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Waste-To-Energy Solutions That Is Technically and Economically Feasible for Investment in India: A MOORA Technique Based on MCDM Method Strategy

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Abstract

In the Vellore District of Tamil Nadu State, Due to the unprofitable nature of phase extension in isolated rural areas, small-scale power generation has recently come to be recognized as a viable option for energy access. It might be possible to develop an Integrated Renewable Energy System to meet the hamlets' energy and culinary requirements. Techno-Economic Research on This article conducts Technologies for converting waste into energy (WtE) has been acknowledged as one solution to India's persistent problem with unannounced power outages and load shedding. Research significance: Which of the four potential WtE technologies—pyrolysis, gasification, plasma arc gasification, and anaerobic digestion—will have the highest techno-economic return on investment? MCDA, or multi-criteria decision analysis, is employed in the current study. Methodology: The four solutions were assessed using 10 chosen techno-economic criteria by five academic and business professionals. After pyrolysis and plasma arc gasification, gasification, according to the available statistics, commonly known as anaerobic digestion, is the third most investable WtE technology in India. The annual energy production and initial investment are, respectively, the most important technical and economic factors. Results: Based on MOORA set theory, some multi-criteria decision-making (MCDM) paradigm is suggested in this paper. Alternative methods include pyrolysis, gasification, plasma arc gasification, and anaerobic digestion. The following criteria are used for evaluation: net present value, internal rate of return, transformative capacity, generational capacity, annual energy generation, initial investment, operations, and maintenance, balanced energy expenditure, repayment duration, and cost of electricity. As a result, the Gasification is in 1st rank and anaerobic digestion is last rank. Conclusion: The results of sensitivity analysis are more robust, Showing stability and consistency. According to the present analysis, anaerobic digestion and gasification should be integrated rather than used separately, because it balances well as a WtE technology. The results of this study will help potential WtE technology investors in India make decisions.

Keywords: Anaerobic digestion, Pyrolysis, Gasification

Introduction

Energy is a necessity for human life as well as for a society's ability to develop economically sustainably. Fossil fuels are the main way to produce electricity on a global scale. Fossil fuels account for 84% of the world's electricity production, according to the most recent statistical analysis of global energy [1]. However, a heavy reliance on traditional fossil fuels poses a serious issue due to the diminishing supply, It increases the cost of fuel and leads to the creation of greenhouse gases and other pollutants, all of which have a big impact on global warming [2]. The advancement of renewable energy sources will play a significant role in the achievement of the Paris Climate Change Agreement and the 2030 Agenda for Sustainable Growth of the United Nations. To address energy issues and preserve the environment, the majority of wealthy countries have made significant investments in technologies converting to renewable energy sources [3]. As a result of their reliance on the weather, alternative energy sources like solar, wind, and hydro have irregular supplies. Municipal solid waste (MSW) has demonstrated to be a very reliable source of plentiful, environmentally friendly energy when employed as the main feedstock for power generation [4]. Due to the numerous economic and environmental advantages of MSW management, it has gained interest in the majority of studies. Both the production and management of MSW have seen tremendous change in the last several decades. Recycling, composting, and energy recovery are becoming increasingly popular alternatives to unmanaged landfills in solid waste management across the globe. In 2018, recycling and energy recovery rates for MSW generated were 32% and 12%, respectively, up from 6% and 0% in 1960. Contrarily, land filling has dramatically dropped, from 94% of the quantity produced in 1960 to 50% of the amount produced in 2018 [5]. Recently, it has become clear that MSW may really be more of a "resource" than a "burden," one of the world's undiscovered resources. Depending on the changing composition and moisture content of the trash as well as the local population and culture, the energy present in MSW can be used to produce heat and power through a variety of biochemical or thermochemical processes [6]. A circular economic system can be created by simultaneously tackling the problems of energy consumption, waste management, and greenhouse gas emissions through the supply chain for waste-to-energy (WtE) technology [7]. The potential for the global market for WtE technologies to produce around 13 GW of energy has increased dramatically despite the recent economic slump, according to predictions from the International Renewable Electricity Agency [8]. Due to advancements in technology, access to sufficient technical and analytical data, and political support, several WtE innovations show significant promise in industrialised nations [9]. This

