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Article

Risk Evaluation of a UHV Power Transmission Construction Project Based on a Cloud Model and FCE Method for Sustainability

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Abstract: In order to achieve the sustainable development of energy, Ultra High Voltage (UHV) power transmission construction projects are being established in China currently. Their high-tech nature, the massive amount of money involved, and the need for multi-agent collaboration as well as complex construction environments bring many challenges and risks. Risk management, therefore, is critical to reduce the risks and realize sustainable development of projects. Unfortunately, many traditional risk assessment methods may not perform well due to the great uncertainty and randomness inherent in UHV power construction projects. This paper, therefore, proposes a risk evaluation index system and a hybrid risk evaluation model to evaluate the risk of UHV projects and find out the key risk factors. This model based on a cloud model and fuzzy comprehensive evaluation (FCE) method combines the superiority of the cloud model for reflecting randomness and discreteness with the advantages of the fuzzy comprehensive evaluation method in handling uncertain and vague issues. For the sake of proving our framework, an empirical study of "Zhejiang-Fuzhou" UHV power transmission construction project is presented. As key contributions, we find the risk of this project lies at a "middle" to "high" level and closer to a "middle" level; the "management risk" and "social risk" are identified as the most important risk factors requiring more attention; and some risk control recommendations are proposed. This article demonstrates the value of our approach in risk identification, which seeks to improve the risk control level and the sustainable development of UHV power transmission construction projects.

Keywords: UHV power transmission construction project; risk evaluation; cloud model; FCE method; sustainability

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1. Introduction

With the rocketing increase in energy demand in China, there are many barriers in achieving the sustainable and healthy development of the economy and society, such as the energy shortage, structural imbalances, low efficiency, serious pollution and so on. Therefore, it is very important to examine sustainable development specifically in the context of China [1]. The "strong smart grid" based on UHV power transmission technology can bring clean power from remote areas to load centers with dense populations. On the one hand, UHV power transmission technology can release environmental pressure of load centers by optimizing resource allocation. On the other hand, the high economic efficiency of UHV power transmission technology means that power transmission over a long-distance, at a high-capacity, and with low pollution can be realized [2]. As a result, UHV power construction projects can provide a solid guarantee for sustainable energy development.

However, compared with traditional construction projects, UHV power construction projects have been characterized by large investments, long project cycles, complicated techniques, numerous unpredictable risk factors, and as having significant impacts on society and the environment [3]. Besides, many districts are still in the exploratory phase of UHV power construction. As a consequence, a number of uncertainties and risks are encountered during the construction of UHV power transmission projects, which may cause project delays, cost overrun, and even negative impacts on society. Thus, risk management is necessary for UHV power transmission projects in order to improve performance and secure the success of a project. Risk management for UHV power transmission projects, however, is intricate and uncertain, especially in the initial phase of a project, because the nature of risk is usually affected by numerous factors including financial factors, natural factors, technical factors, *etc*. In the past few years, many risk assessment techniques have been proposed in the literature and used in practice in the risk management of a project, such as the influence diagram method, risk matrix analysis, fault tree analysis, Monte Carlo Simulation, Bayesian network, *etc*. However, these methods are difficult in assessing the risk of UHV power construction projects, if not impossible. On the one hand, these sophisticated methods deliver reliable risk results only through extensive numerical data, which is impossible to obtain for UHV power construction projects due to the great uncertainty inherent in construction. Moreover, these traditional methods cannot cope with problems that are vague and uncertain in nature. To conquer the difficulties in acquisition of high quality data and description of vague and uncertain factors, many researchers have introduced experts' experience to risk evaluation of a project by way of fuzzy theory. The integration of fuzzy theory in project risk management has allowed obtaining satisfactory results by effectively addressing subjective factors and uncertainties associated with construction activities. Nevertheless, it ignores the randomness and discreteness of the system, since the uncertain randomness and discreteness of problems are unavoidable in the assessment process. One risk which is neglected at the early stage of a UHV power construction project may result in huge damages in the future. It is therefore essential to develop a new risk analysis model to assess and manage the risk of a UHV power construction project in an acceptable way.

To overcome the difficulties mentioned above, this paper proposes a framework based on Analytic Hierarchy Process (AHP), fuzzy theory and cloud model to evaluate the risks of UHV power construction projects. By analyzing the complicated environment these projects operate in, the risk indicators of UHV power transmission construction projects are identified by Delphi method, which relies on extensive perceptual knowledge and experience. Due to the lack of data and foundations of risk assessment, the fuzzy comprehensive evaluation and cloud model are applied in this paper to evaluate risks. The application of the FCE and cloud model provides a systematic tool to deal with uncertainty, randomness and fuzziness in an assessment framework. In the application of a cloud model and FCE, AHP is applied to determine and prioritize risk factors.

The remainder of the paper is organized as follows: Section 2 reviews the related research. Section 3 builds the evaluation index system of UHV power transmission construction projects based on data collection and the Delphi method. Thereafter, the basic information about cloud models and FCE methods, as well as the construction of a risk evaluation model, are outlined respectively in Section 4 and Section 5. In Section 6, a case study on the "Zhejiang-Fuzhou" UHV power transmission construction project is conducted to test the proposed model and point out the risk indicators which should be focused on. The conclusions are drawn in Section 7.

2. Literature Review

Risk management is beneficial when it is implemented in a systematic manner from planning stages to the project completion. Since the 2000s, risk management has gained strong interest from academia and practice. Various methods have been proposed to assess the risk of projects, including the influence diagram method, Probability-Impact model, risk matrix analysis, fault tree analysis, Monte Carlo Simulation, neural network model, AHP, fuzzy set theory, *etc*. Risk assessment techniques vary in the way they combine different aspects into one value. Liu *et al*. [4] and Liu *et al*. [5] analyzed the risk of projects based on influence diagrams. Li *et al*. [6] used the risk matrix to evaluate project risk level from two dimensions: risk impact and risk probability. Chen *et al*. [7] used Monte Carlo Simulation to simulate on the curves of both probability distribution and risks of network schedule and cost, and realized the project risk evaluation. Zhou *et al*. [8] proposed a risk assessment method based on fault tree analysis and Analytic Hierarchy Process (AHP). The fault tree analysis was used to identify risk events and factors associated with projects, and the AHP method was used to determine risk degree. Liu *et al*. [9] presented the use of neural network model in risk analysis of an Information Technology Outsourcing (ITO) project, as well as realized risk early-warning aiming at overall risk of projects. However, compared with conventional projects, the UHV power transmission construction projects face more challenges and risks, and have essential differences with other projects, which hamper the applicability of many risk assessment methods used widely for UHV projects. First of all, the UHV transmission construction projects have unique characteristics, so the experience of other projects cannot be applied to this kind of project. Secondly, since the construction of UHV projects is in preliminary phases, the main source of information provided for the risk assessment is the knowledge of experienced engineers and experts, most of which is not precise data but vague verbal descriptions. Furthermore, there is too much uncertainty, randomness and discreteness inherent during the whole project. Because of these differences, the old methods mentioned above cannot be used for the risk management of UHV power transmission construction projects. To conquer the difficulties in acquisition of high quality data and description of vague and uncertain factors, many researchers have relied on expert experience for risk evaluation of projects by way of fuzzy theory. The integration of fuzzy theory in project risk management provides satisfactory results by effectively addressing subjective factors and uncertainties associated with construction activities. Carreno *et al*. [10] introduced fuzzy set theory to assess project risk, which is a more realistic way than the traditional methods mentioned above to represent the uncertainty and vagueness inherent in the real problem. Tah *et al*. [11] adopted fuzzy theory to appraise risk qualitatively, in which experts' subjective judgments were captured. A fuzzy decision making model was designed by Wang *et al*. [12] to evaluate the risk of a bridge construction project. The overall project risk level was constituted by multiplying the likelihood and risk consequences of each risk factor. Meanwhile, Zeng *et al*. [13] coped with project risk based on fuzzy comprehensive evaluation (FCE) and AHP method. AHP was applied to determine and prioritize risk factors whereas the FCE model made an assessment of vague and uncertain factors.

The FCE model realizes the conversion from fuzzy to precise, overcomes the limitation of having a lack of accurate data, as well as reflects the uncertainty and vagueness of the project. Nevertheless, it ignores the randomness and discreteness of the system, since the uncertain randomness and discreteness of problems are unavoidable in the assessment process. Therefore, traditional comprehensive evaluation methods based on fuzzy theory should be improved to overcome limitations. The cloud model developed in recent years has been widely adopted in complex evaluation situations. Zheng *et al*. [14] evaluated the safety level of flood damage to oil and gas pipelines based on the cloud model, which takes into account qualitative characteristics in the safety evaluation process. Zhao *et al*. [15] used the cloud model to cope with uncertainty, randomness and fuzziness during an outage consequence assessment framework, whereas AHP was applied to break down and prioritize multiple risk sources in a power distribution network.

The evaluation technique based on the cloud model can not only realize the conversion between the quantification and qualification, but also reflect the uncertainty and randomness of risk. The risk analysis for UHV power construction projects, however, is intricate, especially at the early stage of the project, and risk management is filled with fuzzy, uncertain and random factors, because the nature of risk is usually affected by numerous factors including natural factors, technical factors, *etc*. Considering the nature of risk management, and the features of fuzzy theory and cloud model, this study develops a holistic risk evaluation model using a comprehensive fuzzy evaluation method and cloud model to estimate the construction risks, especially for a situation characterized by incomplete data, vagueness, uncertainty, randomness and discreteness.

3. Risk Evaluation Index System for UHV Power Transmission Construction Projects

In this section, through the analysis of internal and external environments of UHV power transmission construction projects, we get a preliminary understanding of the risk factors from the perspective of sustainable development. On this basis, the risk indicators for risk evaluation are identified by the Delphi method [16].

