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A Decision Framework for Electric Vehicle Charging Station Site Selection for Residential Communities under an Intuitionistic Fuzzy Environment: A Case of Beijing

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Abstract: Electric vehicle charging station (EVCS) site selection occupies a prominent position in the development of the electric community to solve the hard problem of Electric Vehicle (EV) charging. However, two critical issues have not been solved by the existing research. Firstly, the scope of EVCS site selection only considers the whole city, which deviates from the actual situation. Secondly, the uncertainty and hesitation of decision information is not well expressed. To handle the above problems, this paper builds a comprehensive EVCS site selection decision framework for Residential Communities (EVCSRC) with triangular intuitionistic fuzzy numbers (TIFNs). First of all, the distinctive index system of EVCSRC site selection factors including economy, social, environment, planning and feature portrait of residential communities is established. Then, the TIFNs is utilized for decision makers (DMs) to express the indeterminate information. Furthermore, a fuzzy Vlsekriterijumska Optimizacija I Komprorisno Resenje (Fuzzy-VIKOR) approach is utilized to rank the alternative EVCSRC sites. Finally, a case of Beijing is studied to demonstrate the validity of the proposed site selection framework. The result shows the EVCSRC site located at Sijiqing community in Haidian district should be selected as the optimal site. This paper presents a feasible and easy-to-use decision-making framework for investors.

Keywords: electric vehicle charging stations; residential community; triangular intuitionistic fuzzy numbers; Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

1. Introduction

With the rapid growth of energy consumption, energy shortages and energy-related environmental pollution have become increasingly severe problems that have attracted worldwide attention. EVs, which have energy saving, zero emissions and pollution free characteristics, have entered a period of rapid development. The Chinese government promotion and public response have accelerated the popularization and use of EVs, which is not only regarded as the focus of the transformation and upgrading of the automobile industry, but also as the key point of the implementation of long term energy strategy adjustment plans. China's efforts have been encouraged by the importance attached by people to the increasingly serious issue of environmental pollution such as the threat of haze. Since the period of 12th Five Year Plan, ensuring the development of EVs has become an important measure to promote the development of urban low-carbon and energy-saving activities. The construction of charging facilities is regarded as an important guarantee for the promotion of EVs.

Nowadays, a number of mega cities are on the list of first batch of key demonstration cities to enhance the promotion and application of EVs in China. However, each mega city is made up of different functional areas, such as residential communities, commercial areas, industrial areas and road traffic. Thus it can be seen that the construction of EVCS in different functional areas cannot be carried out blindly using a uniform standard because the construction objectives are different. At present, the EV charging infrastructure plans of every city all emphasize particularly that it is necessary to standardize the construction of charging facilities for residences, making solved the difficulty of charging in residential communities become the core problem. There are two main difficult points: one is that the mega city is commonly surrounded by many large residential communities with high density and large area. The other is that the demographic characteristics of these residential communities are so diverse that the charging requirements are different. Hence, the construction of charging facilities in residential communities faces the problem of meeting different requirements and priorities.

The site selection of EVCSRCs is a necessary and practical issue. First of all, an outstanding location can save construction, operation and maintenance costs which improves the economic efficiency. The second, the chosen site could meet the needs of more residents to enhance public satisfaction. In addition, a series of environmental pollution problems can be avoided by a feasible location. Ultimately, an excellent site with good service capabilities and scalability for the community can provide a guarantee of sustainable development. Consequently, the site selection for EVCSRCs is a multi-criteria decision-making (MCDM) problem. MCDM is a well-known branch of decision-making, which aims to find the most suitable solutions from a set of alternatives under multiple criteria conditions.

Nowadays, issues related to the development of EVs are being widely studied in China, but few consider EVCS site selection. Guo and Zhao [1] employed the fuzzy Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS) to consider criteria from a sustainability perspective for EVCS site selection. Wu et al. [2] selected an optimal EVCS site based on a cloud model and the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE). Zhao and Li [3] provided a comprehensive and effective method for optimal siting of EVCS based on four considerations: economy, society, environment and technology perspectives. It can be seen that MCDM approaches provide effective decision-making framework for EVCS site selection with multiple criteria systems. Nevertheless, there are still many problems in the decision-making process for EVCSRC site selection, which causes the decision-making frameworks to be far from reality.

Firstly, EVCS site selection lacks the pertinence of the functional area. On the one hand, different functional areas have different city assignments to perform so that the convergence of people and supporting facilities are different. For instance, the behavior of people is diverse in commercial and residential areas which both with high concentrations of population. On the other hand, the same functional areas in different places are different as well, such as average income level, population structure, and per capita vehicle ownership and so on. Therefore, different evaluation criteria systems should be proposed for different functional areas to implement investment decisions before the EVCS construction starts.

Secondly, vagueness and hesitation generally exist in EVCS site selection decision making. For one thing, it is difficult for DMs to predict accurately and quantified precisely based on existing survey information and before the construction of an EVCS. For another thing, DMs' evaluation is not only ambiguous, but there is a situation of hesitance, so that the degrees of satisfaction and dissatisfaction cannot be predicted accurately. That is to say, the decision is made in a vague and hesitant environment. Hence, how to express the uncertainty of the DMs and how to express the different dimensions of the evaluation information are the problems faced by the EVCS site selection problem.

Hence, this paper aims to establish a practical and comprehensive decision-making framework for EVCSRC site selection. For the aforementioned issues, we propose the following solutions:

To begin with, an index system of EVCS site selection specifically for residential communities is established. It includes not only economic criteria, social criteria, environmental criteria, and planning criteria, but also a portrayal of the target residential community, in order to select a superior residential community alternative. Then, the TIFNs replace the numerical value to represent the DMs' score value. TIFNs take into account the maximum degree of membership and the minimum degree of non-membership on the basis of triangular fuzzy numbers, while the decision maker's the degree of the indeterminacy membership can be expressed accurately. After that, to ensure the rationality of determining the weights, we combine an analytic hierarchy process (AHP) with maximum cross entropy to determine the subjective and objective weights of attributes and use the TOPSIS method to determine the weights of DMs. Finally, the fuzzy VIKOR method is used to rank the alternatives. The necessary steps of establishing the framework are shown in Figure 1. It is mainly composed of three stages: preliminary work, execution of evaluation and process the data of evaluation results. The establishment of the framework is done by the different steps of each stage.

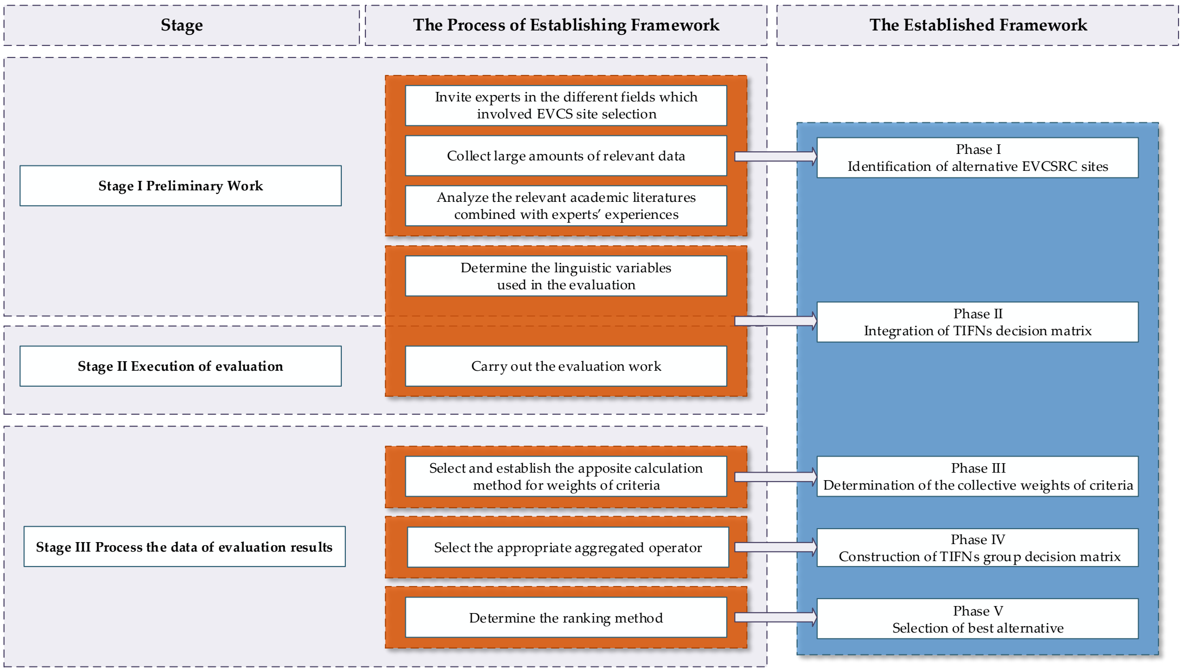

Figure 1. The stages and process of establishing the framework.

The remainder of this paper is composed as follows: Section 2 reviews the defects and insufficiency of the current EVCS site selection research, and major applications of the methods used in this paper. Section 3 elaborates the major factors that influence EVCSRC site selection and establishes the evaluation index system. The definitions and theorems used in this paper are presented in Section 4. Section 5 gives a minute description of the decision framework for EVCSRC site selection. Section 6 takes six Beijing exemplary residential communities as a case study to apply the overall process. Afterwards, a sensitivity analysis and comparative analysis are carried out. The last section concludes the whole paper.

2. Literature Review

A reasonable evaluation system, an accurate description of uncertain information, an apposite ranking method and practicable framework occupy crucial positions in the MCDM of EVCS site selection.

From the perspective of the evaluation system, the EVCS site selection problem was studied comprehensively to reflect the inherent characteristics of EVCS siting. Guo and Zhao [1] built an evaluation index system from a sustainability perspective, which consists of environmental, economic and social criteria. A set of comprehensive evaluation attributes proposed by Wu et al. [2] not only considered the aforementioned factors, but also focused on engineering feasibility, service availability and geographical environment. Reference [3] established an evaluation index system including four aspects: economy, society, environment and technology. Thirteen attributes in consideration of transportation, economy, society and effect were applied in EVCS site selection by [4]. Although the coverage of the evaluation index is extensive, these studies lack specific targeted scope.

With respect of qualitative information, many scholars have applied linguistic values rather than numerical values to evaluate the alternatives, which can overcome the representation obstacles of intricate study objects. In the research of site selection, interval valued fuzzy sets [5,6], triangular fuzzy number [7–11] and trapezoidal fuzzy number [12–14], and intuitionistic fuzzy sets [15] were used to transfer between linguistic variables and quantitative information. However, the vague concept and the degree of the indeterminacy membership, which is regarded as a significant component of uncertainty, are not simultaneously focused on.

In terms of the ranking methods for site selection, we review the MCDM basic methods as follows: AHP, analytic network process (ANP), TOPSIS, PROMETHEE, and Elimination et Choix Traduisant la Realité (ELECTRE). A combination of geographic information systems and AHP was used to determine the best sites for disposal of municipal solid waste in Iran [7,16]. A TOPSIS method to determine flood hazard scores can be easily utilized for site selection of other stormwater management techniques [17], meanwhile, site selection of EVCS, nuclear power plant, and a faculty of management considered predetermined environmental criteria by using fuzzy TOPSIS [1,12,18]. PROMETHEE was applied to choose the best EVCS [2], logistics freight center [8], locations for the implementation of industrial activities [19], and combined with ANP to determine land suitability for landfilling [20]. Wind/solar hybrid power station [21], offshore wind power station [22,23], and air quality monitoring station [24] locations were selected by ELECTRE. However, there are still some shortcomings in the above methods. The TOPSIS method does not consider the relative importance of the distances between these ideal solutions and a non-ideal solution. The individual regret and the group utility are ignored by PROMETHEE and ELECTRE, respectively.

From the standpoint of establishing the framework, different frameworks have different steps so that the function of every step is different. First of all, expert invitation [2,23,25–27], data collection [2,23,25–27], attributes identification [2,23,25–27], and linguistic variables determination [2,23,26,27] were generally applied in preliminary work to analyze material information. Then, detailed evaluation works were provided by [2,25–27], which ensured the evaluation succeed. Finally, the evaluation information should be processed. Wu et al. [23] combined the subjective methods and the objective methods to determine the weights of attributes. For integrating the data, the aggregated operator was utilized by [2,23,26]. The ranking method has been reviewed above, so we will not repeat it here.

Based on our review and the analysis above, the VIKOR method based on TIFNs is recommend to solve the above problems of qualitative information and ranking alternatives. TIFNs were firstly defined by [28], the ambiguities of the membership degree and the non-membership degree for TIFNs that defined the ranking of TIFNs were given by [29]. In addition, the classical TODIM method was extended to deal with multi-criteria group decision-making (MCGDM) problems with TIFNs by [30]. For reflecting the interaction phenomena among the decision making criteria, Li, et al. [31] made use of TIFNs and triangular intuitionistic fuzzy Einstein Choquet integral operator to establish the PROMETHEE II method for ranking alternatives. Reference [32] defined the crisp weighted possibility mean, the Hamming distance and Euclidean distance for TIFNs, and defined the extended VIKOR method for solving the MAGDM with TIFNs. Among them, the VIKOR method was proposed for multi objective optimization of complex problems, and is focused on ranking and selecting from among several alternatives in the face of conflicting criteria [33]. Xu et al. [34] proposed a VIKOR-based approach to assess the service performance of electric vehicle sharing programs. In terms of site selection, the VIKOR method was applied to deal with the selection of a suitable disposal site for municipal solid waste [14,35] and a dam [36]. A fuzzy GRA-VIKOR was employed to choose the best EVCS site by [3]. Though it could efficiently avoid the priority result of fuzzy numbers, the degree of the indeterminacy membership was not taken into account.

Compared with the previous studies, this paper offers the following improvements: first, the scope of the study in EVCS site selection will be narrowed and focus on an urban functional area: a residential community. Second, distinguishing from other linguistic variables, the vague concept and the degree of the indeterminacy membership are simultaneously expressed by using TIFNs. This study will use this more advantageous intuitionistic fuzzy environment so that DMs' performances will be indicated accurately. Third, the VIKOR method has been applied in several site selection studies, so the rationality of this method is self-evident. The fuzzy-VIKOR combined with TIFNs will be applied in the EVCS site selection in this paper for the first time, which could support the development of an effective decision-making framework for selecting the most satisfactory EVCSRC site. In conclusion, the VIKOR method based on the environment of TIFNs is expected to be more reasonable and suitable than before.

3. Evaluation Index System of the EVCSRC Site Selection

A scientific and reasonable evaluation index system plays an essential role in site selection. EVCS site selection is dependent upon various factors. In order to achieve the aim of reasonable construction of EVCSRCs, the evaluation index system for EVCSRC site selection is summarized, including economy criteria, social criteria, environmental criteria, planning criteria according to the relative literatures and feedback from expert consultation. Besides, the features of each residential community are also taken into consideration as part of index system.

3.1. Economy Criteria

The sub-criteria affiliated with economy criteria for EVCSRC site selection are summarized below:

1. Construction cost [1,2,4,21,26,27,31,37–41]. It consists mainly of land lease or acquisition costs, demolition costs, infrastructure costs, power distribution facility costs, and the project investment cost.
2. Annual operation and maintenance cost [1,2,4,21,38–41]. In terms of customer's requirements, EVCS adopt an innovative operation model which is actually unattended and self-service. Thus, operation and maintenance costs include not only electric charges, equipment maintenance and staff wages, but also development and maintenance costs of the necessary intelligent network platform and other financial expenses.
3. Investment payoff period [1,2,21,25,41]. Investment payoff period reflects the speed of returns on the total construction investment. To some extent, the risk profile of investment is also considered.

