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Study of Decision Framework of Shopping Mall Photovoltaic Plan Selection Based on DEMATEL and ELECTRE III with Symmetry under Neutrosophic Set Environment

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Received: 23 April 2018; Accepted: 3 May 2018; Published: 9 May 2018

Abstract: Rooftop distributed photovoltaic projects have been quickly proposed in China because of policy promotion. Before, the rooftops of the shopping mall had not been occupied, and it was urged to have a decision-making framework to select suitable shopping mall photovoltaic plans. However, a traditional multi-criteria decision-making (MCDM) method failed to solve this issue at the same time, due to the following three defects: the interactions problems between the criteria, the loss of evaluation information in the conversion process, and the compensation problems between diverse criteria. In this paper, an integrated MCDM framework was proposed to address these problems. First of all, the compositive evaluation index was constructed, and the application of decision-making trial and evaluation laboratory (DEMATEL) method helped analyze the internal influence and connection behind each criterion. Then, the interval-valued neutrosophic set was utilized to express the imperfect knowledge of experts group and avoid the information loss. Next, an extended elimination et choice translation reality (ELECTRE) III method was applied, and it succeed in avoiding the compensation problem and obtaining the scientific result. The integrated method used maintained symmetry in the solar photovoltaic (PV) investment. Last but not least, a comparative analysis using Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method and VIKOR method was carried out, and alternative plan X1 ranks first at the same. The outcome certified the correctness and rationality of the results obtained in this study.

Keywords: shopping mall; photovoltaic plan; decision-making trial and evaluation laboratory (DEMATEL); interval-valued neutrosophic set; extended ELECTRE III; symmetry

1. Introduction

The frequent occurrence of fog or haze and other negative types of climate change in recent decades is the grave reality that the whole world is experiencing. The pivotal reason behind these environmental problems is atmospheric pollutants and greenhouse gas emissions, mainly produced by fossil fuel consumption. Fossil fuel supplies approximately 80% of the world’s energy, and it is drying up with the rapid increase of the world energy demand [1].

To face this situation, many countries have endorsed policies to submit fossil fuel utilization with renewable energy generation. Among diverse types of alternative energy, solar photovoltaic (PV hereinafter) energy is recognized as promising, since sunlight is unlimited and widespread and the converting efficiencies of photovoltaic are getting higher and higher while the manufacturing costs are becoming lower and lower [2].

The past five years has witnessed the astonishing increase in installed cumulative globe solar PV capacity, which nearly quintupled from 70 GW in 2011, to 275 GW in 2016. China is following the worldwide trend with solar PV rapid development and gained the number one cumulative PV capacity of 65.57 GW in 2016. It is worth noting that the large-scale ground PV power station, newly installed, had 28.45 GW capacity this year, and grew by 75% compared to the last year, accounting for 89% of all new PV power plants in 2016, while the distributed PV, newly installed, with 3.66 GW capacity this year, increased by 45% in comparison to last year, and accounted for 11% of capacity of new installations in 2016. The scale of distributed PV development is significantly lower than that of the large-scale ground PV.

Under these circumstances, the China authorities have launched the feed in tariff adjustment. The feed in tariff of ground solar PV generation will decrease to some extent, but in contrast to that of distributed PV, will not decrease at all. As shown in Figure 1, according to the 13th five-year (2016–2020) solar energy planning objectives of China, the goal is to build a total installed capacity of 150 GW solar PV, in which more than 40% of the new installed capacity will be from distributed PV, and to build 100 distributed PV demonstration areas. In fact, China is a country with high potential of solar radiation, and of generous policy subsidies to promote achieving the ambitious plan. Obviously, in China, distributed solar PV generation is government encouraged, well-resourced, environmentally friendly, and closely following the world trend. It is worth considering investment in such a promising project.

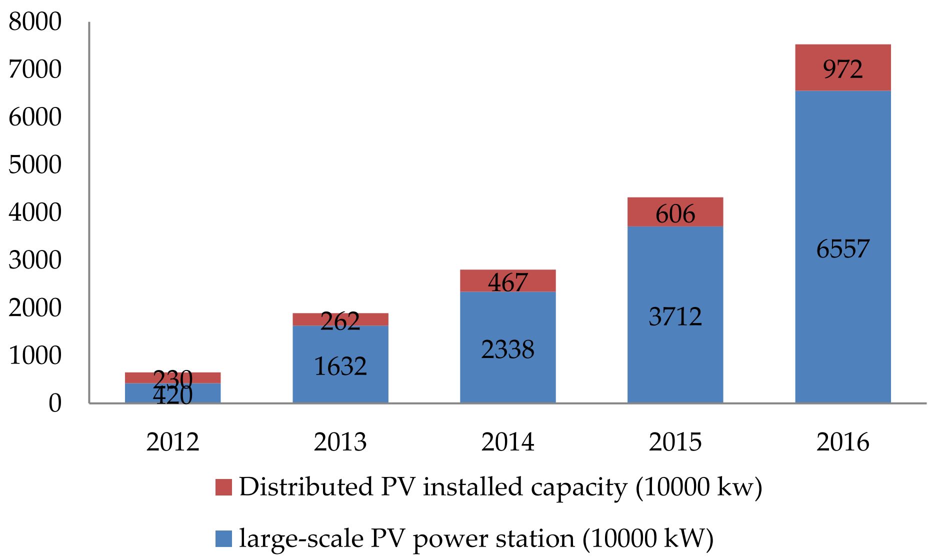

Figure 1. Chinese photovoltaic power structure, 2012–2016.

Numerous vacant roofs of building or structures in the cities provide the best-fitting location for distributed solar PV, and farsighted investors have been preempting outstanding roof resources. There are various types of buildings, such as government building, hospitals, schools, coliseums, or residential and industrial buildings. Among all these types, the shopping centers possesses plenty of advantages, superior to the other types of buildings, and are one of the most promising places worth preempting for PV installation.

First of all, previous construction characters of shopping centers facilitate the rooftop PV installation. According to literature [3], the availability rate of roof space is between 60% and 65% in shopping malls, but just 22% and 50% in residential buildings. That is to say, double or triple PV capacity can be installed in the former roofs, compared to the latter one. Secondly, the shopping malls need a large amount of electricity consumption daily, the most generation can feed the themselves-consumption. Besides, it is usually cited in downtown areas and populated areas. On the one hand, there have a so complete transmission and distribution network that the surplus generation can efficiently feed local electricity consumption. On the other hand, brand advertisement and promotion of the PV manufacturer and the rising level of awareness of the citizen towards sustainable efforts can be greatly obtained for the large visitors there. Last but not least, facing the non-manageable feature through electricity generation in PV facilities, technical management measures need to be taken for protecting distribution system [4]. Fortunately, the shopping malls equipped professional staff and equipment for energy supply, security, air conditioning, and so on. So, the previous staff in shopping malls can condemn the whole new challenge to reduce the extra expenditure in PV management.

It is desirable to adopt a proper methodology for evaluating the shopping mall PV plan in order to demonstrate the optimal possible selections for an investment. Since the following three problems existed in this issue, which are the interaction problems between the criteria, the loss of evaluation information in the conversion process, and the compensation problems between diverse criteria. There is no doubt that traditional multi-criteria decision-making (MCDM) method failed to solve the three problems at the same time. Nevertheless, the decision-making trial and evaluation laboratory (DEMATEL) method can help analyze the internal influence and connection behind each criterion, and the interval-valued neutrosophic set is accomplished in expressing the imperfect knowledge of experts group. Besides, an extended ELECTRE III method as an outstanding outranking method can succeed in avoiding the compensation problem, and the integrated method used maintained symmetry in the solar PV investment. Therefore, in this context, the integrated DEMATEL method and extended ELECTRE III method under interval-valued neutrosophic set environment for searching the optimal shopping mall solar PV plan has been devised.

2. Literature Review

MCDM (multi-criteria decision-making) has been successfully applied in energy planning problems. For example, a review of MCDM methods towards renewable energy development identified MCDM methods as one of the most suitable tools to finding optimal results concerned with energy planning progress in complex scenarios, including various indicators, and conflicting objectives and criteria [5]. For example, Fausto Cavallaro et al. use an intuitionistic fuzzy multi-criteria approach combined with fuzzy entropy to rank different solar-hybrid power plants successfully [6].

In a real case, it is different for decision makers to express preferences when facing inaccurate, uncertain, or incomplete information. Although the fuzz set, intuitionistic fuzzy sets, interval-valued intuitionistic fuzzy sets, and hesitant fuzzy sets can address the situation. However, when being asked the evaluation on a certain statement, the experts can use the interval-valued neutrosophic set (IVNNS) expressing the probability that the statement is true, false, and the degree of uncertainty can be accurately described, respectively [7]. The IVNNS, combined with outrank methods, has addressed many MCDM problems successfully [8]. For example, the IVNNS combined with VIKOR was applied to solve selection of location for a logistic terminal problem [9]. Hong-yu Zhang et al. developed two interval neutrosophic number aggregation operators and applied them to explore multi-criteria decision-making problems [10].

The independence of criteria remains in most of the MCDM methodologies. In recent years, lots of methods appeared to solve the problem, and the DEMATEL method is popularly used. According to the statistic censused in article [11], of the use of MCDM methods in hybrid MCDM methods, the top five methods are Analytical Network Process (ANP), DEMANTEL, Analytic Hierarchy Process(AHP), TOPSIS, and VIKOR.