3.1. The Internal and External Environment of the Project

A UHV power transmission construction project involves multiple complex phases, such as project approval, feasibility research, design, construction, completion acceptance, *etc*. Meanwhile, it is a complex process with a long investment cycle, huge investment scale, large technology requirement and a complex environment [17]. A complex and uncertain construction environment may generate uncertainties for a project as well as affect project progress and quality. Therefore, for the sake of sustainable development of UHV projects, it is crucial to identify and manage risk factors over time by analyzing environmental factors.

The internal environment of a UHV power transmission construction project is the basis of operation control, which directly affects the implementation of the objective. In the whole construction process, management units need to control the internal environment scientifically and strictly in real time. The internal environment of a UHV power transmission construction project may be categorized as follows, according to the financial environment, management environment, and technology environment.

3.1.1. Financial Environment

The grid corporation is the capital contribution unit of UHV power construction projects in China, which is responsible for financing. The investment of UHV project construction is so enormous that the grid corporation must borrow large funds from banks as well as issue corporate debt. Moreover, as a capital-intensive industry, a construction project associated with the electric power industry has a longer investment cycle, which leads to a higher requirement on cash flow and financing ability. In accordance with the characteristics of the financial environment for a UHV project, much more attention should be focused on funding. Therefore, for the sake of sustainability of UHV project construction, the risk factors related to project funding, such as project budget risk, investment risk, and funding risk, should be managed from the beginning of construction.

3.1.2. Management Environment

Owing to the difficulties and complexity of UHV projects, multiple units participate in the construction of a project, which makes the management environment more complex and uncertain. As the major management unit, the grid corporation takes charge of feasibility research, engineering design, material management, project supervision, and preparation related to engineering. The Primavera Project Planner for Enterprise/Construction (P3e/c) project management software has been adopted widely in grid corporations, so as to monitor the construction progress and the harmony among different units. Therefore, the risk factors associated with management should be paid close attention for the sake of sustainable construction. The main management risks in a UHV construction project include feasibility research risk, contract management risk, schedule risk, and supervision risk.

3.1.3. Technology Environment

On the whole, the majority of UHV power transmission construction projects in China are still in an exploratory phase. The technology of UHV power transmission construction projects has been fumbled with and improved continuously. Grid corporations, however, lack experience to cope with different construction environments. Meanwhile, electric power maintenance corporations are clearly deficient in personnel reserve, equipment acquisition and technical training. As we all know, the technology risks in the construction process may delay the completion of a project and cause the loss of finances and the reputation of a corporation. Therefore, an underdeveloped technology environment may bring various risks. In order to accomplish the sustainability of a project, the risk management of UHV project should strengthen its monitoring on risks related to technologies, such as the substation construction risk, large equipment transportation risk, mountain material transportation risk and so on.

Uncertain external environment factors would also affect the project progress and quality as well. Generally speaking, UHV power transmission construction projects are subject to external environmental factors, including the natural environment, policy and legal environment, and social environment [18].

3.1.4. Natural Environment

Owing to the vast territory and complex terrain in China, the natural environment of UHV projects is complicated, and projects must take into account geography, geology, climate and weather, *etc*. Natural factors may lead to torrential rain, frost, landslide, debris flow and other geological risks, which would threaten the smooth construction of a project. Hence, from the perspective of sustainable development, the risk management of UHV projects should fully consider natural environment factors.

3.1.5. Policy and Law Environment

Throughout all stages of the project, UHV power transmission construction projects must adhere to a large number of relevant policies and laws, such as project examination, land requisition and demolishing, power grid planning and construction. Besides, although a UHV power transmission construction project has received government approval, it should comply with the national laws and regulations as well. However, the policy and legal system in China is still in development stage. For the sustainable development of a UHV project, the construction unit should place more attention on policy and legal environment factors, and ensure all works comply with related regulations. Any uncertainty in compliance with the regulatory environment may lead to undesirable impacts on the construction of the UHV project.

3.1.6. Social Environment

As a key infrastructure construction project is given priority by the national government, the social environment is complex and fickle. In the process of a UHV power construction project, there are numerous problems that may cause conflict, such as the land requisition, construction and traffic. In addition, the destruction of landscape and vegetation may cause disputes. A variety of uncertainties and risk factors in the social environment may endanger the performance of UHV power construction projects. Consequently, for the purpose of the sustainability of UHV projects, the risk factors associated with social environment should be carefully considered, such as ecological environmental damage risk, residents' maladjustment risk, life security concerns risk and so on. As we all know, a project without social benefits would not be capable of being sustained.

3.2. Establish the Risk Evaluation Index System for UHV Power Transmission Construction Project

The analysis of internal and external environments above is conducive to the identification of risk factors, which is the basis of establishing a risk evaluation index system, as well as the beginning of UHV power transmission construction project management. In order to accelerate sustainable development of a project, a risk evaluation index system is established, which can improve the risk management of the project and fully exploit its superiority in promoting the sustainable development of energy.

Faced with complicated environments, the risk indicator identification of a UHV power transmission construction project is difficult, which relies on extensive perceptual knowledge and experience. Therefore, in this paper, the Delphi method is used to analyze and classify various risk factors [19]. Delphi method (DM), launched by Dalky and Helmer in 1963, is a technique used to obtain the most reliable consensus among a group of experts, and has been widely used in decision-making and risk identification. The risk index identification procedure based on Delphi method in this paper has four main steps, which are shown as follows:

Step 1: Analyze the features of the UHV power transmission construction project, and collect relevant materials.

Step 2: Establish an expert advisory group.

In order to comprehensively identify key risk factors, 100 experts from different fields are selected to establish an expert advisory group. This group is composed of project managers, scholars who have done some research on the risk management of power grid construction, as well as investors and leaders of the power grid construction, *etc*.

Step 3: Design questionnaire and establish an advisory contact with the expert advisory group.

Step 4: Analyze and check the consistency of experts' opinions.

After collecting experts' opinions, the opinions will be presented to the expert advisory group anonymously, so as to obtain consistent opinions among experts. Based on the repeated research and analysis, the risk evaluation indicators for the UHV power transmission construction project can be identified, which can reflect the opinions of all experts to the greatest extent.

The specific procedure of risk index identification is shown in Figure 1.

In the light of project features and relevant materials focusing on risk management, we compiled an inquiry questionnaire for a UHV power transmission construction project, in which more than 70 risk indicators were selected for the questionnaire. In order to single out the main risk indicators, we identify environment-based and project-based risk factors for the project depending on the questionnaire results from the expert advisory group. As a result, by analyzing the questionnaire results, 38 key risk indicators are singled out to assess the risk of a UHV power transmission construction project, from the perspective of sustainability, which are listed in Figure 2. From Figure 2, it can be seen that the index system is divided into five categories in the second level, namely the policy and legal risk, management risk, technology risk, natural environment risk, and society risk, respectively. Therefore, the risk management in UHV power transmission construction projects would guarantee the sustainable development of projects, due to the risk indicators involving every aspect of the construction.

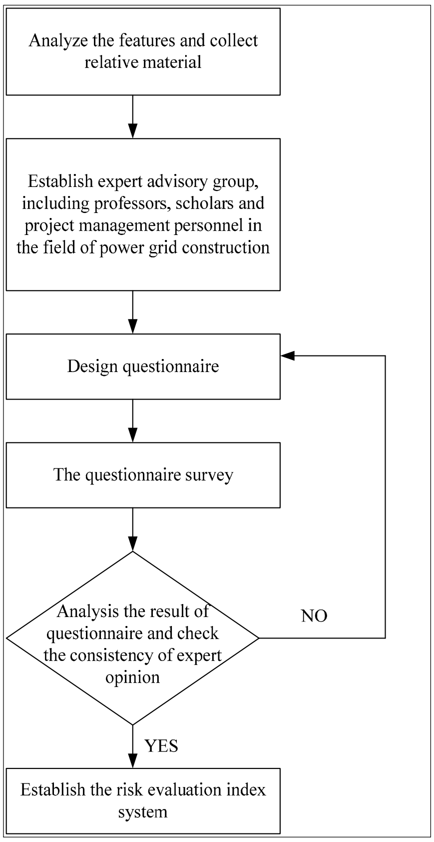

Figure 1. Risk indicator identification procedure.

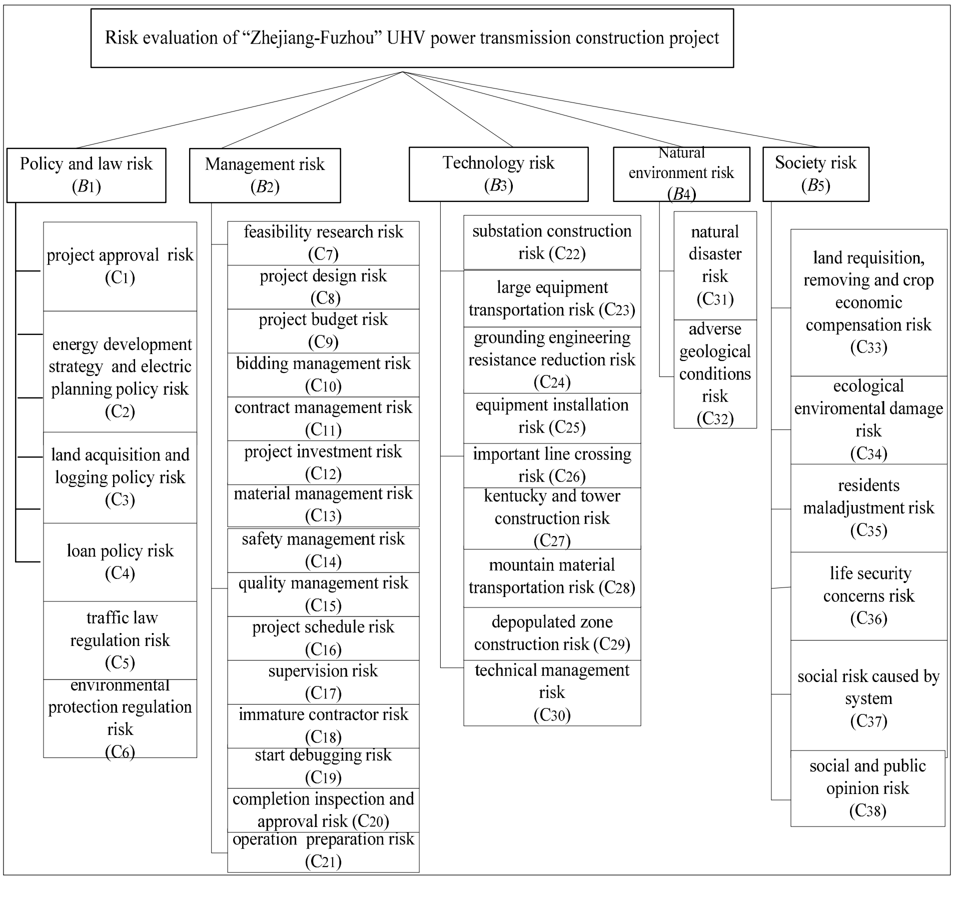

Figure 2. The risk evaluation index system of the UHV power transmission construction project.

