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A Fuzzy Comprehensive Evaluation Model for Sustainability Risk Evaluation of PPP Projects

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Abstract: Evaluating the sustainability risk level of public–private partnership (PPP) projects can reduce project risk incidents and achieve the sustainable development of the organization. However, the existing studies about PPP projects risk management mainly focus on exploring the impact of financial and revenue risks but ignore the sustainability risks, causing the concept of "sustainability" to be missing while evaluating the risk level of PPP projects. To evaluate the sustainability risk level and achieve the most important objective of providing a reference for the public and private sectors when making decisions on PPP project management, this paper constructs a factor system of sustainability risk of PPP projects based on an extensive literature review and develops a mathematical model based on the methods of fuzzy comprehensive evaluation model (FCEM) and failure mode, effects and criticality analysis (FMECA) for evaluating the sustainability risk level of PPP projects. In addition, this paper conducts computational experiment based on a questionnaire survey to verify the effectiveness and feasibility of this proposed model. The results suggest that this model is reasonable for evaluating the sustainability risk level of PPP projects. To our knowledge, this paper is the first study to evaluate the sustainability risk of PPP projects, which would not only enrich the theories of project risk management, but also serve as a reference for the public and private sectors for the sustainable planning and development.

Keywords: sustainability risk evaluation; factor system; FCEM; FMECA; PPP

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1. Introduction

Public–Private Partnership (PPP) has been popular for 15 years, and continues to grow at a fast pace in China. The Chinese government continuously encourages the expansion of PPP applications to boost economic revenues; this emerging management pressure has made the study of PPP project management a research hotspot, and several achievements have been made [1–3].

As a new financing model, the relevant theory of PPP is imperfect [4] and the process of PPP holds great uncertainty [5]. Many uncertain factors can affect the implementation process of PPP projects, including environment risk, payment risk, etc. [6], thus many scholars have conducted an in-depth study for this problem. For example, Marques examined how risk is reflected in infrastructure regulatory contracts and got a conclusion that risk is the key issue in contracting with the private sectors [7]. Roehrich et al. applied the logic of bounded rationality and explored the extent to which companies implement responsible supply chain management (RSCM) as a result of their reputational risk exposure, and how bounded rationality impacts on the decision of RSCM [8,9]. Many other scholars have studied the relationship between public and private sectors in PPP projects [10]. Barlow proved that European governments were increasingly partnering with the private sector to underwrite the costs of constructing and operating public hospitals and other health care facilities and delivering services by constrained national budgets [11]. Hoejmose et al. proposed that responsible supply chain management can help protect a firm's corporate reputation by shielding it from negative media attention and consumer boycotts [12]. However, many studies explored the role of organization and ecosystem in complex PPP projects [13–15]. Even though there are so many studies on PPP projects, unfortunately, little attention has been given to sustainability risk of PPP projects. Here, sustainability risk is the combination of likelihood and consequences of events which affect the achievement of organization's sustainable development. It is related to the concepts of sustainable development and the "triple bottom line" [16], which emphasizes "the development should meet the needs of the present world without compromising the ability of the future generations to meet their own needs" [17]. Sustainability risk has been brought into many areas, and numerous studies have been conducted to discuss its connotations, applications and mechanisms. Among them, Touboulic and Walker [18] investigated theoretical perspectives in sustainable supply chain management and contributed to understanding the current state in the field of PPP and its future development. Cucuzzella [19] presented a series of design projects to illustrate the difference in thinking and outcomes when sustainability is thought of in varying temporal and spatial perspectives. Harclerode et al. [20] developed a foundational framework to define and integrate the sustainability and risk management objectives in the life cycle of complex project towards a more sustainable state. In the area of PPP project management, the common perception of sustainability risk evaluation involves economy, society, resources, and environment aspects, and aims at monitoring changes of PPP projects, adjusting strategies so that a balance among economy, society, resources, and environment can be found. However, there is no recipe for reaching this balance [21,22]. Furthermore, complex arrangements and incomplete contracting in PPP projects have led to increased risks of unsustainability, for both public and private partners [23,24]. Effective sustainability risk evaluation of PPP projects is therefore challenging and demanding.

At the same time, the accuracy of sustainability risk evaluation is crucial for PPP as a whole [25]. Risk evaluation of PPP projects is fundamentally different from that of traditional projects, where traditional projects emphasize the temporary and disposable nature of which risk evaluation is limited to the processes of design and implementation. In PPP projects, investors place special emphasis on the sustainability of projects and are entitled to reducing investments or terminating projects if PPP fails to achieve sustainability standards. Accordingly, one of the most important drivers for value-for-money is sustainability risk evaluation, which means the sustainability risk of a PPP project can be evaluated, prevented, and controlled during the implementation process [26]. As a result, lower-risk and higher-quality PPP projects may be implemented relative to conventional methods.

This work is intended to reduce project risk incidents and achieve the sustainable development of the organization by accurately evaluating the sustainability risk level of PPP projects and achieving the most important objective of providing a reference for the public and private sectors when making decisions on PPP project management. The rest of this paper is organized as follows. Section 2 analyzes the main influencing sustainability risk factors of PPP projects, by classifying these factors into five categories: culture and society, cost and economy, ecology and environment, project and organization, politics and policy, via an extensive literature review, and then this paper builds a factor system of sustainability risk of PPP projects. In Section 3, a fuzzy comprehensive evaluation model for assessing the sustainability risk level of PPP projects, based on FCEM and FMECA, is proposed, which provides a holistic view focused on reflecting the sustainability risk level factors of PPP projects by evaluating the sustainability risk level of each category. Section 4 verifies the effectiveness and feasibility of this model using a computational experiment. Section 5 draws the conclusions.

2. Factor System of Sustainability Risk of PPP Project

Risk management exerts a profound influence on PPP project management and its success [26]; especially, sustainability risk evaluations have been found to be highly variable, intuitive, subjective, and unsophisticated [27,28]. Given its critical importance in PPP projects, many studies have been conducted to seek an approach to evaluate the level of sustainability risk evaluation effectively, such as the work of Xu et al. [25], where a fuzzy synthetic evaluation model for assessing the level of a particular critical risk group, and the sustainability risk level associated with PPP projects in China, based on objective evidence rather than subjective judgment, was developed. Effah Ameyaw [29] conducted a risk perception analysis in water supply projects in Ghana to evaluate the risk criticality, risk management capability, and risk factors that could influence the sustainability risk level of water supply projects. Kumaraswamy [26] analyzed the factors of sustainability risk from the perspective of project teams to empower them to focus on developing sustainable infrastructures and, ultimately, overall sustainable development. Jin [24] established an artificial neural network model for modeling risk allocation decision-making processes in PPP projects. Hayford and Partner [30] proposed an optimal sustainability risk model which could enable partners to deal with external changes and events, and explore the behaviors between different partners, even while confronted with opposite objectives in the allocation of risks. However, this work either deems the sustainability risk level as one that is only affected by the status of the PPP project itself [25] or management capability [29], but lacks foundations and empirical evidence to support their claims.

