*sustainability*

MDPI

*Article*

# Identification of Key Influencing Factors of Sustainable Development for Traditional Power Generation Groups in a Market by Applying an Extended MCDM Model

**Jun Dong, Dongran Liu *, Dongxue Wang and Qi Zhang**

School of Economics and Management, North China Electric Power University, Beijing 102206, China; dongjun624@126.com (J.D.); 18101397665@163.com (D.W.); zq@ncepu.edu.cn (Q.Z.)

* Correspondence: 1182106008@ncepu.edu.cn; Tel.: +86-188-1092-9586

Received: 31 January 2019; Accepted: 19 March 2019; Published: 22 March 2019

check for updates

**Abstract:** With the deepening reform of the power market, the external environment of China's power industry is going through a huge change. China's traditional power generation groups (TPGGs), with assets all over the country, are, due to a lack of market awareness about energy policies, facing serious challenges in developing competitive advantages, improving power transaction modes, optimizing profit models, and even realizing basic corporate strategies. In this study, we focus on identifying the key factors influencing sustainable development in an unprecedented market environment for TPGGs, so as to achieve overall sustainable development for the whole power generation sector in China. A hybrid framework based on Multiple-Criteria Decision-Making (MCDM) was proposed to recognize the key influencing factors under vague rule conditions. We developed a novel method combining three different MCDM methods with triangular fuzzy numbers (TFNs), fuzzy Delphi, fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL), and Analytic Network Process (ANP), to cover uncertainty and make the problem-solving approach closer to the actual problem. A series of analyses indicate that the final 14 factors covering the five dimensions are considered to be important factors in the sustainable development of TPGGs. Based on the results, it can be said that "Gross energy margin" and "Pricing bidding strategy" dominate the impacts of TPGG's sustainable development. Finally, we give some advice relating to practical measures to help TPGGs achieve sustainable development in the market-oriented industry environment.

**Keywords:** corporate sustainability; influencing factors; traditional power generation groups (TPGGs); fuzzy Delphi model; fuzzy decision-making trial and evaluation laboratory (DEMATEL) method; ANP technique

## 1. Introduction

China relies heavily on coal resources to drive economic growth and has become the largest energy consumer and the top $CO_2$ emitter in the world [1]. However, abundant renewable energy in China is not well developed. The energy consumption structure in China is seriously out of balance. Currently, the problems of surplus generating capacity, unbalanced supply and demand of power, and low efficiency of resource utilization are prominent in the power industry. The contradiction between relying heavily on fossil energy and the curtailments of wind, solar, and other renewable energies is becoming more and more serious. These not only affect the sustainable development of the power industry itself, but also have a negative impact on upstream and downstream industries [2]. In order to tackle these problems, the Chinese government has identified a clean, efficient, safe, and sustainable energy strategy, and launched a new round of power industry reform that gives the markets a decisive role in resource allocation.

The new round of electricity reform concerns the overall situation of China's energy security as well as economic and social development. Before the start of the reform, five large generation enterprises, several local generation enterprises, and two power grids dominated the power industry in China. The main problems were that the trading mechanism was absent, the pricing mechanism of China's power industry was seriously distorted, and the electricity price and quantity were not decided by market participants but by the government [2]. Therefore, consumers were just the price receiver for they did not have rights to negotiate with generation plants and grid enterprises. Under such circumstances, all market participants lacked market consciousness. However, after the new round of reform, competition is introduced into the power generation enterprises and selling corporates, and prices of competitive links except transmission and distribution are liberalized. The generation side of China's power industry is facing unprecedented challenges of transition in terms of the trading mode and profit model. In order to realize sustainable development of the power industry, TPGGs should learn to raise market awareness, improve investment decisions, advance technology development, strengthen risk control, adjust organizational structure, and optimize talent management through substantial measures to maintain sustainability in terms of economic, social, and environmental responsibilities.

Sustainability is the core factor in corporate strategies [3]. It is the driving force of corporate decision-making and strategic management. Covering the main comprehensive aspects of sustainability challenges [4], corporate sustainability has become a heated topic [5–8], especially for TPGGs in China. They should transform challenges in the external industrial environment into development opportunities through enhancing sustainability management. However, the different objectives, concepts, methodologies, and expectations make it complex to define sustainability. Sustainability must be measured in terms of multiple dimensions if it is to be analyzed based on the decision-making process [9]. There have been some studies published using sustainability indicators to measure corporate sustainability performance concerning a series of aspects, such as economic [10], society, environment [9,11,12], and time [13]. All of them illustrated the significance of sustainability for enterprises. In order to recommend the most effective measures for TPGG, it is essential to grasp the key factors of sustainability in the process of development. Obviously, a systematic study identifying the key factors of TPGG sustainability is of great value.

Approaches of indicator identification have been proposed in many studies, such as a data envelopment analysis approach [12], the five force model [14], the stepwise approach [11], the analytic hierarchy process method [15–17], Fuzzy AHP [18,19], AHP-PROMETHEE [20], Principal Component Analysis [21], grey relational analysis (GRA) [22,23], the Fuzzy TOPSIS method [24,25], as well as a modified TOPSIS methodology [26,27]. Apparently, a factor may directly or indirectly influence other factors. Significant interactions among these factors are generally implicit. Many studies ignored these correlations in the identification of key factors, leaving some fundamental factors ignored. Therefore, these implicit correlations should be identified initially and then the complexity of massive influencing factors can be simplified. These multiple criteria analyses contribute to a multi-criteria decision-making (MCDM) problem [28]. In recent years, plenty of MCDM techniques have been proposed to analyze such correlations, such as interpretative structural modeling (ISM), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), etc. In order to reveal the interactions between factors more effectively, suitable methods should be selected to screen the critical factors of TPGGs' sustainability.

The Delphi method is a common method to collect the consensus of opinions. Influencing factors can be obtained according to the established processes. Based on the literature review, a DEMATEL method is widely used in macroeconomic management and sustainable development, as well as the enterprise economy and industrial economy fields. Through the Delphi method, the causal relationship [29] between factors can be teased out. Meanwhile, a map of relationships with clear interrelations can be built to identify critical factors in emergency management [30], risk identification [31,32], causal factors evaluation [33], and so on [34–36]. However, the assessments from decision makers are generally based on their experience and knowledge under a fuzzy environment. The importance of the factors may be influenced. Therefore, it is necessary to introduce the fuzzy set theory to quantify the obscure decision information. In order to comprehensively analyze the relationship between different levels of factors, the analytic network process (ANP) is widely used. Based on the causal diagram obtained by the fuzzy DEMATEL method, the preferences of selected factors can be determined. Thus, an extended research framework integrating the fuzzy Delphi, fuzzy DEMATEL and the ANP method is proposed to identify the key influencing factors in a real economic environment. The main contributions of this paper are:

(1) Unlike previous studies researching the whole power industry to pursue sustainable development, this study is focused on representative enterprises based on the real market-oriented renovation, especially systematic research. In this paper, the topic of traditional power generation groups (TPGG) was proposed for the first time, which represents power generation groups that were in the planning environment before but now are facing a transformation due to the power market reform in China.
(2) Most research on corporate sustainability has analyzed one or two aspects, such as leadership, corporate finance, or social responsibility. To the best of our knowledge, this is the first research to provide a deep analysis of the issue of TPGGs from a systematic perspective, covering the five aspects of "society and environment," "economy," "resources and technology," "enterprise management," and "market." Meanwhile, an innovative comprehensive index system on two levels was established to identify the influencing factors of TPGG sustainability.
(3) The fuzzy DEMATEL method functions well in terms of factor identification under obscure circumstances. A novel hybrid MCDM method based on the integration of the fuzzy Delphi method and the fuzzy DEMATEL method into the ANP technique was developed to establish a reasonable index system for identifying the key influencing factors. Moreover, we used triangle fuzzy numbers (TFNs) to process the vague linguistic ratings in this study. Therefore, the application areas of these methods are extended.
(4) In order to recognize the key influencing factors and have a better understanding of their relationships, an analysis of the causal relationship structure was conducted. Moreover, in order to identify the core influencing factors more comprehensively, we used the ANP method to conduct a weight analysis from both an academic and a practical perspective. Finally, a discussion was undertaken based on the calculating results, and several targeted measures were proposed to help TPGGs identify the key factors influencing sustainable development in a new market environment.

The remainder of this paper is organized as follows: in Section 2, the potential influencing factors of TPGG sustainability are summarized by referring to the literature and related reports. Section 3 presents the basic theories of related methods, and then the research framework with integrated technique is elaborated. In Section 4, detailed calculations and analyses are carried out. Section 5 is about how to recognize the core influencing factors and gives relative suggestions based on the discussions. Finally, conclusions are drawn in Section 6.

## 2. Overview of the Factors Influencing Sustainable Capability

Many scholars hold that there is a link between sustainable development and corporate performance. There is a consensus that TPGGs are sensitive to energy policies [37]. Also, there is a positive relationship between the environmental performance [38,39], corporate social consciousness [40], and financial performance of companies. Eco-innovation [41,42] is a relatively new concept and a way for enterprises to gain a sustainable competitive advantage. Many scholars have studied the factors of enterprises' sustainability based on various dimensions, including the economy, society, and environment [43]. However, prior studies on enterprise sustainability mostly focused on the theoretical discussion, but few researchers measured it in a quantitative way, particularly at the power generation group level. In order to comprehensively analyze the key factors affecting the sustainable development of power generation groups, we take into account the factors of China's power market and combine the internal organizational characteristics of TPGGs to establish an indicator system covering five aspects. Considering the complexity of corporate sustainability, we extended the general framework with the dimensions of economy, society, and environment, and added some factors from the aspects of "enterprise management" and "market." Therefore, all influencing factors are classified into five dimensions, including "Society and environment," "Economy," "Resources and technology," "Enterprise management," and "Market":

(1) Society and environment Social and environmental perspectives are regarded as critical factors for corporate sustainability in many studies [44]. Government policy, corporate social responsibility, external environment, and so on will cause enterprises to gain sustainable competitive advantage. Moreover, the generation of reliability is essential for power enterprises, particularly for renewable energy generation companies. In this aspect, the "Society and environment" dimension mainly involves corporations' external public responsibilities including environment protection, social welfare, etc., as well as their internal responsibilities to their own employees.
(2) Economy Some research [45] suggests that indicators of sustainable development should be financial terms. The financial situation of an enterprise directly reflects its sustainable development. Indicators such as generation and integration cost are crucial in actual operations. Also, the profit and risk values are reasonable indictors of the performance of TPGGs in the market environment.
(3) Resources and technology The level of resources and technology reflects the strength of a company. In the long run, the technological level of an enterprise indicates its future competitiveness to a certain extent.
(4) Enterprise management Many studies reveal that corporate culture, a corporate leader's experiences, and staff abilities have critical impacts on corporate sustainability. In order to better analyze the corporate sustainability, the corporate culture, leadership, and staff attitudes and values as well as the setup of corporate processes and reward system should be considered. It is worth noting that risk management is an indispensable link in enterprise sustainable development.
(5) Market The reform of the electricity market in China has brought about great changes to the business environment of TPGGs. Both opportunities and risks have emerged. In addition to the brand effect, market price forecast, competitor analysis, and market strategies are crucial for the future survival of TPGGs.

The various influencing factors discussed in existing literatures are summarized in Table 1.

**Table 1.** A summary of potential factors of sustainability for TPGGs based on the literature.

| Criteria | Sub-Criteria | References |
|---|---|---|
| Society and environment (Z1) | • Electricity market exposure (B11) | [46] |
| | • Renovation of electric power law and enforcement of government documents of power industry reform (B12) | [2,47–49] |
| | • Reliability of power supply (B13) | [50] |
| | • Package design of preferential electricity price for consumers (B14) | [49,51] |
| | • NOx, Fly ash, sulfur dioxide and industrial soot emission (B15) | [47,49,50,52] |
| | • Power grid complaints (B16) | [47,49] |

**Table 1.** *Cont.*

| Criteria | Sub-Criteria | References |
|---|---|---|
| Economy (Z2) | • Capital cost (B21) | [46,50,53] |
| | • O&M costs (B22) | [46,53] |
| | • Return on capital (B23) | [47,50] |
| | • Gross energy margin (GEM) (B24) | [47] |
| | • Average growth rate of selling electricity income (B25) | [47] |
| | • Market to market (B26) | |
| | • Earnings at risk (B27) | |
| Resources and technology (Z3) | • Resources and the allocation level (B31) | [46,51,52] |
| | • Installed capacity (B32) | [50,53,54] |
| | • Renewable energy installed ratio (B33) | [50] |
| | • Equipment utilization rate (B34) | [47] |
| | • Constructions of smart power plant (B35) | [46,55–58] |
| | • Technology maturity/innovation (B36) | [46,47,49,52,57] |
| | • Investment in desulfurization and denitrification units (B37) | [47] |
| Enterprise management (Z4) | • Corporate culture and business philosophy (B41) | [49,54] |
| | • The cognition and determination of top managers/executives (B42) | [49,54] |
| | • Compatibility of organizational structure and institution (B43) | [54,56] |
| | • Clear departmental rights and responsibilities of dispatching and trading(B44) | [54] |
| | • Talent structure and personnel capability suitable for the power market (B45) | [49] |
| | • Employee accidents (B46) | [47] |
| | • Platform or channel of learning and innovation for all staff (B47) | [46,47,49] |
| | • Incentive countermeasures (B48) | [46,49,59] |
| | • Risk management level (B49) | [46,47] |
| Market (Z5) | • Brand effect (B51) | [58] |
| | • Design of marketing trading mechanisms in target market (B52) | [53] |
| | • Analysis of potential competitors (B53) | [12,60] |
| | • Forecasting capability for supply, demand and price in the market (B54) | [46] |
| | • Price of electricity in market (B55) | [53] |
| | • Customers relationship management (B56) | |
| | • Pricing bidding strategy (B57) | [53] |

## 3. Methodology and Framework

### *3.1. Fuzzy Set Theory*

The fuzzy set theory, first introduced by Professor L.A. Zadeh [61], is a mathematical theory that uses precise numerical intervals to deal with complicated problems in real life. There are several types of fuzzy membership functions to describe some fuzzy concepts [48]. Usually, researchers use triangle fuzzy numbers (TFNs) [62] or trapezoidal fuzzy numbers (TrFNs) to solve the relative problems [63]. In this paper, considering the practical applications, we use TFNs in fuzzy logic to identify the key factors of sustainable development capabilities for TPGGs due to the ease of calculation and effectiveness at enhancing the information processing [64]. Moreover, the advantages of fuzzy set here are as follows: (a) it can handle ambiguity and uncertainty in the responses of expert surveys; (b) the efficiency of data collection is improved without many rounds; (c) we completely retain the judgments of decision makers and guarantee the authenticity of the results. However, there are certain limitations, for example, the application of fuzzy set theory will increase the complexity of computation, and the language level division may affect the accuracy of the evaluation results.