3.2. Social Criteria

Three sub-criteria related to the social criteria are aggregated as follows:

1. Comprehensive service capability [2,12,21,27,38,39,41–47]. The service capability of EVCS should be focused on not only the service radius and service volume but also the safety, high reliability and low failure rate.
2. Improvement of employment [48,49]. Construction and maintenance of EVCS can provide more opportunities of employment from different fields so that employment rates are pushed up.
3. Promotion of EVs potential [50,51]. The constant improvement of charging infrastructure can stimulate quite strong demand for EVs. It is conducive to the rapid development of the new energy automobile industry.

3.3. Environmental Criteria

Two sub-criteria related to the environmental criteria are aggregated as follows:

1. Fine particles emission reduction [1,2,25–27,39,52,53]. For the serious problem of air pollution faced, the usage and popularization of EVs is one of effective methods to mitigate emissions of fine particles.
2. Destruction degree on ecological environment [1,2,26,27,39,41,43,44,46,47,54,55]. Ecological balance is destroyed by the EVCS construction process from land development to operation procedures, which leads to vegetation deterioration, soil and water loss and so on.

3.4. Planning Criteria

Planning criteria, including electric power, transportation, land and other factors, relevant to the charging station location problem are considered in one system synthetically. Five sub-criteria related to the planning criteria are aggregated as follows:

1. Proximity to substation [2,25,27,37,41,43,44,47,56]. EVCSRC site selection is necessary to consider the power network planning and the location of substations so that it makes adequate preparations for charging infrastructure assignment optimization strategies. The ideal distance from the charging station to a substation is as short as possible.
2. Influence on the power grid [2,25,26,37,43,44,57,58]. A large number of charging behaviors, which are random but regular in the residential communities, will have an adverse effect on power stability and quality. The characteristics of the residents' activities and power heavy load lines need to be considered to ensure the secure operation of the distribution network.
3. Accessibility of site [12,27,38,39,41–43,45–47,57]. Accessibility is an indicator of the efficiency assessment of urban transport systems, which indicates that demands are allocated to the different charging stations within a certain distance. To a certain extent, there is an internal relation between aspects in the urban structure, land utilization, planning and infrastructure. With the characteristics of convenient transportation and accessibility, the sites not only reduce the traffic facilities are invested in the early stages of construction, but also ensure the convenience of post-maintenance and charging.
4. Available land resources [39,59]. This is determined by the nature of land use and intensity of land development. Under the same conditions of residential land, different residential communities have different development intensities. The larger intense intensity of land development, the greater the demand for charging is.
5. Possibility of capacity expansion in future [2,38,41,56]. The possibility of the charging station capacity expansion is a comprehensive index, which contains a variety of factors such the increased number of charging users, the provision of land resources, upgrades of electricity grids and so on. It is also a necessary condition to accommodate the inevitable trend for the sake of economic growth and environmental protection.

3.5. Feature Portrait of Residential Communities

For EVCSRC site selection research, the comprehensive evaluation of residential communities in EVs is essential. The sub-criteria affiliated with the portraits of residential communities are summarized below:

1. Per capita electric vehicle ownership [60–63]. Electric vehicle ownership refers to the total number of EVs owned in a region, which provides an estimate of EV demand. On this base, population factor is considered so that per capita electric vehicle ownership is calculated. It is the ratio of the total number of EVs owned to the total population in the residential community, which not only reflects the size of residents' requirements for charging in the target community currently, but also expresses the development situation of EVs in different communities, so it is preferable to take the per capita electric vehicle ownership into account.
2. The average income level of residents [64]. The consumption characteristics and income levels of residents in different residential communities are diverse, which are represented by the

employment level, the consumption structure, the growth of consumer expenditure and the cost of living. Median income residents' purchasing power of EVs is extremely powerful.

3. Residents' acceptance [1,2,21,26,27,41,46]. As a result of the negative effects of noise and electromagnetic radiation due to the construction and operation of EVCS, poor acceptance can force the EVCSRC project to shut down and even deny it at the beginning, particularly in residential communities, so investors should change residents' acceptance to reduce investment losses in a well-coordinated manner.

4. Decision Framework of the EVCSRC Site Selection

4.1. Basic Theory of the Intuitionistic Fuzzy Environment

In order to exquisitely express the uncertainty of the DMs in the process of decision-making, TIFNs are applied in the MCDM method. Basic definitions and operations of TIFNs as follows:

Definition 1 [65]: A TIFN $\tilde{a} = \langle(\underline{a}, a, \overline{a}); u_{\tilde{a}}, v_{\tilde{a}}\rangle$ is a special intuitionistic fuzzy set on a real number set R, whose membership function and non-membership function are defined as follows:

$$\mu_{\tilde{a}}(x) = \begin{cases} (x-\underline{a})u_{\tilde{a}}/(a-\underline{a}) & \text{if} \quad \underline{a} \le x < a, \\ u_{\tilde{a}} & \text{if} \quad x = a, \\ (\overline{a}-x)u_{\tilde{a}}/(\overline{a}-a) & \text{if} \quad a < x \le \overline{a}, \\ 0 & \text{if} \quad x < \underline{a} \quad \text{or} \quad x > \overline{a}, \end{cases} \tag{1}$$

and:

$$\nu_{\tilde{a}}(x) = \begin{cases} [a-x+v_{\tilde{a}}(x-\underline{a})]/(a-\underline{a}) & \text{if} \quad \underline{a} \le x < a, \\ v_{\tilde{a}} & \text{if} \quad x = a, \\ [x-a+v_{\tilde{a}}(\overline{a}-x)]/(\overline{a}-a) & \text{if} \quad a < x \le \overline{a}, \\ 0 & \text{if} \quad x < \underline{a} \quad \text{or} \quad x > \overline{a}, \end{cases} \tag{2}$$

depicted as in Figure 2. The values $u_{\tilde{a}}$ and $v_{\tilde{a}}$ represent the maximum degree of membership [28] and the minimum degree of non-membership [28], respectively, such that they satisfy the conditions: $0 \le u_{\tilde{a}} \le 1$, $0 \le v_{\tilde{a}} \le 1$ and $0 \le u_{\tilde{a}} + v_{\tilde{a}} \le 1$. Let $\pi_{\tilde{a}}(x) = 1 - \mu_{\tilde{a}}(x) - \nu_{\tilde{a}}(x)$, which is called an intuitionistic fuzzy index of an element x in $\tilde{a}$. It is the degree of the indeterminacy membership [28] of the element x in $\tilde{a}$, the smaller of $\pi_{\tilde{a}}(x)$ is, the clearer of the fuzzy number is.

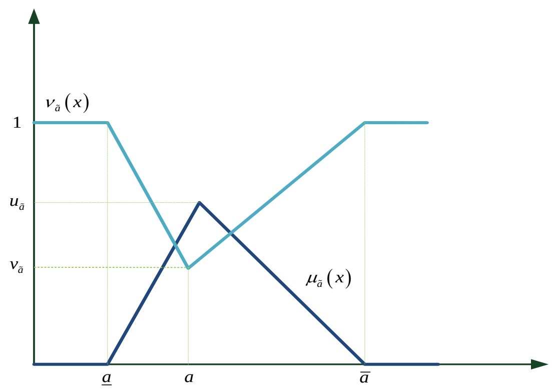

Figure 2. A TIFN $\tilde{a} = \langle(\underline{a}, a, \overline{a}); u_{\tilde{a}}, v_{\tilde{a}}\rangle$.

If $\underline{a} \ge 0$ and one of the three values $\underline{a}$, a and $\overline{a}$ is not equal to 0, then the TIFN $\tilde{a} = \langle(\underline{a}, a, \overline{a}); u_{\tilde{a}}, v_{\tilde{a}}\rangle$ is called a positive TIFN, denoted by $\tilde{a} > 0$.

A TIFN $\tilde{a} = \langle(\underline{a}, a, \overline{a}); u_{\tilde{a}}, v_{\tilde{a}}\rangle$ may express an ill-known quantity "approximate a", which is approximately equal to a. Namely, the ill-known quantity "approximate a" is expressed using any value between $\underline{a}$ and $\overline{a}$ with different degrees of membership and degrees of non-membership. In other words, the most possible value is a with the degree $u_{\widetilde{a}}$ of membership and the degree $v_{\widetilde{a}}$ of non-membership; the pessimistic value is $\underline{a}$ with the degree 0 of membership and the degree 1 of non-membership; the optimistic value is $\overline{a}$ with the degree 0 of membership and the degree 1 of non-membership; other values are any $x \in (\underline{a}, \overline{a})$ with the degree $\mu_{\widetilde{a}}(x)$ of membership and the degree $\nu_{\widetilde{a}}(x)$ of non-membership.

Definition 2 [65]: Let $\widetilde{a}_i = \langle (\underline{a}_i, a_i, \overline{a}_i); u_{\widetilde{a}_i}, v_{\widetilde{a}_i} \rangle (i = 1,2)$ be two TIFNs and $\lambda \geq 0$. Then the operations for TIFNs are defined as follows:

$$\widetilde{a}_1 + \widetilde{a}_2 = \left((\underline{a}_1 + \underline{a}_2, a_1 + a_2, \overline{a}_1 + \overline{a}_2); u_{\widetilde{a}_1} \wedge u_{\widetilde{a}_2}, v_{\widetilde{a}_1} \vee v_{\widetilde{a}_2} \right) \tag{3}$$

$$\widetilde{a}_1 \widetilde{a}_2 = \left((\underline{a}_1 \underline{a}_2, a_1 a_2, \overline{a}_1 \overline{a}_2); u_{\widetilde{a}_1} \wedge u_{\widetilde{a}_2}, v_{\widetilde{a}_1} \vee v_{\widetilde{a}_2} \right) \tag{4}$$

$$\lambda \widetilde{a}_1 = \left((\lambda \underline{a}_1, \lambda a_1, \lambda \overline{a}_1); u_{\widetilde{a}_1}, v_{\widetilde{a}_1} \right) \tag{5}$$

$$\widetilde{a}_1^{\lambda} = \left(\left(\underline{a}_1^{\lambda}, a_1^{\lambda}, \overline{a}_1^{\lambda} \right); u_{\widetilde{a}_1}, v_{\widetilde{a}_1} \right) \tag{6}$$

where the symbols "$\wedge$" and "$\vee$" mean min and max operators, respectively.

Definition 3 [66]: Let $\widetilde{a}_i = \langle (\underline{a}_i, a_i, \overline{a}_i); u_{\widetilde{a}_i}, v_{\widetilde{a}_i} \rangle (i = 1,2)$ be two TIFNs. The Hamming distance between $\widetilde{a}_1$ and $\widetilde{a}_2$ is defined as follows:

$$\begin{aligned} d(\widetilde{a}_1, \widetilde{a}_2) = \tfrac{1}{6} \big[&\left| (1 + u_{\widetilde{a}_1} - v_{\widetilde{a}_1}) \underline{a}_1 - (1 + u_{\widetilde{a}_2} - v_{\widetilde{a}_2}) \underline{a}_2 \right| \\ &+ \left| (1 + u_{\widetilde{a}_1} - v_{\widetilde{a}_1}) a_1 - (1 + u_{\widetilde{a}_2} - v_{\widetilde{a}_2}) a_2 \right| \\ &+ \left| (1 + u_{\widetilde{a}_1} - v_{\widetilde{a}_1}) \overline{a}_1 - (1 + u_{\widetilde{a}_2} - v_{\widetilde{a}_2}) \overline{a}_2 \right| \big] \end{aligned} \tag{7}$$

Definition 4 [67]: Let $\widetilde{a}_j$ $(j = 1, 2, \ldots, n)$ be a collection of TIFNs, then their aggregated value by using the $TIF - WA$ operator is also a TIFN and:

$$TIF - WA(\widetilde{a}_1, \widetilde{a}_2, \ldots, \widetilde{a}_n) = \left(\left(\sum_{j=1}^{n} w_j \underline{a}_j, \sum_{j=1}^{n} w_j a_j, \sum_{j=1}^{n} w_j \overline{a}_j \right); \min_j \left\{ u_{\widetilde{a}_j} \right\}, \max_j \left\{ v_{\widetilde{a}_j} \right\} \right) \tag{8}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $\widetilde{a}_j$ $(j = 1, 2, \ldots, n)$, satisfying $0 \leq w_j \leq 1$ $(j = 1, 2, \ldots, n)$ and $\sum_{j=1}^{n} w_j = 1$.

4.2. Phase I—Identification of Alternative EVCSRC Sites

Since this stage, a five-phase decision framework of EVCSRC site selection is presented shown in Figure 3. And in this phase, the alternative EVCSRC sites are identified. The finite set of possible alternatives is denoted by $A = \{A_1, A_2, \ldots, A_m\}$ and details as follow:

Step 1. n experts are invited by EVCSRC investors to form the decision-making group.

Step 2. The residential communities are collected into the initial list refining mega city planning for different functional areas. After that, the residential communities which are potential feasible for EVCS constructions are identified in accordance with satellite images, grid map, and official statistics from the initial list by the decision-making group.

Step 3. The decision-making group conducts field surveys at these residential communities to collect socioeconomic and other relevant information of each site from environment, planning, and residents' demand. And the decision-making group will determine which alternative EVCSRC sites will stay in the list.

Step 4. The DMs study and identify the attributes relevant to the EVCSRC site selection in conformity with academic literatures and their practical experiences.