4. The Basic Rationale of the FCE and Cloud Model

4.1. The Fuzzy Comprehensive Evaluation Model

As a concrete application of fuzzy mathematics, the fuzzy comprehensive evaluation method was put forward by Wang Peizhuang [20], which quantifies some vague and uncertain factors using the fuzzy weighted average method or maximum membership degree principle. It is a fuzzy bottom-up multi-criteria decision making (MCDM) method, which has merits in handling complicated evaluations with multiple attributes and multiple levels [21].

For the evaluated object F, evaluation index set $U = \{u_1, u_2, \cdots, u_m\}$ is an entirety with an intrinsic structure, which is made up of indicators representing the characteristics of F. The remark set $V = \{v_1, v_2, \cdots, v_n\}$ is composed of different risk grades, and n in the remark set V represents the number of risk grades. The remark set can be determined by interviewing experts and referring to relevant standards and demands [22,23].

Under the fuzzy weighted average method, grade set $R = (r_1, r_2, \cdots, r_m)^T$ is risk score of each index according to experts' experiences. The comprehensive evaluation score (A) can be obtained dependent on weight vector of each index $W = (w_1, w_2, \cdots w_m)$ and grade set R through the fuzzy weighted average method, namely $A = W \circ R$. Then, we can judge the risk level according to the interval in which the comprehensive evaluation score belongs. Unfortunately, the fuzzy weighted average method may introduce numerous subjective factors, which results in the unsatisfactory consequence of having to make multiple decisions.

For the principle of maximum membership degree, subset of grade set $r_i = (r_{i1}, r_{i2}, \cdots, r_{in})$ represents the degree of alternative v_i satisfies the index u_i, whereby membership function can be established by assessment experts. All the evaluations form a fuzzy evaluation matrix R, namely,

$$R = \left(r_{ij}\right) m \times n = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \tag{1}$$

The comprehensive evaluation result can be obtained dependent on weight vector of each index W and evaluation matrix R, denoted by $A = W \circ R$, which can be assembled through the generalized fuzzy multiplication "$\circ$". Then, we can judge the grade which evaluated object belongs to, according to the maximum membership degree principle [24]. However, this principle would generate large biases of judgment, since only the max membership degree is taken into consideration.

4.2. The Cloud Model

Cloud theory is a powerful tool of converting numerical quantitative analysis into conceptual qualitative analysis, which was put forward by Li Deyi in the 1990s [14]. Based on the probability theory and fuzzy mathematics, cloud model organically combines the fuzzy, randomness and discreteness of evaluation object by the Expect (Ex), Entropy (En) and Excess Entropy (He). It can also realize the transformation between uncertainty quantitative language and quantitative description [25].

Suppose B is a quantitative theory domain with accurate numerical data, and C is a qualitative concept related to B. x ($x \in B$) is a random number with stable tendency of qualitative concept C, whose membership of x to C is $\mu_c(x)$ ($\mu_c(x) \in [0,1]$) [26]. Moreover, the distribution of x is a cloud, made up of numerous cloud droplets. Each droplet shows a transformation from qualitative concept to quantitative space, just as shown in Figure 3.

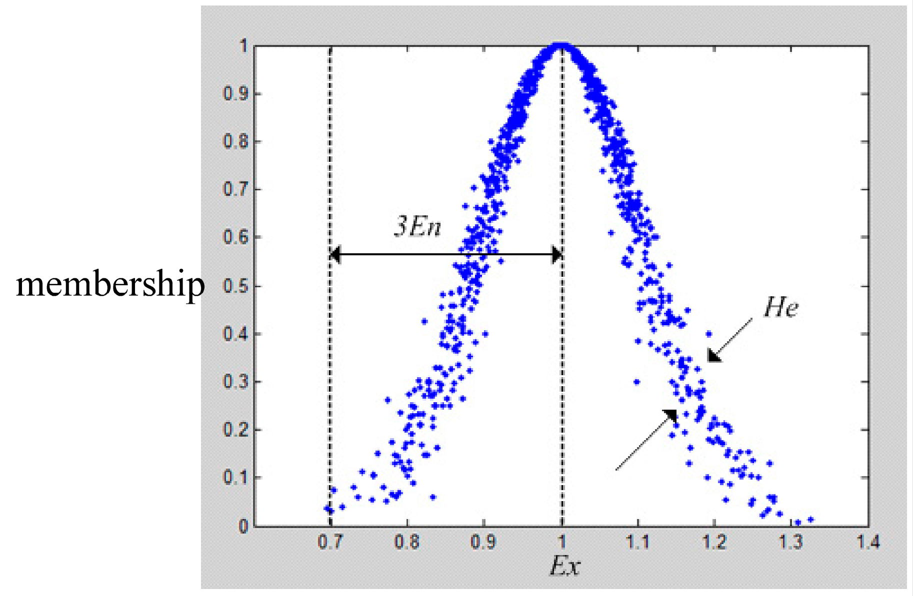

Figure 3. The cloud chart.

In cloud theory, three digital eigenvalues of cloud are used to reflect the quantitative characteristics of the concept, which is made up of Expect (Ex), Entropy (En) and Excess Entropy (He) [26]. Their main contents are as follows:

(1) Expect (Ex) represents the qualitative concept C;
(2) Entropy (En) reflects the uncertainty of C. The greater En is, the fuzzier and more random the object is.
(3) Excess Entropy (He) measures the uncertainty of Entropy (En). It reflects the degree of condensation of cloud droplets. The larger the entropy is, the greater the degree of discrete cloud droplets is, and cloud would be thicker.

Cloud model theory uses cloud generator to realize the mutual transformation between quantification and qualification and reflects the uncertainty, randomness and discreteness of objects. The Positive Cloud Generator maps the qualitative description to quantitative description. It simulates cloud droplets according to the digital eigenvalues of cloud model (Ex, En, He) by Matlab software, in which the quantitative range and distribution can be obtained from the qualitative description, just as shown in Figure 4. The Reverse Cloud Generator is a model transforming the quantitative values to the qualitative concept. It can convert a certain number of accurate data into a qualitative concept by digital eigenvalues (Ex, En, He) [27], just as shown in Figure 5. The specific calculation processes of Reverse Cloud Generator are as follows:

Step 1: Calculate the mean of samples.

$$Ex = \overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{2}$$

Step 2: Calculate the sample variance.

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2 \tag{3}$$

Step 3: Calculate the entropy and excess entropy of cloud.

$$En = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n}\left|x_i - \overline{x}\right| \tag{4}$$

$$He = \sqrt{S^2 - En^2} \tag{5}$$

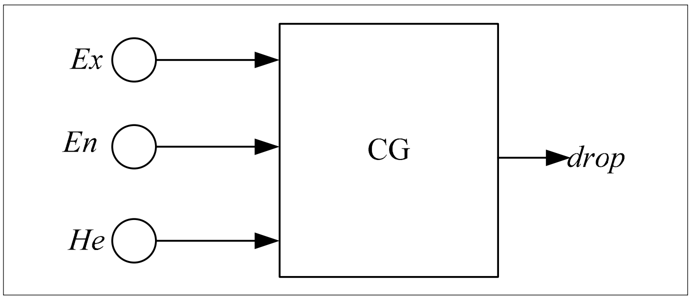

Figure 4. The positive cloud generator.

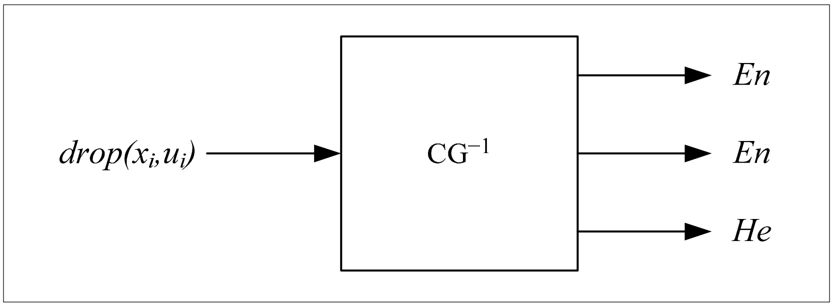

Figure 5. The reverse cloud generator.

5. The Risk Evaluation Model Based on Cloud Model and FCE Method for UHV Power Transmission Construction Project

Due to large numbers of uncertainties inherent in the UHV power transmission construction project, the FCE method should be adopted to cope with the vague and uncertain problems in nature. The integration of the fuzzy theory in project risk management would give rise to satisfactory results by effectively addressing subjective factors and uncertainties associated with construction activities. However, the FCE method has limitations in some aspects, such as ignoring discreteness, excessively subjective results, and deviation of evaluation results. As a consequence, in this paper, cloud model is used to improve traditional FCE method with the help of weight cloud and membership degree cloud.

