up in the landfills.

Utilising these organic wastes for energy production saves disposal sites air space. In addition, there are MSW management benefits from AD which include reduction of cost of transportation and compression of waste to landfills sites. Even though there are countless benefits of energy production from MSW, the primary benefit of AD of MSW is twofold; to divert OFMSW and to mitigate climate change whereas energy production was only a secondary benefit which enhances the attractiveness of this technology. Hacker et al., (2010) [20] reported that 1 Mg of MSW is equivalent to 750 kWh power which can supply an average of 25 American household that uses an average of 30 kWh per day of electricity.

VI. CONCLUSION

From the results, the amount of OFMSW was found to be the highest with 34%. From the MCDA-AHP results, anaerobic digestion was the most preferred technology, taking into consideration; environmental, social culture, technical and economical consideration. Thus, WtE can be viewed as key and economical viable component to renewable (green) energy; electricity generation and liquid biofuel for the transport sector. It is expected that experience acquired on the development of WtE in South Africa can offer lessons to other developing countries.

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