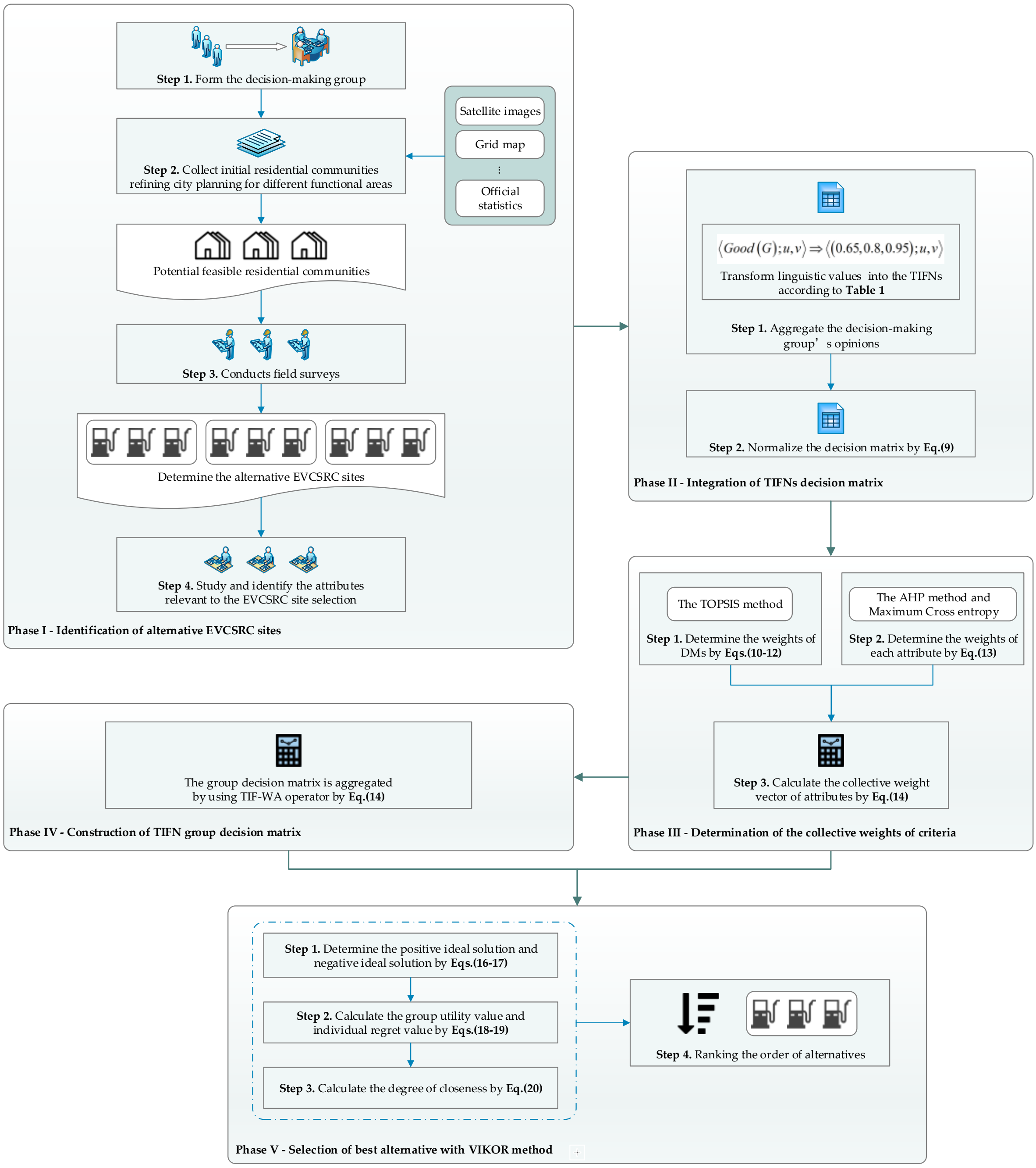

Figure 3. The five-phase decision framework of EVCSRC site selection.

4.3. Phase II—Integration of TIFNs Decision Matrix

Step 1. Aggregate the decision-making group's opinions to construct a decision matrix $\widetilde{D}^k = \left(\widetilde{a}^k_{ij}\right)_{m\times n}$, transform linguistic values of alternative EVCSRC sites into the TIFNs according to Definition 1 in the light of transform in Table 1 which shows the linguistic scales and corresponding TIFNs for rating the alternatives respectively. TIFNs can enable DMs to assess the alternatives in different dimensions.

Table 1. Linguistic variables and the corresponding TIFNs.

Ratings of Alternatives	TIFNs
Very poor (VP)	$\langle(0, 0.05, 0.2); u, v\rangle$
Poor (P)	$\langle(0.05, 0.2, 0.35); u, v\rangle$
Medium poor (MP)	$\langle(0.2, 0.35, 0.5); u, v\rangle$
Medium (M)	$\langle(0.35, 0.5, 0.65); u, v\rangle$
Medium good (MG)	$\langle(0.5, 0.65, 0.8); u, v\rangle$
Good (G)	$\langle(0.65, 0.8, 0.95); u, v\rangle$
Very good (VG)	$\langle(0.8, 0.95, 1); u, v\rangle$

Step 2. Normalize the decision matrix $\widetilde{D}^k$ into $\widetilde{R}^k = \left(\widetilde{r}_{ij}^k\right)_{m\times n}$ using the following equation. To eliminate the influence of different physical dimensions and measurements on the final decision, the decision matrix $\widetilde{D}^k = \left(\widetilde{a}_{ij}^k\right)_{m\times n}$ needs be normalized as $\widetilde{R}^k = \left(\widetilde{r}_{ij}^k\right)_{m\times n}$ where $\widetilde{r}_{ij}^k = \left(\left(\underline{r}_{ij}^k, r_{ij}^k, \overline{r}_{ij}^k\right); u_{\widetilde{r}_{ij}^k}, v_{\widetilde{r}_{ij}^k}\right)$ with $u_{\widetilde{r}_{ij}^k} = u_{\widetilde{a}_{ij}^k}, v_{\widetilde{r}_{ij}^k} = v_{\widetilde{a}_{ij}^k}$ and

$$\left(\underline{r}_{ij}^k, r_{ij}^k, \overline{r}_{ij}^k\right) = \begin{cases} \left(\frac{\underline{a}_{ij}^k}{\overline{a}_{\max j}^k}, \frac{a_{ij}^k}{\overline{a}_{\max j}^k}, \frac{\overline{a}_{ij}^k}{\overline{a}_{\max j}^k}\right) & \text{if} \quad x_j \in F^b \\ \left(1 - \frac{\overline{a}_{ij}^k}{\overline{a}_{\max j}^k}, 1 - \frac{a_{ij}^k}{\overline{a}_{\max j}^k}, 1 - \frac{\underline{a}_{ij}^k}{\overline{a}_{\max j}^k}\right) & \text{if} \quad x_j \in F^c. \end{cases} \tag{9}$$

on the basis of Definition 2.

Here, $\overline{a}_{\max j}^k = \max\left\{\overline{a}_{ij}^k \middle| i = 1, 2, \ldots, m\right\}$, F^b and F^c are the subsets of benefit attributes and cost attributes, respectively.

4.4. Phase III—Determination of the Collective Weights of Criteria

Step 1. Determine the weights of DMs $v = (v_1, v_2, \ldots, v_p)^T$ motivated by idea of TOPSIS as follows [66]:

1. Construct the positive ideal decision matrix $\widetilde{R}^+ = \left(\widetilde{r}_{ij}^+\right)_{m\times n}$ and the negative ideal decision matrix $\widetilde{R}^- = \left(\widetilde{r}_{ij}^-\right)_{m\times n}$, where $\widetilde{r}_{ij}^+ = ((1, 1, 1); 1, 0)$ and $\widetilde{r}_{ij}^- = ((0, 0, 0); 0, 1)$.
2. Calculate the distances between matrixes $\widetilde{R}^k$, $\widetilde{R}^+$ and $\widetilde{R}^-$ as:

$$d_k\left(\widetilde{R}^k, \widetilde{R}^+\right) = \frac{1}{mn}\sum_{i=1}^m\sum_{j=1}^n d\left(\widetilde{r}_{ij}^k, \widetilde{r}_{ij}^+\right), d_k\left(\widetilde{R}^k, \widetilde{R}^-\right) = \frac{1}{mn}\sum_{i=1}^m\sum_{j=1}^n d\left(\widetilde{r}_{ij}^k, \widetilde{r}_{ij}^-\right) \tag{10}$$

   where $d\left(\widetilde{r}_{ij}^k, \widetilde{r}_{ij}^+\right)$ and $d\left(\widetilde{r}_{ij}^k, \widetilde{r}_{ij}^-\right)$ are the Hamming distance defined in Definition 3.
3. Compute the closeness degree of matrixes $\widetilde{R}^k$ with respect to $\widetilde{R}^+$ as:

$$c_k\left(\widetilde{R}^k, \widetilde{R}^+\right) = \frac{d_k\left(\widetilde{R}^k, \widetilde{R}^-\right)}{d_k\left(\widetilde{R}^k, \widetilde{R}^+\right) + d_k\left(\widetilde{R}^k, \widetilde{R}^-\right)} \tag{11}$$

4. Normalize the closeness degrees to obtain the weight v_k of decision maker (DM) e_k as:

$$v_k = c_k\left(\widetilde{R}^k, \widetilde{R}^+\right) / \sum_{k=1}^p c_k\left(\widetilde{R}^k, \widetilde{R}^+\right) \quad (k = 1, 2, \ldots, p) \tag{12}$$

Step 2. Determine the weights of each evaluation criterion described in Section 3 based on s combination of the AHP method and maximum cross entropy.

Since the importance of each criterion is different, AHP is used in this paper to calculate the weight of each first grade criterion. Firstly, each DM should determine the importance among the criteria. After the calculation, maximum cross entropy is used in the weight of each second grade criterion, the specific measures are as follows:

For the criteria C_j $(j = 1, 2, \ldots, n)$, the deviation between alternative A_i $(i = 1, 2, \ldots, m)$ and other alternatives A_t $(t = 1, 2, \ldots, m)$ as $D(w_j) = \sum\limits_{t=1}^{m} d(\widetilde{r}_{ij}, \widetilde{r}_{tj}) w_j$ $(t \neq i)$, and the total deviation between all the alternatives and other alternatives as $\dot{D}(w_j) = \sum\limits_{i=1}^{m} D(w_j) = \sum\limits_{i=1}^{m} \sum\limits_{t=1}^{m} d(\widetilde{r}_{ij}, \widetilde{r}_{tj}) w_j$, for all criteria, the total deviation between all the alternatives and other alternatives as $\ddot{D}(w_j) = \sum\limits_{j=1}^{m} \dot{D}(w_j) = \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{m} \sum\limits_{t=1}^{m} d(\widetilde{r}_{ij}, \widetilde{r}_{tj}) w_j$, if the partial weight information is known, according to Maximum Cross entropy, nonlinear optimization model is constructed as:

$$\max \ddot{D}(w_j) = \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{t=1}^{m} d(\widetilde{r}_{ij}, \widetilde{r}_{tj}) w_j$$
$$s.t. \begin{cases} w_j \in P \\ \sum\limits_{j=1}^{n} w_j = 1 \text{ , } P \text{ is partial known weight information} \\ 0 \leq w_j \leq 1 \end{cases} \tag{13}$$

Step 3. The collective weight vector of attributes $w = (w_1, w_2, \ldots, w_n)^T$ is calculated as follows:

$$w_j = \sum_{k=1}^{p} v_k w_j^k (j = 1, 2, \ldots, n) \tag{14}$$

4.5. Phase IV—Construction of TIFNs Group Decision Matrix

The e_k individual decision matrixes $\widetilde{R}^k = \left(\widetilde{r}_{ij}^k\right)_{m \times n}$ $(k = 1, 2, \ldots, p)$ can be aggregated into the group decision matrix $\widetilde{G} = \left(\widetilde{g}_{ij}\right)_{m \times n}$ by using *TIF-WA* operator described in Definition 4, where:

$$\begin{aligned} \widetilde{g}_{ij} &= \left((g_{1i}(a_j), g_{2i}(a_j), g_{3i}(a_j)); u_{g_{ij}}, v_{g_{ij}} \right) \\ &= TIF - WA(\widetilde{a}_{ij}^1, \widetilde{a}_{ij}^2, \ldots, \widetilde{a}_{ij}^p) \\ &= \sum_{k=1}^{p} v_k \widetilde{a}_{ij}^k \\ &= \left(\left(\sum_{k=1}^{p} v_k \underline{a}_{ij}^k, \sum_{k=1}^{p} v_k \underline{a}_{ij}^k, \sum_{k=1}^{p} v_k \overline{a}_{ij}^k \right); \min_{1 \leq k \leq p} \left\{ u_{\widetilde{a}_{ij}}^k \right\}, \max_{1 \leq k \leq p} \left\{ v_{\widetilde{a}_{ij}}^k \right\} \right) \end{aligned} \tag{15}$$

4.6. Phase V—Selection of Best Alternative with VIKOR Method

Step 1. Determine the positive ideal solution $A^+ = \{\widetilde{a}_1^+, \widetilde{a}_2^+, \ldots, \widetilde{a}_n^+\}$ and negative ideal solution $A^- = \{\widetilde{a}_1^-, \widetilde{a}_2^-, \ldots, \widetilde{a}_n^-\}$, where

$$\widetilde{a}_j^+ = ((\max_{1 \leq i \leq z} \{r_{1i}(a_j)\}, \max_{1 \leq i \leq z} \{r_{2i}(a_j)\}, \max_{1 \leq i \leq z} \{r_{3i}(a_j)\}); 1, 0) \tag{16}$$

$$\widetilde{a}_j^- = ((\min_{1 \leq i \leq z} \{r_{1i}(a_j)\}, \min_{1 \leq i \leq z} \{r_{2i}(a_j)\}, \min_{1 \leq i \leq z} \{r_{3i}(a_j)\}); 0, 1) \tag{17}$$

Step 2. Calculate the group utility value and individual regret value of each alternative; Applied the Hamming distance, the group utility value $S(A_i)$ and individual regret value $R(A_i)$ for alternative A_i can be respectively calculated as follows:

$$S(A_i) = \sum_{j=1}^{n} w_j \frac{d\left(\tilde{a}_j^+, \tilde{r}_{ij}\right)}{d\left(\tilde{a}_j^+, \tilde{a}_j^-\right)} \tag{18}$$

$$R(A_i) = \max_{1 \le j \le n} \left\{ w_j \frac{d\left(\tilde{a}_j^+, \tilde{r}_{ij}\right)}{d\left(\tilde{a}_j^+, \tilde{a}_j^-\right)} \right\} \tag{19}$$

where d is Hamming distance d_h or Euclidean distance d_e.

Step 3. Calculate the degree of closeness of each alternative; Let $S^+ = \min_{1 \le i \le z}\{S(A_i)\}$, $S^- = \max_{1 \le i \le z}\{S(A_i)\}$, $R^+ = \min_{1 \le i \le z}\{-R(A_i)\}$, and $R^- = \max_{1 \le i \le z}\{R(A_i)\}$. The closeness of alternative A_i to the ideal solution can be calculated as follows:

$$Q(A_i) = \lambda \frac{S(A_i) - S^+}{S^- - S^+} + (1 - \lambda) \frac{R(A_i) - R^+}{R^- - R^+} \quad (i = 1, 2, \ldots, z) \tag{20}$$

where the coefficient of decision mechanism λ is the weight of the strategy of maximum group utility, and $1 - \lambda$ is the weight of individual regret, $\lambda \in [0, 1]$.

Step 4. Ranking the order of alternatives according to the increasing order of $Q(A_i)(i = 1, 2, \ldots, z)$ [32].

5. A Case Study of Beijing

5.1. Problem Statement

In order to promote the development of urban low-carbon energy-savings, Beijing has comprehensively implemented the Thirteenth Five-Year plan, and vigorously promoted the construction of charging infrastructures. In Beijing, as one of the first batch key demonstration cities, the scale of the promotion and application of EVs has been on the top list. In this regard, "Special planning of EVs charging infrastructure in Beijing (2016–2020)" has been promulgated, which explicitly emphasizes that it is significant to construct charging facilities for residential communities. The plan emphasized specifically the execution of an "electric community" action plan to solve the difficulty of charging in residential communities.

On the basis of market demands and government support, an electric power company intends to invest in building charging stations for EVs in residential communities in Beijing.

5.2. Procedure and Computation Results

First of all, for the sake of maximizing the benefits of the charging station construction, the company decides to invite three experts (e_1, e_2, e_3) as DMs and form an expert group to carry out the site selection work in the light of Phase I. Specifically, the academic backgrounds of expert group consist of various fields including engineering economy, sociology, environment, power system planning and new energy respectively. In addition, all invited DMs should have high prestige, and at the same time, a master degree and more than three years relevant working experience as the necessary conditions. Moreover, the experts of the expert group play an essential role in the following two aspects: for one thing, on the premise that brainstorming is the way that the experts fully discuss a topic with each other, they not only study and work in their own field, but also learn about other fields with the mutual assistance of the other experts. For another, the experts evaluate the performance of each alternative EVCSRC site with regard to the sub-criteria by using linguistic variables.