The hybrid risk evaluation model based on cloud model and FCE method combines the superiorities of cloud model for reflecting randomness with the advantages of fuzzy comprehensive evaluation method in uncertainty and vagueness, which realizes risk evaluation of all risk indicators comprehensively from bottom to top. The specific steps of the risk evaluation model for a UHV power transmission construction project are as follows:

(1) Build the risk index system and hierarchical relationship for the evaluation of UHV power transmission construction project;
(2) Establish the evaluation index set $U = \{u_1, u_2, \cdots, u_m\}$, and m is the number of evaluation index, according to the risk index system;
(3) Investigate risk index importance and risk value from different experts.

In order to avoid personal experience and subjective factors influencing evaluation results, group decision is chosen to determine index importance and risk value. Namely, we dispatch some questionnaires about "the risk factors of UHV power construction project" to experts. Then, all experts verbally rate the risk index importance and risk value with respect to a subjective criteria and relevant standards.

(4) Count the sample data of risk value according to questionnaires.

After sorting out effective questionnaires, the sample data of risk value should be counted based on the judgment and opinions of experts related to this project according to the questionnaire results.

(5) Calculate the index weight based on AHP and count the sample data of index weights.

In accordance with the features of risk evaluation index system, the analytic hierarchy process (AHP) is appropriate for determining the weights of indexes with a multi-levels structure [28]. AHP uses the pair-wise comparison method to construct the judgment matrixes for both the second level and the third level. The pair-wise comparison is performed by using a nine-point scale which can convert human preference into quantitative value. After the judgment matrixes are obtained, the order weight vector of risk indicators can be calculated by using Eigenvalue method. Then, after passing the consistency checks of judgment matrixes, the global weight of each indicator can be determined by multiplying the local weight of the indicator with the weight of upper layer indicator which is located in the parent node above it.

According to the judgment and opinions of experts related to this project and according to the questionnaire results, the judgment matrixes of the second level and the third level are constructed by the nine-point scale pair-wise comparison. Thereafter, the weights of risk indicators in the second level and third level can be calculated based on AHP, and the sample data of index weight can be obtained [29].

(6) Establish the cloud model matrix of risk index weight and index risk value.

In the fuzzy comprehensive evaluation based on cloud model, the cloud model is used to describe the digital eigenvalues of index weight and risk value, fully considering the randomness and discreteness of membership functions from risk indicators to risk levels. According to sample data about risk indicators from questionnaires, the digital eigenvalues of index risk value cloud and weight cloud can be calculated by Reverse Cloud Generator from cloud droplets (sample data) [27].

The cloud of weight coefficient matrix W and index risk value matrix R are as follows:

$$W = \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{pmatrix} = \begin{pmatrix} Ex_{r1} & En_{r1} & He_{r1} \\ Ex_{r2} & En_{r2} & He_{r2} \\ \vdots & \vdots & \vdots \\ Ex_{rm} & En_{rm} & He_{rm} \end{pmatrix} \tag{6}$$

$$R = \left(r_1, r_2, \cdots, r_m\right)^T = \begin{pmatrix} Ex_1 & En_1 & He_1 \\ Ex_2 & En_2 & He_2 \\ \vdots & \vdots & \vdots \\ Ex_m & En_m & He_m \end{pmatrix} \tag{7}$$

(7) Calculate the comprehensive evaluation cloud model.

The eigenvalues of evaluation cloud model are calculated based on the fuzzy synthetic operator $A = W \circ R = (Ex, En, He)$, while the "$\circ$" is the fuzzy synthetic operator and the rules of cloud computing are as follows [27]:

$$A = W \circ R = \begin{pmatrix} Ex_{r1} & En_{r1} & He_{r1} \\ Ex_{r2} & En_{r2} & He_{r2} \\ \vdots & \vdots & \vdots \\ Ex_{rm} & En_{rm} & He_{rm} \end{pmatrix}^T \circ \begin{pmatrix} Ex_1 & En_1 & He_1 \\ Ex_2 & En_2 & He_2 \\ \vdots & \vdots & \vdots \\ Ex_m & En_m & He_m \end{pmatrix} =$$

$$\begin{pmatrix} Ex_{r1} \times Ex_1 + Ex_{r2} \times Ex_2 + \cdots Ex_{rm} \times Ex_m \\ \sqrt{(\left|Ex_{r1}Ex_1\sqrt{(\frac{En_{r1}}{Ex_{r1}} + \frac{En_1}{Ex_1})^2}\right|)^2 + (\left|Ex_{a2}Ex_2\sqrt{(\frac{En_{r2}}{Ex_{r2}} + \frac{En_2}{Ex_2})^2}\right|)^2 + \cdots + (\left|Ex_{rq}Ex_q\sqrt{(\frac{En_{rm}}{Ex_{rm}} + \frac{En_m}{Ex_m})^2}\right|)^2} \\ \sqrt{(\left|Ex_{r1}Ex_1\sqrt{(\frac{He_{r1}}{Ex_{r1}} + \frac{He_1}{Ex_1})^2}\right|)^2 + (\left|Ex_{r2}Ex_2\sqrt{(\frac{He_{r2}}{Ex_{r2}} + \frac{He_2}{Ex_2})^2}\right|)^2 + \cdots + (\left|Ex_{rq}Ex_q\sqrt{(\frac{He_{rm}}{Ex_{rm}} + \frac{He_m}{Ex_m})^2}\right|)^2} \end{pmatrix} \tag{8}$$

(8) Establish the remark cloud model

The remark cloud model $V = \{v_1, v_2, \cdots, v_n\}$ is established according to the index set $U = \{u_1, u_2, \cdots, u_m\}$ which is the fuzzy description of risk level for each index.

(9) Determine the risk level of evaluation object.

According to the digital eigenvalues of evaluation cloud model and remark cloud model, the cloud chart containing N cloud droplet could be drawn using Forward Cloud Generator. The risk level can be judged qualitatively by comparing the distribution of cloud droplets between evaluation cloud and remark cloud.

On the whole, the risk comprehensive evaluation model for UHV power construction project based on cloud model and FCM method has three advantages:

(a) Unlike traditional evaluation sets, the boundary of improved evaluation sets is blurred. This is more accordant with human language habits and it can reduce the subjective uncertainty of evaluation results in the comparison process.

(b) Based on the group decision and cloud model, the determination of index weight and risk evaluation can overcome the limitation of traditional methods. Moreover, it can reduce the subjective uncertainty in the comparison process.
(c) Different from the evaluation matrix, the improved one can be regarded as a cloud model with expectation (Ex), entropy (En) and excess entropy (He).

The hybrid model realizes a one-to-many mapping between the qualitative and quantitative concepts, as well as reflecting the fuzziness, uncertainty, randomness and discreteness of the UHV power construction projects.

The framework of the proposed hybrid risk evaluation approach is shown in Figure 6.

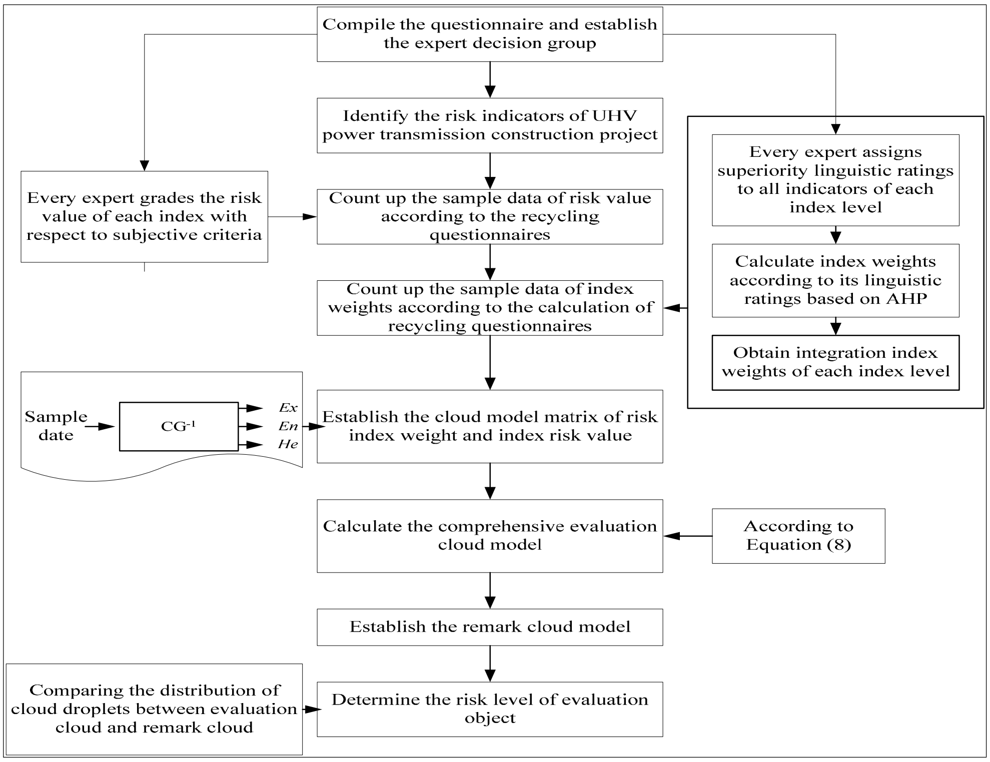

Figure 6. The framework of the proposed hybrid risk evaluation approach based on FCE and cloud model for the UHV power transmission project.

6. A Case Study of the 1000 kV UHV AC Project of Zhejiang-Fuzhou in China

In this section, a 1000 kV UHV AC power transmission construction project of Zhejiang-Fuzhou in China is used to exemplify the applicability of the proposed model. The specific analysis processes are shown as below.

