Entropy-based Multi-criteria Analysis of Thermochemical Conversions for Energy Recovery from Municipal Solid Waste Using Fuzzy VIKOR and ELECTRE III: Case of Azerbaijan Region, Iran

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Rapidly population growth, higher living-standards, technological advancement and increasing diversity of solid waste have made solid waste management an important and urgent issue for most of the countries. In this study, we address the complexity of waste-to-energy (WtE) planning, considering energy security and sustainability, as a treatment for solid waste in the Azerbaijan region of Iran. Decision-making for energy planning includes multiple quantitative and qualitative criteria making reliance on crisp values very difficult. Hence, fuzzy logic with linguistic terms is used to consider the uncertainty in the criteria values that have been determined by a group of experts. In the first step, the Viekriterijumsko Kompromisno Rangiranje (VIKOR) is applied to select the best WtE technology. Suitable installation site is then chosen based on the ELimination Et Choix Traduisant la REalité (ELECTRE) III method. The Fuzzy entropy method has been developed to determine the weights of the criteria. A case study is completed for the Azerbaijan region of Iran. Plasma WtE technology has been found to be the best alternative for WtE energy technology and Zanjan province ranked as the best location for the establishment of the site. In the sensitivity analysis, plasma technology is predominantly ranked as the most appropriate technology through different cases of weights, each of which focusing on a specific aspect of criteria. A linear assignment method is used in sensitivity analysis for the WtE technology selection.

Keywords: *Energy security, Sustainability, Municipal waste management, Waste-to-energy, Multi-criteria decision making, Linear assignment method.*

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1. Introduction

Energy recovery from MSW known as waste-to-energy (WtE) studies in the literature has grown during recent years, proving to be a reliable option for MSW management. WtE technologies provide electricity and heat; reduce landfills; increase material recovery and recycling; mitigate the amount of CO_2; and decrease social and environmental impacts of MSW. Global waste generation will approximately increase to 2.2 billion tones by 2025 [6]. Studies regarding WtE technologies and policies in Iran stem from the necessity of urgent MSW management strategies for approximately 65 million tons MSW annually which is expected to reach 75 million in 2022. This amount for the Azerbaijan region accounts for 5 million tons annually. The Azerbaijan region (Fig 1) is located in the northwest part of Iran, including four provinces: East Azerbaijan (A_1), West Azerbaijan (A_2), Ardabil (A_3) and Zanjan (A_4) with a population of about 4,320,000 (Fig 1). Iran predominantly relies on landfills to manage MSW; however, wastes are being diverted from landfills based on new legislation and strategies concerning waste management. In particular, in Azerbaijan region, the most common way to dispose of wastes is unsanitary landfills in city outskirts. On the other hand, in our case, the Azerbaijan region is located in the northwest of Iran, in which the amount of electricity consumption is high due to the high density of population and cold climate. Also, more than fifty industrial sites with a high number of factories producing a broad range of goods are another reason for high electricity demand in this area.

This area of Iran is highly sensitive and critical since its contribution to the economy of the country is undeniable. This is why energy sustainability and security are two important factors that should always be taken into account in all stakeholders' decisions. Energy security definitions vary based on different situations in time; however, an appropriate definition is given by [7]. This definition, defines energy security as an uninterrupted supply of energy that is critical for the functioning of an economy. Energy security is influenced by several factors such as energy availability, infrastructures, energy prices, social effects, environment, governance, energy efficiency and geography [8]. In this study, we have considered environmental and geographical factors to measure energy security. Energy sustainability is another crucial factor in most of today's countries. As with energy security, there are many definitions of energy sustainability considering society, the economy and the ecology. Energy sustainability can be defined as: dynamic harmony between equitable availability of energy-intensive goods and services for all people and the preservation of the earth for future generations. The solution will lie in finding sustainable energy sources and more efficient means of converting and utilizing energy. As one of the biggest electricity generators in Middle East, Iran always exports a noticeable amount of electricity to its neighbors such as Iraq, Armenia and Turkmenistan. Iran exports about 2000 MWh electricity weekly. Considering the high electricity consumption rate in Iran, sustainability in the electricity capacity should be at the top priority. The electricity distribution network exports electricity to the foreign customers from the closest electricity distribution centers throughout the country. Therefore, not only Azerbaijan region must meet its own electricity demand, but it must also supply the required electricity to export to bordering countries [9]. This issue highlights the presence of new alternative renewable energy sources such as WtE technologies to permanently satisfy the total internal and external electricity demand. In addition, these new energy alternatives must constantly be taken under severe security actions to ensure their availability.

Efficient collection and disposal scenarios and methodologies need to be developed by municipal authorities to manage the gradually growing MSW. Due to its noticeable consequences and effects on the economy and environment, the selection of an efficient methodology requires a comprehensive analysis of many factors. Decisions on this issue are made considering the composition of the solid waste generated in a given area. This means that an efficient scenario or methodology for solid waste management of a city may be inappropriate in another area or city. At this point, the necessity for fast and accurate tools and methods to model the decision alternatives becomes apparent, since the selection of MSW treatment methodology is a complex and multi-dimensional issue. Waste composition is based on the socio-economic structure level of the area in which wastes are produced. In developing countries like Iran, the volume of solid waste is increasing due to industrialization and changes in life standards [10].

WtE technologies in Iran face many challenges such as economic crisis, policy uncertainty and competition with non-renewable resources that are obstacles for the further development and extension of WtE technologies. These challenges plus other possible related issues put investors and energy policy-makers in situations that makes decision-making more complex. Municipalities of several cities in Iran are contracting with foreign companies to construct a WtE power plants. Further, municipalities in Iran has to deal with power plant type and location.

The selection of WtE technologies for a specific location is a complex problem requiring great effort to investigate several criteria which cannot be dealt with manually, except with multi-criteria decision-making methods. Multi-criteria decision-making methods (MCDM) help decision makers compare and evaluate several alternatives based on multiple criteria. MCDM tools are broadly used in the energy industries, in the selecting waste management alternatives and in location selection [11-17]. Fluctuations in real-life conditions lead to the results obtained from these methods do not stay same all the time. Because of this, researchers consider the uncertainty in the methodologies under different uncertainty sets such as fuzzy and grey numbers [14,18]. Considering technical, economic, geographic and demand uncertainties, MCDM methods based on fuzzy logic seem to be more useful. Fuzzy sets were introduced to express linguistic terms to address the complexity and uncertainty in problems [19].

In this paper, we first aim to compare thermochemical WtE technologies for energy recovery (electricity production) from MSW using an integrated fuzzy Entropy-VIKOR. Then we select a suitable location for a WtE plant using an integrated fuzzy Entropy-ELECTRE III for the Azerbaijan region of Iran with a newly focus on energy security.

Fig. 1. Azerbaijan region, Iran

The rest of the paper is structured as follows. In section 2, we review recent studies related to MSW treatments and energy recovery from MSW. In the next section, we present the problem description. Decision-making methods are presented in section 4. In section 5, numerical results of the case study are reported, and the conclusion is given in section 6.

2. Literature

In recent years, studies related to energy recovery from waste have been one of the growing research areas in the literature due to global and local MSW management problems. These studies have mostly aimed to efficiently organize current WtE plants, compare WtE technologies, reduce MSW volumes and select location for plants. The selection of WtE technology is a complex and intricate problem which consists of several quantitative and qualitative criteria such as political, social, technical, financial and environmental factors [10,14,20].