More importantly, sustainability risk evaluation of PPP projects is a complex process, in which all project stakeholders cooperate and compete with each other in accordance with its sustainable development strategic objectives [31]. Running a PPP project at the lowest level of sustainability risk is a challenge for any enterprise, since many unpredictable factors could influence it [26]. This is probably because the studies on PPP project management, including risk management, are mainly concerned with processes and techniques [32,33]. PPP projects have a great impact developing the social economy and building a harmonious society [34]; thus, merely using risk indicators of a PPP project to measure the sustainability risk level is insufficient [35]. Zhang et al. [36] argued that measurements supported by other factors, such as society and the environment, need to be employed. Nonetheless, no further empirical studies have been conducted to support their conclusions.

Recently, Valipour et al. [37], Li and Zou [38] and Chou et al. [39] argued that the sustainability risk factors of PPP projects, if integrated with the aspects of financial, legal, and political risks, can contribute to the evaluation of the sustainability risk level of PPP projects, and allow a more logical and holistic understanding and interpretation of the sustainability risk evaluation process. In addition, although many scholars have already used the determinants of PPP project sustainability risk factors in aspects of economy, society, environment, management ability, and techniques, some of them lacked integrity [40,41].

To evaluate the sustainability risk level of PPP projects and maintain the systematic nature of the factors, the 1st-level sustainability risk factors of PPP projects can be generalized into five categories: culture and society, cost and economy, ecology and environment, project and organization, and politics and policy [24,36,42]. These factors can help evaluate the sustainability risk level of PPP projects and maintain the systematic nature. There are many 2nd-level evaluation factors in each 1st-level sustainability risk factor, so it is important to build a sustainability risk factor system before evaluating the sustainability risk level of a PPP project. Based on existing research and literature, the factor system of the sustainability risk of a PPP project can be built, as shown as Table 1.

Table 1. Factor system of sustainability risk of PPP project.

1st-Level Factors	2nd-Level Factors and Contents		References
1. Culture and Society	1.1. Culture	Local cultural inheritance Cultural heritage protection Respect for local cultural customs Cultural diversity protection Spread of advanced culture	[31,35,36,42–46]
	1.2. Public	Public participation Public awareness Public satisfaction Public happiness Public credit Related organization participation Degree of project on behalf of the public	
	1.3. Safety	Safety of employees Safety of users Safety of local Community Safety of Construction Safety technology training Impact on the safety of other projects	
	1.4. Social	Absorb local employment Social service Harmony between project and society Local employment skills Sustainable construction consciousness Local social environment	
2. Cost and Economy	2.1. Cost	Cost of resettlement Cost of ecological compensation Cost of labor Cost of the user Cost of land	[24,25,45–49]
	2.2. Economic	Interest rate Foreign currency exchange Market demand Project uniqueness Inflation	
3. Ecology and Environmental	3.1. Ecosystem	Natural landscape protection Fauna and flora protection Rate of change of green coverage in built-up area Project barrier effect Rate of green coverage in built-up area Harmony between project and ecosystem Land governance	[42–44,50,51]
	3.2. Environmental Pollution and Governance	Industrial sulfur dioxide emissions Industrial waste water discharge Industrial soot emissions Municipal wastewater treatment rate Domestic garbage harmless treatment rate Industrial dust removal Industrial sulfur dioxide removal Pollution control capital investment Industrial solid waste comprehensive utilization	
4. Project and Organization	4.1. Project	Project design Project financing Project Technology Project construction Daily maintenance Synergy with other projects Renovation	[35,36,42,44–47,52]
	4.2. Organization	Project management maturity Shared resource allocation capabilities Stakeholder coordination Capabilities Project portfolio capabilities Multi-objective optimization capabilities	

Table 1. *Cont.*

1st-Level Factors	2nd-Level Factors and Contents		References
5. Politics and Laws	5.1. Politics	Government decision-making mistakes Policy updates Political opposition Political instability Government dishonesty Project publicization Government decision-making process lengthy	[25,53–57]
	5.2. Laws	Laws and regulations Project contract Third party default	

3. Methodologies

3.1. Fuzzy Comprehensive Evaluation

During the process of risk evaluation, many factors that affect the level of sustainability risk are with a strong fuzzy uncertainty and cannot be analyzed quantitatively, therefore, it is difficult to evaluate the sustainability risk level by a single, defined management criterion [55]. To solve this fuzzy uncertainty problem, Zadeh [56] proposed the concept of fuzzy sets in 1965 and laid the foundation for the application of FCEM in the area of risk evaluation.

FCEM is based on the membership degree theory in fuzzy mathematics, which transform the qualitative evaluation into quantitative evaluation [57–59]. It has now become an effective multi-factor decision-making tool for comprehensive evaluation. Combining with experts grading method, FCEM can make a full reflection on the evaluation criteria and the influence factors of fuzziness, then produce evaluation results closer to the actual situation [60].

From early 1990s, FCEM has been applied to solve real-word problems, and studies on the adoption of this model has been rapidly expanded to various fields, including, but not limited to regional water resources capacity [61], aircraft flight safety [62,63], health, safety and environment management, teaching performance [64] and international relations [65]. According to these studies, the sensitivity of FCEM is much higher compared with other methods thanks to the predetermined weights and decreased fuzziness by establishing membership functions. Therefore, we choose FCEM as the tool to evaluate the sustainability risk level and the process can be divided into 5 steps [66]:

Step 1: Establish a risk assessment factor set. Elements in set Q are the factors that affect the risk evaluation. An integrated level of risk is reflected by these elements at a given time, the risk assessment factor set Q and the elements in this set shown as Equations (1) and (2):

$$Q = \{Q_1, Q_{......}, Q_i, Q_{......}, Q_n\} \tag{1}$$

$$Q_i = \{Q_{i1}, \ldots, Q_{ij}, \ldots, Q_{im}\}\ (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \tag{2}$$

where Q is the risk assessment factor set and n is the number of 1st-level sustainability risk factors in set Q; Q_i ($i = 1, 2, \ldots, n$) is the ith 1st-level sustainability risk factors, Q_{ij} is the jth 2nd-level sustainability risk factor of Q_i and m is the number of 2nd-level sustainability risk factor. A fuzzy logic relationship is existing among different factors in set Q, and this relationship can be expressed in the risk assessment comments set P.

Step 2: Establish a risk assessment comment set P. Comment set P is a collection consisted of 5 comments that evaluators make evaluation to the sustainability risk level according to the criterion of FCEM, shown as Equation (3):

$$P = \{p_1, p_2, p_3, p_4, p_5\} \tag{3}$$

where P is the risk assessment comment set, p_1, p_2, p_3, p_4 and p_5 are the comments representing the sustainability risk level are "Devastating", "Unacceptable", "General", "Acceptable" and

"Desirable", which is represented as the score of comment: 1, 2, 3, 4 and 5, respectively. Thus, the risk assessment comment set can be recorded as $P = \{p_1, p_2, p_3, p_4, p_5\} = \{\text{Devastating, Unacceptable, General, Acceptable, Desirable}\} = \{1, 2, 3, 4, 5\}$. According to this criterion, the fuzzy comprehensive evaluation matrix R and $R_i(i = 1, 2, \ldots, n)$ can be determined, shown as Equation (4):

$$R_i = \left\{ \begin{array}{ccccc} r_{i11} & r_{i12} & r_{i13} & r_{i14} & r_{i15} \\ r_{i21} & r_{i22} & r_{i23} & r_{i24} & r_{i25} \\ r_{i31} & r_{i32} & r_{i33} & r_{i34} & r_{i35} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ r_{im1} & r_{im2} & r_{im3} & r_{im4} & r_{im5} \end{array} \right\} \quad (4)$$

Here $R = \{R_1, R_{\ldots\ldots}, R_i, R_{\ldots\ldots}, R_n\}$ and $R_i(i = 1, 2, \ldots, n)$ are the fuzzy comprehensive evaluation matrix of Q and Q_i, $r_{imk}(k = 1, 2, 3, 4, 5)$ is the comment of 2nd-level sustainability risk factor Q_{im}. Then, the fuzzy comprehensive evaluation matrix of 1st-level sustainability risk factors can be constructed based on the scores of 2nd-level sustainability risk factors.