6.1. Project Profile

The "Zhejiang-Fuzhou" UHV power transmission construction project connects two 1000 kV substations which are located in the north of Zhejiang province and Fuzhou city. There are three new UHV transformer substations (in the middle of Zhejiang, the south of Zhejiang and Fuzhou), and two 603 km-length AC transmission lines will be built. This project plays a critical role in the East China power grid (the strong receiving end), which is a powered platform of AC and DC UHV outside Zhejiang and Fujian. Meanwhile, as the power exchange trunk connecting passage through Fujian, Zhejiang and the Qiantang River, this project is significant in improving the safety and reliability of the power grid. Most of all, during the "twelfth five-year" plan, the power shortage of Zhengjiang and Jiangsu power grid can be addressed by transmitting electricity from Fujian power grid with the help of this project, which would promote the harmonious, stable and sustainable development of energy in Fujian, Zhejiang and Jiangsu.

However, this project is the first UHV power transmission construction project in Fujian province, and Fujian Electric Power Company still lacks experience in the construction of UHV projects. Therefore, in order to guarantee the sustainable construction of the project, it is essential to evaluate risk during the construction process, and make some preparations to prevent risks as well, so as to fully achieve its intended functions.

6.2. Risk Evaluation

Based on the risk evaluation model proposed above, the risk of "Zhejiang-Fuzhou" UHV power transmission construction project is analyzed as follows:

(1) Build the index system and hierarchical relationships of "Zhejiang-Fuzhou" UHV power transmission construction project, just as shown in Figure 2.

There are five risk indicators, including the policy and law risk, management risk, technology risk, natural environment risk, and society risk, respectively. Accordingly, 38 main risk indicators at the index level are singled out to assess the risk of the UHV power transmission construction project.

(2) Take the risk of "Zhejiang-Fuzhou" UHV power transmission construction project as the evaluated object F. The evaluation index set is composed of 38 risk indicators, namely $U=\{u_1,u_2,\cdots u_{38}\}=$ project approval risk, energy development strategy and electric planning policy risk, land acquisition and logging policy risk…social risk caused by system, social and public opinion risk.

(3) Investigate risk index importance and risk value from different experts.

Dispatch 100 questionnaires about "the risk factors of UHV power construction project" to experts. All experts give verbal ratings to the risk indicators' importance and risk values with respect to subjective criteria.

(4) Count the sample data of indicators' risk values based on the questionnaires.

There are 95 valid questionnaires out of 100 questionnaires. After recognizing the judgment and opinions of experts related to this project according to the questionnaire results, 95 sample data about indicators' risk values of the "Zhejiang-Fuzhou" UHV power transmission construction project are obtained. The risk value score for each indicator is in the interval [0,1].

(5) Calculate and count the weights of risk evaluation indicators based on the AHP.

After recognizing the judgment and opinions of experts related to this project according to the questionnaire results, the judgment matrixes of the second level and the third level are constructed by the nine-point scale pair-wise comparison (as shown in Table 1), and then we can obtain 95 sample data values about the risk indicators' weights of this project, containing the weights of indicators at a second level and local weights of indicators at a third level. In this paper, one sample data value is shown as an example to explain the process of determination of the index weight based on AHP.

Table 1. Nine-point comparison scale.

Scale(a_{ij})	Meaning
1	Indicator x_i is the same importance as indicator x_j
3	Indicator x_i is slightly more important than indicator x_j
5	Indicator x_i is obviously more important than indicator x_j
7	Indicator x_i is strongly more important than indicator x_j
9	Indicator x_i is extremely more important than indicator x_j
2, 4, 6, 8	Middle value of the above
Reciprocal	$x_i/x_j=a_{ij}$, then $x_j/x_i=a_{ji}=1/a_{ij}$

According to the analysis above, it shows that $a_{ij} > 0$, $a_{ii} = 1$, $a_{ji} = 1/a_{ij}$.

The judgment matrixes of second layer and index layer by using the nine-point scale pair-wise comparison method are constructed, and the results are shown from Tables 2–7.

Table 2. Pairwise comparison judgment matrixes and weights at the second level.

	B_1	B_2	B_3	B_4	B_5	Weight
B_1	1.00	0.70	0.90	1.50	0.55	0.169
B_2	1.43	1.00	0.90	1.75	0.72	0.212
B_3	1.11	1.11	1.00	1.60	0.85	0.214
B_4	0.67	0.57	0.63	1.00	0.46	0.124
B_5	1.82	1.39	1.18	2.17	1.00	0.280

Notes: λmax = 5.0165; CI = 0.0041; CR = 0.0037 < 0.1.

Table 3. Judgment matrixes and weights of "policy and law risk" indicator.

Policy and law risk	C_1	C_2	C_3	C_4	C_5	C_6	Local weight
C_1	1.00	2.50	0.95	3.20	1.60	1.80	0.255
C_2	0.40	1.00	0.43	1.35	0.90	1.20	0.121
C_3	1.05	2.33	1.00	3.52	1.75	1.93	0.267
C_4	0.31	0.74	0.28	1.00	0.51	0.62	0.080
C_5	0.63	1.11	0.57	1.96	1.00	1.15	0.150
C_6	0.56	0.83	0.52	1.61	0.87	1.00	0.127

Notes: λmax = 6.0232; CI = 0.0046; CR = 0.0037 < 0.1.

Table 4. Judgment matrixes and weights of "management risk" indicator.

Management risk	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	**Local weight**
C_7	1.00	0.32	0.32	0.61	0.57	0.33	0.29	0.52	0.34	0.29	0.89	0.54	0.76	0.86	0.84	0.031
C_8	3.13	1.00	0.89	1.31	1.56	0.72	0.75	1.35	0.48	0.67	2.80	1.73	2.21	2.21	2.32	0.080
C_9	3.13	1.12	1.00	1.52	2.51	0.85	0.95	1.52	0.84	0.99	2.52	2.16	2.56	2.76	2.96	0.098
C_{10}	1.64	0.76	0.66	1.00	1.21	0.52	0.56	0.97	0.45	0.67	1.45	1.22	1.65	1.66	1.56	0.058
C_{11}	1.75	0.64	0.40	0.83	1.00	0.41	0.52	0.79	0.39	0.43	1.43	0.86	1.11	1.23	1.33	0.047
C_{12}	3.03	1.39	1.18	1.92	2.44	1.00	1.21	1.78	0.83	1.22	3.25	2.31	2.78	3.64	3.21	0.112
C_{13}	3.45	1.33	1.05	1.79	1.92	0.83	1.00	1.63	0.83	1.13	2.82	1.64	2.56	2.31	2.14	0.096
C_{14}	1.92	0.74	0.66	1.03	1.27	0.56	0.61	1.00	0.56	0.56	1.83	1.34	1.65	1.57	1.35	0.060
C_{15}	2.94	2.08	1.19	2.22	2.56	1.20	1.20	1.79	1.00	1.24	4.06	2.23	3.57	3.58	3.21	0.123
C_{16}	3.45	1.49	1.01	1.49	2.33	0.82	0.88	1.79	0.81	1.00	2.35	1.89	2.34	2.43	2.34	0.096
C_{17}	1.12	0.36	0.40	0.69	0.70	0.31	0.35	0.55	0.25	0.43	1.00	0.67	0.83	0.91	0.91	0.034
C_{18}	1.85	0.58	0.46	0.82	1.16	0.43	0.61	0.75	0.45	0.53	1.49	1.00	1.53	1.64	1.62	0.052
C_{19}	1.32	0.45	0.39	0.61	0.90	0.36	0.39	0.61	0.28	0.43	1.20	0.65	1.00	1.34	1.26	0.039
C_{20}	1.16	0.45	0.36	0.60	0.81	0.27	0.43	0.64	0.28	0.41	1.10	0.61	0.75	1.00	1.05	0.036
C_{21}	1.19	0.43	0.34	0.64	0.75	0.31	0.47	0.74	0.31	0.43	1.10	0.62	0.79	0.95	1.00	0.037

Notes: $\lambda\text{max} = 15.0758$; CI = 0.0054; CR = 0.0034 < 0.1.

Table 5. Judgment matrixes and weights of "technology risk" indicator.

Technology risk	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	**Local weight**
C_{22}	1.00	0.56	2.22	2.34	1.17	1.76	0.98	0.64	2.33	0.131
C_{23}	1.79	1.00	2.76	3.33	1.59	2.35	1.34	1.26	3.17	0.196
C_{24}	0.45	0.36	1.00	1.19	0.63	0.79	0.63	0.54	1.17	0.072
C_{25}	0.43	0.30	0.84	1.00	0.61	0.75	0.49	0.47	1.31	0.065
C_{26}	0.85	0.63	1.59	1.64	1.00	1.36	0.86	0.94	1.97	0.116
C_{27}	0.57	0.43	1.27	1.33	0.74	1.00	0.66	0.59	1.34	0.084
C_{28}	1.02	0.75	1.59	2.04	1.16	1.52	1.00	0.95	2.16	0.131
C_{29}	1.56	0.79	1.85	2.13	1.06	1.69	1.05	1.00	2.67	0.147
C_{30}	0.43	0.32	0.85	0.76	0.51	0.75	0.46	0.37	1.00	0.058

Notes: λmax = 9.0425; CI = 0.005313; CR = 0.003566 < 0.1.

Table 6. Judgment matrixes and weights of "natural environment risk" indicator

Natural environment risk	C_{31}	C_{32}	**Local weight**
C_{31}	1.00	1.8	0.639
C_{32}	0.56	1.00	0.361

Notes: λmax = 2; CI = 0; CR = 0 < 0.1.

Table 7. Judgment matrixes and weights of "society risk" criteria.

Society risk	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}	**Local weight**
C_{33}	1.00	2.30	1.20	1.79	2.00	3.16	0.276
C_{34}	0.43	1.00	0.64	0.86	0.92	1.35	0.127
C_{35}	0.83	1.56	1.00	1.50	1.70	2.48	0.221
C_{36}	0.56	1.16	0.67	1.00	1.34	1.76	0.156
C_{37}	0.50	1.09	0.59	0.75	1.00	1.64	0.133
C_{38}	0.32	0.74	0.40	0.57	0.61	1.00	0.088

Notes: λmax = 6.0092; CI = 0.0018; CR = 0.0015 < 0.1.

