land

MDPI

Article

Public Private Partnership to Brownfield Remediation Projects in China: A Combined Risk Evaluation Approach

Qingye Han [1,*], Yan Qin [1], Heng Zhang [1] and Ginger Y. Ke [2]

[1] School of Management Science and Real Estate, Chongqing University, Chongqing 400044, China; 20190577@stu.cqu.edu.cn (Y.Q.); bournezhang@cqu.edu.cn (H.Z.)
[2] Faculty of Business Administration, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada; gke@mun.ca
* Correspondence: hanqy11@cqu.edu.cn; Tel.: +86-15023189236

Abstract: Brownfields have been receiving significant attention all over the world because of their potential threats to the environment and public health. However, a funding shortage constitutes the main obstacle to the brownfield remediation (BR). In China, to ease financial dilemmas, the governments seek collaborations with private-sector companies, i.e., the Public Private Partnership (PPP) mode. Despite all the benefits, BR and PPP contain high risks, making stakeholders extremely cautious about investing in such projects. To support the decision-making process of the public and private parties, this paper designs a comprehensive approach to evaluate the risks of BR PPP projects in China. In more detail, several commonly used risk methods, such as TOPSIS, GRE, and FSE, are employed to construct a combined risk evaluation process, which applies multiple combined evaluation techniques to iteratively integrate individual results from those methods until a valid common result is achieved. To show the practical implementation procedure of the proposed combined approach, a hypothetical case study is performed to assess the risks of seven BR PPP projects. The analytical process also verifies that the consistency and reliability of the risk evaluation result can be achieved effectively and efficiently by jointly deploying multiple risk methods through combined techniques. The proposed decision framework facilitates a novel research idea in evaluating complicated risk situations, and can be applied to other similar scenarios where uncertainties and inconsistencies are inevitable.

Keywords: brownfield; public private partnership; risk assessment; combined evaluation

Citation: Han, Q.; Qin, Y.; Zhang, H.; Ke, G.Y. Public Private Partnership to Brownfield Remediation Projects in China: A Combined Risk Evaluation Approach. *Land* **2024**, *13*, 56. https://doi.org/10.3390/land13010056

Academic Editor: Evangelia Golia

Received: 7 November 2023
Revised: 17 December 2023
Accepted: 29 December 2023
Published: 3 January 2024

1. Introduction

Different countries may define the brownfield in different ways [1]. The most widely used definition is that "Brownfields are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination" [2]. A large number of brownfield sites have been produced in the process of global industrialization and de-industrialization. The amount of brownfield sites is estimated at over 0.45 million in America [3]. Many countries have placed the remediation and redevelopment of brownfields in priority on their political calendars, and released corresponding incentive policies like tax relief and specific funds to achieve the potential economic, social, and environmental benefits [4].

Compared to those developed countries, the social awareness of brownfields was formed relatively late in China, and the corresponding policy systems, especially those related to financing, are not yet well-developed [5]. Different from most countries' private ownership, all lands in China are owned by state or rural collectives (i.e., local groups of farmers) [6], which hence become responsible for BR projects despite the fiscal deficit [7]. To ease the relevant fiscal imbalance, Chinese governments have started to seek funding support through the mode of Private Public Partnerships (PPPs).

Through collaboration efforts from both government agencies and private-sector companies, the PPP mode has been broadly used in large-scale government projects, especially in developed countries [8]. The benefit of PPP lies in the integration of private resources and government initiatives, which allows the projects to be completed on time and within the budget. However, PPP also has serious disadvantages, specifically the high risks faced by both sides of the partnership, such as cost overruns, technical defects, and the inability to meet quality standards or agreed-upon fees, to name a few. The highly uncertain nature of BR further escalates the risky level of BR PPP projects. The private party needs to select an appropriate BR project to join in from a PPP project set provided by the local government considering the project risk level, while the governments need to match a suitable private party for each BR project considering their capabilities of risk control. Therefore, risk management is of particular significance to ensure the successful execution of PPP projects [9], and a scientific risk evaluation model for potential BR PPP projects is needed to support the decision-making process and increase the cooperation of the two parties.

It is hard to find research about BR PPP that focuses on risk evaluation from the perspective of project management. The existing BR PPP-related literature pays more attention to incentives that attract investors [10], how to choose the best agreement type [11], performance problems [8], successful factors [12], negotiation issues [13], barriers [14], and how financial risk evolves [15]. Most brownfield-related risk literature is conducted from the view of the environment [16], health [17], or ecology [18]. As to PPP, risk-related research has been conducted on energy generation [19]; sewage treatment [20]; and transportation [21] areas, in terms of risk factor prioritization [22] or risk allocation [23]. But, the application of PPP in BR projects has been overlooked in the literature.