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part investigation of character about attempts using the unique MCDM approach, notably the Multi-Objective Optimization Ratio Analysis (MOORA) method Finding the optimum technology for India's waste-to-energy programme is the study's main objective. The approach began with a review of the literature on MCDM techniques and their applications in waste management and energy planning. The second step was to study WtE technology in order to develop appropriate evaluation criteria for the selection process. Numerous technological and economic considerations are among the parameters taken into consideration in our analysis. Qualitative, quantitative, or a combination of the two can be used as scale weights. Quantitative weights are appropriate for case study topics where there is an abundance of publicly accessible survey data since they numerically reflect the qualities of alternatives. Comparatively, qualitative weights are better suitable for case study regions like India where there is a dearth of research data because they are based on decision makers' views and assessments of the characteristics of options. The current study employs a qualitative decision-making approach to get the desired results. MSW features and economics five participants with substantial experience and knowledge are given a survey on WtE technology for developing countries like India. Since expert judgements are hazy, hazy, and imprecise, the fuzzy change measure introduced by Zadeh can be used to describe the subjective features in numerical values (1965). As previously stated, expert opinions are subject to uncertainty and inaccuracy since human judgements are hazy and ambiguous. As a result, a sensitivity analysis was done to find out how the starting weights allocated to different experts affected the final ranking order of the WtE options.

Material and Methods

It This section's goal is to introduce important technologies that can be used to recover energy (electricity) from MSW and to explore how they are currently being developed at the cutting edge both worldwide and in the Indian context. Biochemical and thermo-chemical processes make up the two main categories of technologies used to produce power from MSW. In the former, materials are broken down by microbes to create biogas and other byproducts like biomethane and hydrogen. Wastes that encourage microbial activity and have a high biodegradable content are ideal for biochemical conversion processes. Thermal degradation, on the other hand, refers to a thermo-chemical conversion procedure that uses MSW to generate heat, gas, or oil. The optimum wastes for this process are those that are dry and include a significant amount of non-biodegradable material. These two WtE conversion methods provide biofuels that can be recovered and used in gas turbines, internal combustion engines, or boiler-steam turbines to produce energy. Both forms of WtE conversion methods can be used due to the features of India's MSW. Gasification, pyrolysis, anaerobic digestion, and plasma arc gasification are the thermochemical and biochemical processes used for this investigation. In the section that follows, the rationale for choosing these technologies will be covered in more detail. However, in the interim, other methods, including landfill gas to energy, plasma treatment, rejected derived fuel, thermal de-polymerization, hydrothermal carbonization, incineration, etc., are not taken into account because they are still in the early stages of technological development. Information about these technologies is often not readily available in the Indian context.

Anaerobic digestion: Anaerobic digestion (AD) is Uses litter to break down organic matter is a technique biologically with the aid of microorganisms to produce dig estate and biogas. The biological process of digestion occurs with little oxygen in a regulated setting. Producing biogas requires: a natural gas replacement that produces energy and heat, methane, carbon dioxide, and water must be added. Dig estate is another byproduct of AD that contains several nutrients and can be used as a bio-fertilizer. High methane (CH_4) and low carbon dioxide (CO_2) content are characteristics of AD (Francoli and Bolton, 2019). Pre-treatment, digestion, and post-treatment are the typical steps in an AD system's operation. To maximise biogas production, pre-treatment divides, categorises, and reduces waste volume in order to produce organic matter. The environment is then maintained at 6.7 pH and 55–60 C to encourage microbial digestion. The remainder of the filth was then removed. AD technology has a few benefits, such as the following: In addition to taking up less space than landfills, recovering resources and redirecting them from them also reduces GHG emissions, may be carried out on a smaller scale, and permits trapped gas generated for closed system use. The fundamental flaw with this approach is that it cannot be used to treat wastes with low quantities of organic matter, necessitating waste separation in order to improve the efficiency of digestion (Doslu et al., 2016). As sewage sludge and livestock manure are used in the majority of AD plants deployed globally, municipal solid waste (MSW) is a material that is difficult and underdeveloped.

Gasification: With the aid of gasification agents, carbonaceous waste (MSW) is converted into energy during the thermo-chemical process known as gasification at high temperatures (usually between 550 and 1000 °C). Through a variety of heterogeneous processes, a gasifying agent (another gaseous chemical) aids in converting the input into gas quickly. This process produces syngas, sometimes referred to as producer gas, It consists mainly of methane, carbon dioxide, carbon monoxide, and hydrogen. Depending on whether ambient air or air with lots of oxygen is used, the gasification process can create between 25% and 40% of the heat content of natural gas. The materials created by gasification can be used to produce high-value consumer items such as transportation fuels, chemicals, fertilisers, and natural gas substitutes, as opposed to only producing heat and electricity, similar to when waste is burned in a waste-to-energy facility.