The DEMATEL methodology has been acknowledged as a proper tool for drawing the relationships concerning interdependencies and the intensity of interdependence between complex criteria in an evaluation index system [12,13]. As a powerful tool to describe the effect relationship, it help evaluate the enablers in solar power developments [11] and evaluate factors which influencing industries' electric consumption [14]. The application of DEMATEL contributed to determining the weight coefficient of the evaluation criteria, and successfully helped identify the suitable locations for installation of wind farms. It is the DEMATEL method that helped the investors improve their decisions when there are many interrelated criteria. Thus, the connection relationship of the climate and economy criteria that exists in this study is of great need of the application of DEMATEL method.

The commonly used outrank models are TOPSIS, AHP, ANP, preference ranking organization method for enrichment evaluations(PROMETHE), and ELECTRE, of which ELECTRE methods are preferred by decision makers in energy planning progress. Among the ELECTRE methods, ELECTRE III method conveys much more information than the ELECTRE I and ELECTRE II methods [15]. In the literature [16], economics of investment in the field of PV, an inclusive decision-making structure using ELECTRE III that would help photo voltaic (PV) system owners, bureaucrats, and the business communities to decide on PV technologies, financial support systems and business strategies were featured. ELECTRE III was used to structure a multi-criteria framework to evaluate the impact of different financial support policies on their attractiveness for domestic PV system deployment on a multinational level [17]. Due to the compensation problem in information processing, incomplete utilization of decision information, and information loss, ELECTRE III was chosen to build a framework for offshore wind farm site selection decision in the intuitionistic fuzzy environment. These literature studies improve the application of ELECTRE III method in the energy planning process, and terrify the effectiveness of evaluation in decision making progress [18].

In conclusion, based on the mentioned evolvement, the shopping mall PV plan evaluation result will be more scientific and reasonable than before.

3. Decision Framework of SMPV Plan Selection

The evaluation criteria are basic to the entire evaluation, so that they are of great importance to the shopping mall photovoltaic plan selection. In view of the special characteristics of photovoltaic plan and the shopping malls, six factors were taken into consideration, namely architectural elements, climate, photovoltaic array, economy, risk, contribution. Table 1 shows six criteria and twenty-one subcriteria.

Table 1. Analysis of evaluation attributes of shopping centers photovoltaic plan selection.

Criteria		Subcriteria	Resources
(a) Architectural elements	a1	Roof pitch and orientation	[2]
	a2	Covering ratio	[2]
	a3	PV roof space	[2]
(b) Economy	b1	Total investment	[19]
	b2	Total profit	[19]
	b3	Annual rate of return	[20]
	b4	Payback year	[20]
(c) Climate	c1	Annual average solar radiation (kwh/m^2/year)	[19,21]
	c2	Land surface temperature (°C)	[19,21]
	c3	Annual sunshine utilization hours (h)	[19,21]
(d) Photovoltaic array	d1	Suitability of the local solar regime	[22]
	d2	PV area	[2]
	d3	PV generation (yearly electricity generation) MWh/year	[2,19]
	d4	Repair and clean rate	[20]
(e) Contribution	e1	Increase in local economy and employment	[22]
	e2	Publicity effects	Own
	e3	Environment protection	[23]
(f) Risk	f1	Grid connection risk	[19]
	f2	Rooftop ownership and occupancy disputes	Own
	f3	Bad climate	[22]
	f4	Government subsidies reduction	Own

3.1. Architectural Elements

Not all the shopping malls are suitable to allocate the photovoltaics, and architectural elements are the primary intrinsic limitations. Steep roof pitch and wrong orientation will increase the difficulty of allocation and maintenance. In addition, building obstructions, and vegetation shading part of the space are not able to allow for the allocation of PV equipment, which can be measured by the covering ratio estimated by Equation (2). Last but not least, the photovoltaic roof space needed to be calculated by the Equation (1). Colmenar-Santos, Antonio et al. [15] assessed the photovoltaic potential in shopping malls by calculating the photovoltaic roof space. We decided to refer to this research method.

$$RS_{PV} = RS \times \alpha \quad (1)$$

RS_{PV} is PV roof space, RS stand for roof space, α is availability ratio

$$CR = L/(a+b) = \frac{\tan\varphi \tan(\alpha_s)^{\alpha}}{\sin\varphi \tan(\alpha_s)^{\alpha} + \sin\varphi \tan\varphi \sin(\gamma_s)^{a}} \quad (2)$$

CR is covering ratio. $(\alpha_s)^{\alpha}$ solar altitude angle $(\gamma_s)^{a}$ φ solar azimuth angle. The value is at nine o'clock on the winter solstice in each location.

3.2. Climate

Not all the locations of the shopping malls have the optimal climate for solar power generation. It is undoubted that the solar resource depends on local climate. Thus, the annual average solar radiation, land surface temperature, and annual sunshine utilization hours, are the four typical criteria to judge whether the local solar energy resource is in abundance.

3.3. Photovoltaic Array

It is well known that the performance of photovoltaic arrays will impact the electricity generation reliability and stability. The dust in the photovoltaic cell panel will reduce the solar energy conversion efficiency, meanwhile, since the photovoltaic cell panel damage and faults are directly related to the electricity supply reliability, the repair and clean rate should be pondered. In addition, it is worth concerning whether the specified type of the photovoltaic panel is absolutely suitable to the local solar regime. The total PV area affects the electricity generated which is calculated by Equation (3). PV generation (yearly electricity generation) is estimated by Equation (4).

$$A_{\text{panel}} = RS_{PV} \times CR \quad (3)$$

$$E = H \times A_{\text{panel}} \times \varepsilon \times \kappa \quad (4)$$

H is the total yearly solar irradiation. A_{panel} is the total area of PV panel. ε is the efficiency of the panel. κ is the comprehensive facility performance efficiency, which is 0.8 [19], and 0.28 is the empirical conversion coefficient of the PV module area to the horizontal area.

3.4. Economy

It is beyond doubt that the economy of the shopping mall photovoltaic plans ought to be taken into account by the decision makers. There are plenty of studies to assess the financial aspects of the photovoltaic projects. Indrajit Das et al. [23] presented an investor-oriented planning model for optimum selection of solar PV investment decisions. Rodrigues Sandy et al. [24] conducted economic analysis of photovoltaic systems under China's new regulation. The economic assessment methods there are so suitable and scientific that they are worth referring to in this paper. The significant economic attributes we considered are pay pack period, total investment, total profit, and annual rate of return, which are calculated by Equations (5)–(7).

$$I = C \times A_{\text{panel}} \times \frac{p_{\text{panel}}}{a_{\text{panel}}} \quad (5)$$

I is the total investment, C is the average cost of building per W roof PV projects. p_{panel} is the max power pin (W) under STC situation of the solar panel, a_{panel} is the area of per photovoltaic panels.

$$B = P_E \times t_{LC} + P_S \times t_S - I \times t_{LC} - O \times t_{LC} \quad (6)$$

B is the total profit, P_E is the electricity price buying from the power supply company, P_S is the electricity price subsidy, t_{LC} is the time of PV projects life cycle, t_S is the time subsidy lasting, O is the cost for operation and maintenance.

$$ROI = \frac{B}{I \times t_{LC}} \quad (7)$$

ROI is the annual rate of return.

$$T_{PB} = \frac{I}{P_E + P_S - I - O} \quad (8)$$

T_{PB} is the pay pack year.

3.5. Contribution

Although the environmental and social contributions the SMPV projects made may not be calculated explicitly as economic profit, there is no denying that these benefits result in increase in local economy and employment, and environment protection and publicity effects are worth the focus of attention. Particularly, the shopping mall holds a great number of visitors. On the one hand, it obtains, easily, the brand advertisement and promotion when PV equipment of a particular company occupies the rooftop of a large commercial building. On the other hand, it is effective to raise the level of awareness of the citizen towards renewable energy and sustainable efforts.

3.6. Risk

Expect that for the above attributes, the risk faced cannot be neglected. First of all, the government subsides policy is likely to change, and the impartiality, sufficiency, stability, and constancy of the subsidy is unable to be ensured. Secondly, the generating capacity is influenced by the climate heavily, so the profits will reduce when facing consecutive rainy days. Thirdly, the rooftop usage needs the allowance from all the owners, however, the rooftop ownership and occupancy disputes are a very common risk. Last but not least, the connected photovoltaic grid is unable to bring any benefits to the grid enterprise because of the intermittent power output. Thus, how long the support to photovoltaic grid connected from the grid enterprise can exist is uncertain.

All in all, the SCPV plan alternatives ought to be appraised from architectural elements, climate, photovoltaic array performance, economy, risk, contribution attributes. The unique custom-made framework of criteria and subcriteria is set up in view of the actual SMPV plans and national conditions.

4. Research Methodology

A decision framework of SMPV selection has been proposed in this section, and there are four phases in this framework, as shown in Figure 2. The research framework is described in the following subsections.