Methodology-wise, several researchers have assessed the risk of whole PPP projects in other fields based on a single method. Each of those risk methods has its own merits. For example, TOPSIS-based methods focus on the distances from the ideal, fuzzy-based methods are capable of handling imprecise and ambiguous data, and grey-based methods aim for situations lacking information. Nevertheless, real-world situations can be exceedingly complicated, and thus a single risk measure cannot properly capture the underlining dynamics and uncertainties. Motivated by this fact, we herein propose a combined risk evaluation approach that jointly applies multiple risk methods, the results of which are then synchronized by using several combined techniques to rationally eliminate non-uniformity and attain a common result.

To the best of our knowledge, the present work is the first exploration to conduct a combined risk evaluation of BR PPP projects in China from the project management perspective. In more detail, based on a risk evaluation criteria system constructed by Han et al. [24], three evaluation methods, namely the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), grey relation evaluation (GRE), and fuzzy synthetic evaluation (FSE), are used to perform risk assessments individually. Multiple combination techniques are applied iteratively when the individual measures are not consistent with each other, until a common final evaluation is attained. Through a hypothetical case study consisting of seven BR PPP projects, it is verified that our proposed combined risk method can achieve a consistent evaluation result effectively and efficiently. Facilitating a novel research idea in evaluating complicated risk situations, the proposed decision framework can be further extended to integrate more or different risk measures, and be applied to other similar scenarios where uncertainties and inconsistencies are inevitable.

The remainder of the paper is organized as follows. Section 2 presents a literature review on relevant publications, followed by the determination of risk criteria and their corresponding weights in Section 3. Then, Section 4 introduces the details of the risk evaluation process of BR PPP projects with multiple methods. A hypothetical case study is used to show the applicability and reliability of the proposed process in Section 5. Moreover, how decisions are made based on perceived results is also explained in this section. Finally, Section 6 concludes the paper and points out possible future directions.

2. Literature Review

2.1. Brownfield Reuse in Different Land Ownership Situations

In most developed countries, brownfields are generally a kind of private real property [25], which means the ownership and use right of land belong to the same individual, and brownfield owners have complete disposal authority including remediation and redevelopment. In most situations, the pollution liability can be clearly defined, and the polluter or who is jointly liable should pay the remediation cost of brownfields [26]. Sometimes, a brownfield cannot be remediated because of enterprise bankruptcy, then the government will take over the brownfield [27]. However, in China, urban construction land is generally taken as a kind of infrastructure, and owned by a specific local government [28], which is obliged to provide qualified land for construction. Note that land-transferring fees account for a large proportion of local fiscal revenue [29], and thus influence the construction of urban infrastructures [30]. With recent adjustments in industrial structure and functional area in China, a large number of factories have moved out of cities and most of these old sites are taken back by the local government [7]. The local planning department needs to redefine the land use types for residences, commercial, etc., according to the surrounding development level. After that, a new developer purchases the land use right for a certain period from the local government and redevelops it to realize its various values. It can be observed that the remediation and redevelopment are generally separated and conducted by different stakeholders under the Chinese land tenure background.

2.2. Research Related to Both PPP and Brownfields

Studies of either PPP or brownfields can date back to about five decades ago, yet research on their combination is rather scarce. To understand the boundary between projects that are initiated by the public or private sector, Howland [31] analyzed three cases of brownfield redevelopment PPP projects in America. Based on interviews, Whitman [10] examined the incentives leading the private sector to invest in brownfield remediation projects. For selecting the best agreement terms, Glumac et al. [11] developed a game model to aid municipalities in the Netherlands. To understand how the interests of the public and private sectors shape the management environment, Alexander [8] detected the network structures and performance of brownfield redevelopment PPPs. Fan et al. [32] proposed a PIPP model to introduce the role of intermediary organizations during the negotiation between public and private parties. Glumac et al. [33] investigated the interaction behavior of the developer and municipality against three kinds of negotiation issues. After that, Glumac et al. [13] designed a decision-making model to support the negotiation between the public and private sectors. Based on cases in Pittsburgh, Li et al. [12] determined several key success elements that influence the application of PPP in residential brownfield redevelopment. Yang et al. [14] used literature research, the Analytic Hierarchy Process, and the Fuzzy DEMATEL method to construct a set of barriers related to brownfield redevelopment PPP projects, and identified four main barriers. van den Hurk et al. [15] analyzed three international cases to demonstrate how financial risk, particularly its bearing, evolves in PPP for brownfield regeneration. Han et al. [24] identified risks of brownfield remediation PPP projects in China and proposed a model to make the interrelationship among these risks clear to determine the key risks. Based on that paper, we conduct the present risk evaluation of brownfield remediation PPP projects in China.