A fuzzy number with piecewise linear membership function $\mu_{\widetilde{a}}(u)$ can be defined [65]. Let $\widetilde{A}_1 = (a_1^L, a_1^M, a_1^R)$ and $\widetilde{A}_2 = (a_2^L, a_2^M, a_2^R)$ be TFNs; some basic operational principles in this paper are as follows:

$$\widetilde{A}_1 \oplus \widetilde{A}_2 = \left(a_1^L + a_2^L, a_1^M + a_2^M, a_1^R + a_2^R\right) \tag{1}$$

$$\widetilde{A}_1 ! \widetilde{A}_2 = \left(a_1^L - a_2^L, a_1^M - a_2^M, a_1^R - a_2^R\right). \tag{2}$$

In order to directly reflect the criteria, a graded mean integration representation (GMIR) approach is employed for removing the ambiguity of a TFN $\widetilde{A} = (a^L, a^M, a^R)$:

$$G(\widetilde{A}) = \frac{a^L + 4a^M + a^R)}{6}. \tag{3}$$

### *3.2. Fuzzy Delphi Method*

The Delphi method, put forward by Dalky and Helmer, is an essential specialist marking method with the merits of anonymous responses, controlled and iterative feedback, and statistical group responses. During a Delphi consensus process, experts are usually invited to take part in a Delphi survey to provide advice and revise previous opinions round by round. No consensus projects in the first round will be broken down into other issues, and it is possible to reach an agreement in a later round. The traditional Delphi method has been widely applied in ecotourism sustainability, economic projection, project evaluation, etc. However, it has some shortcomings in settling intangible decision information, such as high workload and executory costs, excessively long feedback time, low convergence rate, and misrepresentation of statements. Therefore, the fuzzy logic theory was applied into the Delphi method by Murry [66] to overcome those shortcomings of the traditional method. Using the fuzzy Delphi method, experts can pass their views through TFNs. Its benefits compared with the traditional method are as follows: (a) Fuzzy subjective judgments from experts can be thoroughly expounded with little misrepresentation. (b) Only one round of communication is needed to improve collection efficiency instead of multiple rounds of modifications. Moreover, it can screen a large number of indicators and lay a foundation for the analysis of fuzzy DEAMTEL. Hence, the fuzzy Delphi method is applicable to identifying crucial factors for sustainable development of TPGGs. The calculation procedures are followed:

**Step 1:** Make appropriate questionnaires to assess the significance of potential factors. Numerical intervals that stand for the importance of factors ranging from 0 to 10 should be indicated in the questionnaire. 0 and 10 indicate "extremely unimportant" and "extremely important," respectively. The maximum score interval denotes optimistic cognition, while the minimum is defined as pessimistic cognition. Experts give their opinions on the factors through these references.

**Step 2:** Collect the statistics from questionnaires, and then sort out the maximum and minimum values of all score intervals and calculate the geometric mean values for each factor. An optimistic TFN $O_j = (L_j^o, M_j^o, R_j^o)$ and a pessimistic TFN $P_j = (L_j^p, M_j^p, R_j^p)$ for criterion $j$ should be gathered, where $j = 1, 2, \ldots, N$. $L_j^o$ and $L_j^p$ are equivalent to the minimum values of experts' optimistic cognition and pessimistic cognition, respectively. $R_j^o$ and $R_j^p$ are equal to the maximum values of all experts' optimistic cognition and pessimistic cognition, respectively. $M_i^o$ and $M_i^p$ are the geometric mean values of all experts' optimistic cognition and pessimistic cognition, respectively.

**Step 3:** Check the consistency of experts' opinions. The consensus significance value $C_j$ for factor $i$ is computed to measure the consistent class of decision makers' comments on each factor. The larger the $C_j$ value is, the better the consistency. The processing can be performed by:

(1) If $L_j^o \geq R_j^p$, and factor $j$ satisfies a consensus, the $C_j$ value is:

$$C_j = \frac{M_j^o + M_j^p}{2}. \tag{4}$$

(2) If $L_j^o < R_j^p$, there should be a gray interval $T_j = R_j^p - L_j^o$ calculated via Equations (1) and (2).

(i) If $T_j$ is smaller than the interval $H_j = R_j^o - M_j^p$, the comments form a consensus.

$$C_j = \frac{M_j^o \times R_j^p - L_j^o \times M_j^p}{(R_j^p - M_j^p) + (M_j^o - L_j^o)} \tag{5}$$

(ii) If $T_j$ is greater than $H_j$, the comments on criterion $j$ do not reach consistency. New checking for factor $j$ should be performed by repeating steps 1 to 3 until all factors satisfy the consistency.

**Step 4:** Distinguish the significant criteria by setting a threshold $\theta$ compared by $C_j$ value. The $\theta$ value can be defined by the selected experts to denote a minimum level of acceptable consistency. If $C_j$ is lower than $\theta$, criterion $j$ will be removed from the evaluation index system, and the rest of the factors can form a final index system.

### *3.3. The Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL)*

The DEMATEL technique presumes that each criterion has influence on the other criteria of a system (or model), as is commonly observed in a social problem [67]. The causal relationships among factors can be structured with an impact-relation map (IRM). Suppose $n$ significant criteria are included in the final index system according to the fuzzy Delphi method. The fuzzy linguistic variables are classified into five grades, and TFNs for denoting the linguistic scale are shown in Table 2, based on Dalalah et al. [68].

**Table 2.** Corresponding relationship between linguistic variables and TFNs.

| Linguistic Variable | TFNs |
|---|---|
| Very high effects (VH) | (0.75,1,1) |
| High effects (H) | (0.5,0.75,1) |
| Low effects (L) | (0.25,0.5,0.75) |
| Very low effects (VL) | (0,0.25,0.5) |
| No effects (N) | (0,0,0.25) |

K selected experts give their comments with linguistic ratings on the pairwise criteria comparisons based on Table 2. Suppose $\tilde{a}_{ij}^k = (l_{ij}^k, m_{ij}^k, r_{ij}^k)$ denotes a TFN of the linguistic rating provided by expert $k$, $k = 1, 2, \ldots, K$, and $i, j = 1, 2, \ldots, n$. The TFN on the diagonal is $[0, 0, 0]$. A fuzzy matrix $\tilde{a}_K$ is demonstrated in Equation (10). The mathematical processing steps to identify the relationships of influencing factors are as follows:

$$\widetilde{a}_K = \left\{ \begin{array}{cccc} 0 & \widetilde{a}^k_{12} & \cdots & \widetilde{a}^k_{1n} \\ \widetilde{a}^k_{21} & 0 & \cdots & \widetilde{a}^k_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a}^k_{n1} & \widetilde{a}^k_{n2} & \cdots & 0 \end{array} \right\}_{n\times n} . \tag{6}$$

**Step 1:** Form an initial fuzzy matrix. A fuzzy initial direct-relation matrix can be obtained by Equation (7), and denoted as Equation (8).

$$\widetilde{A} = \frac{(\widetilde{a}_1 \oplus \widetilde{a}_2 \oplus \cdots \oplus \widetilde{a}_K)}{K} \tag{7}$$

$$\widetilde{A} = \left\{ \begin{array}{cccc} 0 & \widetilde{A}_{12} & \cdots & \widetilde{A}_{1n} \\ \widetilde{A}_{21} & 0 & \cdots & \widetilde{A}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{A}_{n1} & \widetilde{A}_{n2} & \cdots & 0 \end{array} \right\} \tag{8}$$

**Step 2:** Normalize $\widetilde{A}$ with a linear scale variation. Let $\widetilde{S}$ be a normalized direct relation matrix; TFN $\widetilde{S}_{ij} = (L^s_{ij}, M^s_{ij}, R^s_{ij})$ is an element in $\widetilde{S}$. By referring to Equations (9) and (10), a normalized matrix is obtained.

$$Q = MAX(\sum_{j=1}^{n} R_{ij}) \tag{9}$$

$$\widetilde{S} = \frac{1}{Q} \times \widetilde{A} \tag{10}$$

where $\widetilde{S}_{ij} = (L^s_{ij}, M^s_{ij}, R^s_{ij}) = (\frac{L_{ij}}{Q}, \frac{M_{ij}}{Q}, \frac{R_{ij}}{Q}), \exists i, MAX(\sum\limits_{j=1}^{n} R_{ij}) < Q$.

**Step 3:** Obtain the fuzzy total relation matrix $\widetilde{T}$, where $\widetilde{t}_{ij} = (L'_{ij}, M'_{ij}, R'_{ij})$.

$$\widetilde{T} = \left\{ \begin{array}{cccc} \widetilde{t}_{11} & \widetilde{t}_{12} & \cdots & \widetilde{t}_{1n} \\ \widetilde{t}_{21} & \widetilde{t}_{22} & \cdots & \widetilde{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{t}_{n1} & \widetilde{t}_{n2} & \cdots & \widetilde{t}_{nn} \end{array} \right\}, \tag{11}$$

where $\lim\limits_{\sigma\to\infty} \widetilde{S}^{\sigma} = [0]_{n\times n}$, $\widetilde{T}$ can be calculated as follows:

$$\widetilde{T} = \lim_{\sigma\to\infty} (\widetilde{S} + \widetilde{S}^2 + \cdots + \widetilde{S}^{\sigma}) = \widetilde{S}(I - \widetilde{S})^{-1}. \tag{12}$$

In order to attain $\widetilde{T}$ more easier, $\widetilde{S}$ is extracted into three precise matrices $S_L, S_M, S_R$, which are:

$$S_L = \begin{bmatrix} 0 & L^S_{12} & \cdots & L^S_{1n} \\ L^S_{21} & 0 & \cdots & L^S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ L^S_{n1} & L^S_{n2} & \cdots & 0 \end{bmatrix}, S_M = \begin{bmatrix} 0 & M^S_{12} & \cdots & M^S_{1n} \\ M^S_{21} & 0 & \cdots & M^S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ M^S_{n1} & M^S_{n2} & \ldots & 0 \end{bmatrix}, S_R = \begin{bmatrix} 0 & R^S_{12} & \cdots & R^S_{1n} \\ R^S_{21} & 0 & \cdots & R^S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ R^S_{n1} & R^S_{n2} & \cdots & 0 \end{bmatrix}. \tag{13}$$

So matrices $T_M$, $T_L$ and $T_R$ can be calculated as follows:

$$T_L = S_L(I - S_L)^{-1}, T_M = S_M(I - S_M)^{-1}, T_R = S_R(I - S_R)^{-1} \tag{14}$$

Similarly, matrix $\widetilde{T}$ can be obtained by integrating $T_M$, $T_L$, and $T_R$.

**Step 4:** Calculate the sum of rows and columns of $\widetilde{T}$ (vectors $d$ and $r$ denote row and column values, respectively), as follows:

$$d = (\widetilde{d}_i)_{n\times 1} = \left(\sum_{j=1}^{n} \widetilde{t}_{ij}\right)_{n\times 1} \tag{15}$$

$$r = (\widetilde{r}_j)_{1\times n} = \left(\sum_{i=1}^{n} \widetilde{t}_{ij}\right)_{1\times n}, \tag{16}$$

where $\widetilde{d}_i = (L_i^d, M_i^d, R_i^d)$ and $\widetilde{r}_j = (L_j^r, M_j^r, R_j^r)$.

**Step 5:** Compute $\widetilde{d}_i - \widetilde{r}_i$ and $\widetilde{d}_i + \widetilde{r}_i$ to confirm the performances of influencing factors. Generally, $\widetilde{d}_i - \widetilde{r}_i$ illustrates whether the factor is the cause or the result. $\widetilde{d}_i + \widetilde{r}_i$ reflects the factor's effect intension among criteria: the higher value it has, the greater the effect.

$$\widetilde{d}_i - \widetilde{r}_i = (L_i^d - L_i^r, M_i^d - M_i^r, R_i^d - R_i^r) \tag{17}$$

$$\widetilde{d}_i + \widetilde{r}_i = (L_i^d + L_i^r, M_i^d + M_i^r, R_i^d + R_i^r) \tag{18}$$

For accuracy comparison, GMIR method (Equation (3)) is employed to get a crisp value of $\widetilde{d}_i - \widetilde{r}_i$ and $\widetilde{d}_i + \widetilde{r}_i$. Let $U_i^*$ and $V_i^*$, respectively, denote these in the following equations:

$$U_i^* = \frac{(L_i^d - L_i^r) + 4(M_i^d - M_i^r) + (R_i^d - R_i^r)}{6} \tag{19}$$

$$V_i^* = \frac{(L_i^d + L_i^r) + 4(M_i^d + M_i^r) + (R_i^d + R_i^r)}{6}. \tag{20}$$

**Step 6:** Build a structural model for causal relationships. A cause-and-effect relationship diagram can be drawn by plotting a series of data pairs $(U_i^*, V_j^*)$. Then reasonable analyses are performed to extract important factors as the input for ANP model.

### *3.4. The DEMATEL-Based Analytic Network Process (ANP)*

A traditional MCDM method such as AHP is based on the assumption of independence. However, most problems in reality do not satisfy the independence condition [69]. When the merit of interrelated factors can be considered and analyzed within a system, ANP was developed [70]. ANP combines all possible results in the estimation of the relative influence of the different criteria from which the general priorities derive [71]. Here, ANP is used to obtain the preference of important factors screened by the fuzzy DEMATEL. The advantages of DEMATEL-based ANP are as follows: (a) the relationships between network layer and control layer are more reasonable based on the analyses of fuzzy Delphi and fuzzy DEMATEL; (b) it is not limited to sorting the elements in a hierarchy; (c) the process of dealing with the problem is more realistic. The disadvantages are: the scope of comparison is wider, and calculations are complex. Therefore, we use software to solve the complexity. However, a lot of time was spent entering the data from questionnaires.

The DEMATEL-based ANP methodology proposed is composed of the following steps:

**Step 1**: Collect experts' opinions from the questionnaires. The results of DEMATEL were taken as a reference and sent to two expert groups (academics and practitioners). All of them were invited to give their assessments of the comparison of the elements among clusters with comparison of influence degree and value [72].

**Step 2:** Compare the elements in pairs. Taking $B_j$ as the main criterion, with element $B_{jx}$ in $B_j$ as the sub-criteria, compare the influence degree of the $B_{jx}$ element on other elements. Calculate the normalized feature vector according to the AHP matrix operation, as shown in Table 3.