A solid waste management system is classified into two categories; integrated and sustainable solid waste management systems [21]. The main function of an integrated waste management system is to treat the waste produced over a period of time in a certain area in a proper manner [22]. A sustainable solid waste management system can be defined as an integrated management program considering economic, political, environmental, social-cultural and technical components [23]. A general overview of solid waste data and management practices employed in Turkey is provided during the last decade. Municipal solid waste statistics and management practices including waste recovery and recycling initiatives were evaluated. The results showed that paper and also cardboard are the main composition for recycle waste [24]. Detailed data on solid waste management practices including collection, recovery and disposal, together with the results of cost analyses, were presented. Based on these evaluations basic cost estimations on the collection and sorting of recyclable solid waste in

Turkey were provided. Generation, characteristics, and management of solid waste was evaluated in Malaysia based on published information. They proposed a new institutional and legislation framework with the objectives to establish a holistic, integrated, and cost-effective solid waste management system, with an emphasis on environmental protection and public health [25].

MSW studies in Iran have started likely in late 1990s and increased exponentially during recent years. The status of MSW and its management was analyzed in Tehran in order to draw a strategy regarding their generation, collection, processing, recycling and safe disposal [2]. MSW management status in Rasht, Iran was studied considering the changes in population and lifestyle. The results indicate that MSW management in city with 400 tons per day is well-organized [26]. MSW source reduction potential was quanitifed in Tehran. Then, they outlined the principles and strategies about source reduction. Findings showed that potential for reduction of MSW mass in Tehran is 66% [27]. The potential of dry municipal solid waste recyciling was assessed in Mashahd, Iran via questinaries that were prepared for municpality authorities and people. Results showed that by cosnidering different types of waste composition, the recycling system is not well-designed and needs to be improved [28]. The amount and composition of wastes generated within all key campus operational areas was determined in order to approach the best strategy for waste management in the University of Tabriz. It is indicated that by using educational and policy strategies more than 80% of waste can be reduced through recycling and other means [29]. The status of MSW management practices in the Isfahan, Iran. They implemented an analysis of economic benefits that could be realized by implementing incineration and a discussion of the challenges confronted in Isfahan for implementing changes to the city’s existing MSW management system [6]. Generation, characterization and management strategies of solid wastes in Zanjan, Iran was investigated. By examining the waste composition, they showed that current approach for MSW management is appropriate [30]. Integrated waste management of Isfahan, Iran was investigated through several aspects. They analyzed the current situation as well as opportunities and challenges regarding municipal solid waste management in Isfahan according to the integrated solid waste management framework in six aspects. By taking into account the investigation, the main suggestions for future integrated solid waste management of Isfahan are as i) promoting financial sustainability by taking the solid waste fee and reducing the expenses through the promoting source collection of recyclable materials, ii) improving compost quality and also marketing the compost products simultaneously, iii) promoting the private sector involvements throughout the municipal solid waste management system [31].

Rabbani and his colleagues proposed multimodal transportation system to minimize the total costs of the waste collection routing problem and environmental effects of waste transportation. Genetic algorithm is used to solve the model and the results were validated with the result obtained from GAMS software [32]. A multi-tiered reverse logistic model is proposed for waste management in the presence of stochastic waste generation ratio while considering cycling, remanufacturing, social cost and greenhouse gas emissions for Tehran. Several case studies were also completed for the problem and then they used Taguchi method for the cost of the parameters. Results showed that the proposed model is practical for real-life problems [33].

Multi-criteria decision-making methods (MCDM) is an important support decision tool in the waste management and energy planning as decision making in WtE technology selection is very complex due to large number of factors that contribute to the final decision. Recently, the number of studies using MCDM methods for energy industry has increased noticeably. Most of these studies focus on the MSW treatment technologies and location selection [12,13,16].

A fuzzy multi-criteria decision analysis alongside with a geospatial analysis is presented for the selection of landfill sites. It employs a two-stage analysis synergistically to form a spatial decision support system (SDSS) for waste management in a fast-growing urban region, south Texas. The first-stage analysis makes use of the thematic maps in Geographical information system (GIS) in conjunction with environmental, biophysical, ecological, and socioeconomic variables leading to support the second-stage analysis using the fuzzy multi-criteria decision-making as a tool [34]. A conceptual framework and methodological tool developed for the evaluation of different anaerobic digestion technologies suitable for treating the organic fraction of municipal solid waste, by introducing the multi-criteria decision support method ELECTRE III and demonstrating its related applicability via a test application. Several anaerobic digestion technologies have been proposed over the last years; when compared to biogas recovery from landfills, their advantage is the stability in biogas production and the stabilization of waste prior to final disposal [35].

MCDM methods were presented for renewable energy selection and location selection by using integrated VIKOR-AHP methods for Istanbul, Turkey. Wind energy at Catalca district is selected as the best alternatives [14]. A modified fuzzy TOPSIS method was proposed for the selection of appropriate disposal method for MSW. The weights of the selection criteria are determined by fuzzy pairwise comparison matrices of Analytic Hierarchy Process (AHP). For the location, the result is same as [14]. The results also indicated that weights of criteria strongly effect the final ranking [36].

A multi-criteria decision-making methodology was developed that can be used to evaluate the trade-offs between the benefits, opportunities, costs and risks of alternative energy from waste technologies in both developed and developing countries. The technologies considered are mass burn incineration, refuse derived fuel incineration, gasification, anaerobic digestion and landfill gas recovery. They produced a preference ranking by incorporating quantitative and qualitative assessments [17].

An extended TOPSIS was used to choose the appropriate MSW treatment alternative. VIKOR method was used to validate the results obtained in first step. The mix of recycling and anaerobic digestion and a sanitary landfill with Electricity Production (EP) are the preferred options for MSW management [37]. A fuzzy TOPSIS and PROMOTHEE was used for the selection of solid waste disposal methodology. The applicability of these methodologies is also investigated for Turkey [10]. A AHP model was presented to select the optimal WtE technology including anaerobic digestion, pyrolysis and plasma for Dhaka, Bangladesh considering technological, environmental and economic criteria in [38]. A novel group multi-attribute decision analysis method was presented for prioritizing the MSW treatment alternatives based on the interval-valued fuzzy set theory. Multiple stakeholders participate in the process of decision-making and they are allowed to use linguistic variables to rate the alternatives and determine the weights of the evaluation criteria. DEMATEL method was developed to determine the weights of the evaluation criteria under interval-valued fuzzy set theory. Then, multi-actor interval-valued fuzzy grey relational analysis was developed to rank the waste-to-energy scenarios [39].

A study was done on selecting the location and allocation decisions on landfills and incineration power plant. They proposed multi-objective model to minimize the revenue of selling the recovered energy and visual pollution impacts issued from municipal solid waste. Results of a case study in Tehran shows the reduction on methane emissions of landfills and also an increase in amount of generated power recovery [40].

To best of our knowledge, no research is conducted in the literature to study the MSW management and WtE energy recovery for this region. Besides, there is no integrated entropy with any decision-making methods used for WtE problem. Energy security and energy sustainability are also new criteria used for evaluation of WtE alternatives. We first aim to compare thermochemical WtE technologies (Fig 3) for energy recovery (electricity production) from MSW using integrated fuzzy Entropy-VIKOR, then we select a suitable location for the WtE power plant using integrated fuzzy Entropy-ELECTRE III for Azerbaijan region of Iran.