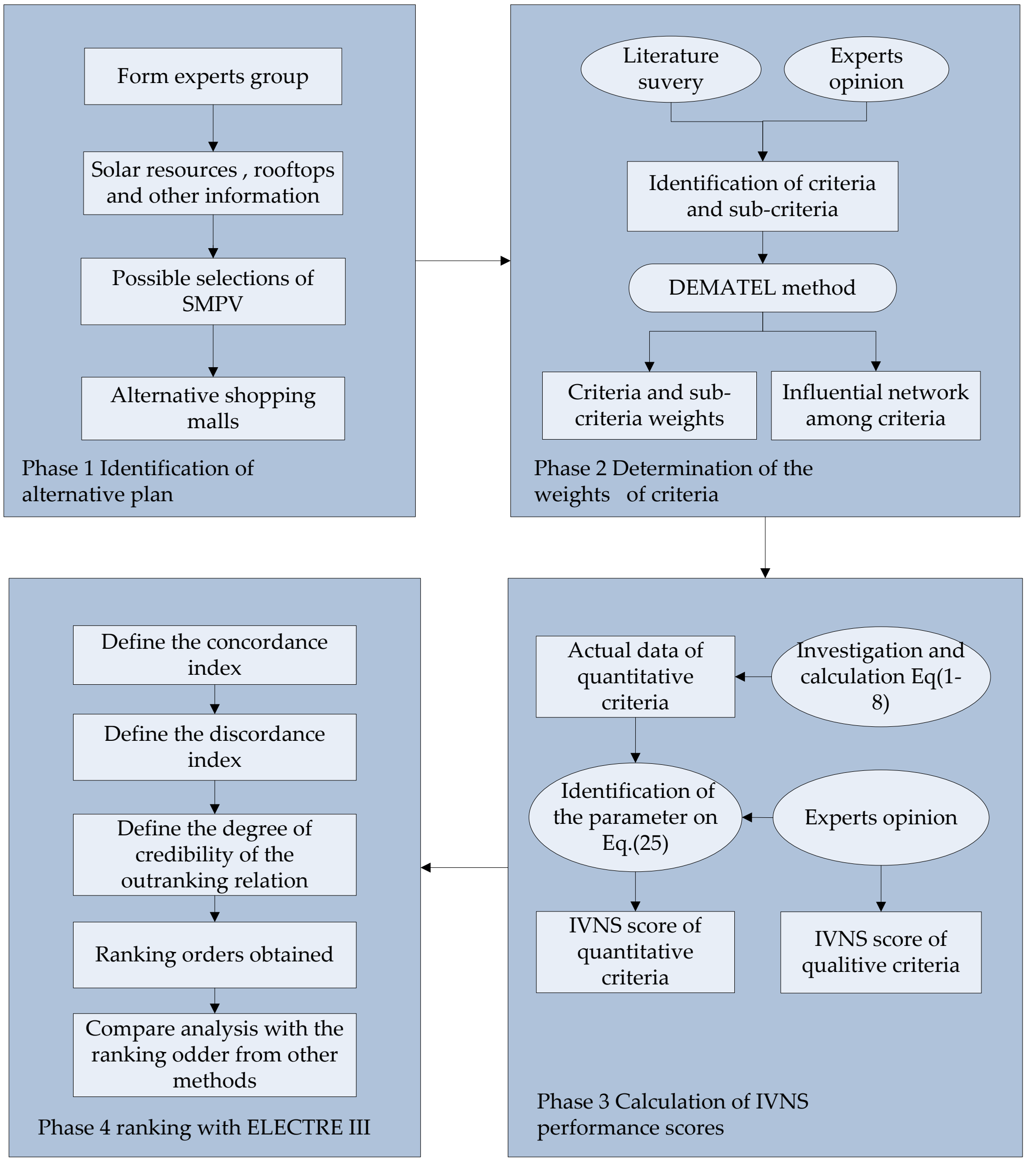

Figure 2. The flowchart of the research methodology. DEMATEL: decision-making trial and evaluation laboratory.

4.1. Preliminary Knowledge in the Neutrosophic Set Environment

Due to the existence of many uncertainties in real decision-making problems, such as indeterminate and inconsistent, the neutrosophic set (NS) is used in the MCDM method, and definition of NS is introduced in this section.

Definition 1 [25]. *Let* X *be a space of objects with a generic element in* X *denoted by* x. *A NS* A *in* X *is defined using three functions: truth-membership function* $T_A(x)$, *indeterminacy-membership function* $I_A(x)$ *and falsity-membership function* $F_A(x)$. *These functions are real standard or nonstandard subsets of* $]0^-,1^+[$, *that is,* $T_A(x)\colon X \to]0^-,1^+[$, $I_A(x)\colon X \to]0^-,1^+[$ *and* $F_A(x)\colon X \to]0^-,1^+[$. *And that the sum of* $T_A(x)$, $I_A(x)$ *and* $F_A(x)$ *satisfies the condition* $0^- \le \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \le 3^+$.

Since the non-standard unit interval $]0^-,1^+[$ is hard to apply in practice, and the degree of truth, falsity, and indeterminacy about a certain statement could not be described precisely in the practical evaluation, the interval-valued neutrosophic set (IVNNS) of standard intervals has been proposed by

Wang [26], and a few definitions and operations of IVNNS are introduced in the GPP technology selection MCDM problem.

Definition 2 [26]. *Let* X *be a space of objects with a generic element in* X *denoted by* x. *An IVNNS* A *can be defined as*

$$A=\{\langle x,T_A(x),I_A(x),F_A(x)\rangle : x\in X\} \tag{9}$$

where $T_A(x): X\to[0,1]$, $I_A(x): X\to[0,1]$, $F_A(x): X\to[0,1]$. *For each element* x *in* X, *these functions can be expressed as* $T_A(x)=[\inf T_A(x),\sup T_A(x)]\subseteq[0,1]$, $I_A(x)=[\inf I_A(x),\sup I_A(x)]\subseteq[0,1]$, $F_A(x)=[\inf F_A(x),\sup F_A(x)]\subseteq[0,1]$ *and* $0\le \sup T_A(x)+\sup I_A(x)+\sup F_A(x)\le 3, x\in X$. *For convenience, the interval-valued neutrosophic number (IVNN) can be expressed as* $\tilde{a}=\langle[T_{\tilde{a}}^L,T_{\tilde{a}}^U],[I_{\tilde{a}}^L,I_{\tilde{a}}^U],[F_{\tilde{a}}^L,F_{\tilde{a}}^U]\rangle$, *and* L,U *represent the inferiors and superiors of IVNN respectively.*

Definition 3 [10]. *Let* $\tilde{a}=\langle[T_{\tilde{a}}^L,T_{\tilde{a}}^U],[I_{\tilde{a}}^L,I_{\tilde{a}}^U],[F_{\tilde{a}}^L,F_{\tilde{a}}^U]\rangle$ *and* $\tilde{b}=\langle[T_{\tilde{b}}^L,T_{\tilde{b}}^U],[I_{\tilde{b}}^L,I_{\tilde{b}}^U],[F_{\tilde{b}}^L,F_{\tilde{b}}^U]\rangle$ *be two IVNNs, and* λ *is a real number for not less than 0. Which operational rules can be expressed as follows*

$$\tilde{a}\oplus\tilde{b}=\langle[T_{\tilde{a}}^L+T_{\tilde{b}}^L-T_{\tilde{a}}^L\cdot T_{\tilde{b}}^L,T_{\tilde{a}}^U+T_{\tilde{b}}^U-T_{\tilde{a}}^U\cdot T_{\tilde{b}}^U],[I_{\tilde{a}}^L\cdot I_{\tilde{b}}^L,I_{\tilde{a}}^U\cdot I_{\tilde{b}}^U],[F_{\tilde{a}}^L\cdot F_{\tilde{b}}^L,F_{\tilde{a}}^U\cdot F_{\tilde{b}}^U]\rangle \tag{10}$$

$$\tilde{a}\otimes\tilde{b}=\langle[T_{\tilde{a}}^L\cdot T_{\tilde{b}}^L,T_{\tilde{a}}^U\cdot T_{\tilde{b}}^U],[I_{\tilde{a}}^L+I_{\tilde{b}}^L-I_{\tilde{a}}^L\cdot I_{\tilde{b}}^L,I_{\tilde{a}}^U+I_{\tilde{b}}^U-I_{\tilde{a}}^U\cdot I_{\tilde{b}}^U],[F_{\tilde{a}}^L+F_{\tilde{b}}^L-F_{\tilde{a}}^L\cdot F_{\tilde{b}}^L,F_{\tilde{a}}^U+F_{\tilde{b}}^U-F_{\tilde{a}}^U\cdot F_{\tilde{b}}^U]\rangle \tag{11}$$

$$\lambda\tilde{a}=\langle[1-(1-T_{\tilde{a}}^L)^\lambda,1-(1-T_{\tilde{a}}^U)^\lambda],[(I_{\tilde{a}}^L)^\lambda,(I_{\tilde{a}}^U)^\lambda],[(F_{\tilde{a}}^L)^\lambda,(F_{\tilde{a}}^U)^\lambda]\rangle \tag{12}$$

$$\tilde{a}^\lambda=\langle[(T_{\tilde{a}}^L)^\lambda,(T_{\tilde{a}}^U)^\lambda],[1-(1-I_{\tilde{a}}^L)^\lambda,1-(1-I_{\tilde{a}}^U)^\lambda],[1-(1-F_{\tilde{a}}^L)^\lambda,1-(1-F_{\tilde{a}}^U)^\lambda]\rangle \tag{13}$$

The original data of selection of SPPV are collected and processed in this phase. The alternative plans of the GPP project are evaluated by the experts, firstly according to the local technical condition data and practical experience. Then, the decision matrices are expressed in the form of IVNNs, which can handle incomplete and indeterminate information. Finally, a comprehensive decision matrix is formed based on interval-valued neutrosophic number weighted geometric operator (IVNNWG) operator. Let A_i denote the technology alternatives ($i=1,2,\cdots m$), and C_j denote the criteria ($j=1,2,\cdots n$). It is assumed that $\tilde{a}_{ij}^k$ can be used to represent the evaluation value of attribute of alternative from every expert $E_k\,(k=1,2,\cdots h)$.