**Table 3.** Element comparison matrix and normalized vector.

| $B_{jx}$ | $B_{i1}B_{i2}\cdots B_{ini}$ | Normalized Eigenvector |
|---|---|---|
| $B_{i1}$<br>$B_{i2}$<br>$\vdots$<br>$B_{ini}$ | $B_i^{(jx)} = \begin{bmatrix} b_{i1,i1} & b_{i1,i2} & \cdots & b_{i1,ini} \\ b_{i2,i1} & b_{i2,i2} & \cdots & b_{i2,ini} \\ \vdots & \vdots & \ddots & \vdots \\ b_{ini,i1} & b_{ini,i2} & \cdots & b_{ini,ini} \end{bmatrix}$ | $W_{Bi}^{(jx)} = \begin{bmatrix} w_{i1}^{(jx)} \\ w_{i2}^{(jx)} \\ \vdots \\ w_{ini}^{(jx)} \end{bmatrix}$ |

**Step 3:** Consistency test. In general, consistency index (C.I.) and consistency ratio (C.R.) are applied to check the consistency. In order to simplify calculations and find the most inconsistent number, we use the "*Inconsistency*" function in "Super decision" [73]. There are three "Most inconsistent" options (with different algorithms); they can find the most inconsistent value in the current comparison matrix.

**Step 4:** Create an unweighted supermatrix and get the sort vector.

According to the above steps, compare the elements in the ANP model, and the unweighted supermatrix $W$ under the $Z_N$ criterion is obtained. The supermatrix is a non-negative matrix, and $W_{ij} = 0$ while the elements of the comparison are irrelevant.

Taking the cluster $B_N$ as a criterion, the cluster under $Z_N$ is compared in pairs. According to the above steps, a normalized sorting vector is obtained. Then, the weighting matrix $Y$ can be obtained, and the sorting vector component of the cluster unrelated to $B_j$ is zero.

**Step 5:** Obtain weighted super matrix and the limit super matrix.

A weighted super matrix can be obtained with the command "Computations→Weighted Super→Matrix Text." Moreover, the acquisition of a limit supermatrix can follow the same operations.

### *3.5. The Proposed Research Framework*

An identification model is proposed to recognize the structure of influencing factors for TPGG sustainability. Considerable factors should be chosen initially from the primary index system according to the fuzzy Delphi method. Then the causal relationships among these significant influencing factors are analyzed by the fuzzy DEMATEL method. Finally, the preferences of key factors are determined by the experts (both academics and practitioners) with ANP technique.

The framework of the integrated MCDM technique involves the following four phases, as shown in Figure 1.

Phase 1: *Establish the expert groups and collect the potential factors to establish the index system.*

Professors, scholars, governors, and enterprise managers in the fields of the electric power industry, the energy market, and sustainable development are selected to establish appropriate expert groups. All potential influencing factors are gathered and listed according to the extensive literature and reports, and then an initial criteria system is established.

Phase 2: *Recognize considerable factors based on the fuzzy Delphi method.*

First, a questionnaire about potential influencing factors is issued to the expert groups. Then the score intervals from experts are gathered to illustrate the significance of the factors. Next, the consensus significance values of each factors are calculated according to optimistic TFNs and pessimistic TFNs. Finally, significant factors are recognized by a threshold that is determined by the expert groups.

Phase 3: *Process a structure model for causal relationships and select key factors with fuzzy DEMATEL method.*

In order to receive the fuzzy ratings of comparisons, a questionnaire on the relationships between significant factors is distributed. Then the total relation fuzzy matrix is obtained according to the calculation and normalization of direct-relation fuzzy matrix. Based on the total relation fuzzy matrix, row values $d$, column value $r$, $\widetilde{d}_i - \widetilde{r}_i$ and $\widetilde{d}_i + \widetilde{r}_i$, are calculated and dufuzzified. Finally, a structural model of TPGG sustainability influencing factors is established with two dimensional criteria and key factors determined based on the deep analyses.

Phase 4: *Build the relationships map and determine the final preference of key influencing factors.*

In this step, a relationships map is drawn based on the analysis results of fuzzy DEMATEL. In order to obtain pairwise comparisons, a questionnaire on the relationships between key factors is issued to two groups, the academic group and the practitioners group, respectively. Then a pairwise comparison matrix was established in the SuperDecision and a consistency test was performed. Finally, a limit supermatrix was built and the final preference of key factors was obtained based on their weights.

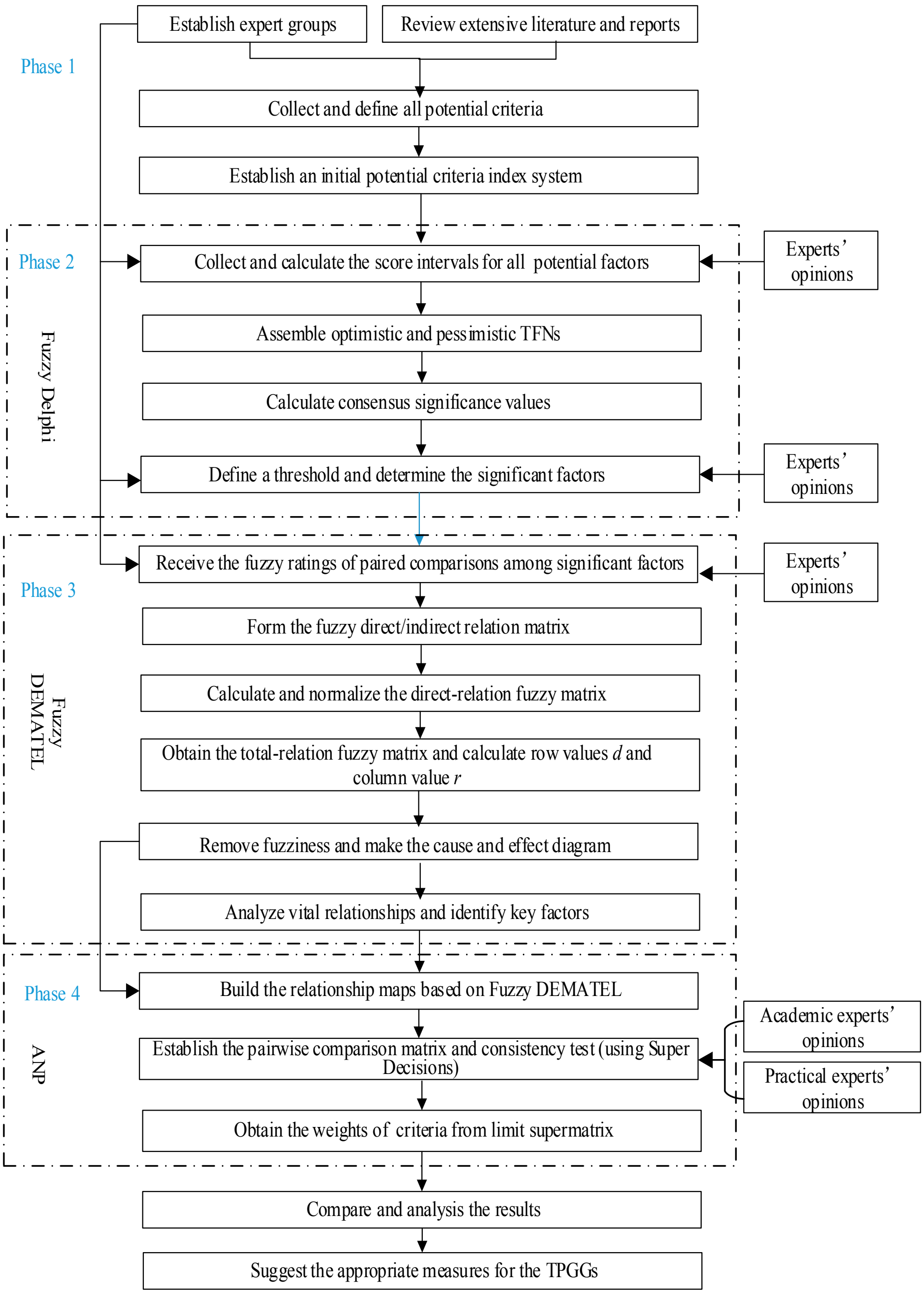



**Figure 1.** A fuzzy Delphi and DEMATEL-based ANP based flowchart of TPGG sustainability influencing factors analysis.

## 4. Research Results and Analysis

### *4.1. Introduction of Expert Groups and Data Collection*

In order to ensure the specialty to solve the problem, the linguistic preference ratings about relations and significances between criteria should be credible. Powerful and professional expert groups can guarantee the credibility and accuracy of the related data and research results. During the decision-making process, opinions from all the representatives are integrated after gathering different viewpoints from a series of communication meetings. The experts are from different organizations. They are government officials for the electricity market reform, executives of different types of TPGGs in China, a power generation group's senior manager with 20 years' experience in European Energy Markets, short-term assets optimization experts in European power companies, as well as researchers for enterprise management and the electricity market. These respondents were divided into five groups; detailed information is given in Table 4.

**Table 4.** The attributes of the five expert groups.

| Number | Educational Level | Experience | Gender | | Age Range | Affiliation |
|---|---|---|---|---|---|---|
| | | | Male | Female | | |
| Expert group 1 | Master's or above | ≥6 | 2 | 2 | 34–60 | Government departments |
| Expert group 2 | Master's or above | ≥8 | 2 | 2 | 33–56 | Traditional power generation groups |
| Expert group 3 | Bachelor's or above | ≥8 | 3 | 1 | 32–58 | Mature power groups abroad |
| Expert group 4 | Doctorate | ≥16 | 2 | 2 | 42–56 | Universities |
| Expert group 5 | Bachelor's or above | ≥8 | 3 | 1 | 45–54 | Enterprises |

The interview was chaired by a member of our research team each time, who is responsible for expressing the indicators when experts had doubts. Experts from five groups expressed the importance of influencing factors for TPGGs' sustainable development in the electricity market in the first place. Based on the rule of "the minority is subordinate to the dominant" [74], the threshold value for the fuzzy Delphi method is determined by the majority. Then the relationships between each pair of influencing factors given by the experts were gathered according to Table 2. The complex arithmetic for these relationships was performed by our research team using the modified methodology. The data collection schedule is shown in Figure 2.

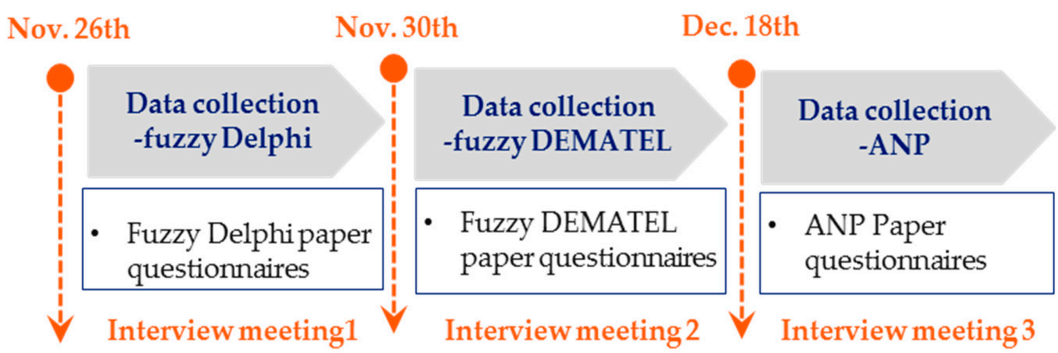



**Figure 2.** Schedule of data collection.

### 4.2. Establish the Primary Index System

In order to effectively identify the core factors influencing the sustainable development of TPGGs, the rationality and veracity of evaluation indicators should be ensured. To comprehensively reflect the sustainable development capability of TPGGs, five aspects of a sustainability perspective are integrated into the evaluation system, including society and environment (Z1), economy (Z2), resources and technology (Z3), enterprise management (Z4), and market (Z5). Based on a large number of studies and reports, sub-criteria are selected and a primary evaluation system with potential factors was built. Finally, all criteria were determined by the expert groups according to the current policy environment, the structure of the electricity market, and the current situation of TPGGs in China. The primary evaluation index system was established as described in Table 5.

**Table 5.** Potential influencing factors of sustainable development capability for TPGGs.

| Criteria | Sub-Criteria | Description |
| --- | --- | --- |
| Society and environment (Z1) | • Electricity market exposure (B11) | Requirements for the TPGGs to adapt to the market environment vary from different degree of electricity market openness. |
| | • Renovation of electric power law and enforcement of government documents of power industry reform [70] (B12) | Relative laws can support reform policies, which can directly affect the effectives of the power industry reform and the motivation to transform for power enterprises. For example, the "No. 9 Document" and its supporting documents. |
| | • Reliability of power supply (B13) | The ability of continuous power supply, including average power outage time, average number of power outages and equivalent hours, which indicates the dependability and stability of power generation. |
| | • Package design of preferential electricity price for consumers (B14) | Can provide personalized service to users based on user data, such as payment scheme of electricity, energy consumption analysis. |
| | • Pollutant emission (B15) | The pollution that TPGGs causes, such as NOx, fly ash, sulfur dioxide, and industrial soot. |
| | • Power grid complaints (B16) | It represents the satisfaction of power grid enterprises, and is also a manifestation of the quality of power service provided by power generation enterprises. |
| Economy (Z2) | • Capital cost (B21) | Capital costs consists of land cost, necessary equipment for the operation of an enterprise. |
| | • O&M costs (B22) | The operation and maintenance fee in generation. |
| | • Return on capital (B23) | Reflexes earning ability of TPGGs. |
| | • Gross energy margin (GEM) (B24) | It is to measure the value of an asset portfolio, which is the sum of the discounted cash flows on the energy market over a specified period (revenue of sales – costs of purchase). |
| | • Average growth rate of selling electricity income (B25) | Increased value of electricity sale income of power generation enterprises over the last year. It reflects the marketing ability and competitiveness of power generation enterprises to a certain extent |
| | • Market to market (B26) | A financial indicator that measures the sum of the discounted unrealized cash flows on the energy market over a specified period. |
| | • Earnings at risk (B27) | It is a financial indicator related to risks, which represents the maximum potential loss on the GEM until maturity with a given probability due to the impact of energy market risks (namely price & volume). In an initial market, investment portfolios, market environment and so on will add the uncertainties in profitability, which can influence the sustainable operation of TPGG. |