3. Material and Methods

For a country, energy is one of the key indicators of the economic development and sustainability. The necessity of deriving energy from renewable sources has increasingly emerged recently even in countries with exhaustible non-renewable resources such as oil. Although there are enough non-renewable sources such as oil, gas and gasoline in Iran, environmental factors have deeply affected energy derivation and consumption. The Renewable Energy and Energy Efficiency organization (SATBA) is responsible to take strategies and make regulations for the energy derivation of renewable resources in Iran. With the support of SATBA and Ministry of Energy, a noticeable number of contracts have been agreed on with the cooperation of foreign companies in order to increase the capacity of WtE technologies around the big cities. For a country like Iran, this would greatly contribute to an increase in the electricity generation rate and a decrease in insalubrious landfills and MSW mass.

Considering the pros and cons of each technology and political regulations, waste management requires policy-makers to take into account several criteria rather than merely an individual criterion to address the problem. To solve this problem, we use MCDM analysis with several criteria to select the best and most suitable WtE technology and WtE plant for the Azerbaijan region. Three experts have been asked to evaluate both the technologies and locations by using fuzzy values with respect to the criteria in the next section.

3.1 Thermochemical WtE technologies

WtE generation technologies are divided in two major types, thermochemical conversion and biochemical conversion. Thermochemical conversion includes incineration, gasification, pyrolysis and plasma. Landfill gas recovery and anaerobic digestion are categorized in biochemical aconversion. Net electricity energy driven from each thermochemical technology is shown in Table 1. As shown in Table 1, Plasma is the top electricity generator with 816 kWh/ ton MSW. Gasification, Pyrolysis and Incineration are other three technologies that can generate electricity [41]

Table 1. Thermochemical technologies [41]

Thermochemical technology	Net electricity generation (kWh/ ton MSW)
Incineration	544
Pyrolysis	571
Gasification	685
Plasma	816

3.1.1 Incineration

The WtE option, is the process of combusting MSW masses to a gaseous phase, while aggregating non-combustible materials as solid residue. An appropriate boiler is used to energy recovery as the hot gases pass through it [42]. This process is commonly used technology for WtE and reduce over the 90% volume of the MSW. A report by Indian government namely manual on municipal solid waste management in 2000 states that 300 tons per day incineration plant requires approximately 0.8 hectares of land. Overall conversion efficiencies are typically in the region of 18–26% [43]. Incineration of waste with high moisture content can lead to energy losses through drying.

The power generation process is divided into several techno- logical processes. After removing the incombustible and poisonous waste, the MSW is put into waste collection pool. After being carried, stirred and fed, the component of MSW is roughly the same. The waste incineration system includes three parts, receiving the waste, incinerating in the secondary combustion chamber and taking out slags. Poisonous and harmful materials are fully decomposed at a high-temperature of 800–1000 °C. After the purification by soot-eliminating devices, the flue gas could be recovered through waste heat recovery system. The hot steam with a certain temperature and pressure can be used to produce electricity [43].

Energy recovery system represents a substantial part of the whole technology which enables to utilize heat contained in flue gas from incinerators or combustion chambers as much as possible [44].

However, after MSW incineration, the flue gas includes some pollutants, such as acid gases, heavy metals, dioxins, etc. After some treatments or facilities, such as absorption and purification, activated carbon adsorption and bag house, the harmful materials of the flue gas could be removed effectively. Emission standards must be fulfilled before flue gas discharging [45]. The waste leachate is produced in the waste collection pool. It contains a variety of pollutants such as organic matter, ammonia, heavy metals, which are high in concentration, often changed by time, weather, etc. The waste leachate must be dealt with by the wastewater treatment station before being sent away.

3.1.2 Gasification

Gasification is a high-developed thermochemical MSW treatment with partial oxidation of a substance [17]. Gasification technology requires a pre-treatment before the main process which is deeply depended on the design of gasification reactor [46]. Syngas is the main product of the gasification that can be converted into energy, chemical feedstock and liquid fuels. The efficiency rate at which waste can be converted to electricity is 18-22%, however, it is suggested that with the use of a gas engine or a gas turbine, the efficiency rate can be increased to 26-28% and 30%, respectively [47]. Gasification can approximately reduce the volume of the waste up to 95%. CO_2 emissions are around 114 CO_2 / KWH which is less than the same in the incineration. There is no gasification plant in Iran, and it is unlikely to be established in coming years due to its high pretreatment cost.

3.1.3 Pyrolysis

In contrast to incineration and gasification, pyrolysis is a thermochemical MSW treatment with the complete absence of the oxygen. Pyrolysis is very sensitive to MSW composition and waste have to be separated before the treatment. An external heat between 300 °C and 850 °C to maintain the temperature is required for conversion.

Like gasification, the main product of this technology is syngas, with other products such as char and oil [48]. Preventing long-distance transportation of wastes, flexible scale and low capital cost are more concerned advantages of the pyrolysis [49]; however, with great development in pyrolysis technology in recent years, it is not operated broadly which is mostly in research level. Burgau in Germany is the only pyrolysis plant in operation since mid-1950s [43]. Recently, there has been some movements to establish pyrolysis plants for energy derivation from tires.

3.1.4 Plasma

Plasma arc gasification is an efficient and relatively a high-temperature gasification process with a focus more on destruction the hazard materials rather than energy recovery. Most suitable waste composites for plasma plants are organic wastes that have been investigated for last thirty years in small-scale plants [50]. Other types of solid wastes used in this process just led to a by-product called vitrified slag. Plasma gasification uses extremely high temperatures in an oxygen starved environment to decompose organic waste materials into basic molecules. The extreme heat and lack of oxygen results in pyrolysis and gasification reactions taking place, which convert the waste into syngas. The heat source is plasma gas, which is generated by the input of electrical energy to a gas (usually air). The plasma gas is the hottest, sustainable heat source available attaining temperatures between 3,000 °C and 8,000 °C [51]. Syngas driven out from MSW in plasma plants has the net efficiency of 31%.

3.2 MSW management in Azerbaijan region

Azerbaijan region is located in north west region of Iran including four provinces. With the total population of 4,320,000 in 39,573 hectares. As shown in Fig 2, a large proportion of MSW composition in this region includes organic wastes [52-56]. This region is one of the main electricity consumers due to its cold climate and also plenty industrial districts. The common policy for the MSW in the region is the use of landfills in suburbs. However, even these limited number of landfills are constructed technically poor to handle the large amount of MSW generated each day. In our study, we consider four metropolises namely Tabriz, Urmia, Zanjan and Ardabil to evaluate the suitable plant location to be established. In recent decade, most of these cities have dealt with MSW with conventional methods but since a few years ago, it turned out that increasing rate of MSW generation and large amount of MSW masses cannot be dealt with only landfills as most of their capacities were not that much enough.

In the Azerbaijan region, there are almost eleven active power plants. Except Meshkin-shar geothermal power plant with the 55 MW capacity electricity generation, others use natural gas and fuel oil as their primary fuel to generate energy. Electricity distribution network in Iran is integrated which can be explained in two points. First, all plants sell their generated electricity to one unique distribution system, then the electricity generated in one state can be used in other states, too. In this step, we can see this by two different points of view. First that electricity generation in Azerbaijan region does not satisfy the demand and considerations should be taken into account to exploit other sources such as MSW to increase the power capacities. Second assumption claims that current electricity generation in Azerbaijan region can completely satisfy the demand, but cities have to take policies to deal with MSW masses and one of efficient ways is to derive electricity from it.