After a concrete detailed investigation, a total of six large communities $(A_i, i = 1, 2, \ldots, 6)$ are chosen as alternatives, which are located in Haidian District, Chaoyang District, Changping District, Fengtai District, Daxing District and Tongzhou District, as shown in Figure 4. These alternatives, with typical features of a large residential community in Beijing, are suitable for construction.

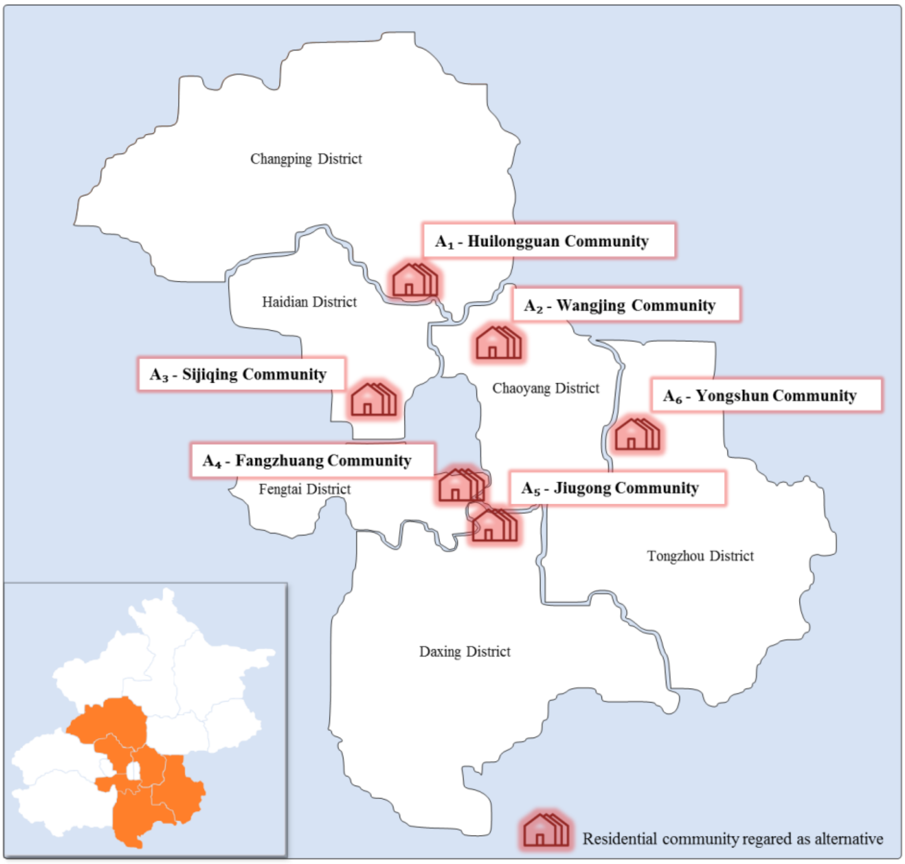

Figure 4. The geographical positions of the potential communities.

According to the relevant academic literature and a wealth of experience of the expert group, the evaluation index system is established and its detailed description is in Section 3, which contains 5 criteria and 16 sub-criteria. C_{11},C_{12},C_{13},C_{32},C_{42},C_{51},C_{52} and C_{53} are the negative sub-criteria [27] and C_{21},C_{22},C_{23},C_{31},C_{41},C_{43},C_{44} and C_{45} are the positive sub-criteria [27].

Then, the three experts of the group provide their preference for each large residential community according to its performance linguistic information in consideration of each of the criterion values stated in the form of TIFNs from VP to VG (see Table 1). Meanwhile, a maximum degree of membership and a minimum degree of non-membership for each linguistic rating are provided as well. During the evaluation, each expert should disregard the others and complete the questionnaires separately, and the results are listed in Tables 2–4. According to Phase II in Step 2, the linguistic variables are transformed into a series of TIFNs. After that, we normalize the decision matrices by Equation (9), and the normalized matrices are listed in Tables A1–A3.

Table 2. Linguistic ratings for the sub-criteria given by e_1.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	(MG; 0.8,0.1)	(G; 0.8,0.1)	(VG; 0.8,0.1)	(G; 0.7,0.2)	(M; 0.8,0.1)	(MP; 0.8,0.1)
C_{12}	(G; 0.7,0.25)	(G; 0.7,0.15)	(G; 0.85,0.1)	(G; 0.8,0.1)	(MG; 0.8,0.15)	(VG; 0.65,0.2)
C_{13}	(P; 0.8,0.1)	(P; 0.7,0.2)	(M; 0.7,0.2)	(MP; 0.75,0.1)	(VP; 0.8,0.1)	(MP; 0.75,0.2)
C_{21}	(MG; 0.65,0.3)	(G; 0.7,0.25)	(VG; 0.75,0.2)	(MG; 0.9,0.05)	(P; 0.7,0.15)	(VP; 0.7,0.25)
C_{22}	(P; 0.8,0.1)	(VG; 0.8,0.1)	(MG; 0.85,0.1)	(MG; 0.8,0.15)	(M; 0.8,0.1)	(M; 0.7,0.2)
C_{23}	(MP; 0.8,0.1)	(MG; 0.85,0.05)	(VG; 0.9,0.05)	(MG; 0.8,0.1)	(MP; 0.85,0.05)	(MP; 0.75,0.15)
C_{31}	(MP; 0.75,0.2)	(P; 0.8,0.15)	(VG; 0.8,0.15)	(M; 0.7,0.25)	(M; 0.8,0.15)	(MG; 0.8,0.15)
C_{32}	(P; 0.8,0.1)	(G; 0.8,0.1)	(M; 0.75,0.15)	(G; 0.7,0.2)	(MG; 0.8,0.1)	(M; 0.8,0.1)
C_{41}	(VG; 0.7,0.2)	(VG; 0.7,0.2)	(MP; 0.8,0.1)	(MP; 0.8,0.1)	(MG; 0.8,0.1)	(MG; 0.8,0.1)
C_{42}	(MP; 0.8,0.1)	(MG; 0.8,0.1)	(M; 0.8,0.1)	(G; 0.7,0.2)	(G; 0.65,0.25)	(P; 0.8,0.1)
C_{43}	(MG; 0.7,0.2)	(MP; 0.9,0)	(P; 0.9,0)	(MP; 0.85,0.05)	(M; 0.7,0.2)	(G; 0.8,0.1)
C_{44}	(MG; 0.7,0.2)	(M; 0.7,0.2)	(MP; 0.7,0.2)	(M; 0.65,0.25)	(VG; 0.7,0.2)	(G; 0.7,0.2)
C_{45}	(M; 0.75,0.2)	(G; 0.65,0.3)	(M; 0.8,0.15)	(G; 0.8,0.15)	(G; 0.7,0.25)	(P; 0.8,0.1)
C_{51}	(G; 0.7,0.2)	(VG; 0.8,0.1)	(G; 0.85,0.1)	(M; 0.9,0.1)	(P; 0.8,0.1)	(G; 0.8,0.1)
C_{52}	(MP; 0.7,0.1)	(MG; 0.7,0.15)	(VG; 0.85,0.1)	(MG; 0.8,0.1)	(MP; 0.75,0.1)	(VP; 0.7,0.1)
C_{53}	(MG; 0.8,0.1)	(G; 0.75,0.15)	(G; 0.9,0.05)	(G; 0.85,0.1)	(G; 0.65,0.15)	(VG; 0.75,0.1)

Table 3. Linguistic ratings for the sub-criteria given by e_2.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	(MP; 0.75,0.2)	(M; 0.9,0.05)	(G; 0.9,0.05)	(MG; 0.75,0.15)	(MP; 0.8,0.15)	(P; 0.75,0.2)
C_{12}	(MG; 0.85,0.1)	(G; 0.8,0.1)	(G; 0.9,0.1)	(MG; 0.65,0.25)	(G; 0.75,0.2)	(G; 0.8,0.25)
C_{13}	(P; 0.7,0.2)	(MP; 0.85,0.05)	(MP; 0.85,0.1)	(VP; 0.7,0.1)	(P; 0.75,0.1)	(M; 0.8,0.15)
C_{21}	(M; 0.9,0.05)	(MG; 0.75,0.2)	(G; 0.7,0.2)	(MG; 0.8,0.1)	(VP; 0.8,0.15)	(P; 0.8,0.15)
C_{22}	(M; 0.8,0.05)	(G; 0.8,0.05)	(VG; 0.7,0.1)	(G; 0.6,0.3)	(MP; 0.7,0.15)	(MP; 0.8,0.05)
C_{23}	(MG; 0.7,0.1)	(G; 0.7,0.15)	(VG; 0.9,0.1)	(G; 0.8,0.1)	(MG; 0.75,0.1)	(M; 0.7,0.1)
C_{31}	(VP; 0.8,0.05)	(MG; 0.8,0.05)	(VG; 0.7,0.15)	(MP; 0.75,0.1)	(P; 0.8,0.05)	(MP; 0.8,0.05)
C_{32}	(MP; 0.8,0.1)	(MG; 0.8,0.1)	(MG; 0.8,0.1)	(G; 0.8,0.1)	(G; 0.8,0.1)	(G; 0.8,0.1)
C_{41}	(G; 0.9,0.05)	(G; 0.9,0.05)	(M; 0.7,0.25)	(M; 0.7,0.25)	(MG; 0.75,0.15)	(MG; 0.75,0.15)
C_{42}	(MG; 0.9,0.1)	(MG; 0.9,0.1)	(MG; 0.9,0.1)	(G; 0.9,0.1)	(G; 0.9,0.1)	(MG; 0.9,0.1)
C_{43}	(MG; 0.8,0.15)	(P; 0.9,0.05)	(VP; 0.85,0.1)	(P; 0.85,0.1)	(MP; 0.9,0.05)	(VG; 0.85,0.1)
C_{44}	(MG; 0.8,0.1)	(M; 0.75,0.2)	(M; 0.8,0.1)	(MP; 0.8,0.1)	(G; 0.8,0.1)	(G; 0.7,0.2)
C_{45}	(M; 0.7,0.1)	(VG; 0.7,0.1)	(G; 0.7,0.1)	(MG; 0.7,0.1)	(P; 0.7,0.1)	(MP; 0.7,0.1)
C_{51}	(M; 0.75,0.1)	(MG; 0.8,0.1)	(G; 0.85,0.1)	(MG; 0.75,0.15)	(M; 0.8,0.1)	(P; 0.7,0.2)
C_{52}	(MP; 0.8,0.1)	(MG; 0.85,0.1)	(VG; 0.9,0.05)	(MG; 0.8,0.1)	(MP; 0.85,0.1)	(MP; 0.75,0.1)
C_{53}	(G; 0.7,0.1)	(VG; 0.75,0.2)	(VG; 0.8,0.1)	(VG; 0.65,0.1)	(G; 0.8,0.15)	(G; 0.85,0.1)

Table 4. Linguistic ratings for the sub-criteria given by e_3.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	(M; 0.85,0.1)	(MG; 0.85,0.1)	(G; 0.8,0.1)	(MG; 0.7,0.2)	(M; 0.7,0.25)	(P; 0.85,0.1)
C_{12}	(G; 0.6,0.25)	(MG; 0.85,0.05)	(MG; 0.7,0.2)	(G; 0.8,0.15)	(MG; 0.75,0.15)	(MG; 0.9,0.05)
C_{13}	(VP; 0.65,0.2)	(VP; 0.65,0.3)	(P; 0.65,0.3)	(P; 0.85,0.1)	(VP; 0.75,0.2)	(VP; 0.9,0.1)
C_{21}	(MP; 0.7,0.2)	(G; 0.8,0.15)	(G; 0.85,0.1)	(G; 0.7,0.15)	(VP; 0.65,0.3)	(P; 0.7,0.15)
C_{22}	(MP; 0.8,0.15)	(G; 0.8,0.15)	(MG; 0.8,0.15)	(M; 0.8,0.15)	(P; 0.8,0.15)	(VP; 0.8,0.15)
C_{23}	(MP; 0.75,0.2)	(VG; 0.8,0.1)	(G; 0.85,0.1)	(M; 0.85,0.1)	(MP; 0.65,0.3)	(MP; 0.85,0.1)
C_{31}	(M; 0.8,0.15)	(MP; 0.8,0.15)	(MG; 0.8,0.15)	(M; 0.7,0.25)	(M; 0.6,0.35)	(G; 0.8,0.15)
C_{32}	(G; 0.75,0.1)	(P; 0.75,0.1)	(G; 0.75,0.1)	(P; 0.75,0.1)	(P; 0.75,0.1)	(P; 0.75,0.1)
C_{41}	(G; 0.8,0.15)	(G; 0.8,0.15)	(MG; 0.75,0.1)	(MG; 0.8,0.1)	(G; 0.75,0.2)	(G; 0.75,0.2)
C_{42}	(P; 0.9,0.05)	(MG; 0.9,0.05)	(M; 0.9,0.05)	(G; 0.9,0.05)	(MG; 0.9,0.05)	(M; 0.9,0.05)
C_{43}	(MG; 0.85,0.1)	(M; 0.8,0.15)	(MP; 0.9,0.05)	(M; 0.75,0.25)	(M; 0.9,0.05)	(G; 0.95,0)
C_{44}	(MP; 0.75,0.2)	(VG; 0.8,0.1)	(G; 0.85,0.1)	(M; 0.85,0.1)	(MP; 0.65,0.3)	(MP; 0.85,0.1)
C_{45}	(MG; 0.7,0.1)	(G; 0.7,0.15)	(VG; 0.85,0.1)	(G; 0.8,0.1)	(MG; 0.75,0.1)	(M; 0.7,0.1)
C_{51}	(P; 0.8,0.1)	(VG; 0.8,0.1)	(MG; 0.85,0.1)	(MG; 0.8,0.15)	(M; 0.8,0.1)	(M; 0.7,0.2)
C_{52}	(MG; 0.75,0.1)	(G; 0.85,0.1)	(VG; 0.85,0.05)	(G; 0.8,0.1)	(MG; 0.7,0.1)	(M; 0.85,0.1)
C_{53}	(G; 0.65,0.2)	(G; 0.65,0.2)	(VG; 0.85,0.15)	(G; 0.75,0.2)	(MG; 0.95,0)	(G; 0.7,0.2)

After the above stages, the subjective weights and the objective weights of attributes and the DMs weights are calculated according to Phase III. First, the weights vector of DMs for alternative A_i with respect to the criterion C_i can be calculated using Equations (10)–(12) as follow: $V_{DMs} = (v_1,v_2,v_3)^T = (0.3210,0.3252,0.3538)^T$. And then the Equation (13) is used in calculating the weights of each criterion, and the results are shown in Figure 5. The group decision matrix $\widetilde{G} = \left(\widetilde{g}_{ij}\right)_{m\times n}$ could be obtained according to Equation (15), as shown in Table A4.