**Table 5.** *Cont.*

| Criteria | Sub-Criteria | Description |
| --- | --- | --- |
| Resources, and technology (Z3) | • Resources and the allocation level (B31) | Including capital, generator units, customer resources, brand image and the platform for large-scale deployment of resources. |
| | • Installed capacity (B32) | Refers to the total amount of power generation potential of a unit's produce ability when operated at full capacity, which is closely connected to power generation technology [75]. |
| | • Renewable energy installed ratio (B33) | Reflects the cleaning energy produce capability. |
| | • Equipment utilization rate (B34) | The ratio of the actual utilization hours of a generator set to the planned utilization hours. It is the technical and economic index that reflects equipment working state and production efficiency. |
| | • Constructions of smart power plant (B35) | Advanced and specialized IT applications such as Assistant Decision-Making System, ERP, CRM as well as big data and cloud computing are conduits for enterprises to strengthen the energy trading management. |
| | • Technology maturity/innovation (B36) | Technics for power asset portfolio optimization, development of risk management tools, information safety, forecasting method, energy management optimization [76] and so on. |
| | • Investment in desulfurization and denitrification units (B37) | The environment affects the development of enterprises, and investment in green technology can increase the competitiveness [47], such as the investment in desulfurization equipment of coal-fired unit [77,78], upgrade to the cleaner production. |
| Enterprise management (Z4) | • Corporate culture and business philosophy (B41) | Corporate culture and business philosophy such as market oriented, responsive, inclusive, open, innovative, those are essential to a group in the market competition. |
| | • The cognition and determination of top managers/executives (B42) | Only when senior managers recognize the opportunities brought by market and have the determination can the transformation in group be implemented. |
| | • Compatibility of organizational structure and institution (B43) | Traditional organization structure doesn't match the new rules in the market environment |
| | • Clear departmental rights and responsibilities of dispatching and trading (B44) | The practice of mature power group abroad shows that clear demarcation of department rights and duties is the basis of ensuring good operation of the organization. |
| | • Talent structure and personnel capability suitable for the power market (B45) | The competition between enterprises is the talent competition, talent reserve and training, talents with proficiency of mathematics, electricity market, financial, technology and economics are critical for TPGGs' development. |
| | • Employee accidents (B46) | It means accidents and injuries in the workplace. Employee accidents could have a huge effect on corporate business, such as reduced productivity, lost sales, lower staff morale, or even closure. |
| | • Platform or channel of learning and innovation for all staff (B47) | Build a physical and virtual platform for joint client-staff learning, knowledge sharing and innovation can enhance the collective capacity to accelerate the transformation in the reform. |
| | • Incentive countermeasures (B48) | An important part of human resources management, and it's the factors that can stimulate employees' behavior and arouse their enthusiasm for work [54]. |
| | • Risk management level (B49) | Compared with power generation enterprises in a mature market, marketing experience of TPGG is less. The power generation-centric business chain structure is not suitable for the market-oriented business environment. Challenges on financial risks, policy risks, technological risks are huge and complex. It includes the capability to minimize group budget volatility caused by uncertainties in the electricity market, and to minimize group financial performance changes due to fluctuations in fuel futures prices between consecutive group budgeting cycles. |

**Table 5.** *Cont.*

| Criteria | Sub-Criteria | Description |
| --- | --- | --- |
| Market (Z5) | • Brand effect (B51) | Power generation enterprises with strong brand effect can attract users more, thus increasing sales revenue in the market environment. |
| | • Design of marketing trading mechanisms in target market (B52) | Due to the actual situation of electricity market construction in China, different mechanisms will directly affect the decision-making of power groups. |
| | • Analysis of potential competitors (B53) | It may help an enterprise to mitigate its sustainability risks [12] to consider competitors' performance in addition to attribute importance because of the open system characteristics of companies and the intense competition in the marketplace [60]. |
| | • Forecasting capability for supply, demand and price in the market (B54) | Capability of forecasting is the basic for enterprise in the market environment, including medium-and long-term forecasts and short-term forecasts. |
| | • Price of electricity in market (B55) | Market price is very important for power generation companies, which directly affects their income, profit and later decision. |
| | • Customers relationship management (B56) | Consumer resource will be an important possession for power group in the electricity market, especially in the retail market. It needs good management to maintain. |
| | • Pricing bidding strategy (B57) | In order to obtain the maximum profit, the enterprise will adjust its quotation strategy according to the market situation, which will affect the market price and their profits. |

*4.3. Identify the Significant Influencing Factors*

The fuzzy Delphi method was first used to identify the significant factors within the indicators listed. All comments on the sub-criteria's relative importance given by the expert groups were expressed by interval numbers. Data were collected and aggregated after the survey; the results are shown in Table 6.

**Table 6.** Relative important degree of sub-criteria.

| Potential Criteria | | Expert Group 1 | | Expert Group 2 | | Expert Group 3 | | Expert Group 4 | | Expert Group 5 | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Main Criteria | Sub-Criteria | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| Society and environment (Z1) | B11 | 6 | 9 | 6 | 8 | 7 | 9 | 8 | 10 | 6 | 9 |
| | B12 | 7 | 9 | 4 | 7 | 5 | 6 | 3 | 5 | 2 | 5 |
| | B13 | 7 | 10 | 8 | 9 | 7 | 9 | 6 | 9 | 8 | 10 |
| | B14 | 7 | 8 | 8 | 9 | 7 | 8 | 4 | 6 | 5 | 7 |
| | B15 | 6 | 7 | 5 | 7 | 5 | 6 | 6 | 7 | 4 | 6 |
| | B16 | 3 | 6 | 4 | 5 | 5 | 8 | 4 | 8 | 5 | 7 |
| Economy (Z2) | B21 | 2 | 5 | 3 | 7 | 4 | 6 | 5 | 6 | 6 | 7 |
| | B22 | 3 | 5 | 2 | 5 | 5 | 7 | 5 | 8 | 3 | 5 |
| | B23 | 7 | 9 | 6 | 7 | 6 | 8 | 7 | 9 | 5 | 7 |
| | B24 | 5 | 8 | 7 | 9 | 6 | 8 | 4 | 7 | 5 | 6 |
| | B25 | 4 | 6 | 5 | 6 | 6 | 8 | 5 | 6 | 5 | 6 |
| | B26 | 5 | 7 | 4 | 7 | 6 | 8 | 7 | 8 | 6 | 9 |
| | B27 | 5 | 6 | 4 | 7 | 7 | 9 | 5 | 6 | 6 | 7 |
| Resources and technology (Z3) | B31 | 6 | 9 | 5 | 7 | 5 | 7 | 4 | 7 | 4 | 8 |
| | B32 | 2 | 4 | 4 | 5 | 3 | 6 | 5 | 7 | 2 | 5 |
| | B33 | 6 | 8 | 7 | 9 | 5 | 8 | 6 | 9 | 6 | 9 |
| | B34 | 2 | 4 | 2 | 3 | 3 | 5 | 3 | 6 | 2 | 4 |
| | B35 | 5 | 7 | 6 | 8 | 6 | 8 | 6 | 8 | 5 | 8 |
| | B36 | 6 | 8 | 5 | 8 | 7 | 9 | 6 | 8 | 7 | 8 |
| | B37 | 5 | 6 | 4 | 6 | 5 | 7 | 5 | 6 | 5 | 9 |

**Table 6.** *Cont.*

| Potential Criteria | | Expert Group 1 | | Expert Group 2 | | Expert Group 3 | | Expert Group 4 | | Expert Group 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Main Criteria** | **Sub-Criteria** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** | **Min** | **Max** |
| Enterprise management (Z4) | B41 | 5 | 6 | 6 | 8 | 7 | 9 | 4 | 6 | 5 | 8 |
| | B42 | 7 | 9 | 5 | 8 | 6 | 9 | 4 | 7 | 5 | 7 |
| | B43 | 5 | 6 | 4 | 6 | 6 | 8 | 4 | 6 | 5 | 6 |
| | B44 | 4 | 6 | 4 | 7 | 6 | 7 | 6 | 8 | 6 | 8 |
| | B45 | 5 | 7 | 5 | 7 | 6 | 7 | 6 | 8 | 5 | 7 |
| | B46 | 1 | 4 | 3 | 5 | 2 | 5 | 2 | 5 | 4 | 7 |
| | B47 | 4 | 5 | 3 | 5 | 5 | 6 | 6 | 7 | 5 | 7 |
| | B48 | 3 | 4 | 5 | 7 | 5 | 8 | 6 | 7 | 6 | 8 |
| | B49 | 6 | 8 | 5 | 8 | 7 | 10 | 6 | 9 | 7 | 10 |
| Market (Z5) | B51 | 6 | 8 | 7 | 8 | 7 | 9 | 7 | 9 | 7 | 8 |
| | B52 | 6 | 9 | 7 | 9 | 4 | 6 | 4 | 5 | 3 | 6 |
| | B53 | 4 | 6 | 6 | 7 | 7 | 9 | 6 | 9 | 7 | 10 |
| | B54 | 7 | 10 | 7 | 10 | 7 | 10 | 7 | 9 | 8 | 10 |
| | B55 | 5 | 8 | 6 | 9 | 6 | 8 | 7 | 8 | 6 | 9 |
| | B56 | 3 | 6 | 4 | 5 | 5 | 7 | 5 | 6 | 7 | 9 |
| | B57 | 6 | 9 | 7 | 9 | 7 | 10 | 8 | 9 | 7 | 9 |

Conservation and optimistic comments in terms of the score intervals above were integrated into pessimistic TFNs and optimistic TFNs. Then the consistency of each expert group's opinions was tested by step 3 of the Fuzzy Delphi Method introduction. Finally, the significant influencing factors are determined according to consensus value $C_j$, which is calculated by Equations (4) and (5). Moreover, the threshold value θ was set to 6.0, as determined by the expert groups. Therefore, the significant influencing factors marked with $\surd$ in Table 7 are selected based on the Fuzzy Delphi Method. Calculation results are shown in Table 7. The final index system is established as shown in Figure 3.

**Table 7.** Calculation results of significant influencing factors based on the fuzzy Delphi method.

| Potential Factors | | Pessimistic TFNs | | | Optimistic TFNs | | | $H_j - T_j$ | Consensus Value | Results |
|---|---|---|---|---|---|---|---|---|---|---|
| **Main Criteria** | **Sub-Criteria** | $L_j^p$ | $M_j^p$ | $R_j^p$ | $L_j^o$ | $M_j^o$ | $R_j^o$ | | $C_j$ | |
| Society and environment (Z1) | B11 | 6 | 6.55 | 8 | 8 | 8.98 | 10 | 3.45 | 7.77 | √ |
| | B12 | 2 | 3.84 | 7 | 5 | 6.24 | 9 | 3.16 | 5.56 | |
| | B13 | 6 | 7.16 | 8 | 9 | 9.39 | 10 | 3.84 | 8.28 | √ |
| | B14 | 4 | 6.01 | 8 | 6 | 7.53 | 9 | 0.99 | 6.87 | √ |
| | B15 | 4 | 5.14 | 6 | 6 | 6.58 | 7 | 1.86 | 5.86 | |
| | B16 | 3 | 4.13 | 5 | 5 | 6.69 | 8 | 3.87 | 5.41 | |
| Economy (Z2) | B21 | 2 | 3.73 | 6 | 5 | 6.15 | 7 | 2.27 | 5.34 | |
| | B22 | 2 | 3.39 | 5 | 5 | 5.88 | 8 | 4.61 | 4.64 | |
| | B23 | 5 | 6.15 | 7 | 7 | 7.95 | 9 | 2.85 | 7.05 | √ |
| | B24 | 4 | 5.3 | 7 | 6 | 7.53 | 9 | 2.7 | 6.47 | √ |
| | B25 | 4 | 4.96 | 6 | 6 | 6.36 | 8 | 3.04 | 5.66 | |
| | B26 | 4 | 5.5 | 7 | 7 | 7.76 | 9 | 3.5 | 6.63 | √ |
| | B27 | 4 | 5.3 | 7 | 6 | 6.92 | 9 | 2.7 | 6.35 | √ |
| Resources and technology (Z3) | B31 | 4 | 4.74 | 6 | 7 | 7.56 | 9 | 5.26 | 6.15 | √ |
| | B32 | 2 | 2.99 | 5 | 4 | 5.3 | 7 | 3.01 | 4.39 | |
| | B33 | 5 | 5.97 | 7 | 8 | 8.59 | 9 | 4.03 | 7.28 | √ |
| | B34 | 2 | 2.35 | 3 | 3 | 4.28 | 6 | 3.65 | 3.32 | |
| | B35 | 5 | 5.58 | 6 | 7 | 7.79 | 8 | 3.42 | 6.69 | √ |
| | B36 | 5 | 6.15 | 7 | 8 | 8.19 | 9 | 3.85 | 7.17 | √ |
| | B37 | 4 | 4.78 | 5 | 6 | 6.71 | 9 | 5.22 | 5.75 | |

**Table 7.** *Cont.*

| Potential Factors | | Pessimistic TFNs | | | Optimistic TFNs | | | $H_j - T_j$ | Consensus Value | Results |
|---|---|---|---|---|---|---|---|---|---|---|
| Main Criteria | Sub-Criteria | $L_j^p$ | $M_j^p$ | $R_j^p$ | $L_j^o$ | $M_j^o$ | $R_j^o$ | | $C_j$ | |
| Enterprise management (Z4) | B41 | 4 | 5.3 | 7 | 6 | 7.3 | 9 | 2.7 | 6.43 | √ |
| | B42 | 4 | 5.3 | 7 | 7 | 7.95 | 9 | 3.7 | 6.63 | √ |
| | B43 | 4 | 4.74 | 6 | 6 | 6.36 | 8 | 3.26 | 5.55 | |
| | B44 | 4 | 5.1 | 6 | 6 | 7.16 | 8 | 2.9 | 6.13 | √ |
| | B45 | 5 | 5.38 | 6 | 7 | 7.19 | 8 | 3.62 | 6.29 | √ |
| | B46 | 1 | 2.17 | 4 | 4 | 5.11 | 7 | 4.83 | 3.64 | |
| | B47 | 3 | 4.48 | 6 | 5 | 5.93 | 7 | 1.52 | 5.38 | |
| | B48 | 3 | 4.86 | 6 | 4 | 6.6 | 8 | 1.14 | 5.39 | |
| | B49 | 5 | 6.15 | 7 | 8 | 8.96 | 10 | 4.85 | 7.56 | √ |
| Market (Z5) | B51 | 6 | 6.79 | 7 | 8 | 8.39 | 9 | 3.21 | 7.59 | √ |
| | B52 | 3 | 4.58 | 7 | 5 | 6.8 | 9 | 2.42 | 5.85 | |
| | B53 | 4 | 5.88 | 7 | 6 | 8.06 | 10 | 3.12 | 6.65 | √ |
| | B54 | 7 | 7.19 | 8 | 9 | 9.79 | 10 | 3.81 | 8.49 | √ |
| | B55 | 5 | 5.97 | 7 | 8 | 8.39 | 9 | 4.03 | 7.18 | √ |
| | B56 | 3 | 4.62 | 7 | 5 | 6.47 | 9 | 2.38 | 5.76 | |
| | B57 | 6 | 6.97 | 8 | 9 | 9.19 | 10 | 4.03 | 8.08 | √ |