Definition 4 [27]. *Let* $\tilde{A}_{ij}^k=(\tilde{a}_{ij}^k)_{m\times n}$ *be the IVNN-decision matrix of the* k*-th DM,* $k=1,2,\cdots h$, *and* $\tilde{a}_{ij}^k=\langle[T_{\tilde{a}_{ij}^k}^L,T_{\tilde{a}_{ij}^k}^U],[I_{\tilde{a}_{ij}^k}^L,I_{\tilde{a}_{ij}^k}^U],[F_{\tilde{a}_{ij}^k}^L,F_{\tilde{a}_{ij}^k}^U]\rangle$. *An IVNNWG operator is a mapping:* $IVNN^n\to IVNN$, *such that*

$$\begin{aligned}&IVNNWG_\omega(\tilde{a}_{ij}^1,\tilde{a}_{ij}^2,\cdots,\tilde{a}_{ij}^h)=\prod_{k=1}^{k=h}(\tilde{a}_{ij}^k)^{\omega_k}\\&=\left\langle\left[\prod_{k=1}^{k=h}\left(T_{\tilde{a}_{ij}^k}^L\right)^{\omega_k},\prod_{k=1}^{k=h}\left(T_{\tilde{a}_{ij}^k}^U\right)^{\omega_k}\right],\left[1-\prod_{k=1}^{k=h}\left(1-I_{\tilde{a}_{ij}^k}^L\right)^{\omega_k},1-\prod_{k=1}^{k=h}\left(1-I_{\tilde{a}_{ij}^k}^U\right)^{\omega_k}\right],\left[1-\prod_{k=1}^{k=h}\left(1-F_{\tilde{a}_{ij}^k}^L\right)^{\omega_k},1-\prod_{k=1}^{k=h}\left(1-F_{\tilde{a}_{ij}^k}^U\right)^{\omega_k}\right]\right\rangle\end{aligned} \tag{14}$$

where $\omega=(\omega_1,\omega_2,\cdots,\omega_h)^T$ *represents the weight vector of DMs, satisfying* $\Sigma_{k=1}^h\omega_k=1$, $\omega_k\in[0,1]$.

4.2. Phase I Identification of Alternative SMPV Plans

At this stage, a group of experts consisting of several doctorate engineers will be constituted by the investor. All the experts possess abundant working experience in solar energy investment field, and are specialized in solar photovoltaic and power grid technologies.

More than twenty famous influential large-scale shopping malls located in those cities with both abundant sunshine and general policy subsidies need to be collected, and based on that information, less than ten alternative plans roughly screened out, based on the plentitude of documents and investigation. After that, the investigation will be carried out by the experts group, and involve meeting the Development and Reform Commission, the Meteorological Bureau, and the local power supply companies, in order to gather information about solar resources, city planning and construction, local solar subsidy policies, distributed solar power planning, economic assessment, and approved shopping mall rooftops for construction. Lastly, there will be less than five of the most potential alternative places presented for the next evaluation.

4.3. Phase II Determination of the Weights of Criteria Based on DEMATEL Method

The importance of the criteria on GPP technology selection is different, so the DEMATEL method is used to decide the weight of criteria in this phase. The direct and indirect causal relations among criteria are considered in the DEMATEL method, and the subjective judgment of DMs is also considered. The steps of determining the weights based on the DEMATEL method are shown as follows [28]:

Step 1. Determine the influence factors in the system

The influence factors of GPP technology selection system are determined based on expert opinions and literature reviews, which is called the criteria, as shown in Table 1.

Step 2. Construct the direct-relation matrix among the criteria

The direct-relation matrix $X = \left(x_{pq}\right)_{n\times n}$ is constructed in stages, where x_{pq} is used to represent the degree of direct influence of p th criterion on q th criterion which is evaluated by the experts, and n is the number of criteria.

Step 3. Normalize the direct-relation matrix

The direct-relation matrix $X = \left(x_{pq}\right)_{n\times n}$ is normalized into $Y = \left(y_{pq}\right)_{n\times n}$. A normalization factor [29] s is applied in the normalized calculation, and the normalized direct-relation matrix Y is calculated by using Equations (1) and (2).

$$Y = s \cdot X \tag{15}$$

$$s = \mathrm{Min}\left(\frac{1}{\mathrm{Max}_{1\le p\le n}\left(\sum_{q=1}^{n} x_{pq}\right)}, \frac{1}{\mathrm{Max}_{1\le q\le n}\left(\sum_{p=1}^{n} x_{pq}\right)}\right) \tag{16}$$

Step 4. Calculate the comprehensive-relation matrix.

The comprehensive-relation matrix T is obtained by using Equation (3).

$$T = \sum_{\lambda=1}^{\infty} Y^{\lambda} = Y\left(I - Y\right)^{-1} \tag{17}$$

where $T = \left(t_{pq}\right)_{n\times n}$, $p,q = 1,2,\cdots n$, and t_{pq} is used to represent the degree of total influence of p th criterion on q th criterion. I represents for the identity matrix.

Step 5. Determine the influence relation among criteria

The influence degree and influenced degree of the criteria is determined after obtaining the comprehensive-relation matrix T. The sum of the row and column values of matrix T can be obtained by the Equations (4) and (5). The sum of row values of T, denoted by D, which represents the overall influence of a given criterion on other criteria. The sum of column values of T, denoted by R, which implies the overall influence of other criteria on a given criterion.

$$D=\left(d_p\right)_{n\times 1}=\sum_{q=1}^{n} t_{pq} \tag{18}$$

$$R=\left(r_q\right)_{1\times n}=\sum_{p=1}^{n} t_{pq} \tag{19}$$

The causal diagram is obtained based on the $D+R$ and $D-R$ values. The $D+R$ value indicates the importance of indicator in the SMPV plan selection system, the greater the $D+R$ value, the more important the corresponding indicator is. On the other hand, the $D-R$ value indicates the influence between a certain indicator and the other indicators, which can be separated into cause and effect groups. The indicator, which has positive values of $D-R$, belongs to the cause group, and dispatches effects to the other indicators. Otherwise, the indicator, which has negative values of $D-R$, belongs to the effect group, and receives effects to the other indicators.

Step 6. Determine the weight of criteria

The criteria are represented by j, and satisfying $j=1,\cdots p,\cdots q,\cdots n$, then the weights of criteria are determined based on the following Equations (6) and (7) [30].

$$w_j'=\left[\left(d_j+r_j\right)^2+\left(d_j-r_j\right)^2\right]^{1/2} \tag{20}$$

$$w_j=\frac{w_j'}{\sum_{j=1}^{n} w_j'} \tag{21}$$

where w_j' denotes the relative importance of the indicators, and w_j denotes the weights of the indicators in SMPV technology selection.

4.4. Phase III Calculation IVNNs Performance Score

ELECTRE is a family of methods used for choosing, sorting and ranking, multi-criteria problems. ELECTRE III was developed by Roy in 1978m, which is valued outranking relation.

$A=\{a_{1,}a_2,\ldots,a_n\}$ is the finite set of alternatives, $Y=\{y_1,y_2,\ldots,y_m\}$ is the finite set of criteria, $y_j(a)$ represents the performance of alternative a on criterion $y_j\in Y$. Assume that all the criteria are of the gain type, which means the greater the value, the better. q_j is the indifference threshold, which represents two alternatives in terms of their evaluations on criterion y_j. In general, q_j is a function of attribute value $q_j(a_i)$, which can be denoted as $q_j(y_j(a_i))$; $p_j(y_j(a_i))$ is preference threshold, which indicates that there is a clear strict preference of one alternative over the other in terms of their evaluations on criterion y_j. In addition, $v_j(y_j(a_i))$ is a veto threshold that indicates that the attribute value $y_j(a_i)$ of scheme a_i is lower than the attribute value $y_j(a_k)$ of scheme a_k, and when it reaches or exceeds $v_j(y_j(a_i))$, it is not recognized that the a_i is preferred to the a_k. $y_j\left(a_i\right)-y_j\left(a_k\right)$ which indicates the situation of preference of a_i over a_k for criterion C_j. A weight w_j expresses the relative importance of criterion y_j, as it can be interpreted as the voting power of each criterion to the outranking relation.

Where $y_j(a_i)$ and $y_j(a_k)$ are expressed in the form of IVNNs in the paper, that is, $y_j(a_i) = \left\langle [T_i^L, T_i^U], [I_i^L, I_i^U], [F_i^L, F_i^U] \right\rangle$, $y_j(a_k) = \left\langle [T_k^L, T_k^U], [I_k^L, I_k^U], [F_k^L, F_k^U] \right\rangle$. In the calculation of Equation (8), let

$$y_j(a_i) = (T_i^L + T_i^U) - (I_i^L + I_i^U) - (F_i^L + F_i^U) \quad (22)$$

$$y_j(a_k) = (T_k^L + T_k^U) - (I_k^L + I_k^U) - (F_k^L + F_k^U) \quad (23)$$

and so

$$y_j(a_i) - y_j(a_k) = (T_i^L + T_i^U - T_k^L - T_k^U) + (I_i^L + I_i^U - I_k^L - I_k^U) + (F_i^L + F_i^U - F_k^L - F_k^U) \quad (24)$$

$$T_{ij=} \begin{cases} \delta_i \dfrac{a_{ij}}{a_i^{\max}} (i \in \theta_B) \\ \lambda_i \dfrac{a_i^{\min}}{a_{ij}} (i \in \theta_C, a_i^{\min} \neq 0) \\ \lambda_i (1 - \dfrac{a_{ij}}{a_i^{\max}})(i \in \theta_C, a_i^{\min} \neq 0) \end{cases}$$

$$I_{ij} = \begin{cases} \varepsilon_i \dfrac{a_{ij}}{a_i^{\max}} (i \in \theta_B) \\ \mu_i \dfrac{a_i^{\min}}{a_{ij}} (i \in \theta_C, a_i^{\min} \neq 0) and \\ \mu_i (1 - \dfrac{a_{ij}}{a_i^{\max}})(i \in \theta_C, a_i^{\min} \neq 0) \end{cases} \quad (25)$$

$$F_{ij} \begin{cases} F_{ij}^U = 1 - T_{ij}^L - I_{ij}^L \\ F_{ij}^L = 1 - T_{ij}^U - I_{ij}^U \end{cases}$$

The δ, λ refer to the certainty parameters of the benefit criteria and cost criteria, respectively [23], while the ε, μ stand for the uncertainty parameters of the benefit criteria and cost criteria respectively, and they obey rule $0 < \delta_i + \varepsilon_i \leq 1, 0 < \lambda_i + \mu_i \leq 1$.