Plasma arc gasification (PAG): During PAG operation, an arc is created in an electric arc gasifier by passing a very high voltage current between two electrodes. The complex feedstock's organic component might be turned into syngas (CO, H_2) by the plasma arc, which has a maximum operating temperature of 13,900 C, while the inorganic component may be transformed into vitrified slag. The heat recovered from a combined cycle design can be used to power a steam turbine, and the recovered sludge can be used for additional processing or to fuel a gas turbine. The absence of tars and purans at this temperature causes inorganic materials like silica, soil, asphalt, glass, gravel, and other inorganic elements to be electrified into a glass and discharged to the furnace's bottom. Metals all melt at this temperature. The main benefits of plasma arc gasification over conventional gasification and incineration are better handling of a variety of waste compositions and heating values, less pollution emissions due to higher temperatures, and effective power production due to integrated cycle design.

Pyrolysis: When the heating rate is quick, the majority of gases are created at temperatures above 800 °C, whereas when the heating rate is sluggish, solid residues are created at temperatures below 450 °C. Bio-oil is a liquid fuel that may be used in gas turbines and diesel engines to generate electricity. Paper, textiles, food waste, garbage (including fallen branches and leaves), plastics, and to a lesser extent, leather and rubber, as well as metals, glass, ceramics, earthy materials, and other items, make up the majority of MSW. Prior to being processed in a pyrolysis reactor, municipal garbage is manually processed to remove glass, metals, and inert elements. The three most popular pyrolysis reactor types are rotating reactors, rotary hearth reactors, and fluidized bed reactors. In comparison to incineration, pyrolysis is more desirable because it lessens CO2 pollution.

MCDM strategy Gasification was found to be the best option and plasma arc gasification to be the least viable WtE technology for investment in India based on MOORA's expert judgements. Under technical criteria, which primarily include annual power production, generation efficiency, and conversion efficiency, gasification is the best suitable technology; the only two economic criteria are NPV and LCOE. Given that gasification earned high priority in the first and second rank criterion, the total ranking outcome is hardly shocking. This result is consistent with research done in Bangladesh, Pakistan, and India, where the best WtE technology was discovered utilising MOORA techniques. Greater gasification-based power generation efficiency will aid the nation in supplying its energy requirements. As India's present waste management system struggles to keep up with rising waste, aggressive waste reduction is currently the government's main focus. This is because the country's current waste management system is unable to keep up with rising waste. Gasification is a preferable option since it may reduce waste weight by around 70%–80%. Given India's limited landfill capacity, gasification also becomes a viable option to reduce the volume of plastic, metal, and ceramic waste, which takes up more space in landfills due to their low degradability. Gas products can be used for a range of purposes, such as transportation, agriculture, and cooking, to produce energy and support other areas of the Ghanaian economy. Additionally, due to Ghana's climate, which is characterised by hot temperatures and intense sunlight, MSW can be thermally treated and transferred to a low-moisture gas. Technical and financial parameters are used to determine which WtE technology is best. Table 3 reviews and summarises these important WtE evaluation criteria. In MCDM problems, there are two different types of criteria, and maximum values (useful criteria) and lowest values are favoured (unfavorable criteria). They are also known as a positive (beneficial) and negative (beneficial) criterion or a benefit (beneficial) and cost (beneficial) criterion in some studies. For instance, WtE technology's cost is classified as negative criteria (ineffective/cost) since decision-makers frequently go for the least expensive option among available options. The WtE technology's efficiency is a benefit/beneficial/positive criterion since the most efficient item (highest efficiency) in a group is chosen during decision-making. Figure 5 shows a hierarchical structure for selecting the best technology for generating electricity from MSW from a techno-economic perspective.