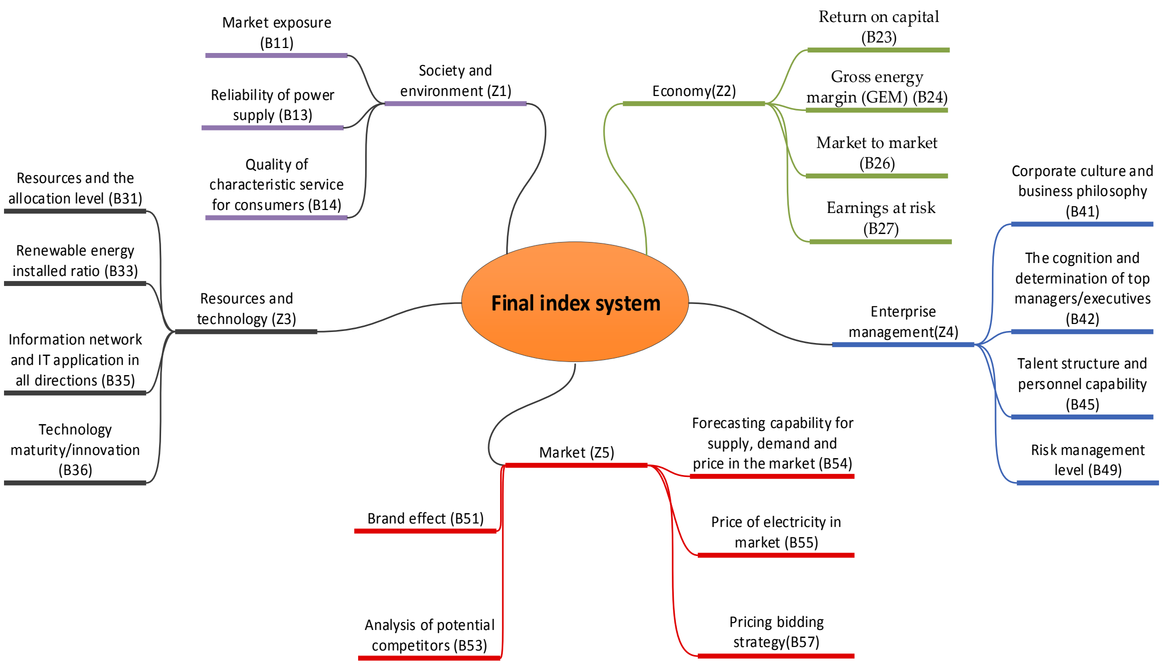



**Figure 3.** The final index system of identifying the key influencing factors for TPGGs' sustainability.

### *4.4. Establish the Structural Model for Causal Relationships*

The inner causal relationships of five dimensions, that is, Society and environment (Z1), Economy (Z2), Resources and Technology (Z3), Enterprise management (Z4), and Market (Z5), and all sub-criteria belonging to each dimension were explained based on the Fuzzy DEMATEL method. Take the computational procedure of main criteria as the example. First, the opinions with fuzzy ratings of criteria were given by experts according to Table 2.

Secondly, the linguistic ratings were gathered and the initial integrated direct causal relationships fuzzy matrix were obtained based on Equation (7). Then, we normalized the fuzzy matrix according to Equations (9) and (10). The initial and normalized fuzzy directed-relation matrix among main criteria is shown in Tables 8 and 9.

**Table 8.** The initial directed-relation matrix among main criteria.

| Main Criteria | Z1 | Z2 | Z3 | Z4 | Z5 |
|---|---|---|---|---|---|
| Z1 | (0,0,0) | (0.6,0.85,0.95) | (0.15,0.4,0.65) | (0.4,0.65,0.85) | (0.6,0.85,1) |
| Z2 | (0,0.05,0.3) | (0,0,0) | (0.6,0.85,1) | (0,0.05,0.3) | (0,0,0.25) |
| Z3 | (0.5,0.75,0.95) | (0.55,0.8,1) | (0,0,0) | (0.3,0.5,0.75) | (0.5,0.75,0.9) |
| Z4 | (0.05,0.2,0.45) | (0.5,0.75,1) | (0.15,0.35,0.6) | (0,0,0) | (0.4,0.65,0.9) |
| Z5 | (0.15,0.35,0.6) | (0.75,1,1) | (0.05,0.2,0.45) | (0.6,0.85,1) | (0,0,0) |

**Table 9.** The normalized directed-relation matrix among main criteria.

| Main Criteria | Z1 | Z2 | Z3 | Z4 | Z5 |
|---|---|---|---|---|---|
| Z1 | (0,0,0) | (0.152,0.215,0.241) | (0.038,0.101,0.165) | (0.101,0.165,0.215) | (0.152,0.215,0.253) |
| Z2 | (0,0.013,0.076) | (0,0,0) | (0.152,0.215,0.253) | (0,0.013,0.076) | (0,0,0.063) |
| Z3 | (0.127,0.19,0.241) | (0.139,0.203,0.253) | (0,0,0) | (0.076,0.127,0.19) | (0.127,0.19,0.228) |
| Z4 | (0.013,0.051,0.114) | (0.127,0.19,0.253) | (0.038,0.089,0.152) | (0,0,0) | (0.101,0.165,0.228) |
| Z5 | (0.038,0.089,0.152) | (0.19,0.253,0.253) | (0.013,0.051,0.114) | (0.152,0.215,0.253) | (0,0,0) |

Thirdly, based on Equations (11)–(14), the fuzzy total-relation matrix is acquired, as shown in Table 10.

**Table 10.** Fuzzy total-relation matrix among main criteria.

| Main Criteria | Z1 | Z2 | Z3 | Z4 | Z5 |
|---|---|---|---|---|---|
| Z1 | (0.019,0.096,0.394) | (0.217,0.423,0.836) | (0.079,0.244,0.621) | (0.136,0.288,0.657) | (0.179,0.33,0.697) |
| Z2 | (0.021,0.073,0.324) | (0.032,0.101,0.39) | (0.159,0.255,0.502) | (0.018,0.075,0.364) | (0.025,0.077,0.367) |
| Z3 | (0.141,0.268,0.61) | (0.213,0.425,0.872) | (0.044,0.158,0.502) | (0.119,0.266,0.66) | (0.166,0.322,0.702) |
| Z4 | (0.026,0.119,0.442) | (0.166,0.336,0.755) | (0.067,0.195,0.547) | (0.025,0.101,0.41) | (0.116,0.244,0.606) |
| Z5 | (0.049,0.155,0.475) | (0.232,0.41,0.769) | (0.057,0.187,0.531) | (0.166,0.295,0.624) | (0.031,0.118,0.432) |

Based on the former steps, the sum of row and column values, marked as d and r, respectively, were calculated by Equations (15) and (16). These were then transformed into crisp values according to Equations (19) and (20). A crisp value of $\widetilde{d}_i - \widetilde{r}_i$ represents the ability to affect the other criteria. The value is positive, indicating that the criterion is the cause of the other criteria. If the value is negative, it denotes that the criterion tends to be affected by others. A crisp value of $\widetilde{d}_i + \widetilde{r}_i$ reflects the correlation intensity of effects among criteria. The higher the $\widetilde{d}_i + \widetilde{r}_i$ crisp value is, the more important the criterion is. Both calculation results of main criteria and sub-criteria were performed by the above process, as shown in Tables 11 and 12.

**Table 11.** The values of $\widetilde{d}_i + \widetilde{r}_i$, $\widetilde{d}_i - \widetilde{r}_i$, $U_i^*$ and $V_i^*$ for the main criteria.

| Main Criteria | $\widetilde{d}_i+\widetilde{r}_i$ | $\widetilde{d}_i-\widetilde{r}_i$ | $V_i^*$ | $U_i^*$ |
|---|---|---|---|---|
| Z1 | (0.886,2.092,5.45) | (0.374,0.67,0.96) | 2.45 | 0.669 |
| Z2 | (1.151,2.276,5.569) | (−0.605,−1.114,−1.675) | 2.631 | −1.123 |
| Z3 | (1.089,2.478,6.049) | (0.277,0.4,0.643) | 2.842 | 0.42 |
| Z4 | (0.864,2.02,5.475) | (−0.064,−0.03,0.045) | 2.403 | −0.0232 |
| Z5 | (0.566,1.283,3.263) | (0.504,1.047,2.399) | 1.494 | 1.182 |

**Table 12.** The values of $\widetilde{d}_i + \widetilde{r}_i$, $\widetilde{d}_i - \widetilde{r}_i$, $U_i^*$ and $V_i^*$ for the sub-criteria.

| Main Criteria | Sub-Criteria | $\widetilde{d}_i+\widetilde{r}_i$ | $\widetilde{d}_i-\widetilde{r}_i$ | $V_i^*$ | $U_i^*$ |
|---|---|---|---|---|---|
| Z1 | B11 | (0.33,0.845,2.185) | (0.33,0.845,0.895) | 0.983 | 0.768 |
| | B13 | (0.487,0.878,2.19) | (0.324,0.203,0.274) | 1.032 | 0.235 |
| | B14 | (0.655,1.047,2.459) | (−0.655,−1.047,−1.169) | 1.217 | −1.002 |

**Table 12.** *Cont.*

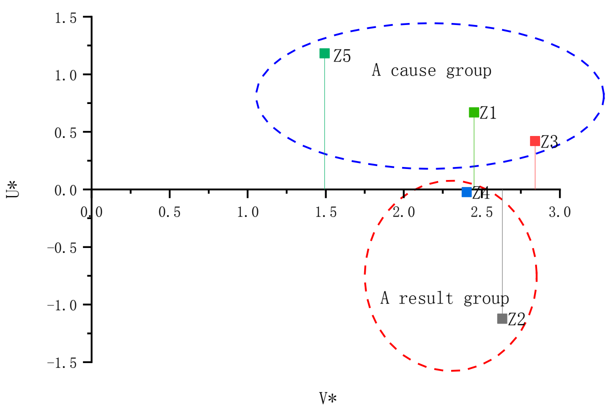
| Main Criteria | Sub-Criteria | $\widetilde{d}_i+\widetilde{r}_i$ | $\widetilde{d}_i-\widetilde{r}_i$ | $V_i^*$ | $U_i^*$ |
|---|---|---|---|---|---|
| Z2 | B23 | (0.373,1.111,9.525) | (−0.195,−0.217,−0.713) | 2.39 | −0.296 |
| | B24 | (0.57,1.527,10.158) | (−0.142,−0.013,0.12) | 2.806 | −0.012 |
| | B26 | (0.262,0.882,8.813) | (0.18,0.14,0.449) | 2.101 | 0.198 |
| | B27 | (0.768,2,11.787) | (0.158,0.09,0.145) | 3.426 | 0.111 |
| Z3 | B31 | (0.777,1.851,6.9) | (−0.228,−0.436,−0.909) | 2.514 | −0.48 |
| | B33 | (0.443,1.212,5.62) | (0.247,0.653,1.33) | 1.819 | 0.698 |
| | B35 | (0.916,2.016,6.797) | (−0.153,−0.398,−0.92) | 2.63 | −0.444 |
| | B36 | (0.914,1.969,6.681) | (0.135,0.181,0.499) | 2.579 | 0.226 |
| Z4 | B41 | (0.586,1.15,2.89) | (0.056,0.244,0.418) | 1.346 | 0.242 |
| | B42 | (0.757,1.381,3.175) | (0.098,0.209,0.307) | 1.576 | 0.207 |
| | B44 | (0.415,0.8,2.395) | (0.083,0.101,0.113) | 1.001 | 0.1 |
| | B45 | (0.392,0.788,2.40) | (−0.233,−0.413,−0.582) | 1.0 | −0.411 |
| | B49 | (0.439,0.913,2.51) | (−0.005,−0.141,−0.257) | 1.1 | −0.137 |
| Z5 | B51 | (0.423,0.889,4.397) | (−0.423,−0.889,−1.894) | 1.396 | −0.979 |
| | B53 | (0.48,1.089,4.903) | (0.052,0.191,0.453) | 1.623 | 0.211 |
| | B54 | (0.854,1.714,6.039) | (0.152,0.309,0.659) | 2.291 | 0.341 |
| | B55 | (0.875,1.875,6.467) | (0.22,0.389,0.783) | 2.474 | 0.426 |
| | B57 | (1.263,2.311,7.198) | (−0.127,−0.388,−1.467) | 2.951 | −0.524 |

For finding the basic factors, first, all total-relation fuzzy matrices should be transformed into crisp total-relation matrices with blurring numbers according to Equation (3), as shown in Table 13. Then take the means of all numbers in matrices as the threshold to identify the significant interrelationships. In order to reflect the causal relationship intuitively, cause and effect diagrams for the main criteria and sub-criteria were drawn according to the crisp total relation matrix, in which significant interrelationships are identified by asterisks (*). The cause and effect diagram with respect to main criteria is shown in Figure 4. Figure 4a represents the causal-result diagram, and Figure 4b shows the significant interrelationships among main criteria. Similarly, the cause and effect diagram and significant interrelationships among sub-criteria for each dimension are presented in Figures 5–9.

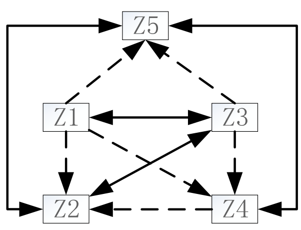
**Table 13.** The crisp total-relation matrix for main criteria.

| Main Criteria | Z1 | Z2 | Z3 | Z4 | Z5 |
|---|---|---|---|---|---|
| Z1 | 0.133 | 0.458 * | 0.279 * | 0.324 * | 0.366 * |
| Z2 | 0.106 | 0.138 | 0.28 * | 0.114 | 0.117 |
| Z3 | 0.304 * | 0.464 * | 0.196 | 0.307 * | 0.359 * |
| Z4 | 0.157 | 0.378 * | 0.232 | 0.14 | 0.283 * |
| Z5 | 0.191 | 0.44 * | 0.223 | 0.328 * | 0.156 |

* Higher than the threshold of 0.259.



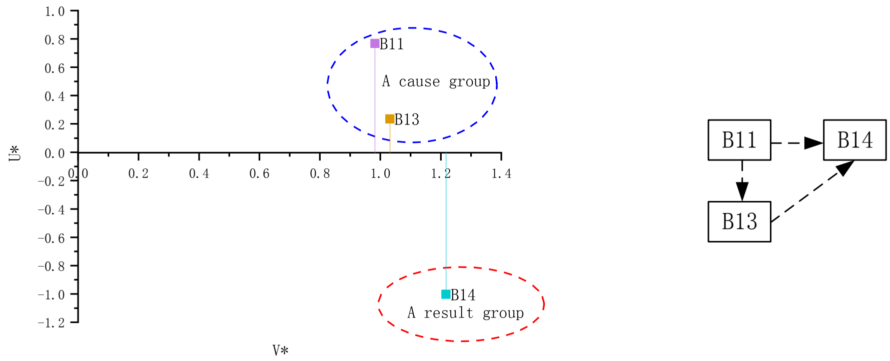

**(a)**




**(b)**

**Figure 4.** Cause and effect diagram with respect to main criteria. (**a**) The causal-results diagram and (**b**) significant interrelationships among main criteria.