4.5. Phase IV Calculation of Outranking Relation of IVNNs Based on Extended ELECTRE-III

Step 1. Define the concordance index

The concordance index $c(a_i, a_k)$ that measures the strength of the coalition of criteria the support the hypothesis "is at least as good as", $c(a_i, a_k)$ is computed for each ordered pair $a_i, a_k \in A$ as follows:

$$c(a_i, a_k) = \sum_{j=1}^{n} w_j c_j(a_i, a_k) / \sum_{i=1}^{n} w_j \quad (26)$$

and the partial concordance index $c(a_i, a_k)$ is defined as

$$c_j(a_i,a_k)=\begin{cases}0 & (y_j(a_i)-y_j(a_k)\le q_j[y_j(a_i)]) \\ 1 & (y_j(a_i)-y_j(a_k)\le q_j[y_j(a_i)]) \\ \dfrac{y_j(a_i)-y_j(a_k)-q_j[y_j(a_i)]}{p_j[y_j(a_i)]-q_j[y_j(a_i)]} & (others)\end{cases} \tag{27}$$

Step 2. Define the discordance index

The discordance index $d_j(a_i,a_k)$ is defined as follows:

$$d_j(a_i,a_k)=\begin{cases}0 & (y_j(a_k)-y_j(a_i)\le -q_j[y_j(a_i)]) \\ 1 & (y_j(a_k)-y_j(a_i)\ge v_j[y_j(a_i)]) \\ \dfrac{y_j(a_k)-y_j(a_i)+q_j[y_j(a_i)]}{v_j[y_j(a_i)]+q_j[y_j(a_i)]} & (others)\end{cases} \tag{28}$$

Step 3. Define the degree of credibility of the outranking relation

The overall concordance and partial discordance indices are combined to obtain a valued outranking relation with credibility $s(a_i,a_k)\in[0,1]$ defined by:

$$s(a_i,a_k)=\begin{cases}c(a_i,a_k) & (\forall j, d_j(a_i,a_k)\le c(a_i,a_k)) \\ c(a_i,a_k)\prod\limits_{j\in J(a_i,a_j)}\dfrac{1-d_j(a_i,a_k)}{1-c(a_i,a_k)} & (others)\end{cases} \tag{29}$$

where $j(a_i,a_k)$ is the set of criteria for which $d_j(a_i,a_k)>c(a_i,a_k)$.

Step 4. Define the ranking of the alternatives

$\sum s(a_i\succ a_k)$ means the sum degree of credibility that alternative a_i outranks all the other alternatives, and $\sum s(a_k\succ a_i)$ means the sum degree of credibility that all the other alternatives outrank alternative a_i. Thus, $\Delta S(a_i)$ represents the ranking of the alternative a_i, and the higher the $\Delta S(a_i)$ value is, the more superior the outranking order is.

$$\Delta S(a_i)=\sum s(a_i\succ a_k)-\sum s(a_k\succ a_i)\ \ (k=1,2\ldots n) \tag{30}$$

5. A Real Case Study

A Chinese renewable energy investment company wants to build a shopping center rooftop photovoltaic power project. In order to seek the optimal shopping mall for rooftop photovoltaic power plants, furthermore, one must judge the weight and the influence network of the criteria. A group of experts consisting of three doctorate engineers (referred to as E1, E2, E3) was constituted by the company. All three experts possess more than 15 years' working experience in solar energy investment field, and are specialized in solar photovoltaic and power grid technologies. The collaboration of the all the experts was needed, thus, a pseudo-delphi method was applied in which each expert has no interaction.

Considering the development target and the investment capacity of the company, the famous influential large-scale shopping malls located in those cities, with both abundant sunshine and general policy subsidies, have been roughly screened out based on the plentitude of documents and investigation. The investigation involved several potential shopping malls located in Beijing, Shanghai, Guangzhou, Chengdu, Hangzhou, and Nanjing. The experts group met the Development and Reform Commission, the Meteorological Bureau, and the local power supply companies, in order to gather information about solar resources, city planning and construction, local solar subsidy policies, distributed solar power planning, economic assessment, and approved shopping mall rooftops for construction. There are four potential shopping malls picked out after the first filter, and they are the Golden Resources shopping mall in Beijing, Super Brand Mall in Shanghai, Deji Plaza in Nanjing, Jiangsu province, The Mixc shopping mall in Shenzhen, Guangdong province (hereafter referred to as X_1, X_2, X_3, X_4), as shown in Figure 3.

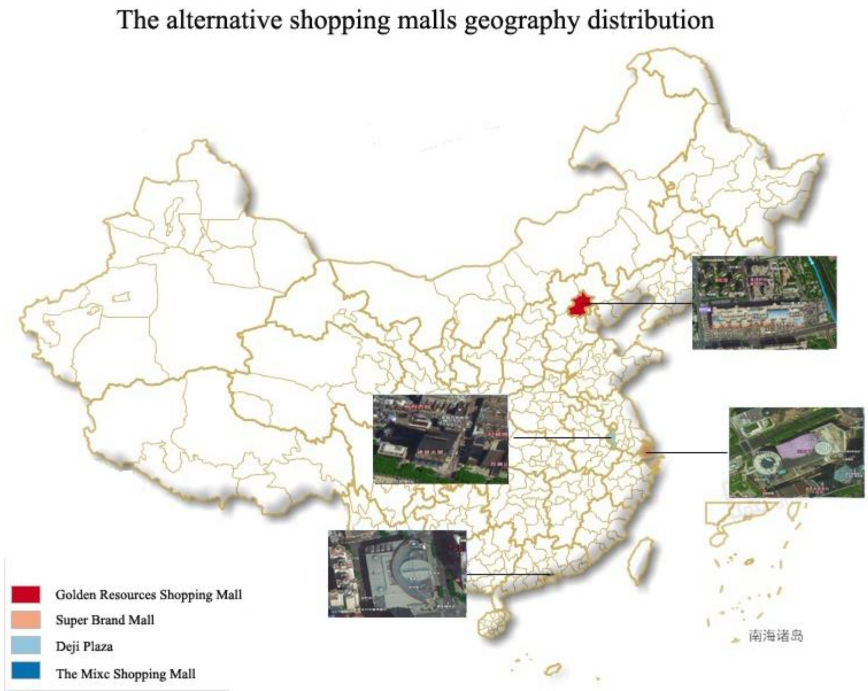

Figure 3. The alternative shopping malls geography distribution.

Firstly, based on the evaluation criteria, the influence of each criteria to the other one criteria was accessed by the experts. Then, the three experts discussed with each other and obtained a consensus about the influence of each criteria, as shown in Table 2. According to the DEMANTEL method, the weight of criteria and subcriteria was calculated based on Equations (15)–(21), and shown in Table 2. For the intuitive and simple understanding and analysis of the criteria and subcriteria, Figures 4 and 5 were drawn. As shown in Figure 4, the horizontal axis represents the importance of a criteria, while the vertical axis indicates the influence between the criteria, and the arrow is from the sender of this influence to the receiver. As we can see, the (b) economy (0.286) obtained the most importance, but was vulnerable to other criteria. The (a) architectural element and (c) climate (0.88) seemed not particularly important, however, they had significant direct impacts to the other four criteria. The (f) risk (0.188), (d) photovoltaic array (0.162), and (e) contribution (0.151) were considered of medium importance, and among them, (f) and (d) had more of an impact, while (e) received more impact. Horizontal histogram clearly and intuitively shows the weight of each subcriteria in Figure 5. It is obvious that the (b1) Total investment, (b2) Total profit, and (b3). Annual rate of return acquired the highest weight, in addition to the (f4) Government subsidies reduction, (e2) Publicity effects and (d2). PV area was considered to be less but also very important. Therefore, it can be imagined that the SMPV plan alternatives which obtained high scores in these criteria are more likely to win the competition.