Multi-objective planning (or programming), multi-attribute or multi-criteria sometimes referred to as optimization It contains more conflicting characteristics (notes) subject to certain restrictions. It is a simultaneous upgrade process. Design of goods and processes, finance, the design of aircraft, the oil and gas business, manufacturing, the design of automobiles, and other fields or trade exchanges where there are two or more competing objectives Many objective optimization issues must be solved in order to make the best choices. Profit maximization and Reducing the price of a product; increasing efficiency and Reducing vehicle fuel consumption; Increases the strength of a particular engineering component Weight loss is for multi-objective optimization problem Common examples are: Real-time production In context, Different interests and with values Decision making process by different decision makers They make it very difficult. In a decision problem, Objectives (Characteristics) Measurable to be, For each decision alternative their consequences can be measured Objective results provide a basis for comparing options, This makes it easier to choose the best (satisfying) option. Therefore, many multi-objective optimization techniques, Based on generally conflicting attributes from the set of available options To rank one or more alternatives or to choose It appears to be a suitable tool. Introduction of MOORA technique by Brauers It is a multipurpose The optimization technique is, This is in a production environment Various complications Decision making problems Solve successfully can be used. M is an indicator of the effectiveness of the ith alternative. Number is the parameter count, followed by n. The resulting team is then normalised, making all of its components equivalent and dimensionless. In relation to that criterion, this normalisation technique uses a ratio system. When compared to a class, representation of all possibilities shows substitution efficiency. Here are the details: It is acceptable to normalise things simply. xij is in the interval [0, 1] dimensionless number, It is in the jth scale Normalized of the ith substitution Indicates performance. Type of criterion (beneficial or unbeneficial) a decision matrix's constituent parts Despite the fact that are homogenised It is important to note here. Although the following normalization procedure is proposed, to a certain criterion Result Matrix Great value while having For that criterion normalized value it is too much than one Can occasionally be noticed. The maximum size value becomes less than one. As for the MOORA method, This is normalized Performance is beneficial Added to the criteria and useless criteria, Maximum criteria, to be reduced Number of criteria And all that Regarding the parameters yi is of substitution is an estimated value. When sorting in descending order, Best alternative assessment High value. To reach the final selection of candidate alternatives Hierarchical ranking of yi values is recommended. This time for stakeholders (decision makers), Breyers and Zavatskas demonstrated that correlations between objectives and objectives and alternatives are very robust. This method is considerably superior to other MCDM techniques now in use since it is objective and based on the most recent data.

Results and Discussions

The This section discusses the results of using the MOORA approach theory to select the best WtE technology for investment in India. The most crucial elements that determined the project's choice are listed in Table 8, which also demonstrates that gasification is the WtE technology that India can use that is both technologically and economically feasible, beating out the least desirable options of anaerobic digestion, pyrolysis, and plasma arc gasification. Figure 1 displays the ranking of WtE possibilities for each criterion.

TABLE 1 Alternative

A1	Anaerobic digestion
A2	Pyrolysis
A3	Gasification
A4	Plasma arc gasification

Alternative methods are presented in Table 1. Alternative methods for A1(anaerobic digestion), A2(pyrolysis), A3(gasification) and A4(plasma arc gasification).

TABLE 2 Evaluation parameters Criteria for segmental attractiveness

C1	Net present value
C2	Internal rate of return
C3	Conversion efficiency
C4	Generation capacity
C5	Energy generation per annum
C6	Initial investment
C7	Operations and Maintenance
C8	Levelized cost of energy
C9	Payback period
C10	Cost of electricity

Table 2 presents the evaluation parameters. Parameters for evaluating practices is net present value (C1), internal rate of return (C2), conversion efficiency (C3), generation efficiency (C4), energy generation per year (C5), initial investment (C6), operations and maintenance (C7), balanced Energy cost (C8), payback period (C9), and electricity cost (C10).

TABLE 3 given a data set

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C7**	**C8**	**C10**
A1	53.12	56.72	65.13	68.43	58.43	29.15	17.45	24.13	12	36.43
A2	46.10	68.43	79.43	61.34	65.39	33.69	16.31	11.69	18	27.30
A3	58.72	49.12	59.16	81.24	81.67	29.18	19.37	19.73	10	23.10
A4	69.45	77.28	35.69	79.13	39.46	24.60	22.43	34.36	9	17.59

Table 3 appears. a set of data. The data collection has high values for annual energy generation. The data set has low values for cannibalization. The data set for the techno-economic viability using the MOORA method is shown in For information on Table 3's Net present value, internal rate of return, conversion efficiency, generation capacity, annual energy production, initial investment, operations, and maintenance, levelized cost of energy, payback period, and cost of electricity, see Table 3.