As shown in Figure 4a, the dimension with the highest value of $U^*$ is "Market (Z5)," indicating that it is a significant cause of other dimensions. "Economy (Z2)" and "Enterprise management (Z4)" are affected by the others easily, so they are the "result" factors. In addition, "Resources and technology (Z3)" possess the most important correlation intensity due to the highest value of $V^*$, and should be given more attention.




(**a**) (**b**)

**Figure 5.** Cause and effect diagram for Society and environment (Z1). (**a**) The causal-results diagram and (**b**) significant interrelationships among these sub-criteria.

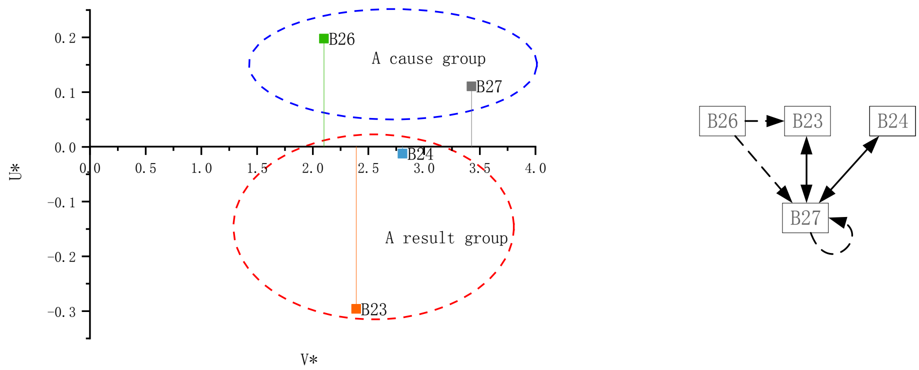
The results and analysis of sub-criteria in each dimension are as follows:

(1) Society and environment

For the Society and environment (Z1) dimension, as shown in Figure 4, "Electricity Market exposure (B11)" and "Reliability of power supply (B13)" are deemed important factors affecting "Package design of preferential electricity price for consumers (B14)" due to the positive value of $U^*$. However, "Package design of preferential electricity price for consumers (B14)" has the negative value of $U^*$, which indicates it is highly affected by the other two factors and itself has no effect on B11 and B13, as shown in Figure 4b. So B14 is excluded from the subsequent ANP analysis.

(2) Economy

As shown in Figure 6, "Economy (Z2)" dimension has four influencing indicators. "Market to market (B26)" and "Earnings at risk (B27)" have positive value of $U^*$, which implies that they are the cause factors. "Gross energy margin (B24)" and "Return on capital (B23)" are result factors. "Return on capital (B23)" is in the lower part of the figure, and has a weak effect. Thus, it should be neglected. Additionally, it is worth noting that "Earnings at risk (B27)" and "Gross energy margin (B24)" have high values of $V^*$, so should be paid more attention in the sustainable development of TPGGs.

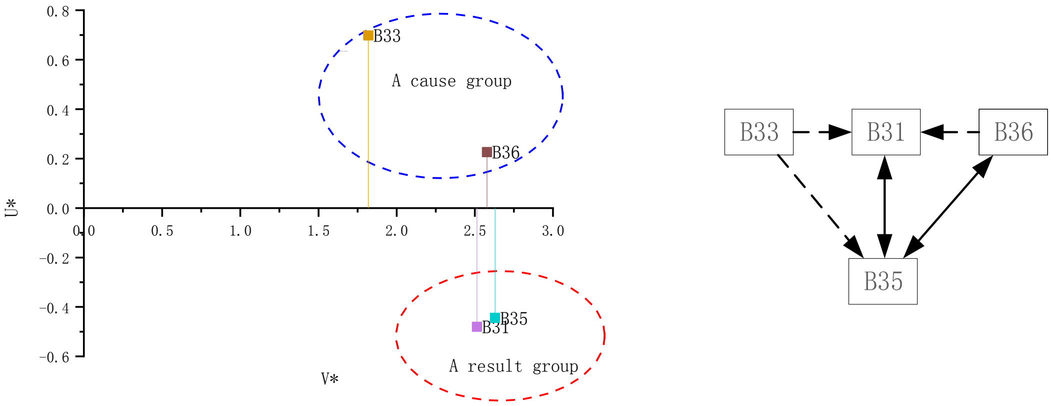



(**a**) (**b**)

**Figure 6.** Cause and result diagram for Economy (Z2). (**a**) The causal-results diagram and (**b**) significant interrelationships among these sub-criteria.

(3) Resources and technology

For the "Resources and technology" dimension, as presented in Figure 7, "Renewable energy installed ratio (B33)" and "Technology maturity/innovation (B36)" are core affecting factors for the other two criteria with a positive value of $U^*$. Moreover, "Resources and the allocation level (B31)" and "Constructions of smart power plant (B35)" are both in the bottom of the diagram, and they are easily affected by the other two factors; accordingly, they are excluded from the latter ANP analysis.



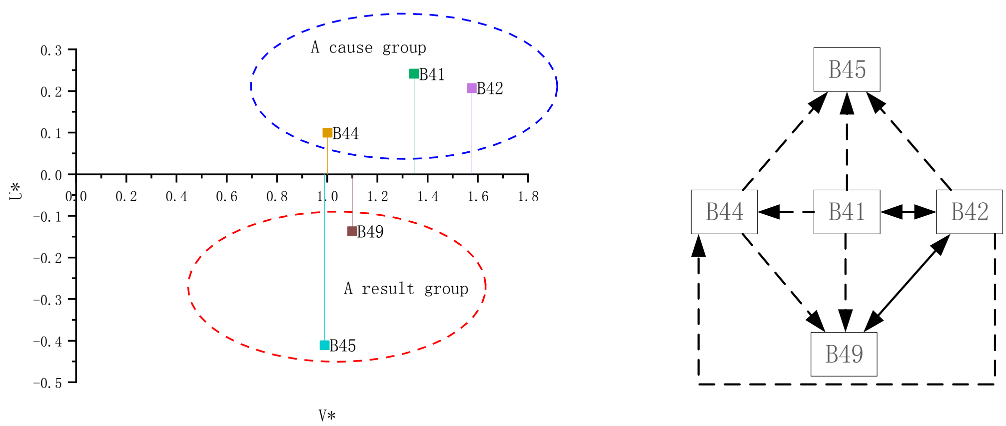

(a) (b)

**Figure 7.** Cause and effect diagram for Resources and technology (Z3). (**a**) The causal-results diagram and (**b**) significant interrelationships among these sub-criteria.

(4) Enterprise and management

Figure 8 illustrates the cause and effect relationship of "Enterprise and management (Z4)".

"Corporate culture and business philosophy (B41)" and "The cognition and determination of top managers/executives (B42)" are both in the top right of the diagram, meaning that they both have strong effects and great importance in influencing the other two factors. However, regarding the location of "Clear departmental rights and responsibilities of dispatching and trading (B44)," "Talent structure and personnel capability suitable for the power market (B45)," and "Risk management level (B49)," they are easily affected by others. In particular, "Clear departmental rights and responsibilities of dispatching and trading (B44)" and "Talent structure and personnel capacity (B45)" should be neglected for the time being due to the low effect.

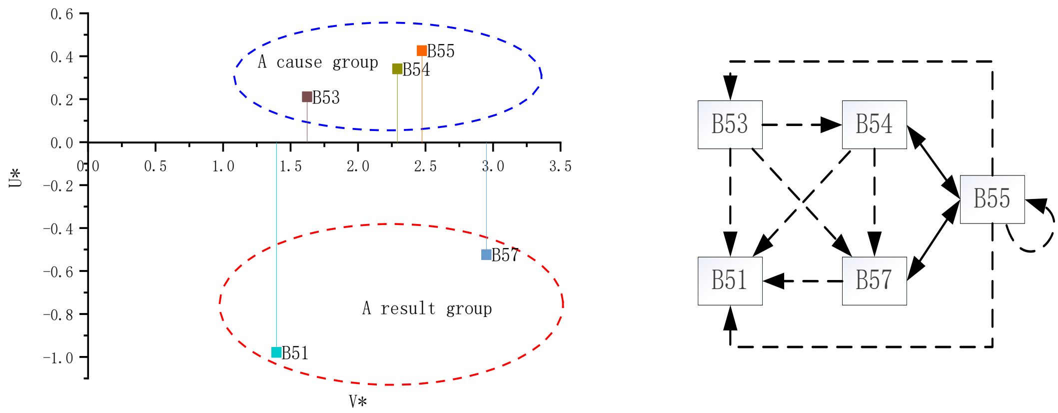



(a) (b)

**Figure 8.** Cause and effect diagram for Enterprise and management (Z4). (**a**) The causal-results diagram and (**b**) significant interrelationships among these sub-criteria.

(5) Market

The cause and result diagram for "Market" dimension is shown in Figure 9. "Forecasting for demand and price in the market (B54)" and "Price of electricity in market (B55)" are assigned as the core cause factors because of the positive value of $V^*$. "Brand effects (B51)" is at the bottom left of the diagram and can be ignored. In addition, "Price bidding Strategy (B57)," with the highest value of $U^*$, should be taken seriously as well as "Price of electricity in market (B55)" in that they interact with each other. Meanwhile, "Forecasting for demand and price in the market (B54)" and "Analysis of potential competitors (B53)" should be included because they can influence "Price bidding Strategy (B57)".




(**a**) (**b**)

**Figure 9.** Cause and effect diagram for Market (Z5). (**a**) The causal-results diagram and (**b**) significant interrelationships among these sub-criteria.

Therefore, 14 criteria were selected as important influencing factors by the above methods, as shown in Figure 10. The interrelationships among the different dimensions and all sub-criteria belonging to each dimension were drawn. Meanwhile, a structural model for ANP analysis was established.

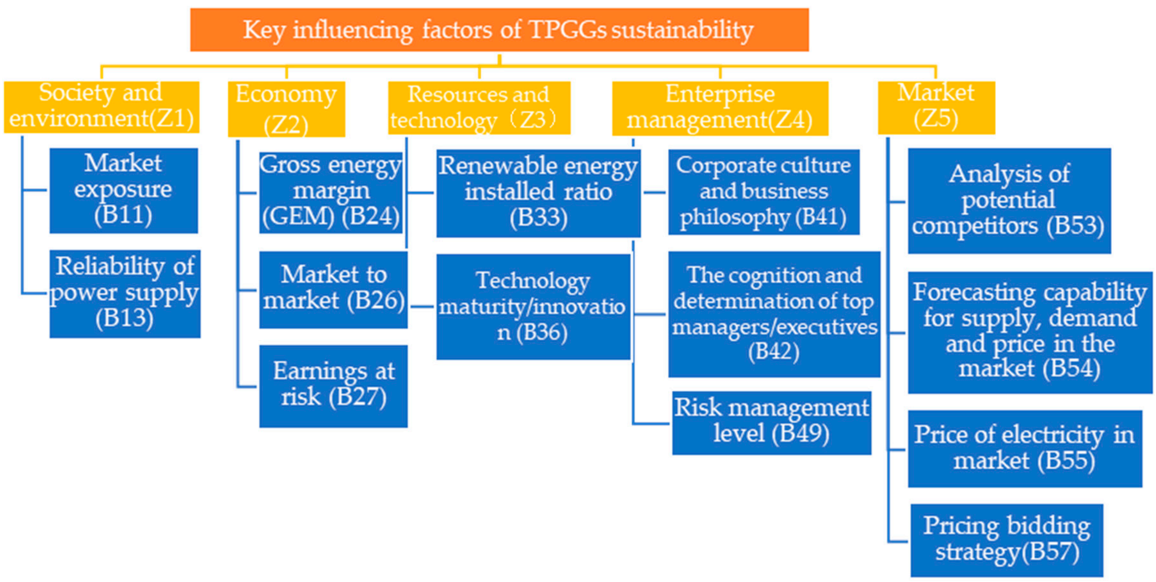



**Figure 10.** The selected important influencing factors.

### 4.5. Obtain the Weights of Important Factors

After the experts filled out questionnaires to give their opinions on significant influencing factors, the data were collected, in which 1 to 9 represent the degree of correlation. Then the software of ANP model "Super Decision" was applied to test the consistency ratio, and only the criteria passing the consistency test were retained. Based on the analysis of the Fuzzy DEMATEL method and consistent results, the interrelationships of all important criteria are clear and definite. A final interrelationship map of all criteria were drawn in the ANP model, as shown in Figure 11.

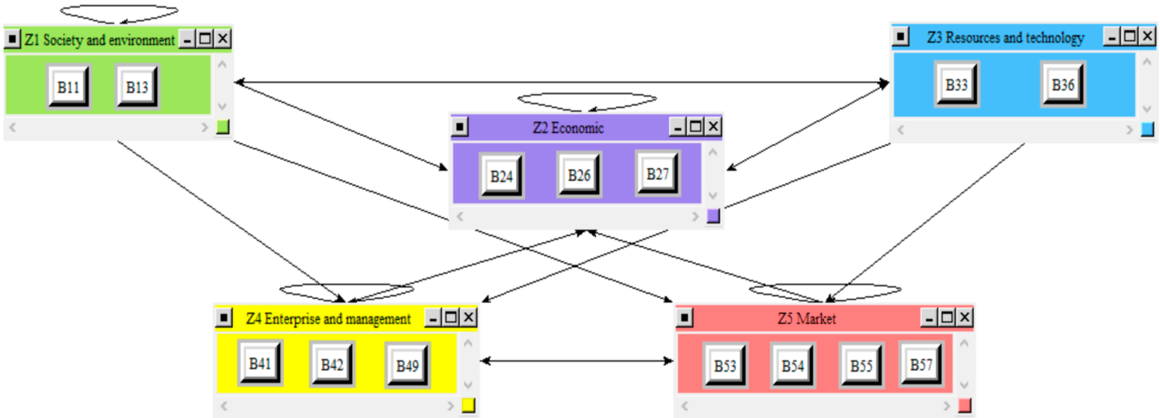



**Figure 11.** The interrelationship map of all important criteria.

Five dimensions' pairwise comparison matrices were built under the ANP model in this phase. Final results of the academic group and the practitioners group were analyzed based on data gathered from the ANP questionnaires answered by professors and entrepreneurs.