Table 2. The score of influence among each subcriteria.

	a1	a2	a3	b1	b2	b3	b4	c1	c2	c3	d1	d2	d3	d4	e1	e2	e3	f1	f2	f3	f4	D	R	W
a1	0	3	4	1	1	1	1	0	0	4	0	0	0	0	0	4	1	0	0	0	0	0.50	0.03	0.023
a2	2	0	5	3	2	2	2	0	2	4	0	1	0	0	0	0	0	0	0	0	0	0.60	0.05	0.028
a3	0	0	0	5	5	4	4	0	0	0	0	3	1	1	2	3	2	0	0	0	0	0.75	0.25	0.037
b1	0	0	0	0	3	5	5	0	0	0	3	3	2	2	4	4	4	1	1	0	0	0.89	1.05	0.064
b2	0	0	0	0	0	5	5	0	0	0	0	1	1	1	5	4	2	0	2	0	3	0.68	1.47	0.075
b3	0	0	0	0	0	0	2	0	0	0	0	1	1	1	5	4	2	0	2	0	3	0.49	1.51	0.074
b4	0	0	0	0	0	2	0	0	0	0	0	1	2	2	4	3	3	1	1	0	2	0.50	1.51	0.074
c1	0	0	0	5	5	5	5	0	5	5	3	3	0	2	1	0	2	1	0	1	2	1.16	0.08	0.054
c2	0	0	0	4	4	4	4	0	0	0	2	2	0	1	0	0	0	0	0	1	0	0.58	0.27	0.030
c3	0	0	0	4	4	4	4	0	3	0	0	3	0	3	0	0	2	0	0	1	0	0.72	0.54	0.042
d1	0	0	0	3	3	3	3	0	0	4	0	3	1	1	0	0	1	3	0	0	2	0.71	0.47	0.039
d2	0	0	0	2	5	3	3	0	0	0	3	0	0	1	2	2	4	5	0	0	3	0.82	0.90	0.056
d3	0	0	0	1	5	3	3	0	0	4	3	2	0	3	1	0	0	0	0	0	0	0.64	0.26	0.032
d4	0	0	0	1	5	3	3	0	0	3	3	3	0	0	1	0	0	0	0	0	0	0.57	0.48	0.034
e1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	4	1	2	0	0	3	0.30	1.05	0.050
e2	0	0	0	2	1	0	0	0	0	0	0	0	0	0	2	0	1	3	3	0	4	0.42	1.17	0.057
e3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	3	2	0	4	0.36	0.86	0.043
f1	0	0	0	3	5	4	4	0	0	0	0	5	0	0	1	2	2	0	0	0	3	0.74	0.66	0.046
f2	0	0	5	5	5	4	4	0	0	0	0	2	0	0	2	2	0	0	0	0	0	0.74	0.39	0.039
f3	0	0	0	1	5	4	4	5	5	5	4	4	0	0	1	0	0	1	0	0	0	1.04	0.06	0.048
f4	0	0	0	5	5	5	5	0	0	0	0	1	0	0	2	2	2	3	0	0	0	0.75	0.91	0.054

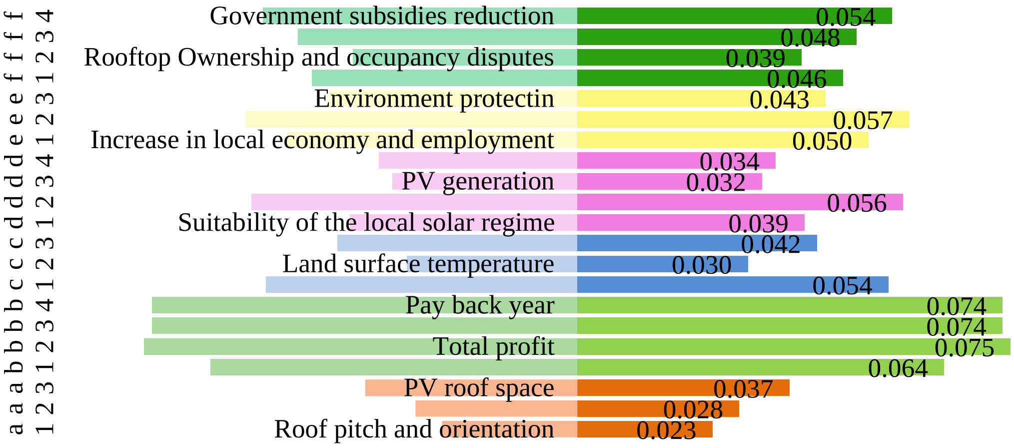

Figure 4. The weights of subcriteria.

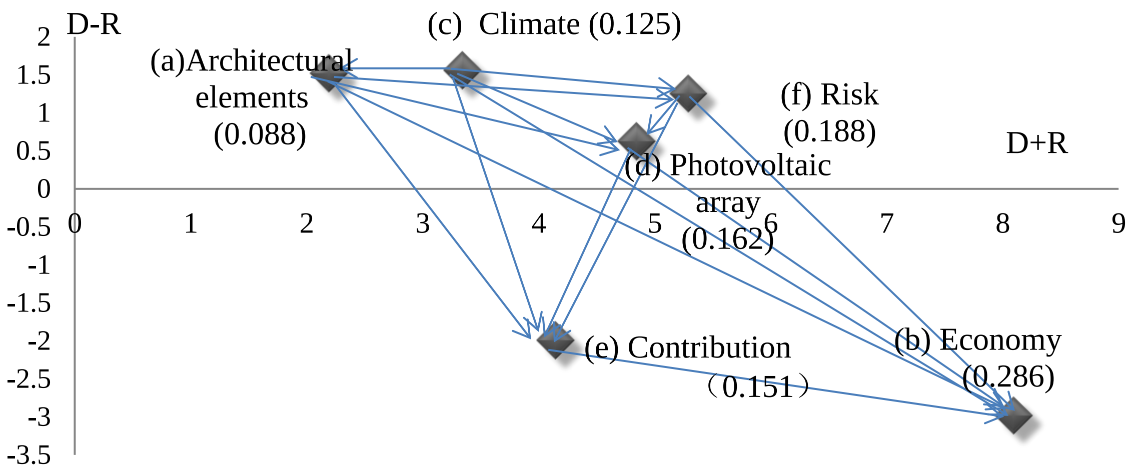

Figure 5. Influential network relationship map within systems.

Secondly, there are two types of criteria, one is quantitative, and the other is qualitative. On one hand, for the quantitative subcriteria, searching from the NASA atmospheric science data center, the data for c1, c2, c3 were obtained. Through using the Google earth map, the roof space data were obtained. Then, according to Equations (1)–(8), the data for a3, b1–b4, d2, d3 were estimated. Because the Equations (1)–(8) are just for rough estimate, these data were not highly accurate. Considering the uncertainty and fuzziness of the data, Equation (25) was used to turn the numerical value into an IVNN value. The performance scores of the quantitative subcriteria are shown in Table 3. On the other hand, for the qualitative subcriteria, the experts group devoted their efforts to investigate the alternative plans and evaluate the performance score for the subcriteria a1, a2, d1, d4, e1–e3, f1–f4. The performance scores of the qualitative subcriteria were shown in Table 4. In addition, the subcriteria were divided into positive and negative. The score of positive criteria higher and negative criteria lower means the alternative better. In this paper, subcriteria b1, d4, f1, f3, f4 are negative and the others are positive.

Table 3. IVNN performance scores of alternative SMPV plans on the quantitative subcriteria.

Subcriteria	S1	S2	S3	S4
(a3)	([0.90,0.90],[0.10,0.10],[0.00,0.00])	([0.32,0.32],[0.04,0.04],[0.65,0.65])	([0.26,0.26],[0.03,0.03],[0.71,0.71])	([0.42,0.42],[0.05,0.05],[0.54,0.54])
(b1)	([0.41,0.41],[0.10,0.10],[0.49,0.49])	([0.70,0.70],[0.08,0.06],[0.23,0.25])	([0.26,0.26],[0.03,0.03],[0.71,0.71])	([0.50,0.50],[0.06,0.06],[0.44,0.44])
(b2)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.40,0.40],[0.04,0.06],[0.56,0.54])	([0.90,0.90],[0.10,0.10],[0.00,0.00])	([0.53,0.53],[0.05,0.05],[0.42,0.42])
(b3)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.65,0.65],[0.07,0.07],[0.28,0.28])	([0.53,0.53],[0.06,0.06],[0.41,0.41])	([0.63,0.63],[0.07,0.07],[0.30,0.30])
(b4)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.72,0.72],[0.08,0.08],[0.20,0.20])	([0.60,0.60],[0.07,0.07],[0.33,0.33])	([0.60,0.60],[0.07,0.07],[0.33,0.33])
(c1)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.79,0.79],[0.10,0.10],[0.11,0.11])	([0.81,0.81],[0.09,0.09],[0.10,0.10])	([0.81,0.81],[0.09,0.09],[0.09,0.09])
(c2)	([0.53,0.53],[0.06,0.06],[0.41,0.41])	([0.70,0.70],[0.08,0.08],[0.22,0.22])	([0.62,0.62],[0.07,0.07],[0.31,0.31])	([0.90,0.90],[0.10,0.10],[0.00,0.00])
(c3)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.71,0.71],[0.08,0.08],[0.21,0.21])	([0.69,0.69],[0.08,0.08],[0.23,0.23])	([0.73,0.73],[0.08,0.08],[0.19,0.19])
(d2)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.53,0.53],[0.06,0.06],[0.41,0.41])	([0.41,0.41],[0.05,0.05],[0.54,0.54])	([0.74,0.74],[0.08,0.08],[0.17,0.17])
(d3)	([0.90,0.90],[0.03,0.03],[0.07,0.07])	([0.47,0.47],[0.05,0.05],[0.48,0.48])	([0.37,0.37],[0.04,0.04],[0.59,0.59])	([0.67,0.67],[0.07,0.07],[0.25,0.25])

Table 4. IVNN performance scores of alternative SMPV plans on the qualitative subcriteria.