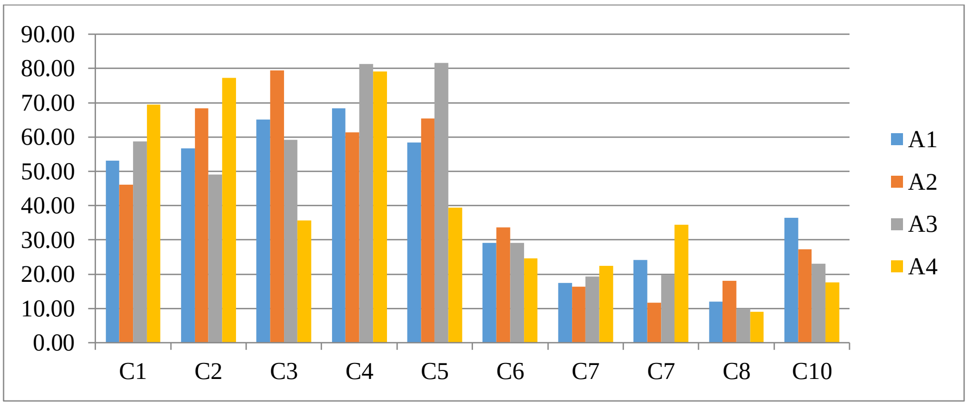

FIGURE 1 Give a data set graph

The data set for the following variables is shown in Figure 1: Net present value, Internal rate of return, Conversion efficiency, Generation capacity, Annual Energy Generation, Initial Investment, Operations and Maintenance, Levelized Cost of Energy, Payback period, and Cost of Electricity.

TABLE 4 square values for data set

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
A1	2821.7344	3217.1584	4241.9169	4682.6649	3414.0649	849.7225	304.5025	582.2569	144.0000	1327.1449
A2	2125.2100	4682.6649	6309.1249	3762.5956	4275.8521	1135.0161	266.0161	136.6561	324.0000	745.2900
A3	3448.0384	2412.7744	3499.9056	6599.9376	6669.9889	851.4724	375.1969	389.2729	100.0000	533.6100
A4	4823.3025	5972.1984	1273.7761	6261.5569	1557.0916	605.1600	503.1049	1180.6096	81.0000	309.4081
SUM(A1:A4)	13218.2853	16284.7961	15324.7235	21306.7550	15916.9975	3441.3710	1448.8204	2288.7955	649.0000	2915.4530

Table 3 shows the Data set of the Square values of the data set and sum of S1 to S6 Square values.

TABLE 5 Normalized Data

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C7**	**C8**	**C10**
A1	0.4620	0.4445	0.5261	0.4688	0.4631	0.4969	0.4584	0.5044	0.4710	0.6747
A2	0.4010	0.5362	0.6416	0.4202	0.5183	0.5743	0.4285	0.2443	0.7066	0.5056
A3	0.5107	0.3849	0.4779	0.5566	0.6473	0.4974	0.5089	0.4124	0.3925	0.4278
A4	0.6041	0.6056	0.2883	0.5421	0.3128	0.4193	0.5893	0.7182	0.3533	0.3258

Table 4 shows the data from which the normalized data is calculated from the data set value is divided by the sum of the square root of the column value. It is the Normalization of Data set of the net present value (C1), internal rate of return (C2), conversion efficiency (C3), generation efficiency (C4), energy generation per year (C5), initial investment (C6), operations and maintenance (C7), balanced Energy cost (C8), payback period (C9), and electricity cost (C10).