Step 3: Build a weights vector W and W_i'. Each element in set Q and Q_i makes different contribution to the realization of risk assessment, so the weight of these factors are different. The assessment index weights vector can be determined, shown as Equations (5)–(8):

$$W = \{W_1, W_2, \ldots, W_i, \ldots, W_n\}\ (i = 1, 2, \ldots, n) \quad (5)$$

$$W_i' = \left\{W_{i1}', W_{i2}', \ldots, W_{ij}', \ldots, W_{im}'\right\}\ (i = 1, 2, \ldots, n; 1 \leq j \leq m) \quad (6)$$

$$\sum_{i=1}^{n} W_n = 1 \quad (7)$$

$$\sum_{j=1}^{m} W_{im}' = 1 \quad (8)$$

where W and W_i' are the weights vector of 1st-level and the 2nd-level sustainability risk factors, W_i and W_{im}' is the weight of Q_i and Q_{im}, respectively. The values of W_i and W_{im}' can be calculated by the method of Failure Mode, Effects and Criticality Analysis (FMECA).

Step 4: Establish a fuzzy comprehensive assessment matrix G to reflect the sustainability risk level of the PPP project, shown as Equations (9) and (10):

$$G = W \cdot B^T \quad (9)$$

$$B = \begin{pmatrix} B_1, & \ldots, & B_i, & \ldots, & B_n \end{pmatrix} \quad (10)$$

$$B_i = W_i' \cdot R_i \quad (11)$$

where G is the fuzzy comprehensive assessment matrix which could reflect the sustainability risk level of PPP project, B_i is the fuzzy comprehensive assessment matrix of the 1st-level sustainability risk factor Q_i $(i = 1, 2, \cdots, n)$, B is the fuzzy comprehensive assessment matrix set. According to Equations (9)–(11), the fuzzy comprehensive assessment matrix of different levels assessment factors can be calculated.

Step 5: Calculate the value of sustainability risk level of PPP project, recorded as Z, and the sustainability risk level of 1st-level risk factor, recorded as Z'. Combined with risk assessment comment set P, fuzzy comprehensive assessment matrix G and B_i, the value of sustainability risk level can be calculated by Equations (12)–(14):

$$Z = P \cdot G \quad (12)$$

$$Z' = \begin{pmatrix} Z_1, & \ldots, & Z_i, & \ldots, & Z_n \end{pmatrix} \quad (13)$$

$$Z_i = P \cdot B_i \tag{14}$$

where Z is the sustainability risk level of the project, Z_i is the sustainability risk level of the 1st-level risk factor Q_i. Z' is the set of the 1st-level risk factors' sustainability risk level. Through Equations (12)–(14), the value of sustainability risk level of the PPP project and the sustainability risk level of 1st-level risk factors can be obtained, which would provide a basis for the sustainability risk management decisions.

3.2. Failure Mode, Effects and Criticality Analysis

According to Step 3 in Section 3.1, the values of weights vector W and W_i' are very important to determine the sustainability risk level and can be calculated by the method of FMECA.

FMECA is an inductive analytical tool provides a systematic, comprehensive evaluation and analyzes the effects of potential failures in the system design [67]. The process of FMECA includes a review and assessment of failure modes, the impact of those failures on system operation and identifies the effects, if any, on the operational safety of the system [65]. FMECA provides appropriate measures depending on the cause of the problem to prevent the recurrence of the failure after determining the possible system failures and failure probabilities, severity and hazards of each component [68,69]. According to FMECA, the weight of sustainability risk factors can be calculated by Equations (15) and (16):

$$W_i'' = \frac{H_i \times S_i \times D_i}{C_i} \tag{15}$$

$$W_{im}'' = \frac{H_{im} \times S_{im} \times D_{im}}{C_{im}} \tag{16}$$

where W_i'' is the cross-sectional area of 1st-level sustainability risk factor Q_i, W_{im}'' is the cross-sectional area of the 2nd-level sustainability risk factor Q_{im}. H_i is the occurrence probability of Q_i. S_i is the loss and impact after Q_i occurs. D_i is the perceived degree of Q_i, C_i is the ability to control and compensate the loss after Q_i occurs. The value of H_i, S_i, D_i and C_i can be obtained by experts grading method (EGM) where $H_i = [1, 5]$, $S_i = [1, 5]$, $D_i = [1, 5]$, $C_i = [1, 5]$. The principle of expert evaluation are shown as Equations (17)–(20):

$$H_i = \begin{cases} 1 & Lowest\ probability\ of\ risk \\ 5 & Highest\ probability\ of\ risk \\ h_i & Otherwise \end{cases} \tag{17}$$

Here $1 < h_i < 5$, the higher h_i, the higher the probability of Q_i.

$$S_i = \begin{cases} 1 & Slightest \\ 5 & Worst\ affected \\ s_i & Otherwise \end{cases} \tag{18}$$

Here $1 < s_i < 5$, the higher s_i, the worse impact after Q_i occurs.

$$D_i = \begin{cases} 1 & Most\ easily\ to\ be\ perceived \\ 5 & Most\ difficult\ to\ be\ perceived \\ d_i & Otherwise \end{cases} \tag{19}$$

Here $1 < d_i < 5$, the higher d_i, the greater the difficulty of being perceived

$$C_i = \begin{cases} 1 & Most\ difficult\ to\ control/\text{compensate the loss} \\ 5 & Most\ easily\ to\ control/\text{compensate the loss} \\ c_i & Otherwise \end{cases} \tag{20}$$

Here $1 < c_i < 5$, the higher h_i, the easier to control/compensate the loss after Q_i occurs.

According to Equations (17)–(19), the values of W_i'' and W_{im}' can be obtained, $W_i'' \in [0.2,\ 125]$, $W_{im}' \in [0.2,\ 125]$. Then, the weight of different levels of sustainability risk factors W_i and W_{im} would be obtained after normalized the value of W_i'' and W_{im}', respectively.

4. Computational Experiment and Results

PPP model has been widely used to deliver infrastructure projects. Over the past two decades, the Chinese government has been embarking on an ambitious program of large investments on infrastructure development. To facilitate urbanization in China, the funds required for urban infrastructure development during the first twenty years of the 21 century are expected to be around 3500–5000 billion RMB. Funds supported by government is unlikely to be used only to finance such large investments and so, reforms need to be undertaken by Chinese government regarding the investment and financing of infrastructure projects. Therefore, the model of PPP was brought in China to alleviate this problem.