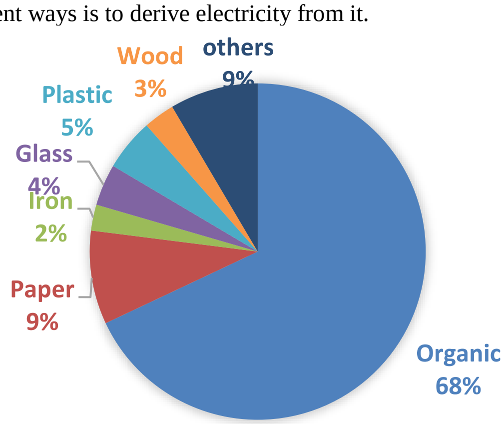

Fig. 2. MSW composition in Azerbaijan region [51-55]

3.3 MCDM methods

Multi-criteria decision-making methods are a group of tools that are used for managerial decision-making in manufacturing centers, business incorporations, logistics problem, energy management, stock market and several other organizations in which managers have to consider more than one criterion to make decisions. Regarding the complexity and importance of decisions, several methods with different extensions are formulated in literature.

In this study, fuzzy VIKOR and fuzzy ELECTRE III are used for the evaluation of the alternatives with respect to criteria. Fuzzy VIKOR is used to select WtE technology in Azerbaijan region. Then, fuzzy ELECTRE III is used to select location for the WtE plant.

Table 2. Fuzzy evaluation scores for the alternatives

Linguistic terms	Fuzzy score
Very poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very good (VG)	(9,10,10)

The importance weight of each criteria is obtained by fuzzy entropy which is introduced in [57]. This method is based on Information entropy, a measurement for the disorder degree of a system. The given information's usefulness can be evaluated by the data entropy. In this study the information about a criterion stands for the weight of the criteria. When the difference of the value among alternatives for a criterion is high, then the entropy for that criteria is small. it means that, this criterion provides more useful information, and the weight of this criteria should be set appropriately high. For a triangular fuzzy variable (r_1, r_2, r_3), ξ, entropy is as follows:

$$H(\xi) = \int_{r_1}^{r_3} S\ (\mathrm{Cr}\{\xi = x\})dx = \frac{1}{2}\ (r_3 - r_1) \tag{1}$$

After obtaining the weights of criteria, we asked three experts to rate the alternatives with respect to each criterion with linguistic terms of Table 2. Then, in next step, the fuzzy decision-making problem can be represented in decision matrix as follows:

Where $\widetilde{x_{ij}}$ is the rating of alternative A_i with respect to criterion j and W_j $(W = [w_1, w_2, \dots, w_n],\quad j = 1,2, \dots, n)$ denotes the importance weight of each criterion. To summarize the methodology, the steps of the fuzzy VIKOR approach are given in Fig 3.

$$x = \begin{bmatrix} x_{11} & . & . & x_{1n} \\ . & . & . & . \\ . & . & . & . \\ x_{m1} & . & . & x_{mn} \end{bmatrix} \tag{2}$$

In this paper, we have utilized fuzzy ELECTRE III, as a fuzzy-based MCDM method for dealing with uncertainties in the problem. ELECTRE III requires an input of criteria evaluations for the alternatives, called decision matrix, preference information, expressed as weights, thresholds, and other parameters. The alternatives' performances can usually be determined with ‘‘certain accuracy”, and the imperfect knowledge about the evaluations can be taken into account when defining the thresholds for the model.

Following concepts used in ELECTRE III method are defined as follows: $F = [g_1, \dots, g_n]$ is the set of criteria. J donates the set of criteria indices. $A = [a, \dots, a_n]$ is the set of alternatives.

$W = [w_1, \dots, w_n]$ is the weight vector that is calculated by fuzzy entropy method. $g_i(a_i)$ is the evaluation of criterion g_i for action a_i.

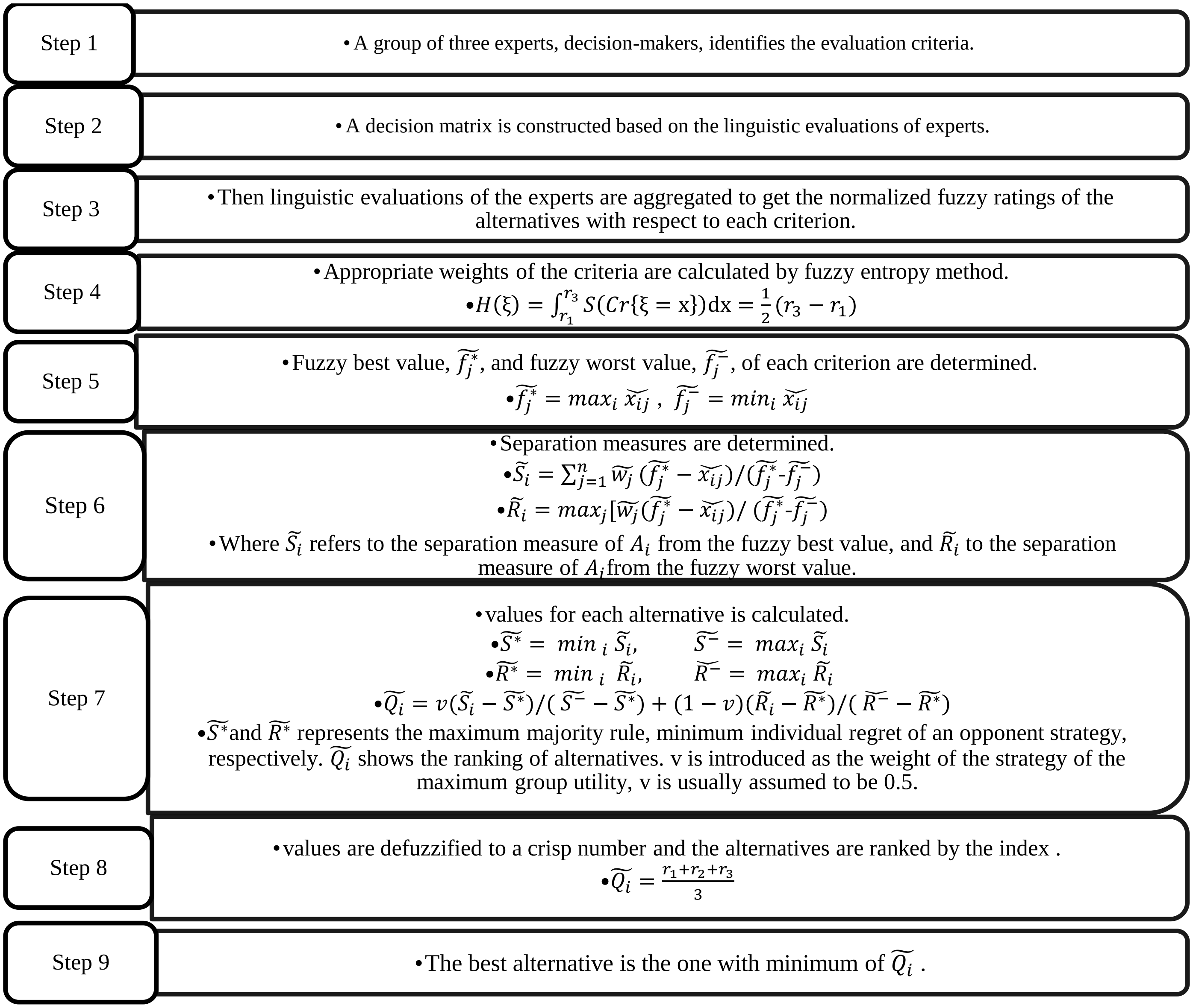

Fig. 3. Fuzzy VIKOR steps

Comparison of two alternatives *a* and *b* is as follows:

- *P* is the strong preference relation, that is *a*P*b* denotes the relation ‘‘*a* is strongly preferred over *b*”.
- *I* is the indifference relation, that is *a*I*b* denotes the relation ‘‘*a* is indifferent to *b*”.
- *Q* is the weak preference relation, that is *a*Q*b* denotes the relation ‘‘*a* is weakly preferred over *b*”, which means hesitation between indifference and preference.
- *R* is the incomparability relation, that is a*R*b denotes that action a and b are incomparable.
- *S* is the outranking relation, that is a*S*b denotes that ‘‘a is at least as good as b”.
- > is the preference relation, that is *a* > *b* denotes that *a* is preferred (strongly or weakly) over *b*.
- q_j is the indifference threshold for the criterion g_i.
- p_j is the preference threshold for the criterion g_i.
- v_j is the veto threshold for the criterion g_i.