(6) Establish the cloud model matrix of risk indicators weights and risk values.

According to the sample data of risk values and weights from questionnaires, the digital eigenvalues of risk values cloud and weights cloud using Reverse Cloud Generator can be calculated, just as shown in Tables 8 and 9.

Table 8. The weight cloud models of risk indicators.

The second level	**The third level**	**Ex**	**En**	**He**
Policy and legal risk (B1) Ex = 1871 En = 0.0014 He = 0.0025	C1	0.1741	0.0079	0.0054
	C2	0.0653	0.0126	0.0098
	C3	0.4051	0.0122	0.0098
	C4	0.0920	0.0065	0.0072
	C5	0.2195	0.0255	0.0195
	C6	0.0440	0.0176	0.0155

Table 8. *Cont.*

The second level	The third level	Ex	En	He
Management risk (B2) Ex = 0.2212 En = 0.0049 He = 0.0947	C7	0.0643	0.0275	0.0165
	C8	0.1769	0.0043	0.0085
	C9	0.2279	0.0020	0.0009
	C10	0.1769	0.0065	0.0032
	C11	0.1233	0.0085	0.0050
	C12	0.2306	0.0010	0.0003
	C13	0.1765	0.0375	0.0246
	C14	0.1765	0.0035	0.0022
	C15	0.0908	0.0005	0.0003
	C16	0.1866	0.0076	0.0058
	C17	0.0605	0.0315	0.0217
	C18	0.0992	0.0228	0.0234
	C19	0.0824	0.0315	0.0163
	C20	0.0672	0.0136	0.0053
	C21	0.0605	0.0347	0.0148
Technical risk (B3) Ex = 0.1631 En = 0.0034 He = 0.1324	C22	0.1340	0.0135	0.0036
	C23	0.2298	0.0335	0.0246
	C24	0.0882	0.0043	0.0002
	C25	0.0725	0.0058	0.0023
	C26	0.1041	0.0250	0.0026
	C27	0.0927	0.0169	0.0535
	C28	0.1073	0.0096	0.0046
	C29	0.1125	0.0057	0.0002
	C30	0.0589	0.0342	0.0046
Natural environmental risk (B4) Ex = 0.0997 En = 0.0076 He = 0.0631	C31	0.8196	0.0053	0.0225
	C32	0.1804	0.0002	0.0003
Society risk (B5) Ex = 0.3289 En = 0.0084 He = 0.0351	C33	0.2986	0.0035	0.0024
	C34	0.1144	0.0005	0.0003
	C35	0.2833	0.0342	0.0135
	C36	0.1187	0.0055	0.0035
	C37	0.1063	0.0213	0.0125
	C38	0.0787	0.0347	0.0116

Table 9. The risk value cloud models of indicators.

Risk indicators	Ex	En	He
C1	0.4209	0.0078	0.0083
C2	0.2092	0.0365	0.0293
C3	0.6643	0.0797	0.0651
C4	0.2103	0.0076	0.0003
C5	0.8065	0.0258	0.0174

Table 9. *Cont.*

Risk indicators	Ex	En	He
C6	0.0967	0.0391	0.0123
C7	0.1132	0.0406	0.0092
C8	0.2810	0.0312	0.0125
C9	0.5752	0.0024	0.0021
C10	0.4782	0.0053	0.0002
C11	0.2810	0.0022	0.0085
C12	0.3081	0.0155	0.0141
C13	0.7256	0.0258	0.0154
C14	0.8144	0.0095	0.0003
C15	0.3411	0.0096	0.0073
C16	0.5630	0.0312	0.0055
C17	0.2092	0.0053	0.0002
C18	0.4079	0.0262	0.0074
C19	0.3391	0.0258	0.0054
C20	0.2642	0.0120	0.0164
C21	0.2064	0.0078	0.0003
C22	0.6483	0.0155	0.0141
C23	0.8123	0.0053	0.0002
C24	0.4062	0.0334	0.0124
C25	0.3370	0.0258	0.0104
C26	0.4400	0.0045	0.0002
C27	0.3739	0.0621	0.0201
C28	0.3256	0.0312	0.0105
C29	0.3739	0.0099	0.0173
C30	0.2599	0.0053	0.0002
C31	0.4995	0.0029	0.0003
C32	0.1294	0.0258	0.0004
C33	0.8255	0.0045	0.0003
C34	0.1665	0.0037	0.0004
C35	0.8144	0.0312	0.0095
C36	0.3454	0.0024	0.0021
C37	0.2785	0.0024	0.0019
C38	0.2269	0.0058	0.0035

(7) Calculate the results of comprehensive evaluation.

According to the index weight cloud model and index value cloud model, the first level fuzzy comprehensive evaluation is performed, just as follows:

$$
\begin{aligned}
A_{B1} &= W_{B1} \circ R_{B1} \\
&= \begin{pmatrix} 0.1741 & 0.0079 & 0.0054 \\ 0.0653 & 0.0126 & 0.0098 \\ 0.4051 & 0.0122 & 0.0098 \\ 0.0920 & 0.0065 & 0.0072 \\ 0.2196 & 0.0255 & 0.0195 \\ 0.0440 & 0.0176 & 0.0155 \end{pmatrix}^T \circ \begin{pmatrix} 0.4209 & 0.0078 & 0.0083 \\ 0.2092 & 0.0365 & 0.0293 \\ 0.6643 & 0.0797 & 0.0651 \\ 0.2103 & 0.0076 & 0.0003 \\ 0.8065 & 0.0258 & 0.0174 \\ 0.0967 & 0.0391 & 0.0123 \end{pmatrix} \\
&= \begin{pmatrix} 0.5567 & 0.1776 & 0.1126 \end{pmatrix}
\end{aligned}
\tag{9}
$$

In a similar way,

$$B_{B2} = \begin{pmatrix} 0.6410 & 0.0714 & 0.0445 \end{pmatrix} \tag{10}$$

$$B_{B3} = \begin{pmatrix} 0.5065 & 0.1203 & 0.0721 \end{pmatrix} \tag{11}$$

$$B_{B4} = \begin{pmatrix} 0.4327 & 0.2640 & 0.0685 \end{pmatrix} \tag{12}$$

$$B_{B5} = \begin{pmatrix} 0.5847 & 0.1867 & 0.0625 \end{pmatrix} \tag{13}$$

Further, construct the secondary fuzzy relationship matrix R :

$$R = \begin{pmatrix} 0.5567 & 0.1776 & 0.1126 \\ 0.6410 & 0.0714 & 0.0445 \\ 0.5065 & 0.1203 & 0.0721 \\ 0.4327 & 0.2640 & 0.0685 \\ 0.5847 & 0.1867 & 0.0625 \end{pmatrix} \tag{14}$$

Combined with the indicator weights in the second level, the secondary evaluation results of the evaluation object are shown as follows:

$$
\begin{aligned}
B = W^T \circ R &= \begin{pmatrix} 0.1871 & 0.0014 & 0.0025 \\ 0.2212 & 0.0049 & 0.0947 \\ 0.1631 & 0.0034 & 0.1324 \\ 0.0997 & 0.0076 & 0.0631 \\ 0.3289 & 0.0084 & 0.0351 \end{pmatrix}^T \circ \begin{pmatrix} 0.5567 & 0.1776 & 0.1126 \\ 0.6410 & 0.0714 & 0.0445 \\ 0.5065 & 0.1203 & 0.0721 \\ 0.4327 & 0.2640 & 0.0685 \\ 0.5847 & 0.1867 & 0.0625 \end{pmatrix} \\
&= \begin{pmatrix} 0.5640 & 0.1161 & 0.0981 \end{pmatrix}
\end{aligned}
\tag{15}
$$

(8) Establish the remark cloud model

The remark cloud model is established according to the model-driven method based on the golden ratio in this paper. Namely, there are five evaluation grades which are in the interval [0,1]. The meaning of different risk grades and the digital eigenvalues of the remark cloud model on each grade are shown in Tables 10 and 11.

Table 10. The meanings of different risk grades.

Risk grades	**Meaning**
Higher	The occurrence probability of project risk is greater, and the risk occurrence would cause much greater loss.
High	The occurrence probability of project risk is great, and the risk occurrence would cause great loss.
Middle	The occurrence probability of project risk is medium, and the risk occurrence would cause medium loss.
Low	The occurrence probability of project risk is low, and the risk occurrence would cause little loss.
Lower	The occurrence probability of project risk is lower, and the risk occurrence would cause much smaller loss.

Table 11. The remark cloud models of the UHV power construction project.

Risk level	**Higher**	**High**	**Middle**	**Low**	**Lower**
Ex	1	0.691	0.5	0.309	0
En	0.1031	0.64	0.039	0.064	0.1031
He	0.013	0.008	0.005	0.008	0.013

(9) Determine the risk level of UHV power construction project.

Input the digital eigenvalues of the evaluation cloud models and remark cloud models into the Forward Cloud Generator, the cloud chart of each kind of risk indicator and overall risk are generated, just as shown in Figures 7–12. According to the relative position of the evaluation cloud and remark cloud, we can obtain the risk level of "Zhejiang-Fuzhou" UHV power transmission construction project.