Yu River Wetland Park (YRWP), in Xi'an, is a PPP demonstration project of the Ministry of Finance of the People's Republic of China, the total area of this park is 5236 acres and the total planned investment is 1.17 billion RMB which will be used in the construction of lake, heap mountain, wetland restoration, landscape greening, sculpture sketch, square construction, as well as other projects. This is a public welfare infrastructure project which focus on the ecological construction, environmental protection and sustainable development of Xi'an and will become the largest wetland park in the Xi'an if built in 2018. Many stakeholders such as Xi'an Municipal Government, GC Investment Group, SBG Construction and Development Co., Ltd. (Shanghai, China) participated in the construction process of this project. Obviously, the construction form of this park is a typical application of PPP model which emphasizes the effective cooperation between government and social capital. Therefore, the YRWP is representable of the wider PPP population. In addition, Xi'an is the ancient historical and cultural capital of China, with many historical sites and many ethnic groups; thus sustainability risk evaluation of this PPP project involves history, economy, culture, and many other aspects. Thus, the YRWP project can be chosen as an example for computational experiments to introduce the application and effectiveness of the sustainability risk evaluation model in this paper.

According to Table 1 and the process of sustainability risk evaluation, described in Section 3.1, the risk evaluation factor set of YRWP, Q, can be established (shown in Table 2).

Table 2. Risk assessment factor set of YRWP, Q.

1st-Level Sustainability Risk Factors Q_i	2nd-Level Sustainability Risk Factors Q_{ij}
Culture and Society Q_1	Local cultural inheritance Q_{11} Cultural heritage protection Q_{12} Respect for local cultural customs Q_{13} Cultural diversity protection Q_{14} Spread of advanced culture Q_{15} Public participation Q_{16} Public awareness Q_{17} Public satisfaction Q_{18} Public happiness Q_{19} Public credit Q_{110} Related organization participation Q_{111} Degree of project on behalf of the public Q_{112} Safety of employees Q_{113} Safety of users Q_{114} Safety of local Community Q_{115} Safety of Construction Q_{116} Safety technology training Q_{117} Impact on the safety of other projects Q_{118} Absorb local employment Q_{119} Social service Q_{120} Harmony between project and society Q_{121} Local employment skills Q_{122} Sustainable construction consciousness Q_{123} Local social environment Q_{124}

Table 2. *Cont.*

1st-Level Sustainability Risk Factors Q_i	2nd-Level Sustainability Risk Factors Q_{ij}
Ecology and Environmental Q_2	Natural landscape protection Q_{21} Fauna and flora protection Q_{22} Rate of change of green coverage in built-up area Q_{23} Project barrier effect Q_{24} Rate of green coverage in built-up area Q_{25} Harmony between project and ecosystem Q_{26} Land governance Q_{27} Industrial sulfur dioxide emissions Q_{28} Industrial waste water discharge Q_{29} Industrial soot emissions Q_{210} Municipal wastewater treatment rate Q_{211} Domestic garbage harmless treatment rate Q_{212} Industrial dust removal Q_{213} Industrial sulfur dioxide removal Q_{214} Pollution control capital investment Q_{215} Industrial solid waste comprehensive utilization Q_{216}
Cost and Economy Q_3	Cost of resettlement Q_{31} Cost of ecological compensation Q_{32} Cost of labor Q_{33} Cost of the user Q_{34} Cost of land Q_{35} Interest rate Q_{36} Foreign currency exchange Q_{37} Market demand Q_{38} Project uniqueness Q_{39} Inflation Q_{310}
Project and Organization Q_4	Project design Q_{41} Project financing Q_{42} Project Technology Q_{43} Project construction Q_{44} Daily maintenance Q_{45} Synergy with other projects Q_{46} Renovation Q_{47} Project management maturity Q_{48} Shared resource allocation capabilities Q_{49} Stakeholder coordination Capabilities Q_{410} Project portfolio capabilities Q_{411} Multi-objective optimization capabilities Q_{412}
Politics and Laws Q_5	Government decision-making mistakes Q_{51} Policy updates Q_{52} Political opposition Q_{53} Political instability Q_{54} Government dishonesty Q_{54} Project publicization Q_{56} Government decision-making process lengthy Q_{57} Laws and regulations Q_{58} Project contract Q_{59} Third party default Q_{510}

In Table 2, Q is the risk assessment factor set of YRWP, n is the number of 1st-level sustainability risk factors in set Q, which is $n = 5$. Q_i $(i \in (1,\ n))$ is the ith 1st-level sustainability risk factor, Q_{ij} is the jth 2nd-level risk factor of Q_i, and m is the number of 2nd-level risk factors. As shown in Table 2, the number of YRWP's risk factors are $m = \begin{cases} 24, & i=1 \\ 16, & i=2 \\ 10, & i=3 \\ 12, & i=4 \\ 10, & i=5 \end{cases}$.

According to the criterion of FCEM, and Equation (3), the risk assessment comment set of YRWP, P, can be established, where $P = \{p_1,\ p_2,\ p_3,\ p_4,\ p_5\} = \{1,\ 2,\ 3,\ 4,\ 5\}$. Fuzzy comprehensive evaluation matrix R and $R_i(i = 1,\ 2,\ \cdots,\ n)$ could also be determined based on the results of the questionnaire survey (the sample of this survey questionnaire is shown in Appendix A).

To collect the risk assessment comments of YRWP, a questionnaire survey was designed (Appendix A). The objective of this questionnaire survey included three categories: Management, implementation, and technical staff, which could ensure the correctness of the survey results. A total of 500 questionnaires were issued and 448 were collected, including nine unfinished and seven identical questionnaires; these 16 questionnaires were considered as invalid according to statistical principles, thus 432 questionnaires were valid. The recovery rate and the valid questionnaire were 89.6% and 86.4%, respectively. Therefore, the results of this survey are considered real and effective, and can be used for further analyses.

Based on the results of the assessment comments of 2nd-level sustainability risk factors, the fuzzy comprehensive evaluation matrix of 1st-level sustainability risk factors, was constructed. This section takes the 1st-level sustainability risk factors, Q_3 (Q_3 was selected because the number of 2nd-level sustainability risk factors of Q_3 is the minimum), as an example to introduce the calculation process of fuzzy comprehensive evaluation matrix R_3.

By analyzing the results of the survey questionnaires, the assessment comment of sustainability risk factor Q_3 can be obtained (Table 3).

Table 3. Assessment comment of sustainability risk factor Q_3.