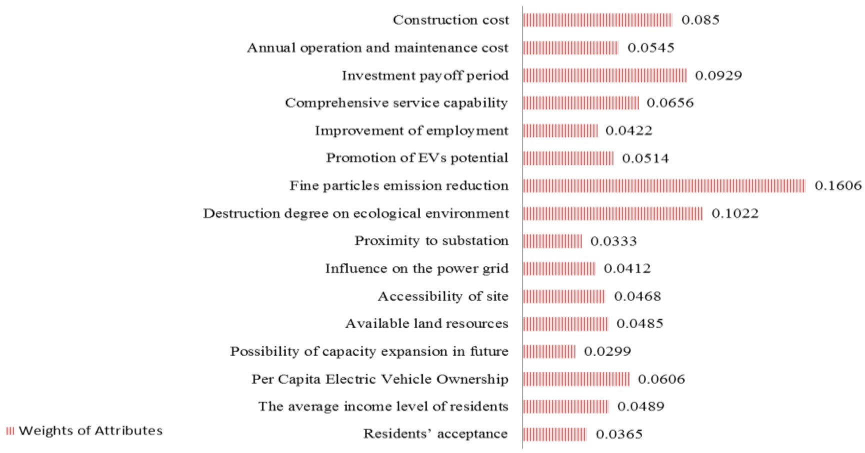

Figure 5. Weights of categories and attributes.

Further, according to Equations (16)–(17), the positive ideal solution and negative ideal solution of the group decision matrix could be respectively obtained as follows:

$$\begin{aligned} A^+ = \{&((0.59,0.74,0.9);1,0),((0.1,0.25,0.4);1,0),((0.72,0.89,0.98);1,0),((0.7,0.85,0.97);1,0),\\ &((0.7,0.85,0.97);1,0),((0.75,0.9,0.98);1,0),((0.69,0.84,0.93);1,0),((0.36,0.51,0.67);1,0),\\ &((0.72,0.88,1);1,0),((0,0.43,0.58);1,0),((0.72,0.88,1);1,0),((0.55,0.71,0.83);1,0),\\ &((0.7,0.85,0.97);1,0),((0.7,0.85,0.93);1,0),((0.8,0.95,1);1,0),((0.75,0.9,1.02);1,0)\} \end{aligned}$$

$$\begin{aligned} A^- = \{&((0.03,0.15,0.3);0,1),((0.05,0.18,0.33);0,1),((0.5,0.65,0.8);0,1),((0.02,0.1,0.26);0,1),\\ &((0.18,0.3,0.46);0,1),((0.26,0.41,0.57);0,1),((0.19,0.32,0.47);0,1),((0.2,0.35,0.5);0,1),\\ &((0.35,0.5,0.65);0,1),((0,0.17,0.33);0,1),((0.09,0.2,0.35);0,1),((0.32,0.47,0.63);0,1),\\ &((0.21,0.37,0.52);0,1),((0.27,0.42,0.58);0,1),((0.2,0.32,0.47);0,1),((0.62,0.77,0.93);0,1)\} \end{aligned}$$

The group utility values and individual regret values for alternatives are calculated by Equations (10)–(11), the process of calculation could be shown as follows:

$$\begin{aligned} S(A_1) = 0.4636,\ S(A_2) = 0.3927, S(A_3) = 0.3744,\\ S(A_4) = 0.4683,\ S(A_5) = 0.5264, S(A_6) = 0.4191,\\ R(A_1) = 0.1111,\ R(A_2) = 0.0962, R(A_3) = 0.0692,\\ R(A_4) = 0.0933,\ R(A_5) = 0.1099, R(A_6) = 0.0589. \end{aligned}$$

Therefore, $S^+ = 0.3744,\ S^- = 0.5264,\ R^+ = 0.0589,\ R^- = 0.1111$.

Finally, the closeness of each alternative to the ideal solution can be computed by using Equation (20). When corresponding coefficient of decision mechanism $\lambda = 0.5$, in that the decision is computed through consensus among the different decision-makers, the sequence of the six alternatives are provided in Table 5. Appendix B explains the algorithm and software of the proposed framework implementation.

Table 5. The collective comprehensive values and ranking orders of all alternatives when $\lambda = 0.5$.

λ	$Q(A_1)$	$Q(A_2)$	$Q(A_3)$	$Q(A_4)$	$Q(A_5)$	$Q(A_6)$	Ranking Orders
0.5	0.7934	0.4180	0.0990	0.6390	0.9888	0.1469	$A_3 > A_6 > A_2 > A_4 > A_1 > A_5$

5.3. Sensitivity Analysis

Since the objective facts may deviate from subjective judgment of DMs, a sensitivity analysis is proposed to inspect whether the results of a sequence will be qualitatively influenced when the decision-making information changes. Different coefficients of the decision mechanism λ value may cause different ranking results of the alternatives which can indicate the DMs' attitudes will not always stay the same.

Here, we measure the influence of change in λ value on the final ranking orders of the alternatives. First, we let $\lambda = 0.0, 0.1, 0.2, \ldots, 1.0$ respectively, which indicates the DMs' different preferences, and the changes of collective comprehensive values are shown in Figure 6.

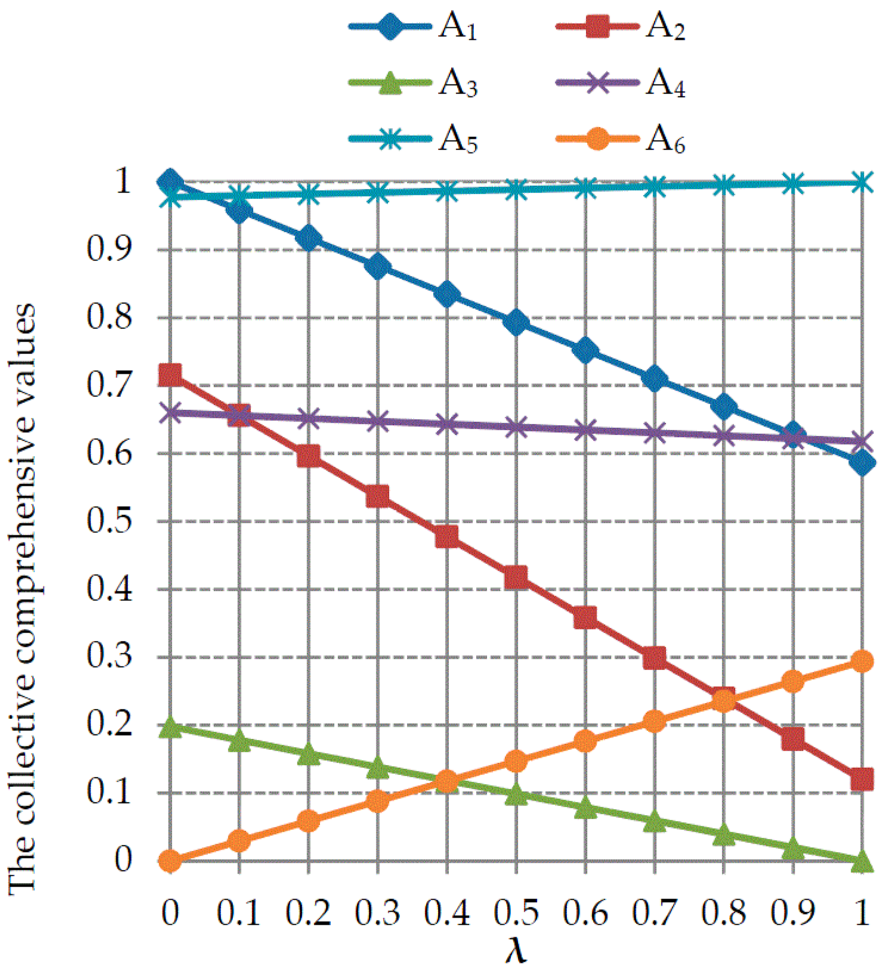

Figure 6. The collective comprehensive values of the alternatives.

From Figure 6, we could find the A_4 and A_5 are stable relatively no matter what λ is, but, A_1, A_2 and A_3 are approximating to the best site gradually. On the contrary, A_6 which is the best site firstly but its collective comprehensive value increases progressively with the increase of λ, which means the preferences of DMs have changed. To take a closer look at the results of sensitivity analysis, we could find that the sequence of the alternatives stay the same when $0.4 \leq \lambda \leq 0.8$ respectively. But when

λ = 0.4, we can see that the top position of A_3 and A_6 exchange in the ranking of the alternatives, which indicates some impact of the DMs' attitudes changes on the decision making results.

Therefore, variation in the λ values provides flexibility for the DMs to make their subjective preferences available. In real-life decision-making, each decision maker's attitude can be considered by the aforementioned method.

5.4. Comparative Analysis

In order to prove that the decision framework proposed above for the EVCSRC site selection based on the VIKOR method is feasible and valid, a comparison based on the same illustrative examples with the results of TOPSIS, PROMETHEE-II and ELECTRE-III is analyzed.

The ranking results of the TOPSIS method depends on the relative closeness $RC(A_i)$ of the alternative A_i by use of the Hamming distance, and the calculation results are shown in Table 6. Different from two methods above, the net flow $\phi(A_i)$ is used to rank the alternatives by PROMETHEE-II and ELECTRE-III. With regard to PROMETHEE-II, we calculate the preference function P^k for the criterion by use of Gaussian Criterion on the basis of the group decision matrix obtained by $TIF - WA$ operator in Table A4 (Appendix A). The ranking orders are listed in Table 6 as well.

Table 6. The results of VIKOR, TOPSIS, PROMETHEE-II and ELECTRE-III.

Algorithm	Calculation Results						Ranking Orders
VIKOR	$Q(A_1)$	$Q(A_2)$	$Q(A_3)$	$Q(A_4)$	$Q(A_5)$	$Q(A_6)$	$A_3 > A_6 > A_2 > A_4 > A_1 > A_5$
	0.7934	0.4180	0.0990	0.6390	0.9888	0.1469	
TOPSIS	$RC(A_1)$	$RC(A_2)$	$RC(A_3)$	$RC(A_4)$	$RC(A_5)$	$RC(A_6)$	$A_3 > A_2 > A_6 > A_4 > A_1 > A_5$
	0.5194	0.5978	0.6289	0.5360	0.4602	0.5675	
PROMETHEE-II	$\phi(A_1)$	$\phi(A_2)$	$\phi(A_3)$	$\phi(A_4)$	$\phi(A_5)$	$\phi(A_6)$	$A_3 > A_6 > A_4 > A_1 > A_2 > A_5$
	-2.22×10^{-5}	-2.96×10^{-6}	4.56×10^{-5}	-1.05×10^{-5}	-3.39×10^{-5}	2.39×10^{-5}	
ELECTRE-III	$\phi(A_1)$	$\phi(A_2)$	$\phi(A_3)$	$\phi(A_4)$	$\phi(A_5)$	$\phi(A_6)$	$A_3 > A_6 = A_2 > A_4 > A_1 > A_5$
	−1	1	2	0	−3	1	

From Table 6, it can be seen that the best alternative is always A_3 with the greatest relative closeness to the ideal solution and the maximum of net flow which are the same as the result of the VIKOR method. Meanwhile, the worst alternative is invariably A_5. The main difference is that the sequence of alternatives located in the places from 2 to 5. The reasons for changes could be interpreted as follows:

The TOPSIS method determines a solution with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution [33,68]. According to the formulation of $RC(A_i)$, the alternative A_2 is better than A_6, which can hold if $D_2^* < D_6^*$ and $D_2^- > D_6^-$, where D^* is the distance from the ideal and D^- is the distance from the negative-ideal. But if we let A_6 be an alternative with $D_6^* = D_6^-$ and $RC(A_6) = 0.5$, and all alternatives $A_i(i = 1,4)$ with $D_i^* > D_6^*$ and $D_i^- > D_i^*$ are better ranked than A_6. That means a ranking order determined by TOPSIS does not always approach the ideal one. The TOPSIS method does not consider the relative importance of the distances D^* and D^-. Beyond that, when in the decision mechanism of the VIKOR method $\lambda = 0.9$, the ranking order is the same as the result of the TOPSIS method. That indicates the calculation results of TOPSIS method are included in the results list of the VIKOR method with the different preferences of the DMs.

The follow-up analysis is the PROMETHEE-II method. Compared with the VIKOR method, the PROMETHEE-II method only considers maximum of group utility and individual regret is not taken into account. Based on the observation results, the main difference is the ranking of A_2 and A_4. According to the decision-making group's opinions, the score of A_2 is obviously superior to A_4, but the ranking order of PROMETHEE-II method is that alternative A_4 is better than A_2.This is inconsistent with the decision-making group's preferences.

Besides, the ELECTRE-III method is also considered in our comparative analysis. From the ranking results, the ELECTRE-III method cannot provide the places of A_6 and A_2 obviously so that distinct decision results cannot be obtained. Moreover, the ELECTRE-III method pursues the minimum of individual regret by using thresholds of indifference and preference without considering the group utility.

By analyzing the reasons given above, the final ranking derived from the VIKOR method $A_3 > A_6 > A_2 > A_4 > A_1 > A_5$ is more accurate and credible than the results obtained by the other mentioned methods. Therefore, the VIKOR method provides the solution closer to the ideal one, and provides a balance between the maximum group utility of the "majority" and the minimum individual regret for the "opponent" at the same time. Moreover, it also takes into account the preferences of DMs. As a result, the VIKOR method is more suitable than the other methods for EVCSRC site selection.

6. Conclusions

Site selection is a crucial procedure in the construction of EVCS. There are two problems and limitations in the existing studies focused on this field. Firstly, the problems solved are so megascopic that a lack of pertinence to actual urban functional areas occurs. Secondly, the uncertainty of decision information is not well expressed. These problems lead to a lack of research significance and the reduction of the evaluation effectiveness.

Therefore, this paper proposes a new comprehensive MCDM framework to solve the aforementioned problems. It is based on the Fuzzy-VIKOR method under the environment of TIFNs in the presence of multiple DMs to deal with the EVCS site selection focused on the residential communities. The advantages of this decision framework are as follows: Firstly, a specialized evaluation index system is established, which provides an effective reference and support for construction of EVCSRC. Secondly, the uncertainty of information is fully described through the conversion from linguistic variable into TIFNs. Thirdly, the Fuzzy-VIKOR method is used to rank the alternatives, which helps DMs determine practicable and satisfactory EVCSRC site. Finally, when applied to a case of Beijing with a sensitive analysis and a comparative analysis, the decision framework shows excellent suitability and sufficient advantages. In the light of case calculation and analysis, the best EVCSRC site located at Sijiqing community in Haidian district received recognition from the expert group and investors.

In conclusion, this proposed decision framework not only overcomes the deficiencies of other studies, but also defines the tasks from different stages and achieves an applicable and reasonable EVCSRC site for investors.