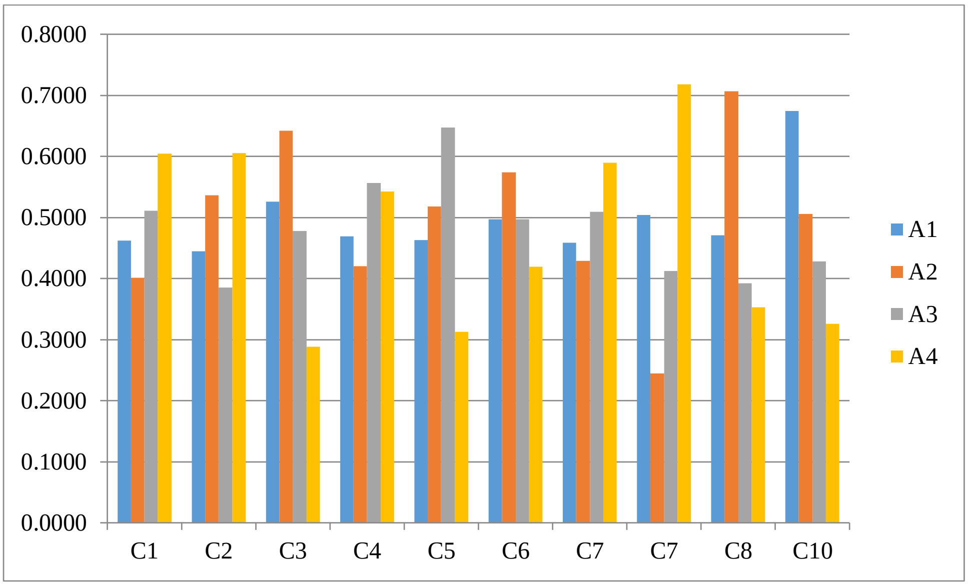

FIGURE 2. Normalized Data

Figure 2 shows the data from which the normalized data is calculated from the data set value is divided by the sum of the square root of the column value.

TABLE 6 gives weight matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C7**	**C8**	**C10**
A1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
A2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
A3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
A4	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Table 3 shows the weight of the data set the weight is equal for all the value in the set of data in the table 1. The weight is multiplied with the previous table to get the next value.

TABLE 7 Normalized decision matrix with weights

	C1	C2	C3	C4	C5	C6	C7	C7	C8	C10
A1	0.1155	0.1111	0.1315	0.1172	0.1158	0.1242	0.1146	0.1261	0.1178	0.1687
A2	0.1002	0.1341	0.1604	0.1051	0.1296	0.1436	0.1071	0.0611	0.1766	0.1264
A3	0.1277	0.0962	0.1195	0.1391	0.1618	0.1244	0.1272	0.1031	0.0981	0.1070
A4	0.1510	0.1514	0.0721	0.1355	0.0782	0.1048	0.1473	0.1796	0.0883	0.0814

Table 7 shows the weight of the data set the weighted normalized decision matrix seeing in figure 3.

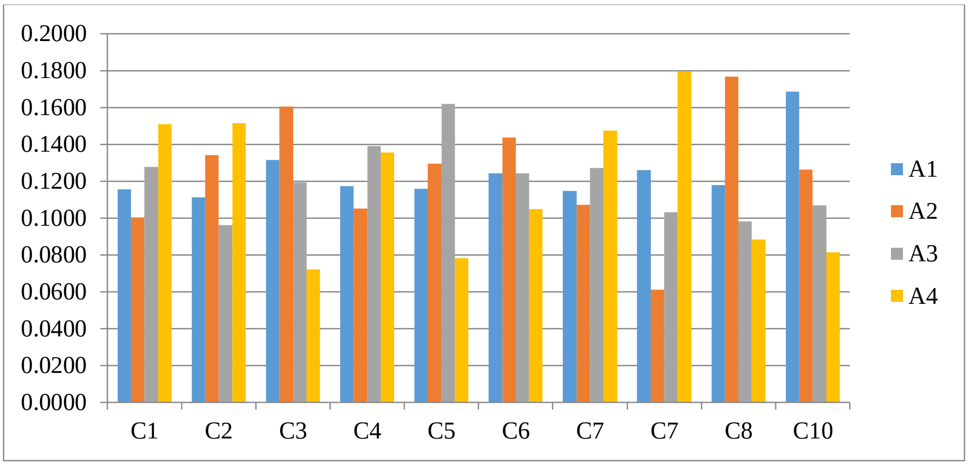

FIGURE 3 Normalized decision matrix with weights

Table 8 Assessment value

	Assessment value
A1	-0.0602
A2	0.0145
A3	0.0846
A4	-0.0133

Table 8 shows the weighted estimation value of the data is assigned to rank values seeing in figure 4.

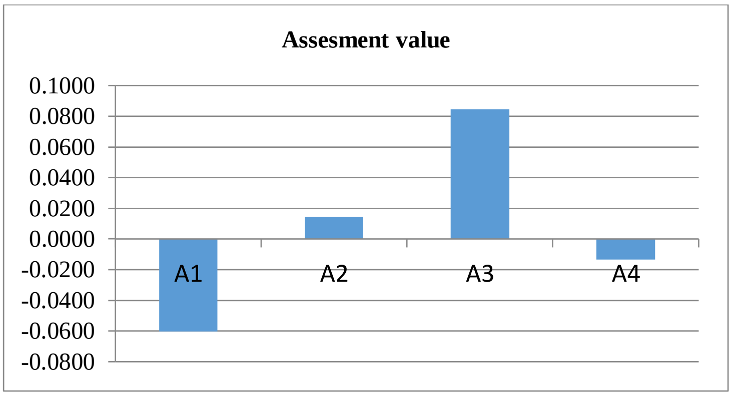

FIGURE 4 Assessment value

Figure 3 shows that the assessment value. A2 and A3 are positive values, A1 and A4 negatives values.