Subcriteria	X1	X2	X3	X4
(a1)	([0.45,0.56],[0.18,0.30],[0.13,0.50])	([0.68,0.79],[0.18,0.30],[0.13,0.50])	([0.56,0.68],[0.18,0.24],[0.38,0.67])	([0.79,0.90],[0.12,0.18],[0.25,0.50])
(a2)	([0.50,0.50],[0.06,0.06],[0.44,0.44])	([0.85,0.85],[0.09,0.09],[0.06,0.06])	([0.80,0.80],[0.09,0.09],[0.12,0.12])	([0.90,0.90],[0.10,0.10],[0.00,0.00])
(d1)	([0.80,0.90],[0.15,0.23],[0.13,0.33])	([0.50,0.60],[0.23,0.30],[0.38,0.67])	([0.40,0.60],[0.15,0.23],[0.25,0.50])	([0.60,0.80],[0.23,0.30],[0.25,0.50])
(d4)	([0.20,0.23],[0.12,0.20],[0.25,0.33])	([0.45,0.60],[0.20,0.30],[0.13,0.17])	([0.60,0.90],[0.15,0.20],[0.13,0.14])	([0.30,0.45],[0.10,0.12],[0.20,0.50])
(e1)	([0.70,0.90],[0.08,0.15],[0.21,0.33])	([0.50,0.60],[0.23,0.30],[0.36,0.58])	([0.30,0.50],[0.08,0.15],[0.43,0.58])	([0.60,0.80],[0.15,0.30],[0.14,0.25])
(e2)	([0.50,0.60],[0.23,0.30],[0.33,0.75])	([0.70,0.80],[0.15,0.23],[0.33,0.75])	([0.70,0.90],[0.15,0.23],[0.17,0.50])	([0.80,0.90],[0.15,0.23],[0.17,0.50])
(e3)	([0.79,0.90],[0.12,0.18],[0.17,0.50])	([0.68,0.90],[0.06,0.12],[0.17,0.75])	([0.68,0.79],[0.18,0.24],[0.33,0.75])	([0.68,0.79],[0.24,0.30],[0.33,0.75])
(f1)	([0.30,0.45],[0.20,0.26],[0.33,0.43])	([0.45,0.90],[0.26,0.30],[0.38,0.43])	([0.23,0.45],[0.20,0.23],[0.38,0.43])	([0.30,0.90],[0.23,0.26],[0.38,0.50])
(f2)	([0.45,0.68],[0.08,0.15],[0.44,0.56])	([0.45,0.68],[0.15,0.23],[0.39,0.56])	([0.23,0.45],[0.15,0.23],[0.44,0.56])	([0.68,0.90],[0.23,0.30],[0.33,0.44])
(f3)	([0.23,0.26],[0.12,0.20],[0.25,0.33])	([0.60,0.90],[0.20,0.30],[0.13,0.17])	([0.60,0.90],[0.15,0.20],[0.13,0.14])	([0.30,0.45],[0.10,0.12],[0.20,0.50])
(f4)	([0.30,0.34],[0.15,0.30],[0.25,0.50])	([0.30,0.39],[0.15,0.30],[0.17,0.25])	([0.68,0.90],[0.03,0.04],[0.13,0.25])	([0.68,0.90],[0.04,0.05],[0.17,0.25])

Thirdly, based on the weight of the sub-criteria and the IVNN scores of each alternative on each subcriteria, the final composite scores were calculated by improved ELECTRIC III method. After being told that q_j is the indifference threshold, p_j is the preference threshold and v_j is the veto threshold, the experts group suggested that $\sum s(a_i, a_k) - \sum s(a_k, a_i)$ $(k = 1, 2 \ldots n)$, respectively. The concordance index $c(X_i, X_k)$ and the partial concordance index $c_j(X_i, X_k)$ were calculated by Equations (26) and (27), as shown in Table 5. The discordance index $d_j(X_i, X_k)$ was achieved by Equation (28), as shown in Table 6. Then, overall concordance and partial discordance indices was obtained by Equation (29) as shown in Table 7. Finally, the degree of credibility of the outranking relation was calculated by Equation (30), and the rankings of alternative X1, X2, X3, X4 was shown in Table 8.

From Table 8, the SMPV plan X1 of the Golden Resources shopping mall in Beijing is the optimal selection. The alternative X1 is particularly superior to other alternative plans in terms of the economy, photovoltaic array, and contribution criteria, while these three criteria weighed more than a half of the entire criteria weights, so there is no doubt that plan X1 obtained the best position. However, plan X1 performs badly in the risk and architectural elements criteria. Respectively, Plan X2 have strength on the economy, but are weak on photovoltaic criteria. Yet, plan X2 is much better than plan X3 and X4, so that it can be the stand-by choice.

Table 5. The concordance index and the partial concordance index for each pair of SMPV plans.

	a1	**a2**	**a3**	**b1**	**b2**	**b3**	**b4**	**c1**	**c2**	**c3**	**d1**
c(X1 ≥ X2)	0.00	0.00	1.00	0.00	1.00	0.62	0.43	0.24	0.00	0.46	0.83
c(X1 ≥ X3)	0.05	0.00	1.00	0.36	0.00	0.92	0.74	0.20	0.00	0.50	0.61
c(X1 ≥ X4)	0.00	0.00	1.00	0.00	0.93	0.68	0.74	0.19	0.00	0.41	0.45
c(X2 ≥ X1)	0.26	0.85	0.00	0.70	0.00	0.00	0.00	0.00	0.41	0.00	0.00
c(X2 ≥ X2)	0.34	0.10	0.11	1.00	0.00	0.26	0.28	0.00	0.19	0.01	0.00
c(X2 ≥ X3)	0.00	0.00	0.00	0.47	0.00	0.02	0.28	0.00	0.00	0.00	0.00
c(X3 ≥ X1)	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00
c(X3 ≥ X2)	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.01	0.00	0.00	0.19
c(X3 ≥ X4)	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.00	0.00	0.00
c(X4 ≥ X1)	0.44	0.99	0.00	0.19	0.00	0.00	0.00	0.00	0.92	0.00	0.00
c(X4 ≥ X2)	0.15	0.11	0.22	0.00	0.30	0.00	0.00	0.02	0.48	0.02	0.35
c(X4 ≥ X3)	0.52	0.24	0.37	0.59	0.00	0.21	0.00	0.00	0.69	0.05	0.13

	d2	**d3**	**d4**	**e1**	**e2**	**e3**	**f1**	**f2**	**f3**	**f4**	**C**
c(X1 ≥ X2)	0.91	1.00	0.00	0.74	0.00	0.12	0.00	0.03	0.00	0.00	0.38
c(X1 ≥ X3)	1.00	1.00	0.00	0.78	0.00	0.46	0.02	0.35	0.00	0.00	0.40
c(X1 ≥ X4)	0.37	0.55	0.00	0.14	0.00	0.54	0.00	0.00	0.00	0.00	0.32
c(X2 ≥ X1)	0.00	0.00	0.44	0.00	0.32	0.00	0.26	0.00	0.70	0.21	0.18
c(X2 ≥ X2)	0.28	0.23	0.00	0.01	0.00	0.30	0.32	0.29	0.00	0.00	0.19
c(X2 ≥ X3)	0.00	0.00	0.24	0.00	0.00	0.38	0.06	0.00	0.53	0.00	0.11
c(X3 ≥ X1)	0.00	0.00	0.85	0.00	0.66	0.00	0.00	0.00	0.81	1.00	0.19
c(X3 ≥ X2)	0.00	0.00	0.37	0.00	0.30	0.00	0.00	0.00	0.08	0.81	0.16
c(X3 ≥ X4)	0.00	0.00	0.65	0.00	0.00	0.05	0.00	0.00	0.65	0.00	0.13
c(X4 ≥ X1)	0.00	0.00	0.17	0.00	0.72	0.00	0.17	0.22	0.13	1.00	0.20
c(X4 ≥ X2)	0.51	0.49	0.00	0.56	0.37	0.00	0.00	0.28	0.00	0.78	0.21
c(X4 ≥ X3)	0.82	0.75	0.00	0.61	0.03	0.00	0.22	0.60	0.00	0.00	0.25

Table 6. The discordance index for each pair of SMPV plans.

d(Xi ≥ Xj)	a1	a2	a3	b1	b2	b3	b4	c1	c2	c3	d1
d(X1 ≥ X2)	0.00	0.00	1.00	0.00	0.91	0.47	0.34	0.21	0.00	0.36	0.61
d(X1 ≥ X3)	0.08	0.00	1.00	0.30	0.02	0.68	0.56	0.19	0.00	0.39	0.46
d(X1 ≥ X4)	0.00	0.00	0.88	0.00	0.68	0.51	0.56	0.17	0.00	0.33	0.35
d(X2 ≥ X1)	0.22	0.63	0.00	0.52	0.00	0.00	0.00	0.00	0.33	0.00	0.00
d(X2 ≥ X2)	0.28	0.11	0.12	0.80	0.00	0.23	0.24	0.00	0.17	0.05	0.00
d(X2 ≥ X3)	0.00	0.00	0.00	0.37	0.00	0.06	0.24	0.00	0.00	0.00	0.00
d(X3 ≥ X1)	0.00	0.54	0.00	0.00	0.02	0.00	0.00	0.00	0.18	0.00	0.00
d(X3 ≥ X2)	0.00	0.00	0.00	0.00	0.91	0.00	0.00	0.05	0.00	0.00	0.17
d(X3 ≥ X4)	0.00	0.00	0.00	0.00	0.68	0.00	0.02	0.01	0.00	0.00	0.00
d(X4 ≥ X1)	0.35	0.72	0.00	0.18	0.00	0.00	0.00	0.00	0.68	0.00	0.00
d(X4 ≥ X2)	0.15	0.12	0.20	0.00	0.25	0.00	0.00	0.06	0.37	0.06	0.29
d(X4 ≥ X3)	0.41	0.21	0.30	0.45	0.00	0.19	0.02	0.03	0.52	0.08	0.13
d(Xi ≥ Xj)	**d2**	**d3**	**d4**	**e1**	**e2**	**e3**	**f1**	**f2**	**f3**	**f4**	
d(X1 ≥ X2)	0.67	0.78	0.00	0.55	0.00	0.13	0.00	0.06	0.00	0.00	
d(X1 ≥ X3)	0.89	0.96	0.00	0.58	0.00	0.36	0.06	0.29	0.00	0.00	
d(X1 ≥ X4)	0.30	0.43	0.00	0.14	0.00	0.41	0.00	0.00	0.00	0.00	
d(X2 ≥ X1)	0.00	0.00	0.35	0.00	0.27	0.00	0.23	0.00	0.52	0.19	
d(X2 ≥ X2)	0.24	0.20	0.00	0.05	0.00	0.25	0.26	0.25	0.00	0.00	
d(X2 ≥ X3)	0.00	0.00	0.21	0.00	0.00	0.31	0.09	0.00	0.41	0.00	
d(X3 ≥ X1)	0.00	0.00	0.63	0.00	0.50	0.00	0.00	0.00	0.60	0.77	
d(X3 ≥ X2)	0.00	0.00	0.30	0.00	0.25	0.00	0.00	0.00	0.10	0.60	
d(X3 ≥ X4)	0.00	0.00	0.49	0.00	0.00	0.08	0.00	0.00	0.49	0.05	
d(X4 ≥ X1)	0.00	0.00	0.16	0.00	0.54	0.00	0.16	0.19	0.13	0.75	
d(X4 ≥ X2)	0.39	0.38	0.00	0.43	0.30	0.00	0.00	0.24	0.00	0.58	
d(X4 ≥ X3)	0.61	0.56	0.00	0.46	0.07	0.00	0.20	0.46	0.00	0.00	