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Author Contributions: Yunna Wu designed the decision framework; Chao Xie established the evaluation index system, collected the relative data and calculated the result; Chao Xie and Chuanbo Xu studied the method application and analyzed the result collectively; after that, Chuanbo Xu and Fang Li corrected the paper; Finally, Chao Xie wrote the paper and formatted the manuscript for submission.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The normalized decision matrix given by e_1.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	((0.16,0.32,0.4); 0.8,0.1)	((0.05,0.2,0.35); 0.8,0.1)	((0,0.05,0.2); 0.8,0.1)	((0,0.16,0.32); 0.7,0.2)	((0.32,0.47,0.63); 0.8,0.1)	((0.5,0.65,0.8); 0.8,0.1)
C_{12}	((0,0.16,0.32); 0.7,0.25)	((0.05,0.2,0.35); 0.7,0.15)	((0.05,0.2,0.35); 0.85,0.1)	((0,0.16,0.32); 0.8,0.1)	((0.16,0.32,0.47); 0.8,0.15)	((0,0.05,0.2); 0.65,0.2)
C_{13}	((0.63,0.79,0.9); 0.8,0.1)	((0.65,0.8,0.95); 0.7,0.2)	((0.35,0.5,0.65); 0.7,0.2)	((0.47,0.63,0.79); 0.75,0.1)	((0.79,0.95,1); 0.8,0.1)	((0.5,0.65,0.8); 0.75,0.2)
C_{21}	((0.5,0.65,0.8); 0.65,0.3)	((0.65,0.8,0.95); 0.7,0.25)	((0.8,0.95,1); 0.75,0.2)	((0.53,0.68,0.84); 0.9,0.05)	((0.05,0.2,0.35); 0.7,0.15)	((0,0.05,0.21); 0.7,0.25)
C_{22}	((0.05,0.2,0.35); 0.8,0.1)	((0.8,0.95,1); 0.8,0.1)	((0.5,0.65,0.8); 0.85,0.1)	((0.53,0.68,0.84); 0.8,0.15)	((0.35,0.5,0.65); 0.8,0.1)	((0.37,0.53,0.68); 0.7,0.2)
C_{23}	((0.2,0.35,0.5); 0.8,0.1)	((0.5,0.65,0.8); 0.85,0.05)	((0.8,0.95,1); 0.9,0.05)	((0.53,0.68,0.84); 0.8,0.1)	((0.2,0.35,0.5); 0.85,0.05)	((0.21,0.37,0.53); 0.75,0.15)
C_{31}	((0.2,0.35,0.5); 0.75,0.2)	((0.05,0.2,0.35); 0.8,0.15)	((0.8,0.95,1); 0.8,0.15)	((0.37,0.53,0.68); 0.7,0.25)	((0.35,0.5,0.65); 0.8,0.15)	((0.53,0.68,0.84); 0.8,0.15)
C_{32}	((0.63,0.79,0.95); 0.8,0.1)	((0.05,0.2,0.35); 0.8,0.1)	((0.35,0.5,0.65); 0.75,0.15)	((0,0.16,0.32); 0.7,0.2)	((0.16,0.32,0.47); 0.8,0.1)	((0.35,0.5,0.65); 0.8,0.1)
C_{41}	((0.8,0.95,1); 0.7,0.2)	((0.8,0.95,1); 0.7,0.2)	((0.2,0.35,0.5); 0.8,0.1)	((0.21,0.37,0.53); 0.8,0.1)	((0.5,0.65,0.8); 0.8,0.1)	((0.53,0.68,0.84); 0.8,0.1)
C_{42}	((0.47,0.63,0.79); 0.8,0.1)	((0.2,0.35,0.5); 0.8,0.1)	((0.35,0.5,0.65); 0.8,0.1)	((0,0.16,0.32); 0.7,0.2)	((0,0.16,0.32); 0.65,0.25)	((0.65,0.8,0.95); 0.8,0.1)
C_{43}	((0.5,0.65,0.8); 0.7,0.2)	((0.2,0.35,0.5); 0.9,0)	((0.05,0.2,0.35); 0.9,0)	((0.21,0.37,0.53); 0.85,0.05)	((0.35,0.5,0.65); 0.7,0.2)	((0.68,0.84,1); 0.8,0.1)
C_{44}	((0.5,0.65,0.8); 0.7,0.2)	((0.35,0.5,0.65); 0.7,0.2)	((0.2,0.35,0.5); 0.7,0.2)	((0.37,0.53,0.68); 0.65,0.25)	((0.8,0.95,1); 0.7,0.2)	((0.68,0.84,1); 0.7,0.2)
C_{45}	((0.35,0.5,0.65); 0.75,0.2)	((0.65,0.8,0.95); 0.65,0.3)	((0.35,0.5,0.65); 0.8,0.15)	((0.68,0.84,1); 0.8,0.15)	((0.65,0.8,0.95); 0.7,0.25)	((0.05,0.21,0.37); 0.8,0.1)
C_{51}	((0.65,0.8,0.95); 0.7,0.2)	((0.8,0.95,1); 0.8,0.1)	((0.65,0.8,0.95); 0.85,0.1)	((0.37,0.53,0.68); 0.9,0.1)	((0.05,0.2,0.35); 0.8,0.1)	((0.68,0.84,1); 0.8,0.1)
C_{52}	((0.2,0.35,0.5); 0.7,0.1)	((0.5,0.65,0.8); 0.7,0.15)	((0.8,0.95,1); 0.85,0.1)	((0.53,0.68,0.84); 0.8,0.1)	((0.2,0.35,0.5); 0.75,0.1)	((0,0.05,0.21); 0.7,0.1)
C_{53}	((0.5,0.65,0.8); 0.8,0.1)	((0.65,0.8,0.95); 0.75,0.15)	((0.65,0.8,0.95); 0.9,0.05)	((0.68,0.84,1); 0.85,0.1)	((0.65,0.8,0.95); 0.65,0.15)	((0.84,1,1.05); 0.75,0.1)

Table A2. The normalized decision matrix given by e_2.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	((0.47,0.63,0.79); 0.75,0.2)	((0.35,0.5,0.65); 0.9,0.05)	((0.05,0.2,0.35); 0.9,0.05)	((0.2,0.35,0.5); 0.75,0.15)	((0.47,0.63,0.79); 0.8,0.15)	((0.63,0.79,0.95); 0.75,0.2)
C_{12}	((0.16,0.32,0.47); 0.85,0.1)	((0.05,0.2,0.35); 0.8,0.1)	((0.05,0.2,0.35); 0.9,0.1)	((0.2,0.35,0.5); 0.65,0.25)	((0,0.16,0.32); 0.75,0.2)	((0,0.16,0.32); 0.8,0.25)
C_{13}	((0.63,0.79,0.95); 0.7,0.2)	((0.5,0.65,0.8); 0.85,0.05)	((0.5,0.65,0.8); 0.85,0.1)	((0.8,0.95,1); 0.7,0.1)	((0.63,0.79,0.95); 0.75,0.1)	((0.32,0.47,0.63); 0.8,0.15)
C_{21}	((0.37,0.53,0.68); 0.9,0.05)	((0.5,0.65,0.8); 0.75,0.2)	((0.65,0.8,0.95); 0.7,0.2)	((0.53,0.68,0.84); 0.8,0.1)	((0,0.05,0.21); 0.8,0.15)	((0.05,0.2,0.35); 0.8,0.15)
C_{22}	((0.37,0.53,0.68); 0.8,0.05)	((0.65,0.8,0.95); 0.8,0.05)	((0.8,0.95,1); 0.7,0.1)	((0.68,0.84,1); 0.6,0.3)	((0.21,0.37,0.53); 0.7,0.15)	((0.2,0.35,0.5); 0.8,0.05)
C_{23}	((0.53,0.68,0.84); 0.7,0.1)	((0.65,0.8,0.95); 0.7,0.15)	((0.8,0.95,1); 0.9,0.1)	((0.68,0.84,1); 0.8,0.1)	((0.53,0.68,0.84); 0.75,0.1)	((0.35,0.5,0.65); 0.7,0.1)
C_{31}	((0,0.05,0.21); 0.8,0.05)	((0.5,0.65,0.8); 0.8,0.05)	((0.8,0.95,1); 0.7,0.15)	((0.21,0.37,0.53); 0.75,0.1)	((0.05,0.21,0.37); 0.8,0.05)	((0.2,0.35,0.5); 0.8,0.05)
C_{32}	((0.47,0.63,0.79); 0.8,0.1)	((0.2,0.35,0.5); 0.8,0.1)	((0.2,0.35,0.5); 0.8,0.1)	((0.05,0.2,0.35); 0.8,0.1)	((0,0.16,0.32); 0.8,0.1)	((0,0.16,0.32); 0.8,0.1)
C_{41}	((0.68,0.84,1); 0.9,0.05)	((0.65,0.8,0.95); 0.9,0.05)	((0.35,0.5,0.65); 0.7,0.25)	((0.37,0.53,0.68); 0.7,0.25)	((0.53,0.68,0.84); 0.75,0.15)	((0.5,0.65,0.8); 0.75,0.15)
C_{42}	((0.16,0.32,0.47); 0.9,0.1)	((0.2,0.35,0.5); 0.9,0.1)	((0.2,0.35,0.5); 0.9,0.1)	((0.05,0.2,0.35); 0.9,0.1)	((0,0.16,0.32); 0.9,0.1)	((0.16,0.32,0.47); 0.9,0.1)
C_{43}	((0.53,0.68,0.84); 0.8,0.15)	((0.05,0.2,0.35); 0.9,0.05)	((0,0.05,0.2); 0.85,0.1)	((0.05,0.21,0.37); 0.85,0.1)	((0.21,0.37,0.53); 0.9,0.05)	((0.8,0.95,1); 0.85,0.1)
C_{44}	((0.53,0.68,0.84); 0.8,0.1)	((0.35,0.5,0.65); 0.75,0.2)	((0.35,0.5,0.65); 0.8,0.1)	((0.21,0.37,0.53); 0.8,0.1)	((0.68,0.84,1); 0.8,0.1)	((0.65,0.8,0.95); 0.7,0.2)
C_{45}	((0.37,0.53,0.68); 0.7,0.1)	((0.8,0.95,1); 0.7,0.1)	((0.65,0.8,0.95); 0.7,0.1)	((0.53,0.68,0.84); 0.7,0.1)	((0.05,0.21,0.37); 0.7,0.1)	((0.2,0.35,0.5); 0.7,0.1)
C_{51}	((0.37,0.53,0.68); 0.75,0.1)	((0.5,0.65,0.8); 0.8,0.1)	((0.65,0.8,0.95); 0.85,0.1)	((0.53,0.68,0.84); 0.75,0.15)	((0.37,0.53,0.68); 0.8,0.1)	((0.05,0.2,0.35); 0.7,0.2)
C_{52}	((0.21,0.37,0.53); 0.8,0.1)	((0.5,0.65,0.8); 0.85,0.1)	((0.8,0.95,1); 0.9,0.05)	((0.53,0.68,0.84); 0.8,0.1)	((0.21,0.37,0.53); 0.85,0.1)	((0.2,0.35,0.5); 0.75,0.1)
C_{53}	((0.68,0.84,1); 0.7,0.1)	((0.8,0.95,1); 0.75,0.2)	((0.8,0.95,1); 0.7,0.1)	((0.84,1,1.05); 0.65,0.1)	((0.68,0.84,1); 0.8,0.15)	((0.65,0.8,0.95); 0.85,0.1)

Table A3. The normalized decision matrix given by e_3.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	((0.32,0.47,0.63); 0.85,0.1)	((0.2,0.35,0.5); 0.85,0.1)	((0.05,0.2,0.35); 0.8,0.1)	((0.16,0.32,0.47); 0.7,0.2)	((0.19,0.38,0.56); 0.7,0.25)	((0.63,0.79,0.95); 0.85,0.1)
C_{12}	((0,0.16,0.32); 0.6,0.25)	((0.2,0.35,0.5); 0.85,0.05)	((0.2,0.35,0.5); 0.7,0.2)	((0,0.16,0.32); 0.8,0.15)	((0,0.19,0.38); 0.75,0.15)	((0.16,0.32,0.47); 0.9,0.05)
C_{13}	((0.79,0.95,1); 0.65,0.2)	((0.8,0.95,1); 0.65,0.3)	((0.65,0.8,0.95); 0.65,0.3)	((0.63,0.79,0.95); 0.85,0.1)	((0.75,0.94,1); 0.75,0.2)	((0.79,0.95,1); 0.9,0.1)
C_{21}	((0.21,0.37,0.53); 0.7,0.2)	((0.65,0.8,0.95); 0.8,0.15)	((0.65,0.8,0.95); 0.85,0.1)	((0.68,0.84,1); 0.7,0.15)	((0,0.05,0.21); 0.65,0.3)	((0.05,0.21,0.37); 0.7,0.15)
C_{22}	((0.21,0.37,0.53); 0.8,0.15)	((0.65,0.8,0.95); 0.8,0.15)	((0.5,0.65,0.8); 0.8,0.15)	((0.37,0.53,0.68); 0.8,0.15)	((0.05,0.21,0.37); 0.8,0.15)	((0,0.05,0.21); 0.8,0.15)
C_{23}	((0.21,0.37,0.53); 0.75,0.2)	((0.8,0.95,1); 0.8,0.1)	((0.65,0.8,0.95); 0.85,0.1)	((0.37,0.53,0.68); 0.85,0.1)	((0.21,0.37,0.53); 0.65,0.3)	((0.21,0.37,0.53); 0.85,0.1)
C_{31}	((0.37,0.53,0.68); 0.8,0.15)	((0.2,0.35,0.5); 0.8,0.15)	((0.5,0.65,0.8); 0.8,0.15)	((0.37,0.53,0.68); 0.7,0.25)	((0.37,0.53,0.68); 0.6,0.35)	((0.68,0.84,1); 0.8,0.15)
C_{32}	((0,0.16,0.32); 0.75,0.1)	((0.65,0.8,0.95); 0.75,0.1)	((0.05,0.2,0.35); 0.75,0.1)	((0.63,0.79,0.95); 0.75,0.1)	((0.56,0.75,0.94); 0.75,0.1)	((0.63,0.79,0.95); 0.75,0.1)
C_{41}	((0.68,0.84,1); 0.8,0.15)	((0.65,0.8,0.95); 0.8,0.15)	((0.5,0.65,0.8); 0.75,0.1)	((0.53,0.68,0.84); 0.8,0.1)	((0.68,0.84,1); 0.75,0.2)	((0.68,0.84,1); 0.75,0.2)
C_{42}	((0.63,0.79,0.95); 0.9,0.05)	((0.2,0.35,0.5); 0.9,0.05)	((0.35,0.5,0.65); 0.9,0.05)	((0,0.16,0.32); 0.9,0.05)	((0,0.19,0.38); 0.9,0.05)	((0.32,0.47,0.63); 0.9,0.05)
C_{43}	((0.53,0.68,0.84); 0.85,0.1)	((0.35,0.5,0.65); 0.8,0.15)	((0.2,0.35,0.5); 0.9,0.05)	((0.37,0.53,0.68); 0.75,0.25)	((0.37,0.53,0.68); 0.9,0.05)	((0.68,0.84,1); 0.95,0)
C_{44}	((0.21,0.37,0.53); 0.75,0.2)	((0.8,0.95,1); 0.8,0.1)	((0.65,0.8,0.95); 0.85,0.1)	((0.37,0.53,0.68); 0.85,0.1)	((0.21,0.37,0.53); 0.65,0.3)	((0.21,0.37,0.53); 0.85,0.1)
C_{45}	((0.53,0.68,0.84); 0.7,0.1)	((0.65,0.8,0.95); 0.7,0.15)	((0.8,0.95,1); 0.85,0.1)	((0.68,0.84,1); 0.8,0.1)	((0.53,0.68,0.84); 0.75,0.1)	((0.37,0.53,0.68); 0.7,0.1)
C_{51}	((0.05,0.21,0.37); 0.8,0.1)	((0.8,0.95,1); 0.8,0.1)	((0.5,0.65,0.8); 0.85,0.1)	((0.53,0.68,0.84); 0.8,0.15)	((0.37,0.53,0.68); 0.8,0.1)	((0.37,0.53,0.68); 0.7,0.2)
C_{52}	((0.53,0.68,0.84); 0.75,0.1)	((0.65,0.8,0.95); 0.85,0.1)	((0.8,0.95,1); 0.85,0.05)	((0.68,0.84,1); 0.8,0.1)	((0.53,0.68,0.84); 0.7,0.1)	((0.37,0.53,0.68); 0.85,0.1)
C_{53}	((0.68,0.84,1); 0.65,0.2)	((0.65,0.8,0.95); 0.65,0.2)	((0.8,0.95,1); 0.85,0.15)	((0.68,0.84,1); 0.75,0.2)	((0.53,0.68,0.84); 0.95,0)	((0.68,0.84,1); 0.7,0.2)

Table A4. The group decision matrix obtained by the *TIF-WA* operator.