Concerning the coalition of criteria in which a*S*b:

$$J^s = \{ j \in J : g_i(b) - g_i(a) \leq q_j(g_i(a)) \} \quad (3)$$

Concerning the coalition of criteria in which aQb:

$$J^Q = \{ j \in J : q_j(g_i(a) \leq g_i(b) - g_i(a) \leq p_j(g_i(a)) \} \quad (4)$$

To summarize the methodology, the steps of the fuzzy ELECTRE III approach are given in Fig 4.

An improved ranking method has been introduced instead of the normal ranking method, since it requires an additional threshold to be introduced. The ranking of alternatives in this method depends on the amount of the threshold for which there is no correct value [57]. The concordance credibility degree is defined by:

$$\phi^+(A_i) = \sum_{b \in A} S(a,b) \quad (5)$$

The concordance credibility degree is the measure of the outranking character of b (how b dominates all the other alternatives of A). The discordance credibility degree is defined by:

$$\phi^{-}(\mathrm{A}_i) = \sum_{b\in A} S(b,a) \quad (6)$$

The discordance credibility degree gives the outranked character of b (how b is dominated all the other alternatives of A). The net credibility degree is defined by:

$$\phi(\mathrm{A}_i) = \phi^{+} + (\mathrm{A}_i) - \phi^{-} + (\mathrm{A}_i) \quad (7)$$

The net credibility degree represents a value function, where a higher value reflects a higher attractiveness of alternative (A_i) . Then, alternatives can be ranked based on the net credibility degree.

Step 1
- A group of three experts, decision-makers, identifies the evaluation criteria.

Step 2
- A decision matrix is constructed based on the linguistic evaluations of experts, then they are aggregated and normalized to get a mean value for each alternative.

Step 3
- Linguistic evaluations of the experts are aggregated to get the fuzzy ratings of the alternatives with respect to each criterion.

Step 4
- Appropriate weights of the criteria are calculated by fuzzy entropy method.
- $H(\xi) = \int_{r_1}^{r_3} S(Cr\{\xi = x\})dx = \frac{1}{2}(r_3 - r_1)$

Step 5
- Fuzzy values of indifference threshold q_j and preference threshold p_j are determined.

Step 6
- Partial and comprehensive concordance function are calculated.
- $c_j(a,b) = \begin{cases} 1 & g_j(a) + q_j \geq g_j(b) \\ 0 & g_j(a) + p_j \leq g_j(b) \\ (p_j + g_j(a) - g_j(b))/(p_j - q_{j)} & otherwise \end{cases}$

Step 7
- After computing the partial concordance indices, the comprehensive concordance index is calculated as a weighted sum:
- $C(a,b) = \sum_{j\epsilon J} w_j * c_j(a,b)$

Step 8
- The discordance of a criterion gj describes the veto effect that the criterion provides against the assertion aSb. The discordance indices are computed separately for all criteria.
- $d_j(a,b) = \begin{cases} 1 & g_j(a) + q_j \geq g_j(b) \\ 0 & g_j(a) + p_j \leq g_j(b) \\ (g_j(b) - g_j(a) - p_j)/(v_j - p_{j)} & otherwise \end{cases}$

Step 9
- In ordinary ELECTRE III, the outranking relation is constructed by defining the credibility of the assertion aSb as follows (Tervonen, 2004):
- $S(a,b) = \begin{cases} C(a,b) & \forall j \;\; d_j(a,b) \leq C(a,b) \\ C(a,b) * \prod_{j\epsilon J} \frac{1-d_j(a,b)}{1-c_j(a,b)} & otherwise \end{cases}$

Step 10
- Use net credibility degree, based on equations (2)-(4), rank the alternatives

Fig. 4. Fuzzy ELECTRE III steps

3.4 Case study

In this study, we have evaluated the suitability of WtE technology and the location for a WtE plant in the Azerbaijan region considering the most frequent technical, environmental, economic and social criteria. Almost all of the criteria used in this paper are derived from related research papers in the literature. We also introduce a new criterion, named Energy Security. The criteria used in this study for technology selection are categorized according to technical, economic, environmental and social criteria, and their sub criteria are as follow:

- **Technical criteria:**

Efficiency (C1): Net obtainable electricity from an energy source, which is generally defined as the ratio of the output energy to the input source in an energy conversion process. This is the most prevalent criterion to evaluate energy systems. In this study, this criterion refers to a power generation of a system (kWh/ ton solid waste).

Inadequate waste segregation (C2): This criterion measures the availability of a desired waste type to be processed for each technology, the maximum amount of moisture that can be processed in each technology, and the ability to process wet waste.

Lack of skilled resources/technical expertise (C3): This criterion measures the shortage of available local skilled labors and technical experts to be employed in the plants.

- **Economic criteria**:

Initial investment cost (C4): This criterion compromises all the cost pertaining to the installations, mechanical equipment, constructions of the road and all incidental constructions.

Operating and maintenance cost (C5): Operation and maintenance cost consist of fixed and variable wages and service costs for the energy.

Technology accessibility (C6): This criterion measures the access to buy the mechanical equipment of each technology from local or foreign companies.

Pretreatment cost (C7): Pretreatment cost consists of all the costs of the services to segregate the waste type to be processed in each technology.

- **Environmental criteria**:

Emissions (C8): Emissions of WtE technologies compromise a group of molecules such as NO_x, CO, CO_2 and other materials which contribute to air pollutions.

Land use suitability (C9): This criterion measures the minimum amount of land to construct each type of plants.

Air quality (C10): This criterion considers the prevalence air quality of each province. It is needless to say that the air quality plays an important role.

- **Social criteria**:

Employment potential (C11): Employment potential of energy systems has significant concern among people and government. This criterion evaluates the energy system by measuring the job opportunities they make.

Social support (C12): A qualitative criterion that considers public opinions toward energy systems. It dramatically stems from the time to finish the project.

Governmental support (C13): Prospective governmental programs in the field of renewable energies development and funding, concerning each technology of thermochemical power generation.

The technical criteria for location selection are as follows (Fig 5). *Energy security (C14)* is important because power generation plants as a basic industry of a country play an indispensable role in economic development. The sustainability and continuity of power supply of national network grid is in order to stabilize the energy cost. the average electricity demand in each province along a year is *electricity demand (C1۵)* criteria. The quantitative criterion, *plants per person* (*C1۶*), evaluates the total number of plants in each province per person. *Solid waste generation rate (C۱۷)* is the amount of waste production rate in each province. *Solid waste management (C۱۸)* evaluates solid waste management organizations in a province, the more an organized management system we have, the more the energy out of waste can be derived. *Environmental criteria are landfill availability (C1۹), population growth (C۲۰)* and *unemployment rate (C2۱)*. The more the Population growth, the more the energy consumption. Unemployment rate demonstrates the need for job creation and available potential for employment. This criterion measures the population growth using current population growth rate.