Frequency / Risk Evaluation Indicators	**Comment**	P_1	P_2	P_3	P_4	P_5
Cost and Economy Q_3	Cost of resettlement Q_{31}	43	56	137	110	86
	Cost of ecological compensation Q_{32}	47	95	143	82	65
	Cost of labor Q_{33}	26	75	104	137	90
	Cost of the user Q_{34}	53	107	142	75	55
	Cost of land Q_{35}	50	96	144	80	62
	Interest rate Q_{36}	48	98	144	75	55
	Foreign currency exchange Q_{37}	75	107	131	62	57
	Market demand Q_{38}	39	90	140	91	72
	Project uniqueness Q_{39}	43	90	142	87	70
	Inflation Q_{310}	43	111	105	73	56

In Table 3, the level of comment of 2nd-level risk factor Q_{im} can be calculated by $r_{imk} = \frac{Frequency(Q_{imp_\alpha})}{\sum_{\alpha=1}^{5} Frequency(Q_{imp_\alpha})}$; here, $Frequency(Q_{imp_\alpha})$ is the time that the object of this questionnaire survey evaluated the sustainability risk level of Q_{im} is p_α ($\alpha = 1, 2, 3, 4$ or 5). Then, fuzzy comprehensive evaluation matrix R_3 can be established:

$$R_3 = \begin{bmatrix} r_{311} & r_{312} & \cdots & r_{315} \\ r_{321} & r_{322} & \cdots & r_{325} \\ r_{331} & r_{332} & \cdots & r_{335} \\ \cdots & \cdots & \cdots & \cdots \\ r_{3m1} & r_{3m2} & \cdots & r_{3m5} \end{bmatrix} = \begin{bmatrix} 0.100 & 0.130 & 0.317 & 0.255 & 0.199 \\ 0.109 & 0.220 & 0.331 & 0.190 & 0.150 \\ 0.060 & 0.174 & 0.241 & 0.317 & 0.208 \\ 0.123 & 0.248 & 0.329 & 0.174 & 0.127 \\ 0.116 & 0.222 & 0.333 & 0.185 & 0.144 \\ 0.111 & 0.227 & 0.333 & 0.174 & 0.155 \\ 0.174 & 0.248 & 0.303 & 0.144 & 0.132 \\ 0.090 & 0.208 & 0.324 & 0.211 & 0.167 \\ 0.100 & 0.208 & 0.329 & 0.201 & 0.162 \\ 0.201 & 0.257 & 0.243 & 0.169 & 0.130 \end{bmatrix}$$

Similarly, the fuzzy comprehensive evaluation matrix of the other 1st-level sustainability risk factors R_1, R_2, R_4, and R_5, can be established:

$$R_1 = \begin{bmatrix} 0.049 & 0.225 & 0.354 & 0.225 & 0.148 \\ 0.231 & 0.313 & 0.280 & 0.083 & 0.093 \\ 0.118 & 0.285 & 0.394 & 0.086 & 0.118 \\ 0.241 & 0.313 & 0.282 & 0.074 & 0.090 \\ 0.219 & 0.291 & 0.323 & 0.072 & 0.095 \\ 0.058 & 0.236 & 0.352 & 0.215 & 0.139 \\ 0.113 & 0.275 & 0.396 & 0.090 & 0.125 \\ 0.030 & 0.238 & 0.368 & 0.218 & 0.146 \\ 0.046 & 0.204 & 0.275 & 0.280 & 0.194 \\ 0.060 & 0.229 & 0.356 & 0.220 & 0.134 \\ 0.044 & 0.201 & 0.280 & 0.289 & 0.185 \\ 0.074 & 0.236 & 0.396 & 0.148 & 0.146 \\ 0.049 & 0.231 & 0.366 & 0.220 & 0.134 \\ 0.039 & 0.241 & 0.368 & 0.206 & 0.146 \\ 0.037 & 0.243 & 0.377 & 0.188 & 0.155 \\ 0.116 & 0.273 & 0.398 & 0.088 & 0.125 \\ 0.111 & 0.269 & 0.400 & 0.088 & 0.132 \\ 0.037 & 0.215 & 0.363 & 0.236 & 0.148 \\ 0.030 & 0.238 & 0.368 & 0.220 & 0.144 \\ 0.019 & 0.211 & 0.280 & 0.294 & 0.197 \\ 0.030 & 0.236 & 0.352 & 0.238 & 0.144 \\ 0.025 & 0.241 & 0.370 & 0.222 & 0.141 \\ 0.037 & 0.250 & 0.359 & 0.208 & 0.146 \\ 0.171 & 0.301 & 0.373 & 0.053 & 0.102 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0.058 & 0.225 & 0.345 & 0.275 & 0.097 \\ 0.088 & 0.243 & 0.368 & 0.236 & 0.065 \\ 0.090 & 0.285 & 0.391 & 0.167 & 0.067 \\ 0.079 & 0.231 & 0.350 & 0.257 & 0.083 \\ 0.039 & 0.199 & 0.313 & 0.287 & 0.162 \\ 0.037 & 0.236 & 0.343 & 0.269 & 0.116 \\ 0.058 & 0.231 & 0.356 & 0.271 & 0.083 \\ 0.065 & 0.245 & 0.366 & 0.262 & 0.063 \\ 0.060 & 0.236 & 0.340 & 0.280 & 0.083 \\ 0.081 & 0.273 & 0.370 & 0.234 & 0.042 \\ 0.243 & 0.315 & 0.280 & 0.123 & 0.039 \\ 0.250 & 0.301 & 0.273 & 0.132 & 0.044 \\ 0.171 & 0.229 & 0.347 & 0.167 & 0.086 \\ 0.174 & 0.287 & 0.289 & 0.181 & 0.069 \\ 0.183 & 0.236 & 0.285 & 0.199 & 0.097 \\ 0.213 & 0.241 & 0.363 & 0.104 & 0.079 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0.060 & 0.231 & 0.361 & 0.271 & 0.076 \\ 0.039 & 0.201 & 0.313 & 0.287 & 0.160 \\ 0.069 & 0.234 & 0.350 & 0.264 & 0.083 \\ 0.141 & 0.324 & 0.296 & 0.174 & 0.065 \\ 0.065 & 0.243 & 0.366 & 0.262 & 0.065 \\ 0.063 & 0.238 & 0.336 & 0.280 & 0.083 \\ 0.032 & 0.213 & 0.370 & 0.282 & 0.102 \\ 0.035 & 0.225 & 0.343 & 0.280 & 0.118 \\ 0.014 & 0.192 & 0.273 & 0.331 & 0.190 \\ 0.079 & 0.280 & 0.347 & 0.213 & 0.081 \\ 0.049 & 0.197 & 0.289 & 0.292 & 0.174 \\ 0.211 & 0.231 & 0.366 & 0.113 & 0.079 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0.056 & 0.236 & 0.354 & 0.273 & 0.081 \\ 0.148 & 0.262 & 0.361 & 0.167 & 0.063 \\ 0.063 & 0.234 & 0.338 & 0.282 & 0.083 \\ 0.042 & 0.174 & 0.382 & 0.331 & 0.072 \\ 0.141 & 0.294 & 0.282 & 0.222 & 0.060 \\ 0.030 & 0.238 & 0.354 & 0.292 & 0.086 \\ 0.079 & 0.213 & 0.326 & 0.257 & 0.125 \\ 0.030 & 0.227 & 0.350 & 0.280 & 0.113 \\ 0.060 & 0.248 & 0.361 & 0.167 & 0.164 \\ 0.250 & 0.234 & 0.301 & 0.141 & 0.074 \end{bmatrix}$$