TABLE 9 Ranking

A1	Anaerobic digestion	4
A2	Pyrolysis	2
A3	Gasification	1
A4	Plasma arc gasification	3

Table 8 shows that the Gasification is in 1st rank, Pyrolysis is in 2nd rank, Plasma arc gasification is in 3rd rank and Anaerobic digestion are last rank. Figure 6 shown in ranking.

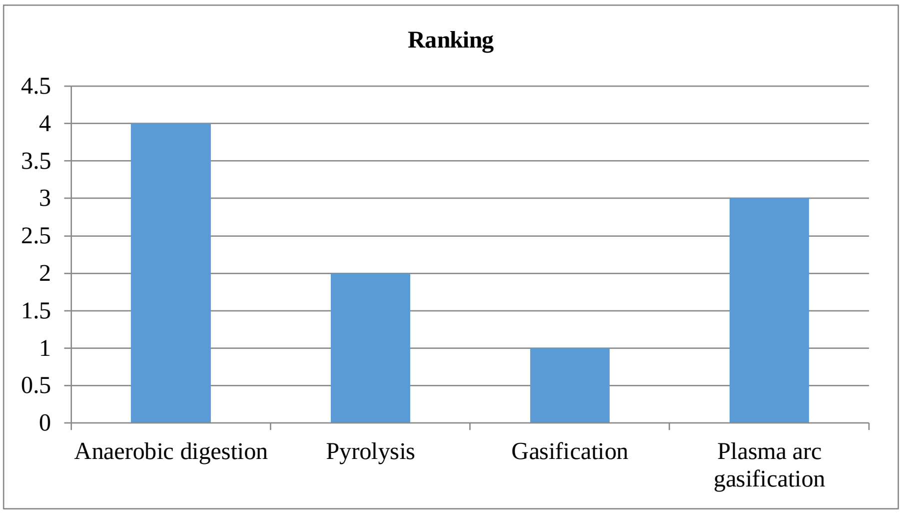

FIGURE 5 shown in ranking

Conclusion

India and other developing countries lack practical waste-to-energy system knowledge. Nearby landfills and open warehouses the volume of municipal solid waste is increasing. Which is leading to severe health and environmental issues, as well as the current electrical crisis, these waste-to-energy technologies provide it has forced the government to work on alternatives and adapt. For waste-to-energy development in India Possibilities has been explored. By giving a multi-criteria analysis, we add to the literature. Decisions are based on a combination of technical and financial considerations that simultaneously assess many waste-to-energy solutions. The four WtE solutions that have been assessed using techno-economic criteria are anaerobic digestion, gasification, pyrolysis, and plasma arc gasification. Income, payback period, power cost, and net present value. After the waste-to-energy alternatives had been examined by five carefully picked experts based on all the selection criteria, the alternatives were ranked using the MOORA multicriteria decision model. Anaerobic digestion is ranked first in terms of annual power generation, production efficiency, conversion efficiency, NPV, and LCOE O&M costs, IRR, repayment period, and initial investment Gasification comes in first place in terms of power cost. Based on the proportional weights of the key criteria, gasification has emerged as a waste-to-energy technology that is superior in India, according to overall ranking data. Utilizing the MOORA technique is simple. So, work with MOORA to solve dependency and feedback issues The author proposed the MCDM model, and It helps the decision makers to take optimal decision. On the other hand, between the complicating factors by establishing IR A problem of causality One of the scales used for measurement is MOORA. Therefore, the systematic and objective assessment model is more accurate MOORA is a great contribution to reflect. In other words, than traditional method to solve MCDM problem The MOORA research method is most suitable. Pyrolysis, Plasma arc gasification, and anaerobic digestion come next. The sensitivity analysis's findings, Very reliable despite changes in the early stages and showed that a stable result was still reached. Combining anaerobic digestion and gasification the results also proved to significantly improve waste management. A decision maker in India's waste-to-energy sector and research provides relevant information to potential investors.

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