## 5. Discussion and Implications

Based on the modified MCDM model, 14 sub-criteria were denoted as important influencing factors in the sustainable development of TPGGs based on the DEMATEL method, as shown in Figure 9. The intensity of these important influencing factors can be compared and ranked according to the final weights in the ANP analysis, as shown in Table 14. In order to reflect the similarities and differences of the judgments of the two groups in a visual way, Figure 12 was drawn. The closer the value point is to the edge of the circle, the higher priority this indicator has.

**Table 14.** Ranks and intensity of the key influencing factors in the academic and practitioners group.

| Items | B11 | B13 | B24 | B26 | B27 | B33 | B36 | B41 | B42 | B49 | B53 | B54 | B55 | B57 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Academic Ranks | 14 | 10 | 2 | 13 | 1 | 4 | 5 | 12 | 9 | 8 | 11 | 7 | 6 | 3 |
| Practical Ranks | 14 | 9 | 2 | 10 | 1 | 5 | 3 | 13 | 12 | 6 | 11 | 7 | 8 | 4 |
| Cause | √ | √ | - | √ | √ | √ | √ | √ | √ | - | √ | √ | √ | - |
| Result | - | - | √ | - | - | - | - | - | - | √ | - | - | - | √ |

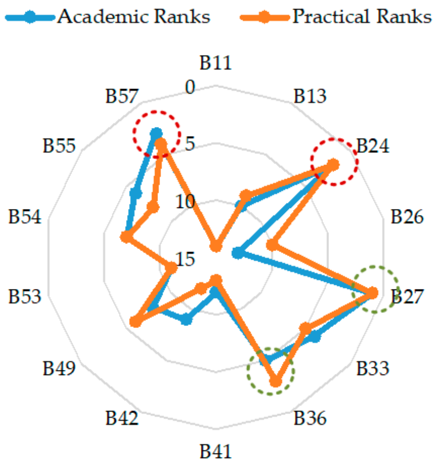



**Figure 12.** The ranks of key influencing factors for TPGGs' sustainability from the two groups.

It can be clearly seen that the results from the two groups are pretty much the same. "Earnings at risk (B27)" and "Gross energy margin (B24)" are affiliated to "Economy," "Technology maturity innovation (B36)" is affiliated to "Resources and technology," and "Pricing bidding strategy (B57)" is affiliated to "Market," which are much more important than the others. In addition, B33 and B49 are considered the subdominant influencing factors, and should be paid more attention in TPGGs' operations. However, both groups thought market exposure is affected by main body behaviors to some extent, and B11 was the least important factor. On the other hand, the opinions on "Market to market (B26)," "The cognition and determination of top managers/executives (B42)," and "Price of electricity in market (B55)" from the two expert groups are different.

"Earnings at risk" is the most crucial factor that influences the TPGG's sustainable development. Because market business increases rapidly in the short term, the power generation-centric business chain structure is not suitable for the market-oriented business environment. Uncertainty of market price and trading volume increases business risks, which directly influence the TPGG's operation. In order to reduce the value at risks, the market risk management system needs to be strengthened. TPGGs should: (a) pay attention to the financial and regulatory risks that may be brought about by the rapid increase of market volume; (b) set up a unified market risk and compliance management policy at the group level and resolutely implement it; (c) undertake continuous research and development of a variety of risk management models, quantitative risk assessments, and impact analysis; and (d) make full use of financial instruments to hedge risks and effectively control market risks.

"Price bidding strategy" is also considered an important factor. It is essential for TPGGs to participate in the electricity market and gain as much revenue as possible. However, how to bid and offer in a spot market, a forward market, and even a green certificate market directly influences revenue. In order to optimize bidding strategies, accurate forecast of bidding and offering curves should be prepared, as well as research and application of an optimal portfolio model. Moreover, external environment analysis, including policies and competitors, is also essential.

According to the different opinions on "Market to market (B26)," "The cognition and determination of top managers/executives (B42)," and "Price of electricity in market (B55)" from two expert groups, it can be concluded that these factors are often neglected in theoretical research, but have a significant influence on practical work.

Some favorable recommendations for other important factors were also made to assist TPGGs in developing sustainable capabilities, as shown in Table 15.

**Table 15.** Suggested countermeasures to develop sustainable capabilities of TPGGs.

| Dimensions | Sub-Criteria | Suggested Measures |
|---|---|---|
| Z1 | B11 | As the market opening process is largely guided by the government's policy, TPGGs need to (a) track the policy issues of electricity market, such as the degree of openness, the transaction rules, whether power grid companies participate in electricity sales, dispatching and the degree of independence of trading institutions; (b) improve its adaptability, be able to predict the policy orientation, prepare in advance and respond in time. |
| | B13 | Improve the automation level of the control system, simplify the operation procedures of the equipment, and improve the reliability and economy of the generator equipment.To forecast the load peak and trough, check the running state of the unit frequently, ensure the fuel supply, check the unit frequently and ensure the normal processing of the units. |
| Z2 | B24<br>B26 | A long-term development plan should be established to assure margins. The marketing plan should be explicit. The price quoting strategies and techniques should be mastered. For example, investment in future market can be used as a hedging tool. However, the spot market is risky and profitable. Besides, China is now carrying out pilot market of ancillary services. Compensation for ancillary services will make power generation enterprises more profitable in a certain period. |
| | B27 | TPGGs should improve their ability in managing risk through a serious of technological means, including a deep knowledge of derivatives assets valuation and market risk management theories; tools to simulate electricity market prices scenarios and tools to compute risk indicators to measure hedging strategies' effectiveness. |
| Z3 | B33 | Since the majority of clean energy power investment in China has been made by TPGGs, risks such as high generation cost, mismatch between capacity and generation, deficient policy and so on should be considered in an initial market. Therefore, rational allocation of renewable energy and full play to the advantages of renewable energy power generation are critical. |
| | B36 | On the one hand, TPGGs should develop enterprise marketing management system, market transaction simulation system, and other systems with the practical needs. On the other hand, TPGGs should develop medium- and long-term electricity price forecast, asset portfolio optimization and risk control tools to provide strong technical R&D support for marketing business |
| Z4 | B41 | Combining corporate culture with corporate strategy, corporate culture penetrates into enterprise management thinking, organizational structure and other aspects. As for business philosophy, renew the concept of enterprise development, that is, from planning to market, from a single power grid to many customers. |
| | B42 | In terms of personal leadership, change the concept of leadership management, constantly learn and accumulate practical experience, and constantly improve reflection. In terms of organization, the leadership decision-making mechanism of senior managers of TPGGs should be optimized to form a scientific and institutionalized leadership style and pay attention to creating a positive and harmonious enterprise culture to enhance the team influence of managers. |
| | B49 | Grasp a deep knowledge of derivatives assets valuation and market risk management theories; develop tools for assets valuation, taking into account their dynamic operating constraints (minimum and maximum load constraints, ramp-up and down power constraint, starting costs, minimum run time) and storages; develop tools to compute risk indicators and provide a consistent set of compatible tools for risk managers, from price modelling to hedging strategies. |
| Z5 | B53 | Collect the market data and detect the competitor's information by data mining. |
| | B54 | Establish a database of market supply and demand, market quotation and results, and periodically analyze historical transaction data, which can contribute to the accurate prediction. |
| | B55 | As market price is affected by quotations from market participants, while the price itself also affects the quotations of participators in return, TPGGs should learn to analyze the game behavior among the market subjects, and reasonably predict the market price. |
| | B57 | In order to optimize investment choices, it is necessary to build economic projections far beyond market horizons. Therefore, it is necessary to construct price scenarios over several decades, with different assumptions, using supply-demand equilibrium models. Moreover, it must be done for each province where the company expands business. |

## 6. Conclusions

We made an in-depth analysis of the major factors influencing the sustainable development of traditional generation companies. Firstly, a literature survey about the TPGG topic in articles was presented to highlight the core ideas of the study. Thirty-six potential influencing factors were collected to build an initial index system. Secondly, 22 important indicators were selected from the potential influencing factors by the fuzzy Delphi method. Thirdly, the causal relationships and the structural model were built by fuzzy DEMATEL. Fourthly, the final preference of key factors was determined with a DEMATEL-based ANP technique. The proposed method based on fuzzy Delphi and fuzzy DEMATEL-based ANP has been shown to be an efficient and practical tool for the identification of key influencing factors. The main findings of our study are as follows:

(1) Five dimensions are considered in recognizing the core factors influencing sustainable development for traditional power generation enterprises, including “society and environment,” “economy,” “resources and technology,” “enterprise management,” and “market.”
(2) A hybrid research framework combining the ANP with fuzzy DEMATEL and fuzzy Delphi methods was established according to the primary index system. Twenty-two significant factors were distinguished with the fuzzy Delphi method. Their causal relationships were shaped using the fuzzy DEMATEL method. In these two processes, the expert groups’ opinions were expressed as linguistic ratings to express the factors’ characteristics. Finally, we identified the final preferences of key influencing factors through the ANP technique. Thus, core influencing factors were effectively recognized after clear computation procedures.
(3) All causal relationships among different criterion groups were built in Figures 3–8. Fourteen criteria were selected as key factors, including “Electricity Market exposure (B11),” “Gross energy margin (B24),” “Market to market (B26),” “Earnings at risk (B27),” “Renewable energy installed ratio (B33),” “Technology maturity (B36),” “Price of electricity in market (B55),” “Pricing bidding strategy (B57),” etc. All of them were listed in Figure 8. Moreover, the final weights of 14 key factors were calculated and analyzed from both an academic and a practical perspective, as shown in Table 14. The views of the core factors from these two groups are basically the same. “Earnings at risk (B27)” and “Gross energy margin (B24)” both attracted more attention than other factors in these two groups. However, “Pricing bidding strategy (B57)” and “Renewable energy installed ratio (B33)” have drawn considerable attention from the academic group. On the other hand, the group of practitioners believes that “Technology maturity (B36)” and “Pricing bidding strategy (B57)” are important.
(4) In order to put the research findings into practice, we gathered a series of suggestions from these expert groups with respect to key factors about actual countermeasures for TPGGs. They are listed in Table 15, including long-term development plan, establishing the trading management information system, developing asset portfolio and risk management tools, etc.

All in all, the findings show that the critical influencing factors are earnings at risk, gross energy margin, technology innovation, and pricing bidding strategy. These are related to the “Economy” (earnings at risk, gross energy margin), “Market” (pricing bidding strategy), and “Resource and Technology” (technology innovation). Some recommendations to help TPGGs achieve sustainable development in the market-oriented industry environment are: build a market-oriented marketing system, strengthen the market risk control system, and cultivate a high-quality marketing team to provide strong technical research and development support for marketing. Factors related to the policy and market environment are less controllable since they depend on external factors. However, TPGGs should strengthen their self-construction and adaptability and adjust their actions based on critical factors and practice so as to achieve a steady transformation in the changing electricity market.

It is obvious that this research is focused on the initial construction of the electricity market in China and those key factors that are crucial for the transformation and development of TPGGs. However, core factors influencing the sustainable development for TPGGs are not fixed; rather, they depend on the practice of companies and construction situations in the electricity market. In order to track the revolution of key influencing factors, potential criteria and the research framework should be regathered and created again, respectively. Moreover, this combined methodology can be used in other fields. In future studies, key factors of sustainable development capabilities for TPGGs with different types of generation can be further analyzed.

**Author Contributions:** Conceptualization, J.D. and D.L.; Formal analysis, D.L.; Investigation, Q.Z.; Methodology, D.W.; Writing–original draft, D.L.

**Funding:** This research received no external funding.

**Acknowledgments:** This study is supported by the 111 project (B18021) and China Three Gorges consulting project.

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

## References


1. Wang, H.; Zhang, Y.; Lu, X.; Nielsen, C.P.; Bi, J. Understanding China's carbon dioxide emissions from both production and consumption perspectives. *Renew. Sustain. Energy Rev.* **2015**, *52*, 189–200. [CrossRef]
2. Zeng, M.; Yang, Y.Q.; Wang, L.H.; Sun, J.H. The power industry reform in China 2015: Policies, evaluations and solutions. *Renew. Sustain. Energy Rev.* **2016**, *57*, 94–110. [CrossRef]
3. Liu, X.; Liu, G.; Yang, Z.; Chen, B.; Ulgiati, S. Comparing national environmental and economic performances through emergy sustainability indicators: Moving environmental ethics beyond anthropocentrism toward ecocentrism. *Renew. Sustain. Energy Rev.* **2016**, *58*, 1532–1542. [CrossRef]
4. Nikolaou, I.E.; Tsalis, T.A.; Evangelinos, K.I. A framework to measure corporate sustainability performance: A strong sustainability-based view of firm. *Sustain. Prod. Consum.* **2019**, *18*, 1–18. [CrossRef]
5. Fuisz-Kehrbach, S.K. A three-dimensional framework to explore corporate sustainability activities in the mining industry: Current status and challenges ahead. *Resour. Policy* **2015**, *46*, 101–115. [CrossRef]
6. Shad, M.K.; Lai, F.W.; Fatt, C.L.; Klemeš, J.J.; Bokhari, A. Integrating sustainability reporting into enterprise risk management and its relationship with business performance: A conceptual framework. *J. Clean. Prod.* **2019**, *208*, 415–425. [CrossRef]
7. Schulz, K.P.; Finstad-Milion, K.; Janczak, S. Educating corporate sustainability—A multidisciplinary and practice-based approach to facilitate students' learning. *J. Clean. Prod.* **2018**, *198*, 996–1006. [CrossRef]
8. Moldavska, A.; Welo, T. A Holistic approach to corporate sustainability assessment: Incorporating sustainable development goals into sustainable manufacturing performance evaluation. *J. Manuf. Syst.* **2019**, *50*, 53–68. [CrossRef]
9. Beekaroo, D.; Callychurn, D.S.; Hurreeram, D.K. Developing a sustainability index for Mauritian manufacturing companies. *Ecol. Indic.* **2019**, *96*, 250–257. [CrossRef]
10. Ilinitch, A.Y.; Soderstrom, N.S.; Thomas, T.E. Measuring corporate environmental performance. *J. Account. Public Policy* **1998**, *17*, 383–408. [CrossRef]
11. Butnariu, A.; Avasilcai, S. The assessment of the companies' sustainable development performance. *Procedia Econ. Financ.* **2015**, *23*, 1233–1238. [CrossRef]
12. Lee, K.H.; Saen, R.F. Measuring corporate sustainability management: A data envelopment analysis approach. *Int. J. Prod. Econ.* **2012**, *140*, 219–226. [CrossRef]
13. Lozano, R.; Carpenter, A.; Huisingh, D. A review of 'theories of the firm' and their contributions to Corporate Sustainability. *J. Clean. Prod.* **2015**, *106*, 430–442. [CrossRef]
14. Zhao, Z.Y.; Zuo, J.; Wu, P.H.; Yan, H.; Zillante, G. Competitiveness assessment of the biomass power generation industry in China: A five forces model study. *Renew. Energy* **2016**, *89*, 144–153. [CrossRef]
15. Kumar, S.; Luthra, S.; Haleem, A.; Mangla, S.K.; Garg, D. Identification and evaluation of critical factors to technology transfer using AHP approach. *Int. Strateg. Manag. Rev.* **2015**, *3*, 24–42. [CrossRef]
16. Ghimire, L.P.; Kim, Y. An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renew. Energy* **2018**, *129*, 446–456. [CrossRef]
17. Rahman, S.; Yang, L.; Waters, S. Factors affecting RFID adoption in Chinese manufacturing firms: An investigation using AHP. *IFAC Proc. Vol.* **2013**, *46*, 869–874. [CrossRef]
18. Sharma, Y.K.; Yadav, A.K.; Mangla, S.K.; Patil, P.P. Ranking the Success Factors to Improve Safety and Security in Sustainable Food Supply Chain Management Using Fuzzy AHP. *Mater. Today Proc.* **2018**, *5*, 12187–12196. [CrossRef]
19. Calabrese, A.; Costa, R.; Levialdi, N.; Menichini, T. Integrating sustainability into strategic decision-making: A fuzzy AHP method for the selection of relevant sustainability issues. *Technol. Forecast. Soc. Chang.* **2019**, *139*, 155–168. [CrossRef]
20. Salari, M.; Rakhshandehroo, G.R.; Nikoo, M.R. Degradation of ciprofloxacin antibiotic by Homogeneous Fenton oxidation: Hybrid AHP-PROMETHEE method, optimization, biodegradability improvement and identification of oxidized by-products. *Chemosphere* **2018**, *206*, 157–167. [CrossRef]
21. Schrippe, P.; Ribeiro, J.L.D. Preponderant criteria for the definition of corporate sustainability based on Brazilian sustainable companies. *J. Clean. Prod.* **2019**, *209*, 10–19. [CrossRef]