	A_1	A_2	A_3	A_4	A_5	A_6
C_{11}	((0.32,0.47,0.63); 0.75,0.2)	((0.2,0.35,0.5); 0.8,0.1)	((0.03,0.15,0.3); 0.8,0.1)	((0.12,0.28,0.43); 0.7,0.2)	((0.32,0.49,0.66); 0.7,0.25)	((0.59,0.74,0.9); 0.75,0.2)
C_{12}	((0.05,0.21,0.37); 0.6,0.25)	((0.1,0.25,0.4); 0.7,0.15)	((0.1,0.25,0.4); 0.7,0.2)	((0.07,0.22,0.38); 0.65,0.25)	((0.05,0.22,0.39); 0.75,0.2)	((0.06,0.18,0.33); 0.65,0.25)
C_{13}	((0.69,0.85,0.97); 0.65,0.2)	((0.65,0.8,0.92); 0.65,0.3)	((0.5,0.65,0.8); 0.65,0.3)	((0.64,0.79,0.91); 0.7,0.1)	((0.72,0.89,0.98); 0.75,0.2)	((0.54,0.7,0.82); 0.75,0.2)
C_{21}	((0.35,0.51,0.67); 0.65,0.3)	((0.6,0.75,0.9); 0.7,0.25)	((0.7,0.85,0.97); 0.7,0.2)	((0.58,0.74,0.9); 0.7,0.15)	((0.02,0.1,0.26); 0.65,0.3)	((0.03,0.16,0.31); 0.7,0.25)
C_{22}	((0.21,0.37,0.52); 0.8,0.15)	((0.7,0.85,0.97); 0.8,0.15)	((0.6,0.75,0.87); 0.7,0.15)	((0.52,0.68,0.84); 0.6,0.3)	((0.2,0.35,0.51); 0.7,0.15)	((0.18,0.3,0.46); 0.7,0.2)
C_{23}	((0.31,0.47,0.62); 0.7,0.2)	((0.65,0.8,0.92); 0.7,0.15)	((0.75,0.9,0.98); 0.85,0.1)	((0.52,0.68,0.84); 0.8,0.1)	((0.31,0.47,0.62); 0.65,0.3)	((0.26,0.41,0.57); 0.7,0.15)
C_{31}	((0.19,0.32,0.47); 0.75,0.2)	((0.25,0.4,0.55); 0.8,0.15)	((0.69,0.84,0.93); 0.7,0.15)	((0.32,0.47,0.63); 0.7,0.25)	((0.26,0.42,0.57); 0.6,0.35)	((0.48,0.63,0.79); 0.8,0.15)
C_{32}	((0.36,0.51,0.67); 0.75,0.1)	((0.31,0.46,0.6); 0.75,0.1)	((0.2,0.35,0.5); 0.75,0.15)	((0.24,0.4,0.55); 0.7,0.2)	((0.25,0.42,0.59); 0.75,0.1)	((0.34,0.49,0.65); 0.75,0.1)
C_{41}	((0.72,0.88,1); 0.7,0.2)	((0.7,0.85,0.97); 0.7,0.2)	((0.35,0.5,0.65); 0.7,0.25)	((0.37,0.53,0.69); 0.7,0.25)	((0.57,0.73,0.88); 0.75,0.2)	((0.57,0.73,0.88); 0.75,0.2)
C_{42}	((0.43,0.58,0.74); 0.8,0.1)	((0.2,0.35,0.5); 0.8,0.1)	((0.3,0.45,0.6); 0.8,0.1)	((0.02,0.17,0.33); 0.7,0.2)	((0,0.17,0.34); 0.65,0.25)	((0.37,0.53,0.68); 0.8,0.1)
C_{43}	((0.52,0.67,0.83); 0.7,0.2)	((0.2,0.35,0.5); 0.8,0.15)	((0.09,0.2,0.35); 0.85,0.1)	((0.22,0.37,0.53); 0.75,0.25)	((0.31,0.47,0.62); 0.7,0.2)	((0.72,0.88,1); 0.8,0.1)
C_{44}	((0.41,0.56,0.72); 0.7,0.2)	((0.51,0.66,0.7); 0.7,0.2)	((0.41,0.56,0.71); 0.7,0.2)	((0.32,0.47,0.63); 0.65,0.25)	((0.55,0.71,0.83); 0.65,0.3)	((0.51,0.66,0.82); 0.7,0.2)
C_{45}	((0.42,0.57,0.73); 0.7,0.2)	((0.7,0.85,0.97); 0.65,0.3)	((0.61,0.76,0.87); 0.7,0.15)	((0.63,0.79,0.95); 0.7,0.15)	((0.41,0.57,0.72); 0.7,0.25)	((0.21,0.37,0.52); 0.7,0.1)
C_{51}	((0.35,0.5,0.66); 0.7,0.2)	((0.7,0.85,0.93); 0.8,0.1)	((0.6,0.75,0.9); 0.85,0.1)	((0.48,0.63,0.79); 0.75,0.15)	((0.27,0.42,0.58); 0.8,0.1)	((0.37,0.52,0.68); 0.7,0.2)
C_{52}	((0.32,0.47,0.63); 0.7,0.1)	((0.55,0.7,0.85); 0.7,0.15)	((0.8,0.95,1); 0.85,0.1)	((0.58,0.74,0.9); 0.8,0.1)	((0.32,0.47,0.63); 0.7,0.1)	((0.2,0.32,0.47); 0.7,0.1)
C_{53}	((0.63,0.78,0.94); 0.65,0.2)	((0.7,0.85,0.97); 0.65,0.2)	((0.75,0.9,0.98); 0.7,0.15)	((0.74,0.89,1.02); 0.65,0.2)	((0.62,0.77,0.93); 0.65,0.15)	((0.72,0.88,1); 0.7,0.2)

Appendix B

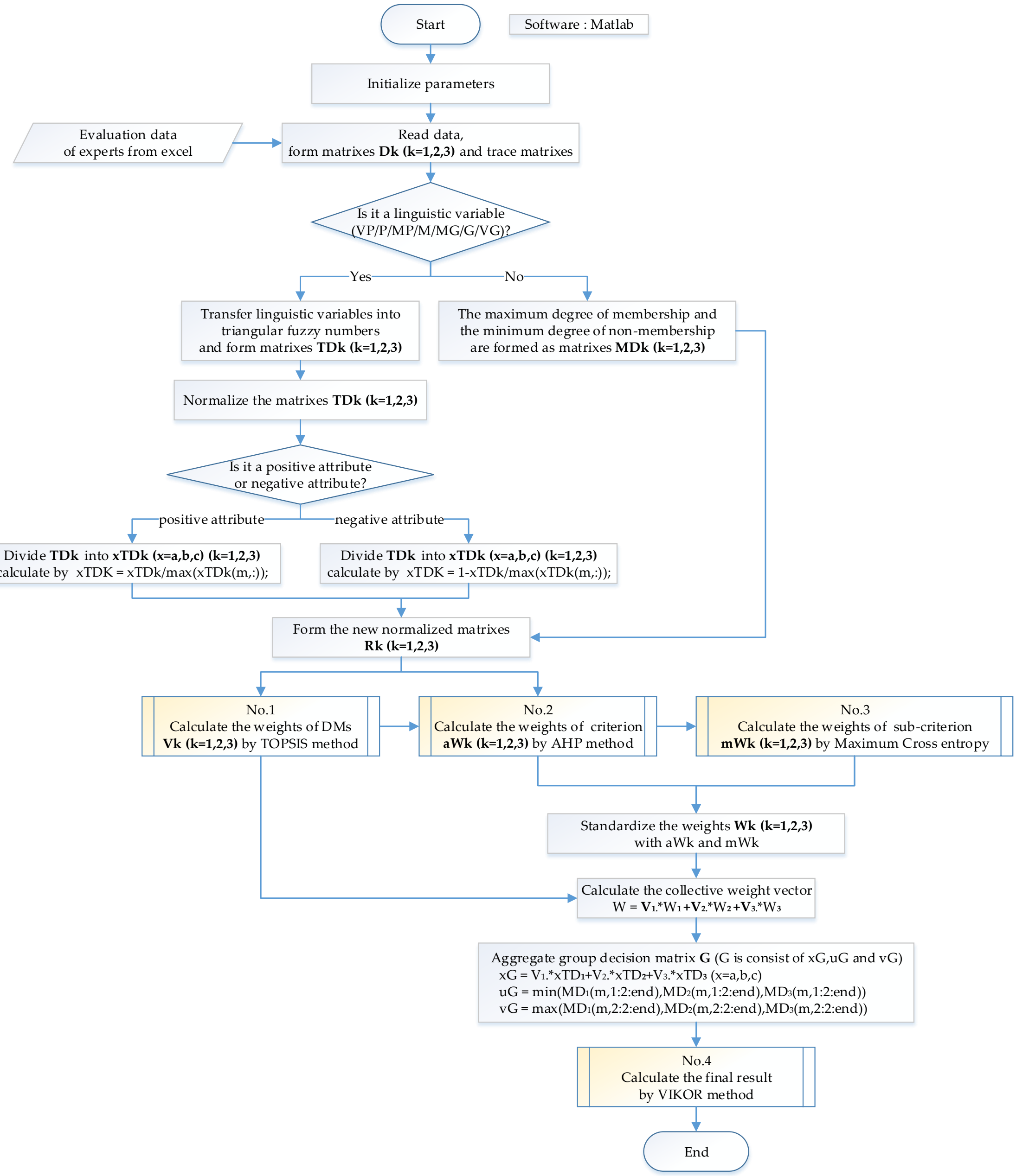

Figure A1. The flowchart of algorithm implementation about proposed framework.

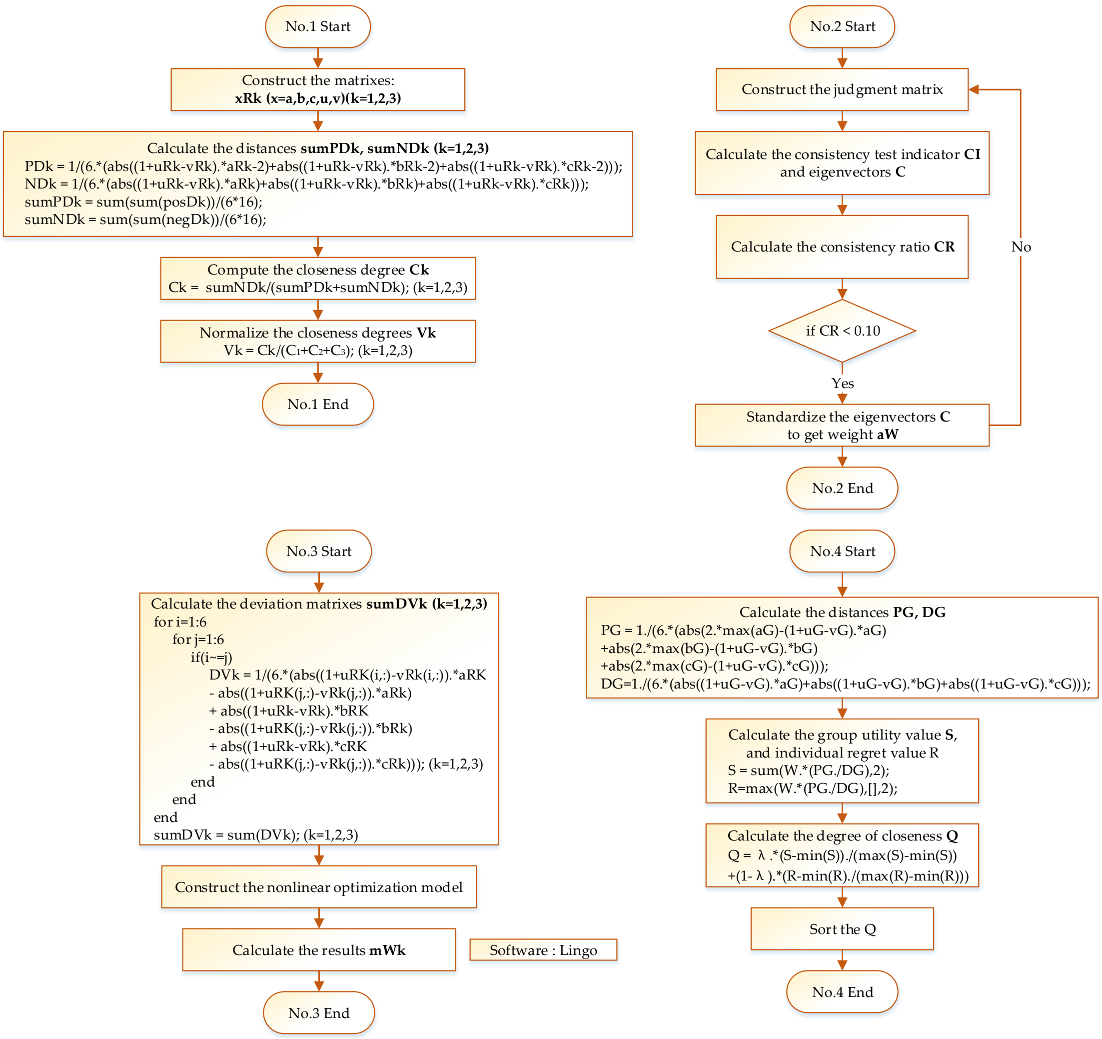

Figure A2. The secondary flowchart of algorithm implementation about proposed framework.