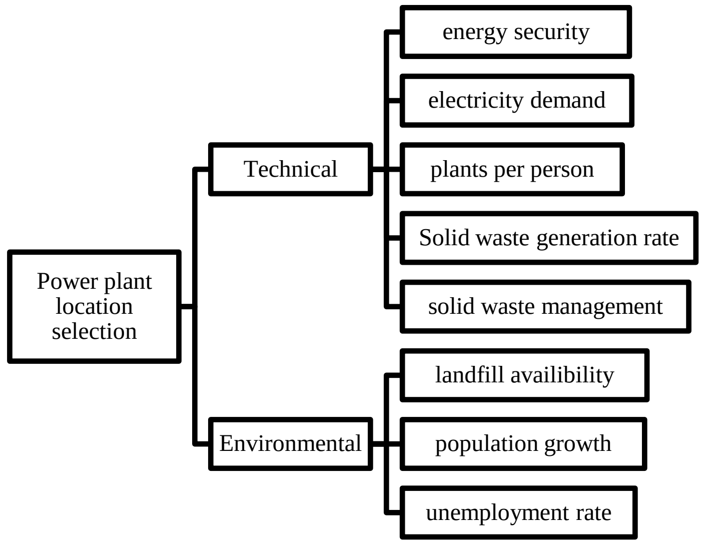

Fig. 5. power plant location selection criteria

4. Results and discussion

Three experts including E_1, E_2 and E_3 evaluated four technology alternatives, Incineration, Pyrolysis, Gasification and Plasma with respect to the criteria as explained in section 3.4. The experts evaluate alternatives based on linguistic terms expressed in Table 2. Then the decision matrix containing the whole of evaluations presented in Table 3. For example, in the decision matrix, the scores of the all of experts for A_1 with respect to criterion C_1 are medium good (MG). Then, based on the steps of Fig. 3, Values in fuzzy matrix are first combined for all experts scores and then normalized. Fuzzy normalized evaluation matrix of technology alternatives and the weight scores of each criterion is calculated with fuzzy entropy method are presented in Table 4. Then, we calculated fuzzy separation measures of each alternative from the best fuzzy and worst fuzzy values in Table 5. Then, the results for $\check{S}^*, \check{S}^-, \check{R}^*, R^-$ values are (0.38,0.42,0.90), (1.10,1.15,1.47), (0.06, 0.07,0.10) and (0.22,0.22,0.22), respectively. Finally, the ranking of the alternatives is shown in Table 5 by the defuzzification of $\check{Q}_i$. According to the last step, the best alternative is A_4 (Plasma). The orders of the other alternatives are Pyrolysis, Gasification and Incineration.

Table 3. Decision matrix by experts for WtE technology alternatives

A_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	E1:MG E2:MG E3:MG	E1:MP E2:P E3:MP	E1:MG E2:MG E3:MG	E1:G E2:G E3:G	E1:MG E2:MG E3:MG	E1:F E2:MG E3:MG	E1:P E2:P E3:MP	E1:MG E2:MG E3:MG	E1:G E2:G E3:G	E1:F E2:P E3:MP	E1:F E2:MP E3:F	E1:P E2:VP E3:MP	E1:F E2:P E3:MP
A_2	E1:G E2:G E3:G	E1:MG E2:MG E3:MG	E1:MG E2:MG E3:MG	E1:MG E2:MG E3:MG	E1:MG E2:MG E3:MG	E1:G E2:G E3:G	E1:F E2:F E3:F	E1:P E2:P E3:P	E1:F E2:F E3:F	E1:MG E2:MP E3:F	E1:MG E2:MG E3:MG	E1:MG E2:MG E3:F	E1:MG E2:MG E3:F
A_3	E1:MG E2:MG E3:G	E1:MG E2:MG E3:G	E1:VG E2:VG E3:VG	E1:VG E2:VG E3:VG	E1:G E2:G E3:G	E1:MG E2:MG E3:MG	E1:MG E2:MG E3:MG	E1:P E2:P E3:P	E1:F E2:F E3:F	E1:MG E2:MP E3:F	E1:F E2:MP E3:F	E1:MG E2:MP E3:F	E1:MG E2:MP E3:F
A_4	E1:G E2:G E3:VG	E1:MG E2:MG E3:G	E1:VG E2:VG E3:VG	E1:VG E2:VG E3:VG	E1:VG E2:VG E3:VG	E1:F E2:F E3:MP	E1:MG E2:MG E3:MG	E1:MP E2:MP E3:P	E1:MP E2:MP E3:MP	E1:MG E2:MP E3:F	E1:F E2:MG E3:MG	E1:G E2:MP E3:F	E1:F E2:MP E3:F

Table 4. Normalized fuzzy evaluation matrix of technology alternatives and criteria weights

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A1	(5,7,9)	(0,2.08,4.21)	(5,7,9)	(7,9,10)	(5,7,9)	(4.21,6.25,827)	(0.1.44,3.55)	(5,7,9)	(7,9,10)	(0,2.46,4.71)	(2.08,4.21,6.25)	(0,0,2.46)	(0,2.46,4.71)
A2	(7,9,10)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,10)	(3,5,7)	(0,1,3)	(3,5,7)	(2.46,4.71,6.80)	(5,7,9)	(4.21,6.25,8.27)	(4.21,6.25,8.27)
A3	(5.59,7.61,9.32)	(5.59,7.61,9.32)	(9,10,10)	(9,10,10)	(7,9,10)	(5,7,9)	(5,7,9)	(0,1,3)	(3,5,7)	(2.46,4.71,6.80)	(2.08,4.21,6.25)	(2.46,4.71,6.80)	(2.46,4.71,6.80
A4	(7.61,9.32,10)	(5.59,7.61,9.32)	(9,10,10)	(9,10,10)	(9,10,10)	(2.08,4.21,6.25)	(5,6.25,8.27)	(0,2.08,4.21)	(1,3,5)	(2.46,4.71,6.80)	(4.21,6.25,8.27)	(2.75,5.12,7.04)	(2.08,4.21,6.25)
W	0.09	0.04	0.19	0.22	0.13	0.04	0.04	0.08	0.03	0.03	0.01	0.06	0.04

Table 5. Separation measures of A_i from the fuzzy best, fuzzy worst values and final ranking

	$\breve{S}_i$	$\breve{R}_i$	$\breve{Q}_i$	Q_i	Ranking
A_1	(1.10,1.14,1.47)	(0.19,0.19,0.19)	(0.54,0.89,0.90)	0.78	4
A_2	(1.01,1.08,1.19)	(0.22,0.22,0.22)	(0.53,0.54,0.55)	0.54	3
A_3	(0.48,0.50,0.86)	(0.08,0.08,0.08)	(0.01,0.07,0.10)	0.06	2
A_4	(0.38,0.42,0.90)	(0.06,0.07,0.08)	(0.00,0.00,0.00)	0.00	1