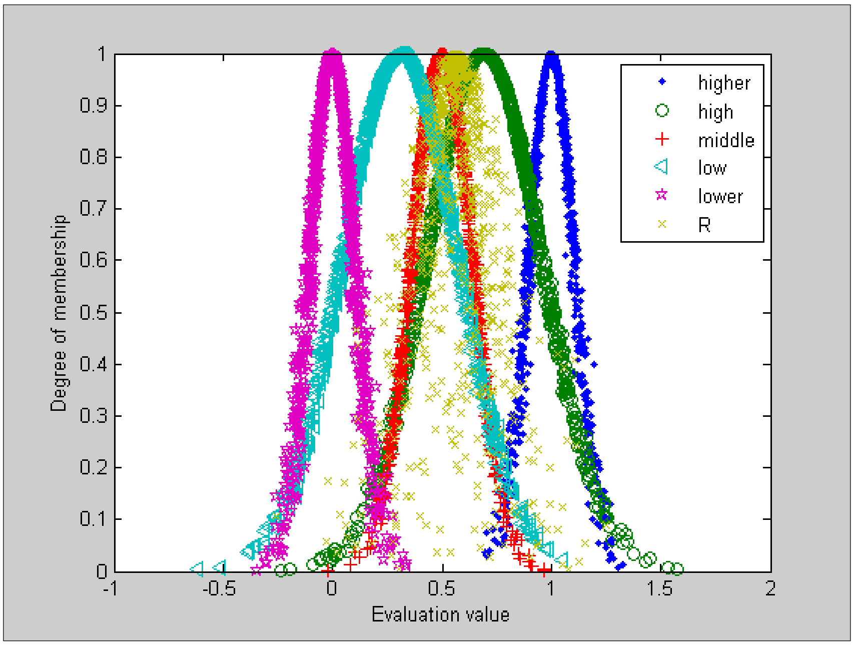

Figure 7. The cloud chart of overall risk.

As shown in Figure 7, the risk evaluation cloud model of “Zhejiang-Fuzhou” UHV power transmission construction project lies between “middle” and “high” level and closer to “middle” level. According to the cloud model eigenvalues (Ex = 0.5640, En = 0.1160， He = 0.0981) of the overall risk, the entropy and excess entropy are smaller which means that the cloud droplets are relatively concentrated. Therefore, the overall risk level of “Zhejiang-Fuzhou” UHV power transmission construction project is closer to “middle”. The risk value centered on 0.5640 and there exists the possibility of “middle” or “high” level risk at a smaller range. Obviously, it is essential to analyze the important risk indicators and put forward specific control measures, so as to provide a safeguard for the sustainable development of the project.

Figure 8 shows the evaluation cloud chart of the “policy and law risk” on “Zhejiang-Fuzhou” UHV power transmission construction project. The “policy and law risk” level lies between the “middle” and “high” level and closer to the “middle” level. In accordance with the cloud model eigenvalues (Ex = 0.5567, En = 0.1776, He = 0.1126) of the “policy and law risk”, the entropy and excess entropy are bigger, which means that the cloud droplets are relatively dispersed. Therefore, the “policy and law risk” level of “Zhejiang-Fuzhou” UHV power transmission construction project is closer to the “middle” level. The risk value centers on 0.5567 and there exists the possibility of “low” and “high” level risk.

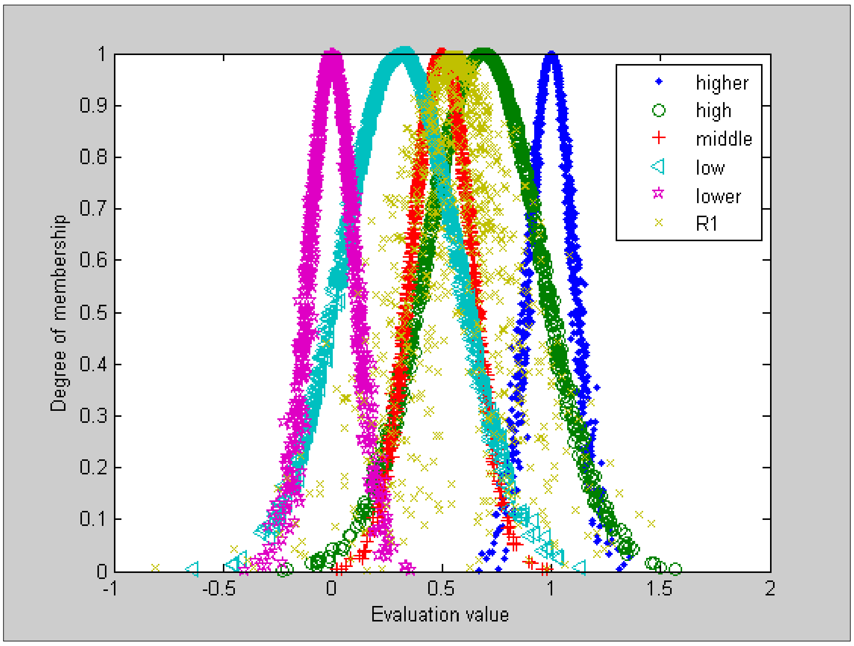

Figure 8. The cloud chart of the policy and law risk.

Figure 9 shows the evaluation cloud chart of the “management risk” for the “Zhejiang-Fuzhou” UHV power transmission construction project. The “management risk” level lies between “middle” and “high” levels and closer to “high” level. According to the cloud model eigenvalues (Ex = 0.6410, En = 0.0714, He = 0.0445) of the “management risk”, the entropy and excess entropy are smaller, which means that the cloud droplets are relatively concentrated. Therefore, the “management risk” level of the “Zhejiang-Fuzhou” UHV power transmission construction project is closer to “middle” level. The risk value centers on 0.6410 and there exists the possibility of “low” and “high” level risk at a smaller range.

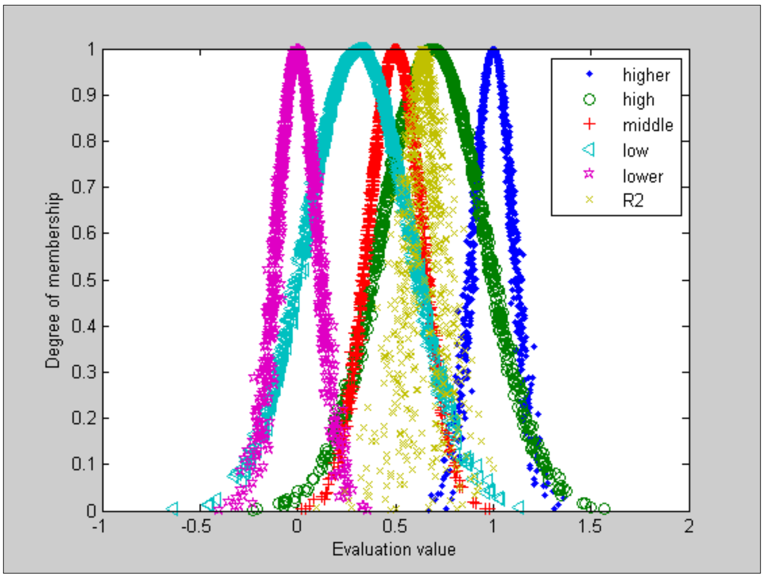

Figure 9. The cloud chart of management risk.

Figure 10 shows the evaluation cloud chart of the "technical risk" of the "Zhejiang-Fuzhou" UHV power transmission construction project. The "technical risk" level lies between "middle" and "high" levels and closer to the "middle" level. According to the cloud model eigenvalues (Ex = 0.5065, En = 0.1203, He = 0.0721) of the "technical risk", the entropy and excess entropy are rather small, which means that the cloud droplets are relatively concentrated. Therefore, the "technical risk" level of "Zhejiang-Fuzhou" UHV power transmission construction project is closer to the "middle". The risk value centers on 0.5065 and there exists the possibility of "middle" and "high" level risk.

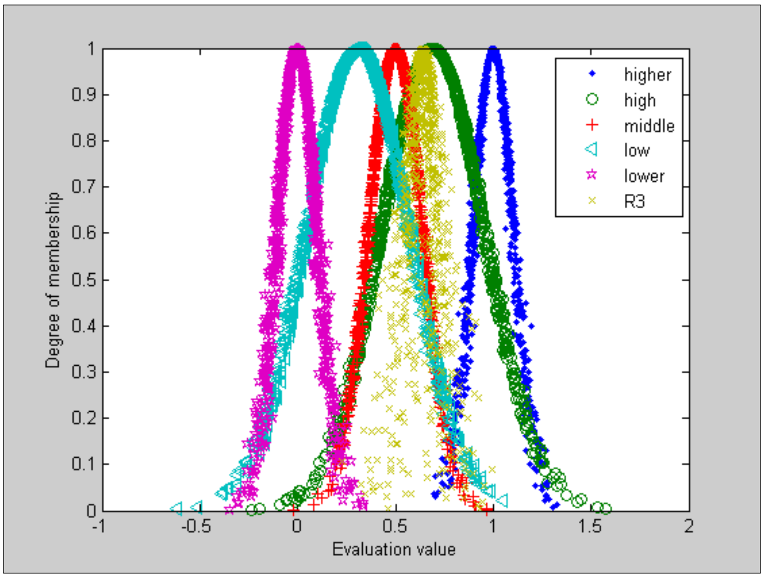

Figure 10. The cloud chart of technical risk.

Figure 11 shows the evaluation cloud chart of the "natural environmental risk" for the "Zhejiang-Fuzhou" UHV power transmission construction project. The "natural environmental risk" lies between "low" and "middle" levels and closer to "middle" level. According to the cloud model eigenvalues (Ex = 0.4327, En = 0.2640, He = 0.0685) of the "natural environmental risk", the entropy is rather big and excess entropy is smaller, which means that the cloud droplets are relatively dispersed. Therefore, the "natural environmental risk" level of "Zhejiang-Fuzhou" UHV power transmission construction project is closer to the "middle" level. The risk value centers on 0.4327 and there exists the possibility of "middle" and "high" level risk.