Table 7. The overall concordance and partial discordance indices for each pair of SMPV plans.

s(Xi ≥ Xj)	a1	a2	a3	b1	b2	b3	b4	c1	c2	c3	d1
s(X1 ≥ X2)	1.62	1.67	0.00	1.67	0.15	0.88	1.10	1.32	1.67	1.07	0.64
s(X1 ≥ X3)	1.54	1.67	0.00	1.18	1.63	0.54	0.74	1.36	1.67	1.02	0.90
s(X1 ≥ X4)	1.48	1.48	0.18	1.48	0.47	0.73	0.66	1.22	1.48	1.00	0.96
s(X2 ≥ X1)	0.95	0.45	1.22	0.58	1.22	1.22	1.22	1.22	0.82	1.22	1.22
s(X2 ≥ X2)	0.88	1.09	1.08	0.25	1.23	0.95	0.94	1.23	1.02	1.17	1.23
s(X2 ≥ X3)	1.12	1.12	1.12	0.70	1.12	1.05	0.85	1.12	1.12	1.12	1.12
s(X3 ≥ X1)	1.23	0.57	1.23	1.23	1.20	1.23	1.23	1.23	1.01	1.23	1.23
s(X3 ≥ X2)	1.19	1.19	1.19	1.19	0.10	1.19	1.19	1.13	1.19	1.19	0.98
s(X3 ≥ X4)	1.14	1.14	1.14	1.14	0.36	1.14	1.12	1.13	1.14	1.14	1.14
s(X4 ≥ X1)	0.82	0.34	1.25	1.03	1.25	1.25	1.25	1.25	0.40	1.25	1.25
s(X4 ≥ X2)	1.09	1.12	1.02	1.27	0.95	1.27	1.27	1.20	0.80	1.20	0.91
s(X4 ≥ X3)	0.79	1.06	0.94	0.73	1.33	1.08	1.30	1.29	0.64	1.22	1.16
s(Xi ≥ Xj)	**d2**	**d3**	**d4**	**e1**	**e2**	**e3**	**f1**	**f2**	**f3**	**f4**	**s**
s(X1 ≥ X2)	0.55	0.36	1.67	0.75	1.67	1.45	1.67	1.56	1.67	1.67	0.38
s(X1 ≥ X3)	0.19	0.06	1.67	0.69	1.67	1.07	1.57	1.19	1.67	1.67	0.40
s(X1 ≥ X4)	1.04	0.85	1.48	1.27	1.48	0.87	1.48	1.48	1.48	1.48	0.32
s(X2 ≥ X1)	1.22	1.22	0.79	1.22	0.89	1.22	0.94	1.22	0.58	0.98	0.18
s(X2 ≥ X2)	0.94	0.98	1.23	1.16	1.23	0.92	0.91	0.93	1.23	1.23	0.19
s(X2 ≥ X3)	1.12	1.12	0.88	1.12	1.12	0.78	1.02	1.12	0.66	1.12	0.11
s(X3 ≥ X1)	1.23	1.23	0.46	1.23	0.62	1.23	1.23	1.23	0.49	0.28	0.19
s(X3 ≥ X2)	1.19	1.19	0.83	1.19	0.89	1.19	1.19	1.19	1.07	0.47	0.16

s(X3 ≥ X4)	1.14	1.14	0.58	1.14	1.14	1.06	1.14	1.14	0.58	1.09	0.13
s(X4 ≥ X1)	1.25	1.25	1.05	1.25	0.58	1.25	1.05	1.01	1.08	0.32	0.20
s(X4 ≥ X2)	0.77	0.79	1.27	0.72	0.89	1.27	1.27	0.97	1.27	0.54	0.21
s(X4 ≥ X3)	0.52	0.59	1.33	0.71	1.24	1.33	1.07	0.72	1.33	1.33	0.25

Table 8. Final composite scores and rankings of alternative SMPV plans.

Xi	$\sum s(a_i \succ a_k)$	$\sum s(a_k \succ a_i)$	$\Delta S(a_i)$
X1	0.73	0.29	0.44
X2	0.47	0.37	0.1
X3	032	0.39	−0.07
X4	0.56	1.02	−0.47

The ranking order using ELECTRI III is X1 > X2 > X3 > X4. In order to check the validity of the results, TOPSIS and VIKOR methods were used to reorder the alternative SMPV plans as shown in Table 9. The result obtained by TOPSIS method is X1 > X4 > X3 > X2, while the result achieved by VIKOR method is X1 > X4 > X3 > X2. from these three rankings, alternative plan X1 is the optimal selection, no matter what method was used. That is to say, the alternative X1 is much better than the remaining alternatives, and there is no doubt in choosing X1 first. However, the rankings for X2, X3, and X4 are different between these three methods. There is the veto threshold, which indicates when the value of alternative Xi is lower than the value of alternative Xj, and the lower value exceeds the veto threshold, and it is not recognized that Xi is preferred to the Xj in general. However, it is the other term in TOPSIS method and VIKOR method, and some really bad performance in a certain criterion can be tolerated and remedied by other good performances in other criteria. In that case, an alternative with some fatal defect in a certain criterion of an alternative may be neglected, which leads to an unsatisfactory selection. When an alternative is vetoed better than the other alternative in ELECTRE III, it can still come out in front in the TOPSIS and VIKOR methods. That why the X2, X3, X4 ranked differently in TOPSIS and VIKOR methods.

Table 9. The rankings of SMPV plans using TOPSIS and VIKOR.

Method	TOPSIS				VIKOR			
	y+	y−	C	Rankings	s	r	Q	Rankings
X1	0.62	1.43	0.70	1	−2.57	0.12	0.00	1
X2	1.17	0.47	0.29	4	1.88	1.18	0.922	4
X3	1.35	0.71	0.35	3	−1.74	1.06	0.526	2
X4	0.76	0.74	0.49	2	2.74	1.01	0.919	3

6. Conclusions

The selection of SMPV plan is crucial to the entire life of SMPV project. Although there has been some research on this issue, several questions still need addressing. Firstly, the interaction of the criteria lay in the evaluation criteria. Secondly, the loss of evaluation information exited in the information conversion process. Thirdly, the compensation problem between best and worst performance in diverse criteria was not easily to avoided.

In this paper, an integrated MCDM framework was proposed to address the SMPV plan selection problem. First of all, the compositive evaluation index was constructed, and the application of DEMATEL method helped analyze the internal influence and connection behind each criterion. From the influential network-relationship map, we discovered that the criteria (b) economy obtained the most importance but was vulnerable to other criteria as well as the (a) architectural element and (c) climate had significant direct impacts to the other four criteria. These three criteria should be the first for the decision maker to consider when selecting the SMPV plan. Then, the interval-valued neutrosophic set is utilized to express the imperfect knowledge of experts group. Since the application of IVNNS, the experts can clearly express their evaluation information, including their certainty, uncertainty, as well as hesitation attitude. Following this, an extended ELECTRE III method as an outstanding outranking method was applied, and it succeed in avoiding the compensation problem and obtaining the scientific result. In the case of China, the integrated method has been successfully applied to select the SMPV plan X1 as the optimal selection which is particularly superior to other alternative plans in terms of the economy, photovoltaic array, and contribution criteria. Also, the integrated method used maintained symmetry in the solar PV investment. Last but not least, a comparative analysis using TOPSIS method and VIKOR method was carried out, and alternative plan X1 ranks first at the same. The outcome certified the correctness and rationality of the results obtained from this paper.

Therefore, this study has not only served to evaluate the SMPV plans, it has also demonstrated how it is possible to combine IVNNS, DEMATEL method, and ELECTRE III method for application in handling MCDM problems in the field of solar energy.

Author Contributions: M.L. designed the decision framework of shopping mall photovoltaic plan selection, and studied the proposed method. Then, J.F. collected the relative data, calculated the result, and drafted the paper. Next, Y.L. adjusted the format of the paper and formatted the manuscript for submission.

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

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