References

1. Guo, S.; Zhao, H. Optimal site selection of electric vehicle charging station by using fuzzy topsis based on sustainability perspective. *Appl. Energy* **2015**, *158*, 390–402. [CrossRef]
2. Wu, Y.; Yang, M.; Zhang, H.; Chen, K.; Wang, Y. Optimal site selection of electric vehicle charging stations based on a cloud model and the promethee method. *Energies* **2016**, *9*, 157. [CrossRef]
3. Zhao, H.; Li, N. Optimal siting of charging stations for electric vehicles based on fuzzy delphi and hybrid multi-criteria decision making approaches from an extended sustainability perspective. *Energies* **2016**, *9*, 270. [CrossRef]
4. Tang, Z.; Guo, C.; Hou, P.; Fan, Y. Optimal siting of electric vehicle charging stations based on voronoi diagram and fahp method. *Energy Power Eng.* **2013**, *5*, 1404–1409. [CrossRef]
5. Mokhtarian, M.N.; Sadi-Nezhad, S.; Makui, A. A new flexible and reliable interval valued fuzzy vikor method based on uncertainty risk reduction in decision making process: An application for determining a suitable location for digging some pits for municipal wet waste landfill. *Comput. Ind. Eng.* **2014**, *78*, 213–233. [CrossRef]
6. Bai, X.; Liu, Y. Minimum risk facility location-allocation problem with type-2 fuzzy variables. *Sci. World J.* **2014**, *2014*, 472623. [CrossRef] [PubMed]
7. Rahmat, Z.G.; Niri, M.V.; Alavi, N.; Goudarzi, G.; Babaei, A.A.; Baboli, Z.; Hosseinzadeh, M. Landfill site selection using gis and ahp: A case study: Behbahan, Iran. *Ksce J. Civil Eng.* **2017**, *21*, 111–118. [CrossRef]

8. Elevli, B. Logistics freight center locations decision by using fuzzy-promethee. *Transport* **2014**, *29*, 412–418. [CrossRef]
9. Beskese, A.; Demir, H.H.; Ozcan, H.K.; Okten, H.E. Landfill site selection using fuzzy ahp and fuzzy topsis: A case study for istanbul. *Environ. Earth Sci.* **2015**, *73*, 3513–3521. [CrossRef]
10. Ding, J.F.; Chou, C.C. An evaluation model of quantitative and qualitative fuzzy multi-criteria decision-making approach for location selection of transshipment ports. *Math. Probl. Eng.* **2013**, *2013*, 927–940. [CrossRef]
11. Kabir, G.; Sumi, R.S. Power substation location selection using fuzzy analytic hierarchy process and promethee: A case study from bangladesh. *Energy* **2014**, *72*, 717–730. [CrossRef]
12. Kurt, Ü. The fuzzy topsis and generalized choquet fuzzy integral algorithm for nuclear power plant site selection—A case study from turkey. *J. Nucl. Sci. Technol.* **2014**, *51*, 1241–1255. [CrossRef]
13. Chou, C.C.; Yu, K.W. Application of a new hybrid fuzzy ahp model to the location choice. *Math. Probl. Eng.* **2013**, *2013*, 601–622. [CrossRef]
14. Liu, H.C.; You, J.X.; Chen, Y.Z.; Fan, X.J. Site selection in municipal solid waste management with extended vikor method under fuzzy environment. *Environ. Earth Sci.* **2014**, *72*, 4179–4189. [CrossRef]
15. Devi, K.; Yadav, S.P. A multicriteria intuitionistic fuzzy group decision making for plant location selection with electre method. *Int. J. Adv. Manuf. Technol.* **2013**, *66*, 1219–1229. [CrossRef]
16. Alavi, N.; Goudarzi, G.; Babaei, A.A.; Jaafarzadeh, N.; Hosseinzadeh, M. Municipal solid waste landfill site selection with geographic information systems and analytical hierarchy process: A case study in mahshahr county, Iran. *Waste Manag. Res.* **2013**, *31*, 98–105. [CrossRef] [PubMed]
17. Ahmadisharaf, E.; Tajrishy, M.; Alamdari, N. Integrating flood hazard into site selection of detention basins using spatial multi-criteria decision-making. *J. Environ. Plan. Manag.* **2016**, *59*, 1397–1417. [CrossRef]
18. Suder, A.; Kahraman, C. Minimizing environmental risks using fuzzy topsis: Location selection for the itu faculty of management. *Hum. Ecol. Risk Assess. Int. J.* **2015**, *21*, 1326–1340. [CrossRef]
19. Gonzalez, J.P.L.; Hurtado, M.E.R. Introduction of sustainability criteria in the selection of industrial locations through multicriteria models. *DYNA* **2014**, *89*, 192–201.
20. Hamzeh, M.; Ali, A.R.; Davalou, R. Raster-based outranking method: A new approach for municipal solid waste landfill (msw) siting. *Environ. Sci. Pollut. Res. Int.* **2015**, *22*, 12511–12524. [CrossRef] [PubMed]
21. Dong, J.; Feng, T.T.; Yang, Y.S.; Yu, M. Macro-site selection of wind/solar hybrid power station based on electre-II. *Renew. Sustain. Energy Rev.* **2014**, *35*, 194–204.
22. Fetanat, A.; Khorasaninejad, E. A novel hybrid mcdm approach for offshore wind farm site selection: A case study of Iran. *Ocean Coast. Manag.* **2015**, *109*, 17–28. [CrossRef]
23. Wu, Y.; Zhang, J.; Yuan, J.; Geng, S.; Zhang, H. Study of decision framework of offshore wind power station site selection based on electre-iii under intuitionistic fuzzy environment: A case of China. *Energy Convers. Manag.* **2016**, *113*, 66–81. [CrossRef]
24. Hacıoğlu, H.İ.; Ari, A.; Özkan, A.; Elbir, T.; Tuncel, G.; Yay, O.D.; Gaga, E.O. Article in press a new approach for site selection of air quality monitoring stations: Multi-criteria decision-making. *Aerosol Air Qual. Res.* **2016**, *16*, 1390–1402. [CrossRef]
25. Wu, Y.; Geng, S. Multi-criteria decision making on selection of solar–wind hybrid power station location: A case of China. *Energy Convers. Manag.* **2014**, *81*, 527–533.
26. Wu, Y.; Geng, S.; Xu, H.; Zhang, H. Study of decision framework of wind farm project plan selection under intuitionistic fuzzy set and fuzzy measure environment. *Energy Convers. Manag.* **2014**, *87*, 274–284. [CrossRef]
27. Wu, Y.; Geng, S.; Zhang, H.; Gao, M. Decision framework of solar thermal power plant site selection based on linguistic choquet operator. *Appl. Energy* **2014**, *136*, 303–311. [CrossRef]
28. Shu, M.H.; Cheng, C.H.; Chang, J.R. Using intuitionistic fuzzy sets for fault-tree analysis on printed circuit board assembly. *Microelectron. Reliab.* **2006**, *46*, 2139–2148. [CrossRef]
29. Li, D.F.; Nan, J.X.; Zhang, M.J. A ranking method of triangular intuitionistic fuzzy numbers and application to decision making. *Int. J. Conmput. Intell. Syst.* **2010**, *3*, 522–530. [CrossRef]
30. Qin, Q.; Liang, F.; Li, L.; Chen, Y.W.; Yu, G.F. A todim-based multi-criteria group decision making with triangular intuitionistic fuzzy numbers. *Appl. Soft Comput.* **2017**, *55*, 93–107. [CrossRef]

31. Li, L.; Wang, L.; Liao, B. Einstein choquet integral operators for promethee II group decision making method with triangular intuitionistic fuzzy numbers. In Proceedings of the International Conference on Oriental Thinking and Fuzzy Logic, Dalian, China, 17–20 August 2015; Cao, B.Y., Wang, P.Z., Liu, Z.L., Zhong, Y.B., Eds.; Springer International Publishing: Berlin, Germany, 2016.
32. Wan, S.P.; Wang, Q.Y.; Dong, J.Y. The extended vikor method for multi-attribute group decision making with triangular intuitionistic fuzzy numbers. *Knowl. Based Syst.* **2013**, *52*, 65–77. [CrossRef]
33. Opricovic, S.; Tzeng, G.H. Compromise solution by mcdm methods: A comparative analysis of vikor and topsis. *Eur. J. Oper. Res.* **2004**, *156*, 445–455. [CrossRef]
34. Xu, F.; Liu, J.; Lin, S.; Yuan, J. A vikor-based approach for assessing the service performance of electric vehicle sharing programs: A case study in Beijing. *J. Clean. Prod.* **2017**, *148*, 254–267. [CrossRef]
35. Milosevic, I.; Naunovic, Z. The application of a multi-parameter analysis in choosing the location of a new solid waste landfill in serbia. *Waste Manag. Res.* **2013**, *31*, 1019–1027. [CrossRef] [PubMed]
36. Minatour, Y.; Khazaie, J.; Ataei, M.; Javadi, A.A. An integrated decision support system for dam site selection. *Scientia Iranica* **2015**, *22*, 319–330.
37. Azoumah, Y.; Ramdé, E.W.; Tapsoba, G.; Thiam, S. Siting guidelines for concentrating solar power plants in the sahel: Case study of burkina faso. *Sol. Energy* **2010**, *84*, 1545–1553. [CrossRef]
38. Choudhary, D.; Shankar, R. An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India. *Energy* **2012**, *42*, 510–521. [CrossRef]
39. Ekmekçioğlu, M.; Kaya, T.; Kahraman, C. Fuzzy multicriteria disposal method and site selection for municipal solid waste. *Waste Manag.* **2010**, *30*, 1729. [CrossRef]
40. Erol, İ.; Sencer, S.; Özmen, A.; Searcy, C. Fuzzy mcdm framework for locating a nuclear power plant in turkey. *Energy Policy* **2014**, *67*, 186–197. [CrossRef]
41. Wu, Y.N.; Yang, Y.S.; Feng, T.T.; Kong, L.N.; Liu, W.; Fu, L.J. Macro-site selection of wind/solar hybrid power station based on ideal matter-element model. *Int. J. Electr. Power Energy Syst.* **2013**, *50*, 76–84.
42. Xiao, J.; Yao, Z.; Qu, J.; Sun, J. Research on an optimal site selection model for desert photovoltaic power plants based on analytic hierarchy process and geographic information system. *J. Renew. Sustain. Energy* **2013**, *5*, 89–1041. [CrossRef]
43. Abudeif, A.M.; Moneim, A.A.A.; Farrag, A.F. Multicriteria decision analysis based on analytic hierarchy process in gis environment for siting nuclear power plant in egypt. *Ann. Nucl. Energy* **2015**, *75*, 682–692. [CrossRef]
44. Gorsevski, P.V.; Cathcart, S.C.; Mirzaei, G.; Jamali, M.M.; Ye, X.; Gomezdelcampo, E. A group-based spatial decision support system for wind farm site selection in northwest Ohio. *Energy Policy* **2013**, *55*, 374–385. [CrossRef]
45. Latinopoulos, D.; Kechagia, K. A gis-based multi-criteria evaluation for wind farm site selection. A regional scale application in greece. *Renew. Energy* **2015**, *78*, 550–560. [CrossRef]
46. Ekmekçioglu, M.; Kutlu, A.C.; Kahraman, C. A fuzzy multi-criteria swot analysis: An application to nuclear power plant site selection. *Int. J. Comput. Intell. Syst.* **2011**, *4*, 583–595. [CrossRef]
47. Tsiourtis, N.X. Criteria and procedure for selecting a site for a desalination plant. *Desalination* **2008**, *221*, 114–125. [CrossRef]
48. Savva, P.G.; Costa, C.N.; Charalambides, A.G. Environmental, economical and marketing aspects of the operation of a waste-to-energy plant in the kotsiatis landfill in cyprus. *Waste Biomass Valoriz.* **2013**, *4*, 259–269. [CrossRef]
49. Wu, Y.; Chen, K.; Zeng, B.; Yang, M.; Geng, S. Cloud-based decision framework for waste-to-energy plant site selection—A case study from china. *Waste Manag.* **2016**, *48*, 593–603. [CrossRef] [PubMed]
50. Noshadravan, A.; Cheah, L.; Roth, R.; Freire, F.; Dias, L.; Gregory, J. Stochastic comparative assessment of life-cycle greenhouse gas emissions from conventional and electric vehicles. *Int. J. Life Cycle Assess.* **2015**, *20*, 854–864. [CrossRef]
51. Zhang, X.; Rao, R.; Xie, J.; Liang, Y. The current dilemma and future path of China's electric vehicles. *Sustainability* **2014**, *6*, 1567–1593. [CrossRef]
52. Lin, B.; Tan, R. Estimation of the environmental values of electric vehicles in Chinese cities. *Energy Policy* **2017**, *104*, 221–229. [CrossRef]
53. Zhang, J.; Liu, J.; Kong, Y. The correlation of vehicle emission and haze phenomenon in Beijing. *North. Environ.* **2013**, *11*, 115–117. (In Chinese)

54. Ji, Y.; Huang, G.H.; Sun, W. Risk assessment of hydropower stations through an integrated fuzzy entropy-weight multiple criteria decision making method: A case study of the xiangxi river. *Expert Syst. Appl.* **2015**, *42*, 5380–5389. [CrossRef]
55. Shi, X.; Wang, X.; Yang, J.; Sun, Z. Electric vehicle transformation in Beijing and the comparative eco-environmental impacts: A case study of electric and gasoline powered taxis. *J. Clean. Prod.* **2016**, *137*, 449–460. [CrossRef]
56. Yao, W.; Zhao, J.; Wen, F.; Dong, Z.; Xue, Y.; Xu, Y.; Meng, K. A multi-objective collaborative planning strategy for integrated power distribution and electric vehicle charging systems. *IEEE Trans. Power Syst.* **2014**, *29*, 1811–1821. [CrossRef]
57. Phonrattanasak, P.; Leeprechanon, N. Optimal placement of ev fast charging stations considering the impact on electrical distribution and traffic condition. In Proceedings of the International Conference and Utility Exhibition on Green Energy for Sustainable Development, Pattaya City, Thailand, 19–21 March 2014; pp. 1–6.
58. Liu, J. Electric vehicle charging infrastructure assignment and power grid impacts assessment in Beijing. *Energy Policy* **2012**, *51*, 544–557. [CrossRef]
59. Boroushaki, S.; Malczewski, J. Using the fuzzy majority approach for gis-based multicriteria group decision-making. *Comput. Geosci.* **2010**, *36*, 302–312. [CrossRef]
60. Wirges, J.; Linder, S.; Kessler, A. Modelling the development of a regional charging infrastructure for electric vehicles in time and space. *Eur. J. Transp. Infrastruct. Res.* **2012**, *12*, 391–416.
61. He, S.Y.; Kuo, Y.H.; Wu, D. Incorporating institutional and spatial factors in the selection of the optimal locations of public electric vehicle charging facilities: A case study of Beijing, China. *Transp. Res. Part C* **2016**, *67*, 131–148. [CrossRef]
62. Sathaye, N.; Kelley, S. An approach for the optimal planning of electric vehicle infrastructure for highway corridors. *Transp. Res. Part E Logist. Trannsp. Rev.* **2013**, *59*, 15–33. [CrossRef]
63. Sweda, T.; Klabjan, D. An agent-based decision support system for electric vehicle charging infrastructure deployment. In Proceedings of the Vehicle Power and Propulsion Conference, Chicago, IL, USA, 6–9 September 2011; pp. 1–5.
64. Peters, A.; Dütschke, E. How do consumers perceive electric vehicles? A comparison of german consumer groups. *J. Environ. Policy Plan.* **2014**, *16*, 359–377. [CrossRef]
65. Li, D.F. A ratio ranking method of triangular intuitionistic fuzzy numbers and its application to madm problems. *Comput. Math. Appl.* **2010**, *60*, 1557–1570. [CrossRef]
66. Wan, S.P.; Wang, F.; Lin, L.L.; Dong, J.Y. Some new generalized aggregation operators for triangular intuitionistic fuzzy numbers and application to multi-attribute group decision making. *Comput. Ind. Eng.* **2016**, *93*, 286–301. [CrossRef]
67. Wan, S.P. Power average operators of trapezoidal intuitionistic fuzzy numbers and application to multi-attribute group decision making. *Appl. Math. Model.* **2013**, *37*, 4112–4126. [CrossRef]
68. Chen, S.J.J.; Hwang, C.L.B.; Martin, J.; Krelle, W. *Fuzzy Multiple Attribute Decision Making: Methods and Applications*; Springer-Verlag New York, Inc.: New York, NY, USA, 1992; pp. 287–288.