Table 6. Experts evaluation of WtE location alternatives and criteria weights

	C_{10}	C_{12}	C_{14}	$C_{1٥}$	$C_{1٦}$	$C_{١٧}$	$C_{١٨}$	$C_{1٩}$	$C_{٢٠}$	$C_{2١}$
A_1	(5,7,9)	(7,9,10)	(221,271,321)	(6400,7200,8000)	(3,5,7)	(0.5,0.6,0.7)	(7,9,10)	(5,7,9)	(0.56,0.66,0.76)	(0.06,0.07,0.08)
A_2	(3,5,7)	(5,7,9)	(225,305,355)	(4500,5000,5500)	(1,3,5)	(0.3,0.4,0.5)	(3,5,7)	(3,5,7)	(1.3,1.4,1.5)	(0.09,0.1,0.11)
A_3	(7,9,10)	(5,7,9)	(443,493,543)	(1300,1500,1700)	(0,1,3)	(0.6,0.7,0.8)	(3,5,7)	(1,3,5)	(0.23,0.33,0.43)	(0.105,0.115,0.125)
A_4	(5,7,9)	(3,5,7)	(524,574,624)	(2800,3200,3600)	(1,3,5)	(0.25,0.35,0.45)	(1,3,5)	(3,5,7)	(0.94,1.04,1.14)	(0.09,0.1,0.11)
W	0.03	0.03	0.08	0.22	0.16	0.07	0.12	0.07	0.20	0.03

For the second phase, the scores of alternatives are shown in Table 6 which consist of real-world data and linguistic scores. Score values are defuzzied in next step. As same as the first phase, we used fuzzy entropy to obtain the weights of the criteria shown in Table 6. In the next step, we calculated concordance and discordance values for alternatives. The results are presented in Table 7. Following this, we calculated $S(A_i,A_k)$ for alternatives that are also shown in Table 7. Finally, the ranking is summarized in Table 8 which shows the order of the alternatives. The values for $\phi(A_i)$ in the Table 8 shows that highest value is for fourth alternative, A_4 (Zanjan). So, this is ranked as the first alternative. Ardabil, Urumie and Tabriz are ordered in the following rankings, respectively. So, based on the primal experts' idea the best decision is establishment of Plasma power plants in Zanjan province.

Table 7. Concordance, discordance values and Credibility of the assertion

Alternatives	$C(A_i,A_k)$				$D(A_i,A_k)$				$S(A_i,A_k)$			
	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4
A_1	1	0.79	0.91	0.81	1	1	1	1	1	0	0	0
A_2	0.62	1	0.90	0.94	1	1	1	1	0	1	0	0
A_3	0.35	0.45	1	0.63	0.78	0.99	1	1	0.12	0.01	1	0
A_4	0.44	0.83	0.93	1	0.91	1	0.94	1	0.07	0	0.91	1

Table 8. Ranking of alternatives with net credibility degree

Alternatives	φ^+	φ^-	φ	Ranking
A_1	1	1.19	-0.19	4
A_2	1	0.19	0.81	3
A_3	1.12	0.19	0.93	2
A_4	1.98	0.07	1.91	1

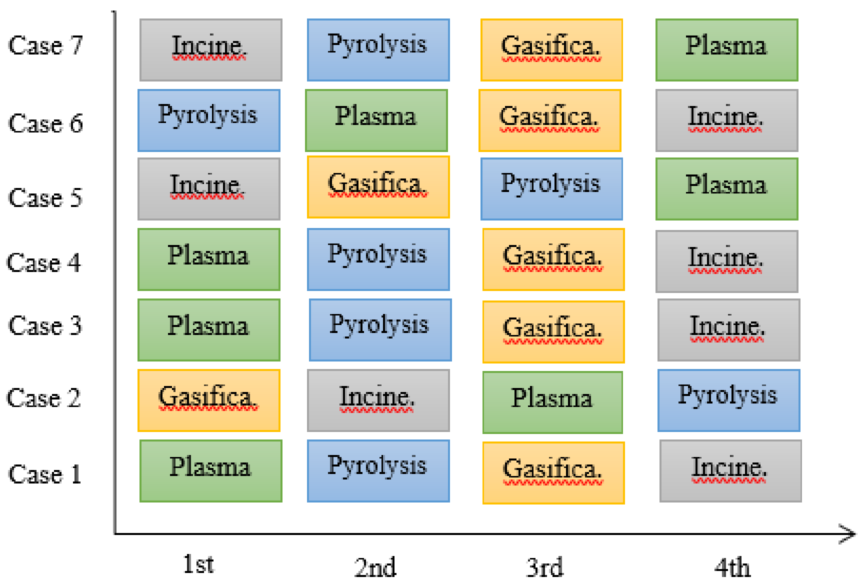

Fig. 6. Results of the sensitivity analysis of technology alternatives

4.1 Sensitivity analysis

In this part, we considered a procedure to perform a sensitivity analysis. For technology selection, we used different criteria weights. The results are presented in Fig 6. Case 1 is the current order of weights. Weights in both Case 1 is generated by experts. Case 2 and Case 3 are generated by authors. Weights in Case 4, Case 5, Case 6, Case 7 are generated with respect to economic, technology, environment and social preferences, respectively. Criteria weights in the sensitivity analysis are given below:

Case 1: W= (0.09, 0.04, 0.19, 0.22, 0.13, 0.04, 0.04, 0.08, 0.03, 0.03, 0.01, 0.06, 0.04)

Case 2: W= (0.12, 0.01, 0.19, 0.3, 0.05, 0.04, 0.04, 0.01, 0.05, 0.03, 0.01, 0.04, 0.02)

Case 3: W= (0.05, 0.04, 0.08, 0.3, 0.17, 0.06, 0.02, 0.07, 0.05, 0.04, 0.04, 0.06, 0.02)

Case 4: W= (0.09, 0.4, 0.1, 0.25, 0.14, 0.04, 0.14, 0.01, 0.03, 0.03, 0.01, 0.02, 0.1)

Case 5: W= (0.19, 0.1, 0.25, 0.1, 0.03, 0.04, 0.04, 0.08, 0.03, 0.03, 0.01, 0.06, 0.04)

Case 6: W= (0.05, 0.04, 0.1, 0.1, 0.1, 0.04, 0.04, 0.2, 0.15, 0.11, 0.01, 0.02, 0.04)

Case 7: W= (0.09, 0.04, 0.09, 0.08, 0.1, 0.04, 0.04, 0.05, 0.03, 0.03, 0.11, 0.16, 0.14)

Following results are obtained from comparison of cases. New weights have changed the ranking of the alternatives dramatically. In case 4, we considered to focus more on economic aspect and increased the weights of related criteria in which the result was as the case 1. In case 5, we slightly increased the weights of technical criteria. Incineration and Gasification have switched their orders. In case 6, a sudden increase in environmental criteria switched order of Pyrolysis to the best alternative. With a decrease in criteria except for social ones, Incineration was ranked as the most suitable alternative; however, unlike the case1, Plasma was placed in the last rank.

Pyrolysis to the best alternative. With a decrease in criteria expect social ones, Incineration was ranked as the most suitable alternative; however, unlike the case1, Plasma was placed in the last rank.

Next, we use a fuzzy linear assignment method for the optimal selection of WtE technologies with respect to different cases introduced in former part. As, it is visible from Fig 6, we cannot definitely select an optimal alternative for our problem, since there are fluctuations in the ranking of alternatives in each case. Here, we utilize this method for the first time in WtE technology selection literature.

In this method, we assign fuzzy weights for the cases introduced in sensitivity analysis section derived from three experts. Scores of alternatives are obtained from the Fig. 6. The steps of the method are summarized as follows:

Step 1: We consider cases as the criteria in original problem.