Weight vectors W and W_i' are very important to determine the level of sustainability risk and can be calculated using FMECA according to Section 3.2. To obtain the weights of sustainability risk factors, five experts of PPP risk management were invited to score the values of H_i, S_i, D_i and C_i with the principle shown as Equations (15)–(20) (the scoring table is shown in Appendix B), and the scoring results of the 1st-level sustainability risk factors are shown in Table 4. Taking the average as the final score, the weight of 1st-level sustainability risk factors, W_i, can be obtained after normalization:

$$W = \{W_1, W_2, W_3, W_4, W_5\} = \{0.102, 0.183, 0.232, 0.362, 0.121\}$$

Similarly, the weight of 2nd-level sustainability risk factors W_i' can be obtained:

$$W_1' = \begin{bmatrix} W_{11}' & ,\ldots, & W_{112}', \\ W_{113}' & ,\ldots, & W_{124}' \end{bmatrix} = \begin{bmatrix} 0.059, 0.025, 0.043, 0.015, 0.026, 0.013, 0.046, 0.039, 0.063, 0.053, 0.103, 0.024, \\ 0.034, 0.053, 0.032, 0.043, 0.041, 0.043, 0.046, 0.082, 0.042, 0.017, 0.027, 0.031 \end{bmatrix}$$

$$W_2' = \begin{bmatrix} W_{21}' & ,\ldots, & W_{28}', \\ W_{29}' & ,\ldots, & W_{216}' \end{bmatrix} = \begin{bmatrix} 0.031, 0.038, 0.036, 0.064, 0.108, 0.088\ 0.044, 0.048, \\ 0.100, 0.058, 0.066, 0.048, 0.096, 0.049, 0.040, 0.086 \end{bmatrix}$$

$$W_3' = \begin{bmatrix} W_{31}' & ,\ldots, & W_{310}' \end{bmatrix} = [0.090, 0.155, 0.098, 0.110, 0.061, 0.139, 0.048, 0.103, 0.083, 0.114]$$

$$W_4' = \begin{bmatrix} W_{41}' & ,\ldots, & W_{412}' \end{bmatrix} = [0.076, 0.058, 0.043, 0.137, 0.111, 0.102, 0.08, 0.068, 0.100, 0.062, 0.107, 0.056]$$

$$W_5' = \begin{bmatrix} W_{51}' & ,\ldots, & W_{510}' \end{bmatrix} = [0.045, 0.106, 0.193, 0.097, 0.089, 0.093, 0.095, 0.133, 0.079, 0.07]$$

According to Equation (11), the fuzzy comprehensive assessment matrix of 1st-level risk factors can be calculated:

$$B_1 = |0.070\ 0.241\ 0.345\ 0.197\ 0.148|$$

$$B_2 = |0.116\ 0.246\ 0.336\ 0.217\ 0.085|$$

$$B_3 = |0.116\ 0.215\ 0.309\ 0.218\ 0.158|$$

$$B_4 = |0.071\ 0.238\ 0.329\ 0.255\ 0.106|$$

$$B_5 = |0.083\ 0.235\ 0.342\ 0.248\ 0.092|$$

According to Equations (9) and (10), fuzzy comprehensive assessment matrix G, which reflects the sustainability risk level of YRWP, can be established:

$$G = \mathrm{W}\cdot\mathrm{B}^T = \mathrm{W}\cdot\begin{vmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{vmatrix}$$

$$= |0.102\ 0.183\ 0.232\ 0.362\ 0.121| \cdot \begin{vmatrix} 0.070 & 0.241 & 0.345 & 0.197 & 0.148 \\ 0.116 & 0.246 & 0.336 & 0.217 & 0.085 \\ 0.116 & 0.215 & 0.309 & 0.218 & 0.158 \\ 0.071 & 0.238 & 0.329 & 0.255 & 0.106 \\ 0.083 & 0.235 & 0.342 & 0.248 & 0.092 \end{vmatrix}$$

$$= |0.091\ 0.234\ 0.329\ 0.233\ 0.117|$$

According to Equations (12)–(14), the value of YRWP's sustainability risk assessment, Z, and the sustainability risk level of 1st-level risk factors, Z_i, can be calculated:

$$Z = P\cdot G = \begin{vmatrix} 1 & 2 & 3 & 4 & 5 \end{vmatrix} \cdot \begin{vmatrix} 0.091 \\ 0.234 \\ 0.329 \\ 0.233 \\ 0.117 \end{vmatrix} = 3.061$$

$$Z_1 = P\cdot B_1 = \begin{vmatrix} 1 & 2 & 3 & 4 & 5 \end{vmatrix} \cdot \begin{vmatrix} 0.070 \\ 0.241 \\ 0.345 \\ 0.197 \\ 0.148 \end{vmatrix} = 3.113$$

$$Z_2 = 2.909,\ Z_3 = 3.133,\ Z_4 = 3.088,\ Z_5 = 3.030.$$

In addition, Figure 1 shows the sustainability risk level of 1st-level risk factors.

Table 4. Values of H_i, S_i, D_i and C_i scored by five experts.

Q		Evaluation of 1st Expert					Evaluation of 2nd Expert					Evaluation of 3rd Expert					Evaluation of 4th Expert					Evaluation of 5th Expert					Average
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	
	H			√					√						√				√					√			
	S					√				√			√					√						√			
Q_1	D		√				√									√				√			√				6.6
	C				√					√					√				√						√		
	W_1''			7.5					3					10					8					4.5			
	H				√					√					√				√						√		
	S			√					√						√					√						√	
Q_2	D	√						√						√					√					√			11.8
	C				√			√							√				√					√			
	W_2''			3					12					12					12					20			
	H				√						√				√				√						√		
	S			√					√					√						√				√			
Q_3	D		√					√						√				√						√			15
	C	√						√					√				√					√					
	W_3''			24					15					8					24					4			
	H					√			√					√						√					√		
	S				√					√					√				√						√		
Q_4	D				√						√				√					√						√	23.34
	C		√						√			√								√				√			
	W_4''			10					20					48					12					26.7			
	H		√					√				√					√					√					
	S				√					√					√				√							√	
Q_5	D					√					√					√				√						√	7.8
	C				√					√				√					√					√			
	W_5''			10					10					6.7					4					8.3			

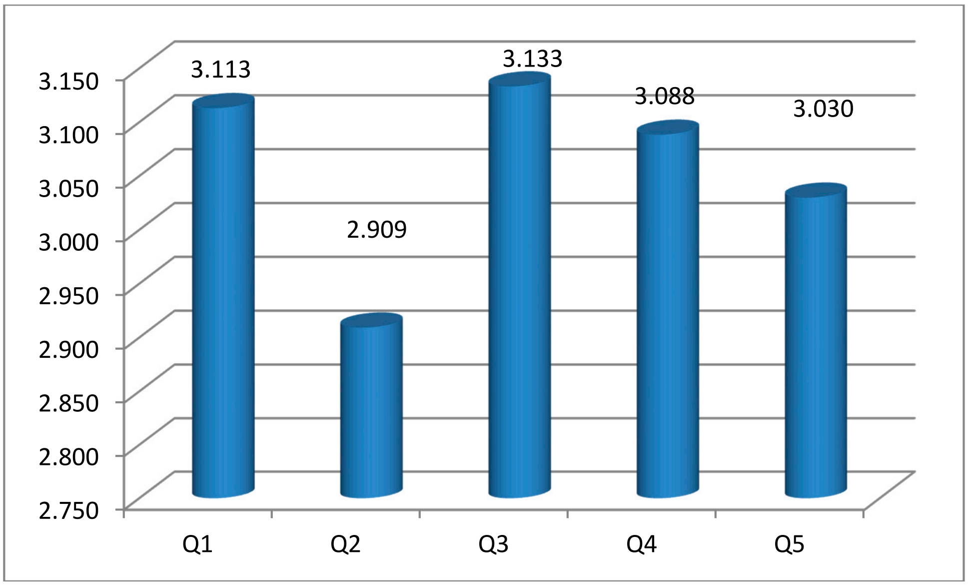

Figure 1. Sustainability risk level of 1st-level risk factors.