22. Lin, X.; Cui, S.; Han, Y.; Geng, Z.; Zhong, Y. An improved ISM method based on GRA for hierarchical analyzing the influencing factors of food safety. *Food Control* **2018**, *99*, 48–56. [CrossRef]
23. Kung, C.Y.; Yang, P.Y.; Jiang, W.L. Applying Grey Relational Analysis to Quality Function Deployment Process-A Case Study of Middle Medical Centers. In Proceedings of the The 11th Grey Theory and Applications Conference, Hsinchu City, Taiwan, 28 October 2006; pp. 7–9.
24. Hsieh, M.C.; Wang, E.M.Y.; Lee, W.C.; Li, L.W.; Hsieh, C.Y.; Tsai, W.; Liu, T.C. Application of HFACS, fuzzy TOPSIS, and AHP for identifying important human error factors in emergency departments in Taiwan. *Int. J. Ind. Ergon.* **2018**, *67*, 171–179. [CrossRef]
25. Subramaniya, K.P.; Dev, C.A.G.; SenthilKumar, V.S. Critical Success Factors: A TOPSIS approach to increase Agility Level in a Textile Industry. *Mater. Today Proc.* **2017**, *4*, 1510–1517. [CrossRef]
26. Suganthi, L. Multi expert and multi criteria evaluation of sectoral investments for sustainable development: An integrated fuzzy AHP, VIKOR/DEA methodology. *Sustain. Cities Soc.* **2018**, *43*, 144–156. [CrossRef]
27. Gupta, H. Assessing organizations performance on the basis of GHRM practices using BWM and Fuzzy TOPSIS. *J. Environ. Manag.* **2018**, *226*, 201–216. [CrossRef] [PubMed]
28. Zeleny, M. *Multiple Criteria Decision Making*; McGraw Hill: New York, NY, USA, 1982.
29. Quezada, L.E.; López-Ospina, H.A.; Palominos, P.I.; Oddershede, A.M. Identifying causal relationships in strategy maps using ANP and DEMATEL. *Comput. Ind. Eng.* **2018**, *118*, 170–179. [CrossRef]
30. Ding, X.F.; Liu, H.C. A 2-dimension uncertain linguistic DEMATEL method for identifying critical success factors in emergency management. *Appl. Soft Comput.* **2018**, *71*, 386–395. [CrossRef]
31. Lin, S.; Li, C.; Xu, F.; Liu, D.; Liu, J. Risk identification and analysis for new energy power system in China based on D numbers and decision-making trial and evaluation laboratory (DEMATEL). *J. Clean. Prod.* **2018**, *180*, 81–96. [CrossRef]
32. Fan, Z.P.; Suo, W.L.; Feng, B. Identifying risk factors of IT outsourcing using interdependent information: An extended DEMATEL method. *Expert Syst. Appl.* **2012**, *39*, 3832–3840. [CrossRef]
33. Gardas, B.B.; Raut, R.D.; Narkhede, B. Evaluating critical causal factors for post-harvest losses (PHL) in the fruit and vegetables supply chain in India using the DEMATEL approach. *J. Clean. Prod.* **2018**, *199*, 47–61. [CrossRef]
34. Mavi, R.K.; Standing, C. Critical success factors of sustainable project management in construction: A fuzzy DEMATEL-ANP approach. *J. Clean. Prod.* **2018**, *194*, 751–765. [CrossRef]
35. Wang, L.; Cao, Q.; Zhou, L. Research on the influencing factors in coal mine production safety based on the combination of DEMATEL and ISM. *Saf. Sci.* **2018**, *103*, 51–61. [CrossRef]
36. Liang, H.; Ren, J.; Gao, Z.; Gao, S.; Luo, X.; Dong, L.; Scipioni, A. Identification of critical success factors for sustainable development of biofuel industry in China based on grey decision-making trial and evaluation laboratory (DEMATEL). *J. Clean. Prod.* **2016**, *131*, 500–508. [CrossRef]
37. Jianfei, S.; Song, X.; Ming, Z.; Yi, W.; Yuejin, W.; Xiaoli, L.; Zhijie, W. Low-carbon development strategies for the top five power generation groups during China's 12th Five-Year Plan period. *Renew. Sustain. Energy Rev.* **2014**, *34*, 350–360. [CrossRef]
38. Orlitzky, M.; Schmidt, F.L.; Rynes, S.L. Corporate social and financial performance: A meta-analysis. *Organ. Stud.* **2003**, *24*, 403–441. [CrossRef]
39. Zhang, X.; Wu, Z.; Feng, Y.; Xu, P. "Turning green into gold": A framework for energy performance contracting (EPC) in China's real estate industry. *J. Clean. Prod.* **2015**, *109*, 166–173. [CrossRef]
40. Hsu, C.H.; Chang, A.Y.; Luo, W. Identifying key performance factors for sustainability development of SMEs–integrating QFD and fuzzy MADM methods. *J. Clean. Prod.* **2017**, *161*, 629–645. [CrossRef]
41. Díaz-García, C.; González-Moreno, Á.; Sáez-Martínez, F.J. Eco-innovation: Insights from a literature review. *Innovation* **2015**, *17*, 6–23. [CrossRef]
42. Rennings, K. Redefining innovation—Eco-innovation research and the contribution from ecological economics. *Ecol. Econ.* **2000**, *32*, 319–332. [CrossRef]
43. Chang, A.Y.; Cheng, Y.T. Analysis model of the sustainability development of manufacturing small and medium-sized enterprises in Taiwan. *J. Clean. Prod.* **2019**, *207*, 458–473. [CrossRef]
44. Carroll, A.B.; Shabana, K.M. The business case for corporate social responsibility: A review of concepts, research and practice. *Int. J. Manag. Rev.* **2010**, *12*, 85–105. [CrossRef]
45. Atkinson, G. Measuring corporate sustainability. *J. Environ. Plan. Manag.* **2000**, *43*, 235–252. [CrossRef]

46. Chofreh, A.G.; Goni, F.A.; Klemeš, J.J. Evaluation of a framework for sustainable Enterprise Resource Planning systems implementation. *J. Clean. Prod.* **2018**, *190*, 778–786. [CrossRef]
47. Zhao, H.; Li, N. Evaluating the performance of thermal power enterprises using sustainability balanced scorecard, fuzzy Delphic and hybrid multi-criteria decision making approaches for sustainability. *J. Clean. Prod.* **2015**, *108*, 569–582. [CrossRef]
48. de Jesus Pacheco, D.A.; Carla, S.; Jung, C.F.; Ribeiro, J.L.D.; Navas, H.V.G.; Cruz-Machado, V.A. Eco-innovation determinants in manufacturing SMEs: Systematic review and research directions. *J. Clean. Prod.* **2017**, *142*, 2277–2287. [CrossRef]
49. Tomšič, N.; Bojnec, Š.; Simčič, B. Corporate sustainability and economic performance in small and medium sized enterprises. *J. Clean. Prod.* **2015**, *108*, 603–612. [CrossRef]
50. Li, R.; Dong, J.; Wang, D. Competition ability evaluation of power generation enterprises using a hybrid MCDM method under fuzzy and hesitant linguistic environment. *J. Renew. Sustain. Energy* **2018**, *10*, 055905. [CrossRef]
51. Matinaro, V.; Liu, Y.; Poesche, J. Extracting key factors for sustainable development of enterprises: Case study of SMEs in Taiwan. *J. Clean. Prod.* **2019**, *209*, 1152–1169. [CrossRef]
52. Klemes, J.J. (Ed.) *Assessing and Measuring Environmental Impact and Sustainability*; Butterworth-Heinemann: Oxford, UK, 2015.
53. Ruhang, X.; Zixin, S.; Qingfeng, T.; Zhuangzhuang, Y. The cost and marketability of renewable energy after power market reform in China: A review. *J. Clean. Prod.* **2018**, *204*, 409–424. [CrossRef]
54. Weerts, K.; Vermeulen, W.; Witjes, S. On corporate sustainability integration research: Analysing corporate leaders' experiences and academic learnings from an organisational culture perspective. *J. Clean. Prod.* **2018**, *203*, 1201–1215. [CrossRef]
55. Leyh, C.; Rossetto, M.; Demez, M. Sustainability management and its software support in selected Italian enterprises. *Comput. Ind.* **2014**, *65*, 386–392. [CrossRef]
56. Witjes, S.; Vermeulen, W.J.; Cramer, J.M. Assessing Corporate Sustainability integration for corporate self-reflection. *Resour. Conserv. Recycl.* **2017**, *127*, 132–147. [CrossRef]
57. ur Rehman, M.H.; Chang, V.; Batool, A.; Wah, T.Y. Big data reduction framework for value creation in sustainable enterprises. *Int. J. Inf. Manag.* **2016**, *36*, 917–928. [CrossRef]
58. Sun, S.; Feng, Y.; Zhou, J. Research on the Influencing Factors of Dynamic Marketing Capability Based on Grounded Theory—Taking IT Industry as an Example. *J. Technol. Econ. Manag.* **2014**, *5*, 38–42.
59. Shi, G.; Han, H. Analysis and Countermeasures of Incentive Factors for New Generation Knowledge Workers. *Enterp. Econ.* **2014**, *11*, 62–66.
60. Albayrak, T. Importance Performance Competitor Analysis (IPCA): A study of hospitality companies. *Int. J. Hosp. Manag.* **2015**, *48*, 135–142. [CrossRef]
61. Zadeh, L.A. Fuzzy sets as a basis for a theory of possibility. *Fuzzy Sets Syst.* **1999**, *100*, 9–34. [CrossRef]
62. Wang, Y.-J. Ranking triangle and trapezoidal fuzzy numbers based on the relative preference relation. *Appl. Math. Model.* **2015**, *39*, 586–599. [CrossRef]
63. Xu, J.; Wan, S.P.; Dong, J.Y. Aggregating decision information into Atanassov's intuitionistic fuzzy numbers for heterogeneous multi-attribute group decision making. *Appl. Soft Comput.* **2016**, *41*, 331–351. [CrossRef]
64. Liu, H.C.; You, J.X.; You, X.Y.; Shan, M.M. A novel approach for failure mode and effects analysis using combination weighting and fuzzy VIKOR method. *Appl. Soft Comput.* **2015**, *28*, 579–588. [CrossRef]
65. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
66. Murray, T.J.; Pipino, L.L.; van Gigch, J.P. A pilot study of fuzzy set modification of Delphi. *Hum. Syst. Manag.* **1985**, *5*, 76–80.
67. Huang, J.; Shen, K.Y.; Shieh, J. Strengthen Financial Holding Companies' Business Sustainability by Using a Hybrid Corporate Governance Evaluation Model. *Sustainability* **2019**, *11*, 582. [CrossRef]
68. Dalalah, D.; Hayajneh, M.; Batieha, F. A fuzzy multi-criteria decision making model for supplier selection. *Expert Syst. Appl.* **2011**, *38*, 8384–8391. [CrossRef]
69. Singh, R.K.; Benyouce, L. A fuzzy TOPSIS based approach for e-sourcing. *Eng. Appl. Artif. Intell.* **2011**, *24*, 437–448. [CrossRef]
70. Saaty, T.L. *Decisions with the Analytic Network Process (ANP)*; Springer: New York, NY, USA, 2006.
71. Yunn, W.; 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. [CrossRef]

72. Sun, H.; Tian, P.; Wang, L. *Network Analytic Hierarchy Process and Decision Science*; National Defense Industry Press: Beijing, China, 2011.
73. Fabjanowicz, M.; Bystrzanowska, M.; Namieśnik, J.; Tobiszewski, M.; Płotka-Wasylka, J. An analytical hierarchy process for selection of the optimal procedure for resveratrol determination in wine samples. *Microchem. J.* **2018**, *142*, 126–134. [CrossRef]
74. Dong, J.; Huo, H.; Liu, D.; Li, R. Evaluating the Comprehensive Performance of Demand Response for Commercial Customers by Applying Combination Weighting Techniques and Fuzzy VIKOR Approach. *Sustainability* **2017**, *9*, 1332. [CrossRef]
75. Şengül, Ü.; Eren, M.; Shiraz, S.E.; Gezder, V.; Şengül, A.B. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renew. Energy* **2015**, *75*, 617–625. [CrossRef]
76. Bourbon, R.; Ngueveu, S.U.; Roboam, X.; Sareni, B. Energy management optimization of a smart wind power plant compaing heuristic and linear programming methods. *Math. Comput. Simul.* **2019**, *158*, 418–431. [CrossRef]
77. Huang, Y.; Zhang, Y.; Li, L. Foreign direct investment and cleaner production choice: Evidence from Chinese coal-fired power generating enterprises. *J. Clean. Prod.* **2019**, *212*, 766–778. [CrossRef]
78. Chan, H.R.; Fell, H.; Lange, L.; Li, S. Efficiency and environmental impacts of electricity restructuring on coal-fired power plants. *J. Environ. Econ. Manag.* **2017**, *81*, 1–18. [CrossRef]