Step 2: Asses the importance of each case C_j by three experts, using linguistic variables.

Step 3: Convert the linguistic terms into triangular fuzzy numbers. $\widetilde{W}_{jt} = (a_{jt}, b_{jt}, c_{jt})$, j = 1,…,n (*n*=7); *t* = 1,..,k (*k*=3).

Step 4: Then, Pool the experts' opinion to get the aggregated fuzzy $\widetilde{W}_{jt}$ for each case. The aggregated fuzzy weight of case C_j can be computed as:

$$\tilde{W}_{jt} = (\tilde{W}_{j1} * \tilde{W}_{j2} * ... * \tilde{W}_{jk})^{1/k} \quad \textbf{(8)}$$

Step 5: Construct non-negative matrix π_{ip} whose element represent the summation of the fuzzy weights of the cases in which A_i is ranked the *p*th attribute-wise ranking.

Step 6: Defuzzification of matrix π_{ip} in order to change the fuzzy number $\widetilde{Q}_i(r_1, r_2, r_3)$ to a crisp number as:

$$\tilde{Q}_i = \frac{r_1 + r_2 + r_3}{3} \quad \textbf{(9)}$$

Step 7: Solve a linear assignment programming described below to get the ranking of the alternatives. Let us define y_{ik}=1 when A_i is assigned to rank p, and y_{ik}= 0 otherwise.

$$\max \sum_{i=1}^{4} \sum_{p=1}^{4} \pi_{ip} y_{ip} \quad \textbf{(10)}$$

$$s.t.$$

$$\sum_{p=1}^{4} y_{ip} = 1 \qquad \forall i = 1,...,4 \quad \textbf{(11)}$$

$$\sum_{i=1}^{4} y_{ip} = 1 \qquad \forall i = 1,...,4 \quad \textbf{(12)}$$

Linguistic term weights obtained from experts are reported in Table 9. We converted these linguistic terms into fuzzy numbers in Table 10. The aggregated fuzzy weights of each case is also shown in Table 10.

Table 9. Fuzzy evaluation scores for the weights

Linguistic terms	Fuzzy score
Absolutely strong (AS)	(2,5/2,3)
Very strong (VS)	(3/2,2,5/2)
Fairly strong (FS)	(1,3/2,2)
Slightly strong (SS)	(1,1,3/2)
Equal (E)	(1,1,1)
Slightly weak (SW)	(2/3,1,1)
Fairly weak (FW)	(1/2,2/3,1)
Very weak (VW)	(2/5,1/2,2/3)
Absolutely weak (AW)	(1/3,2/5,1/2)

Based on Table 10 and ranking of alternatives with respect to each case in Fig. 6, we constructed the fuzzy matrix $\tilde{\pi}_{ip}$ as follows:

$\tilde{\pi}_{ip}$=

	1st	2nd	3rd	4th
A_1	(1.39,1.74,2)	(1,1.14,1.44)	(0,0,0)	(4.59,5.71,7.38)
A_2	(1,1.14,1.44)	(0.6,0.87,1)	(5.38,6.58,8.38)	(0,0,0)
A_3	(1.25,1.55,2.08)	(4.13,5.03,6.30)	(0.6,0.87,1)	(1,1.14,1.44)
A_4	(3.34,4.16,5.30)	(1.25,1.55,2.08)	(1,1.14,1.44)	(1.39,2.42,3.08)

After obtaining the matrix $\tilde{\pi}_{ip}$, we converted fuzzy numbers to crisp numbers shown as π_{ip}. Then, we solved the linear assignment model introduced by equations (1) – (4) using CPLEX solver in GAMS. Followings are final results of linear assignment model with X as the optimal permutation matrix.

π_{ip}=

	1st	2nd	3rd	4th
A1	1.71	1.19	0	5.89
A2	1.19	0.82	6.78	0
A3	1.62	5.15	0.82	1.19
A4	4.26	1.62	1.19	2.29

Table 10. Importance weights of criteria in terms of fuzzy numbers for each experts (E_d)

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
E_1	(2,5/2,3)	(1,1,3/2)	(1,1,1)	(1,3/2,2)	(2/3,1,1)	(2,5/2,3)	(1,1,1)
E_2	(3/2,2,5/2)	(1,1,1)	(2/3,1,1)	(1,1,3/2)	(1/2,2/3,1)	(1,1,3/2)	(1,1,1)
E_3	(3/2,2,5/2)	(1,3/2,2)	(1/2,2/3,1)	(1,1,3/2)	(2/3,1,1)	(1,3/2,2)	(1/2,2/3,1)
W	(1.65,2.15,2.65)	(1,1.14,1.44)	(0.69,0.87,1)	(1,1.14,1.65)	(0.60,0.87,1)	(1.25,1.55,2.08)	(0.79,0.87,1)

In second phase, we generated three random indifference threshold and preference threshold for each criterion. Case 1 shows the current indifference and preference thresholds. The sensitivity results of this part is represented in Fig 7.

In comparison to case 1, Zanjan city almost is chosen as the suitable location for production site in most of the cases by being ranked first or second. In case 3, Tabriz city is found the best alternative among others. Ardabil city has switched its ranking to the first alternative in case 4.

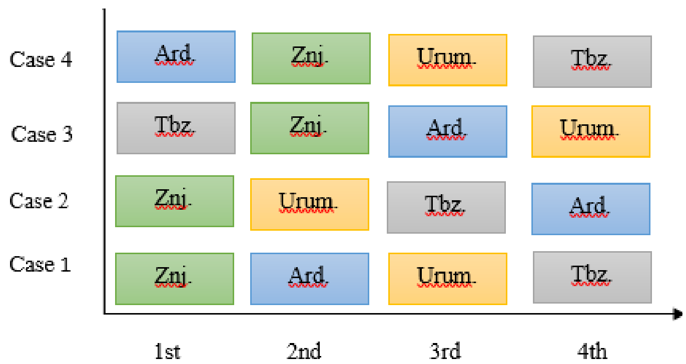

Fig. 7. Results of the sensitivity analysis of production location

5. Conclusion

In this paper, we proposed two integrated decision-making methods for evaluating and selecting WtE technologies and production location. For the complexity and uncertainty in the data and also qualitative criteria, we have utilized fuzzy linguistic values. Scores for alternatives in both methods are obtained from three experts. In determining the weights of the criteria, fuzzy entropy is used in order to express the fuzziness in weights, too. In the first and second part, steps of VIKOR and ELECTRE III methods were implemented. Azerbaijan region of Iran was presented as a case study. The plasma technology and Zanjan city were found to be the most suitable alternatives in each part.

Our analyses based on results obtained from decision making methods shows that the application of WtE technologies in this region would led to advantageous solutions. First, Iranian government totally supports the establishment of WtE power plants in the country based on the enacted laws explained in Introduction section. WtE power plants would strongly decrease the unemployment rate in this region by providing many new jobs for the local people. Besides, MSW generation rate is experiencing an increasing trend in this region as well as other parts of Iran. The total amount of waste increased by 14% in this region during 2012-2017. With respect to traditional, unhealthy and low-capacity landfills around cities and the necessity to manage the huge mass of generated MSW, we believe that WtE power plants will both decrease the large mass of MSW and landfills usage. Iran acts as one of the major electricity exporter in the middle east. High domestic electricity demand and also the amount being exported to the foreign countries reveal the suitably of having WtE power plants to satisfy the total demand.

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