$Z = 3.061$ means that the value of YRWP's sustainability risk level is 3.061, which is higher than the average value of risk comments, 2.5, which indicates that the YRWP's sustainability risk level is relatively higher and needed for scientific management in process of project implementation.

In Figure 1, the value of YRWP's sustainability risk assessment is in accordance with the order, from highest to lowest: cost and economy (Q_3), society and culture (Q_1), project and organization (Q_4), politics and policy (Q_5), and ecology and environment (Q_2). Cost and economy (Q_3), and society and culture (Q_1) are the highest sustainability risk level factors Therefore, if managers want to control the sustainability risk of YRWP effectively, Q_3 and Q_1 are the key factors to be addressed first.

According to Figure 1, the 1st-level sustainability risk factor of cost and economy in YRWP is the highest, which is because the YRWP project is a social welfare project focused on ecological construction, environmental protection, and sustainable development of Xi'an, although the relationship between public and private sectors is not very clear causing the investment plan and expense being relatively unclear, which would keep the risks of cost and economy at a higher level. Compared to different PPP projects, it is not difficult to find that the sustainability risk level of the same factors, such as ecology and environment, society, and culture, in different projects are different due to the particularity of each project; it reflects that the sustainability risk level of different factor is relative, which requires managers to take the actual situation into account when making decision on sustainability risk management for different PPP projects.

5. Discussions and Conclusions

Nowadays, many studies on PPP project management have been carried out to study the problems of risk assessment [6–9], relationship recognition between public and private sectors [10], and analysis of the roles for different organizations [13–15]. Besides, many other scholars have researched the area of sustainability risk and presented the connotations, applications and mechanisms from different fields, including, but not limited to, organization's sustainable development [16], sustainable chain management [18], and project design selection [19]. These studies greatly contribute to promote the application of PPP model in infrastructure construction projects and provide a theoretical support for sustainable risk management. However, even though there are many studies about PPP projects and sustainability risk, little attention has been given to sustainability risk of PPP projects, especially the area of sustainability risk evaluation of PPP projects, and the method used to evaluate the sustainability risk level of PPP is also missed which causes the sustainability risk of a PPP project cannot be evaluated, prevented, and controlled during the implementation process. This emerging management pressure has made the study of sustainability risk evaluation of PPP projects important.

To solve this problem, this paper brings the concept of "sustainability" into the risk evaluation of PPP projects and constructs a factor system of sustainability risk of PPP projects covering five 1st-level factors and 72 2nd-level factors via an extensive literature review. In addition, this paper adapts a comprehensive approach to establish a fuzzy evaluation model for sustainability risk evaluation based on the methods of FCEM and FMECA for evaluating the sustainability risk level of PPP projects, the effectiveness and feasibility of which is verified by a computational experiment. According to the results of this computational experiment, we can see that the approach proposed in this paper is reasonable for evaluating the sustainability risk levels of PPP projects and could achieve the most important objective of providing a reference for stakeholders when making decisions on sustainability risk management of PPP projects. In addition, this evaluation model has also laid a useful foundation for future case analyses; the stakeholders of PPP, i.e., not only public sectors such as government departments, but also private sectors including enterprises and government agents, may adopt this model to assess the sustainability risk level of each PPP project and review the strengths and weaknesses of their current sustainability risk management, so that better risk management plans can be conceived toward the implementation of PPP projects.

This paper, to our knowledge, is the first study to research the sustainability risk in the field of PPP project management, which not only bridges the research areas of sustainability risk and PPP project management, filling the gap between traditional risk management and organization's sustainable development, but also provides a reference for the public and private sectors for the sustainable planning and development. However, there are two shortcomings in this study: (1) the systematic deficiencies of the factors are induced by the negative synergistic relationship between factors having not been taken into account, and might affect the scientific nature of the evaluation results; and (2) the effectiveness and feasibility of this proposed model was verified using a computational experiment, however, the selected project to be implemented was only consistent for the problem of sustainability risk evaluation, thus, the results of the computational experiment should initially be generalized. These limitations should be studied in the future.

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Author Contributions: Libiao Bai designed the approach and conceived the experiments; Yi Li and Qiang Du wrote most of the manuscript. Yadan Xu designed the survey questionnaire and analyzed the data.

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

Appendix A. A Sample of Survey Questionnaire

Appendix A.1. Basic Information

1. Gender: ☐ male ☐ female
2. Age: ☐ 20–29 ☐ 30–39 ☐ 40–49 ☐ 50 or more
3. Length of service: ☐ Within 1 year ☐ 1–5 years ☐ 6–10 years
   ☐ 11–20 years ☐ 20 years or more
4. Your duties:
5. Department:
6. Nature of your department: ☐ management ☐ implementation ☐ technology ☐ other

Appendix A.2.

Table A1. Assessment comments of YRWP's sustainability risk factors.