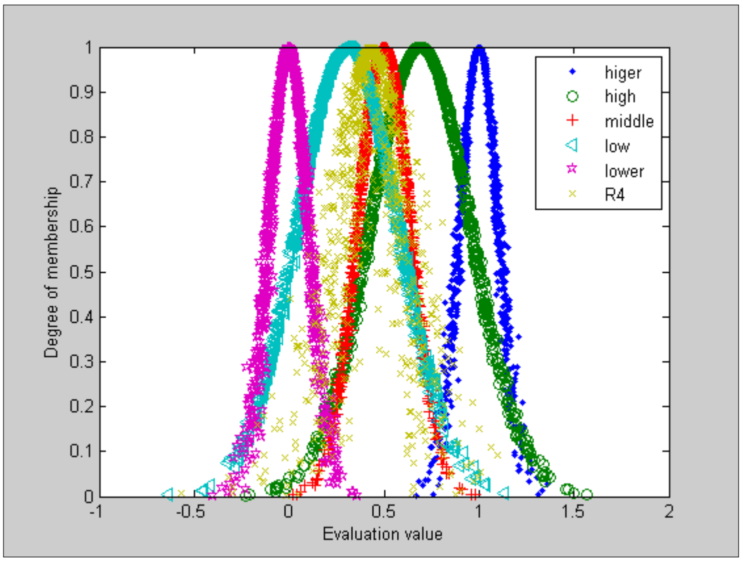

Figure 11. The cloud chart of natural environment risk.

Figure 12 shows the evaluation cloud chart of the "society risk" for the "Zhejiang-Fuzhou" UHV power transmission construction project. The "society risk" level lies between "middle" and "high" levels and closer to the "middle" level. According to the cloud model eigenvalue (Ex = 0.5847, En = 0.1867, He = 0.0625) of the "society risk", the entropy is bigger and the excess entropy is rather small, which means that the cloud droplets are relatively dispersed. Therefore, natural environmental risk level of the "Zhejiang-Fuzhou" UHV power transmission construction project is closer to the "middle". The risk value centers on 0.5847 and there exists the possibility of "middle" and "high" level risk.

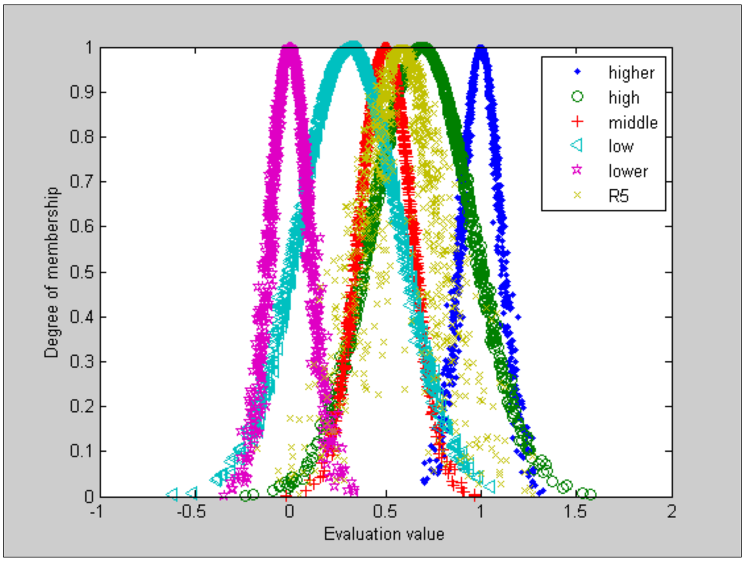

Figure 12. The cloud chart of society risk.

Generally speaking, based on the comparison of the eigenvalues and cloud charts of the secondary risk evaluation indicators, the "management risk" is the highest, followed by the "society risk", "policy and legal risk", "technology risk" and "natural environmental risk". Moreover, the "management risk" and "social risk" are higher than the overall risk of the project, while the other three secondary risk indicators are lower than it. This suggests that the secondary indicators "management risk" and "social risk" should be paid more attention in the context of risk management and control of "Zhejiang-Fuzhou" UHV power transmission construction project.

6.3. Risk Control Recommendations

As we all know, the UHV power transmission construction plays a key role in the sustainable development of energy in China. Therefore, the risk management on the UHV project is necessary, so as to fully realize its vital functions. According to the risk evaluation results, the "management risk" and "social risk" should be paid more attention, so as to improve the chance of success and reduce potential risk. The specific risk control recommendations are as follows.

6.3.1. Risk Control Recommendations for "Management Risk"

Learning from the experience of similar projects, the budget for the "Zhejiang-Fuzhou" UHV power transmission project should be prepared as reasonably as possible. In accordance with the characteristics of project and practice, it is appropriate to establish engineering budget tables using valuation type contracts, so as to reduce the contract risk. The total price contract should be chosen when the risk of the project is low. On the contrary, when the risk possibility of a project is large, it is better to offer a contract based on the unit price. When the cost cannot be measured, the contract of "cost plus remuneration" should better be used.

It is necessary to establish a reasonable project bidding rule for the "Zhejiang-Fuzhou" UHV power transmission project. In the process of project bidding, on the one hand, the bidding work should comply with relevant laws and regulations of the country. On the other hand, in the organization of the project, reasonable project bidding rules should be established to eliminate risk. At the same time, a strict qualification examination process is essential to remove unqualified bidders from the bidding.

An effective early warning system for the "Zhejiang-Fuzhou" UHV power transmission project should be established, so as to find out all significant problems affecting the project progress as soon as possible. Then, effective solutions will be put forward to avoid these problems causing more serious impacts. In view of the problems in engineering construction, a long-term communicating mechanism should be established to create a favorable external environment and realize a barrier-free construction. The construction progress plan should be formulated in accordance with the contract. In additional, supervision engineers should review the construction according to the plan over time. When some factors delay the project, supervision engineers should require the contractor to revise the plan and increase construction machinery, so as to complete the project before the completion time.

Strengthen the management of budget, material and internal control, so as to improve the effectiveness of corporate decisions. The construction organization should transform the traditional logistics management mode into a modern one, with a unified organization, an information system, unified selection standard for equipment, allocation and distribution, *etc*. On this basis, the corporation can improve the management efficiency by allocating resources and controlling operational risk efficiently.

For the "Zhejiang-Fuzhou" UHV power transmission project, the investment risk should be controlled by establishing an efficient cost information system. In this cost information system, the budget cost, quota determination and claims can be monitored and managed. At the same time, the security management risks should be controlled during each stage. The construction unit should strengthen safety education, so as to improve the safety technology and safety awareness of each constructor. In addition, more supervisors should be employed to intensify supervision and inspection functions, and supervise the construction by way of inspection and field study.

6.3.2. Risk Control Recommendations for "Society Risk"

Before the construction of "Zhejiang-Fuzhou" UHV power transmission project, public communication should be made through TV, radio, newspapers, brochures, *etc*. During the communication process, the construction significance and engineering safety knowledge related to this project should be disseminated. At the same time, an information communication platform should be established to strengthen the communication between different interested subjects. Based on these measures, the worries from members of the community and local villagers about this UHV power transmission project can be eliminated.

The power grid company should sign a contract with local government for the sake of coordination. The local government is responsible for land requisition, house relocation, crop compensation and so on. In addition, all these assignments above should be brought into the annual appraisal of the local government. On the other hand, the power grid company should make full use of its resources to complete the external coordination work.

In order to reduce the risk of ecological environment destruction, the option of transmission line path should fully take the proposals from related departments into consideration. The line path should be far from ecologically sensitive areas, such as the nature reserve, scenic area and water area. Simultaneously, the line path should be away from dense forest areas so as to reduce deforestation and protect the environment. In order to decrease potential impacts on the local economy, the line path should be established away from cities, large-scale enterprises and important communication facilities.

The power grid company should keep in close contact with the local government and public security organization, so as to strengthen the security of project construction. Facing "mass incidents", such as petitions, demagoguism and demonstration, the power grid company should pay closer attention and introduce relevant measures to address concerns in a timely manner. In summary, social issues should be addressed during construction to keep negative impacts on local communities to a minimum.

7. Conclusions

In addressing the large number of risks in UHV power construction projects, this paper adds insight on risk management, so as to fully realize the advantages of UHV technology in promoting energy sustainability. Firstly, the risk evaluation index system is established based on Delphi method, from a view of sustainable development. For the fuzziness, uncertainty and randomness of the UHV power construction projects, a hybrid evaluation model is implemented to evaluate the risk of UHV power transmission construction projects. At last, an empirical example concerning the risk of the "Zhejiang-Fuzhou" UHV power transmission construction project is illustrated. The main results of this study are as follows:

(1) The risk evaluation index system for the UHV power transmission construction project based Delphi method contains five second-level indicators and 38 third-level indicators. The second-level indicators are policy and law risk, management risk, technology risk, natural environment risk, and society risk. All this indicators are selected based on a view of sustainable development for UHV projects.
(2) The risk of the "Zhejiang-Fuzhou" UHV power transmission construction project lies at a "middle" to "high" level and closer to "middle" level, which indicates that we should increase risk control of the project. The "management risk" has the highest level, followed by "society risk", "policy and legal risk", "technology risk" and "natural environmental risk", respectively. We should reinforce the risk management and control on "management risk" and "society risk" for the "Zhejiang-Fuzhou" UHV power transmission construction project. Additionally, some specific risk control recommendations are put forward to control the "management risk" and "society risk", so as to make sure the sustainable construction of the project is achieved.
(3) The hybrid evaluation model proposed in this paper takes on board all advantages of group decision, which reduce influence from the incompleteness of information and subjective judgment. Moreover, it realizes the transformation between qualitative and quantitative evaluation, and reflects the fuzziness, uncertainty, randomness and discreteness of evaluation objects, with the help of the FCE and cloud model. The case study illustrates the effectiveness of the present model in providing accurate estimates on the risk of UHV power transmission construction projects. In addition, through risk identification and control, the level of risk management can be improved, which can promote the sustainable construction of UHV projects.

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Author Contributions

Huiru Zhao and Nana Li conceived and designed the research method in this paper; Nana Li performed the empirical analysis and wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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