Factors	Assessment Comments	Level of Sustainability Risk Factor				
		1	**2**	**3**	**4**	**5**
Culture and Society Q_1	Local cultural inheritance Q_{11}	☐	☐	☐	☐	☐
	Cultural heritage protection Q_{12}	☐	☐	☐	☐	☐
	Respect for local cultural customs Q_{13}	☐	☐	☐	☐	☐
	Cultural diversity protection Q_{14}	☐	☐	☐	☐	☐
	Spread of advanced culture Q_{15}	☐	☐	☐	☐	☐
	Public participation Q_{16}	☐	☐	☐	☐	☐
	Public awareness Q_{17}	☐	☐	☐	☐	☐
	Public satisfaction Q_{18}	☐	☐	☐	☐	☐
	Public happiness Q_{19}	☐	☐	☐	☐	☐
	Public credit Q_{110}	☐	☐	☐	☐	☐
	Related organization participation Q_{111}	☐	☐	☐	☐	☐
	Degree of project on behalf of the public Q_{112}	☐	☐	☐	☐	☐
	Safety of employees Q_{113}	☐	☐	☐	☐	☐
	Safety of users Q_{114}	☐	☐	☐	☐	☐
	Safety of local community Q_{115}	☐	☐	☐	☐	☐
	Safety of construction Q_{116}	☐	☐	☐	☐	☐
	Safety technology training Q_{117}	☐	☐	☐	☐	☐
	Impact on the safety of other projects Q_{118}	☐	☐	☐	☐	☐
	Absorb local employment Q_{119}	☐	☐	☐	☐	☐
	Social service Q_{120}	☐	☐	☐	☐	☐
	Harmony between project and society Q_{121}	☐	☐	☐	☐	☐
	Local employment skills Q_{122}	☐	☐	☐	☐	☐
	Sustainable construction consciousness Q_{123}	☐	☐	☐	☐	☐
	Local social environment Q_{124}	☐	☐	☐	☐	☐
Ecology and Environmental Q_2	Natural landscape protection Q_{21}	☐	☐	☐	☐	☐
	Fauna and flora protection Q_{22}	☐	☐	☐	☐	☐
	Rate of change of green coverage in built-up area Q_{23}	☐	☐	☐	☐	☐
	Project barrier effect Q_{24}	☐	☐	☐	☐	☐
	Rate of green coverage in built-up area Q_{25}	☐	☐	☐	☐	☐
	Harmony between project and ecosystem Q_{26}	☐	☐	☐	☐	☐
	Land governance Q_{27}	☐	☐	☐	☐	☐
	Industrial sulfur dioxide emissions Q_{28}	☐	☐	☐	☐	☐
	Industrial waste water discharge Q_{29}	☐	☐	☐	☐	☐
	Industrial soot emissions Q_{210}	☐	☐	☐	☐	☐
	Municipal wastewater treatment rate Q_{211}	☐	☐	☐	☐	☐
	Domestic garbage harmless treatment rate Q_{212}	☐	☐	☐	☐	☐
	Industrial dust removal Q_{213}	☐	☐	☐	☐	☐
	Industrial sulfur dioxide removal Q_{214}	☐	☐	☐	☐	☐
	Pollution control capital investment Q_{215}	☐	☐	☐	☐	☐
	Industrial solid waste comprehensive utilization Q_{216}	☐	☐	☐	☐	☐
Cost and Economy Q_3	Cost of resettlement Q_{31}	☐	☐	☐	☐	☐
	Cost of ecological compensation Q_{32}	☐	☐	☐	☐	☐
	Cost of labor Q_{33}	☐	☐	☐	☐	☐
	Cost of the user Q_{34}	☐	☐	☐	☐	☐
	Cost of land Q_{35}	☐	☐	☐	☐	☐
	Interest rate Q_{36}	☐	☐	☐	☐	☐
	Foreign currency exchange Q_{37}	☐	☐	☐	☐	☐
	Market demand Q_{38}	☐	☐	☐	☐	☐
	Project uniqueness Q_{39}	☐	☐	☐	☐	☐
	Inflation Q_{310}	☐	☐	☐	☐	☐
Project and Organization Q_4	Project design Q_{41}	☐	☐	☐	☐	☐
	Project financing Q_{42}	☐	☐	☐	☐	☐
	Project Technology Q_{43}	☐	☐	☐	☐	☐
	Project construction Q_{44}	☐	☐	☐	☐	☐
	Daily maintenance Q_{45}	☐	☐	☐	☐	☐
	Synergy with other projects Q_{46}	☐	☐	☐	☐	☐
	Renovation Q_{47}	☐	☐	☐	☐	☐
	Project management maturity Q_{48}	☐	☐	☐	☐	☐
	Shared resource allocation capabilities Q_{49}	☐	☐	☐	☐	☐
	Stakeholder coordination Capabilities Q_{410}	☐	☐	☐	☐	☐
	Project portfolio capabilities Q_{411}	☐	☐	☐	☐	☐
	Multi-objective optimization capabilities Q_{412}	☐	☐	☐	☐	☐

Table A1. *Cont.*

Factors	Assessment Comments	Level of Sustainability Risk Factor				
		1	2	3	4	5
Politics and Laws Q_5	Government decision-making mistakes Q_{51}	☐	☐	☐	☐	☐
	Policy updates Q_{52}	☐	☐	☐	☐	☐
	Political opposition Q_{53}	☐	☐	☐	☐	☐
	Political instability Q_{54}	☐	☐	☐	☐	☐
	Government dishonesty Q_{55}	☐	☐	☐	☐	☐
	Project publication Q_{56}	☐	☐	☐	☐	☐
	Government decision-making process lengthy Q_{57}	☐	☐	☐	☐	☐
	Laws and regulations Q_{58}	☐	☐	☐	☐	☐
	Project contract Q_{59}	☐	☐	☐	☐	☐
	Third party default Q_{510}	☐	☐	☐	☐	☐

Appendix B. A Sample of Expert Scoring Table

Table A2. Expert scoring table.

Factors / Scoring	Occurrence Probability (H)					Loss and Impact (S)					Perceived Degree (D)					Ability to Control and Compensate (C)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Culture and Society Q_1																				
Local cultural inheritance Q_{11}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cultural heritage protection Q_{12}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Respect for local cultural customs Q_{13}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cultural diversity protection Q_{14}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Spread of advanced culture Q_{15}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Public participation Q_{16}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Public awareness Q_{17}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Public satisfaction Q_{18}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Public happiness Q_{19}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Public credit Q_{110}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Related organization participation Q_{111}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Degree of project on behalf of the public Q_{112}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety of employees Q_{113}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety of users Q_{114}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety of local community Q_{115}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety of construction Q_{116}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety technology training Q_{117}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Impact on the safety of other projects Q_{118}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Absorb local employment Q_{119}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Social service Q_{120}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Harmony between project and society Q_{121}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Local employment skills Q_{122}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sustainable construction consciousness Q_{123}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Local social environment Q_{124}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Ecology and Environmental Q_2																				
Natural landscape protection Q_{21}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fauna and flora protection Q_{22}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rate of change of green coverage in built-up area Q_{23}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project barrier effect Q_{24}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rate of green coverage in built-up area Q_{25}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Harmony between project and ecosystem Q_{26}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Land governance Q_{27}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial sulfur dioxide emissions Q_{28}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial waste water discharge Q_{29}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial soot emissions Q_{210}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Municipal wastewater treatment rate Q_{211}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Domestic garbage harmless treatment rate Q_{212}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial dust removal Q_{213}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial sulfur dioxide removal Q_{214}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Pollution control capital investment Q_{215}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industrial solid waste comprehensive utilization Q_{216}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cost and Economy Q_3																				
Cost of resettlement Q_{31}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cost of ecological compensation Q_{32}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cost of labor Q_{33}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cost of the user Q_{34}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cost of land Q_{35}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Interest rate Q_{36}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Foreign currency exchange Q_{37}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Market demand Q_{38}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project uniqueness Q_{39}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inflation Q_{310}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Table A2. *Cont.*

Factors \ Scoring	Occurrence Probability (H)					Loss and Impact (S)					Perceived Degree (D)					Ability to Control and Compensate (C)				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Project and Organization Q_4																				
Project design Q_{41}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project financing Q_{42}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project Technology Q_{43}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project construction Q_{44}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Daily maintenance Q_{45}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Synergy with other projects Q_{46}	☐																			
Renovation Q_{47}	☐																			
Project management maturity Q_{48}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Shared resource allocation capabilities Q_{49}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Stakeholder coordination Capabilities Q_{410}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project portfolio capabilities Q_{411}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Multi-objective optimization capabilities Q_{412}	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐
Politics and Laws Q_5	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Government decision-making mistakes Q_{51}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Policy updates Q_{52}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Political opposition Q_{53}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Political instability Q_{54}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Government dishonesty Q_{55}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project publication Q_{56}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Government decision-making process lengthy Q_{57}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Laws and regulations Q_{58}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Project contract Q_{59}	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐
Third party default Q_{510}	☐	☐	☐	☐	☐	☐	☐	☐		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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