2.3. Risk Evaluation on PPP Projects

PPP risk analysis has been conducted in many areas, including water supply projects [34], power generation projects [35], toll road projects [36] and electric vehicle charging infrastructure projects [21,37] etc. These existing studies can provide some experiences from the view of evaluation methodologies. The risk evaluation on PPP projects can be classified into two categories, the assessment of risk factors and assessment of a whole project.

To rank risk factors, Yu et al. [22] utilized intuitionistic Fuzzy Analytic Hierarchy Process and case study methods in transnational PPP projects; Rezaeenour et al. [38] used the Fuzzy Synthetic Evaluation (FSE) method in water supply PPP projects. To identify the interactions among PPP risk factors, Ahmadabadi and Heravi [39] built a framework of megaprojects integrating the Structural Equation Modeling; Li and Wang [40] developed an assessment model based on the Fuzzy Analytic Network Process and Interpretative Structural Modeling method; Han et al. [24] established a model by using Interpretative Structural Modeling and Impact Matrix Cross-reference Multiplication Applied to a Classification method.

There are also multiple studies of risk assessment on specific whole PPP projects in other areas. Xu et al. [41] proposed a risk evaluation model for PPP projects in China by using the FSE approach. Li and Zou [42] presented a Fuzzy Analytic Hierarchy Process based on risk assessment methodology for PPP projects. Han et al. [43] analyzed the investment feasibility in toll highway PPP projects from the perspective of risk level based on the Monte Carlo Simulation method. Mao and Zhang [44] designed a risk evaluation system for utility tunnel PPP projects with the Fuzzy Comprehensive Evaluation method. Wu et al. [35] evaluated the risk of straw-based power generation PPP projects in China using the FSE. Bai et al. [45] conducted a sustainability risk evaluation of PPP projects based on Fuzzy Comprehensive Evaluation. Wu et al. [46] established a risk assessment framework of waste-to-energy incineration PPP projects in China under a two-dimensional linguistic environment. Liu and Wei [37] evaluated the risk of electric vehicle charging infrastructure PPP projects in China by using the fuzzy TOPSIS method. Luo et al. [19] put forward a methodology based on weighted multigranulation fuzzy rough sets over two universes to perform risk evaluation for PPP waste-to-energy incineration plant projects. Gupta et al. [21] examined the risk factors associated with the PPP of Electric Vehicles across India using the Fuzzy Analytic Hierarchy Process. Song et al. [47] constructed a new cloud analytic hierarchy process method for the risk evaluation of PPP projects. Li et al. [20] established a risk evaluation model for water environmental treatment PPP projects based on the intuitionistic fuzzy Multi-Objective Optimization based on a Ratio Analysis plus the full Multiplicative form improved Failure Mode and Effects Analysis method.

2.4. Risk Evaluation on Brownfields

The majority of studies on brownfield-related risk evaluation are from the perspectives of human health and environment. Ofungwu and Eget [48] presented a methodology to apply existing models for estimating residual landfill hazardous compounds emissions and quantifying associated health risks. James et al. [49] compared the reduced health risks among different human exposure pathways in an urban brownfield when paving roads, and concluded that paving roads is an effective method to reduce the health risk. Wu et al. [50] investigated a toxic soil event in Changzhou, China to reveal the extent of the environmental and health risks involved, and concluded that environmental management regulations and improved public health perceptions are needed to ensure sustainable suburbanization. By using a Monte Carlo simulation, Guo et al. [25] investigated the health risk of a brownfield site in Beijing, China, and concluded that pollutant concentration, mean action time, and exposure duration are the three parameters with the highest sensitivity to the health risk. Some scholars have conducted ecological or environmental risk evaluation research on brownfields. For example, Sun et al. [51] built a comprehensive environmental risk assessment of brownfield reuse according to life cycle theory by using the Analytic Hierarchy Process and GCE methods; taking a brownfield site in Xi’an, China as an example, Liu et al. [52] enforced an integrated analysis of man–land interrelations from the perspective of heavy metal pollution and ecological risk assessment. There are also some brownfield risk studies from special views. For example, Chen and Ma [53] developed a small-scale risk map to determine the relationship between population risk and damaged land value to facilitate flexible land reutilization plans; Enell et al. [54] studied the benefits and potential risks of brownfields by using the bioenergy-crops technique. Mahammedi et al. [55] designed a framework by identifying hazards and exposing the degree of presence to assist professionals in rapidly judging a site’s suitability for acquisition or redevelopment.

Examining the soil–heavy metal level of the Mianyang thermal power plant area in Sichuan, China, Zhao et al. [18] proposed an effective method of discernment for the ecological remediation of soils' heavy metals.

2.5. Research Gaps

Existing studies related to both brownfields and PPP are scarce because most developed countries allow private ownership of land. In recent years, scholars have made an effort to identify risk factors associated with BR PPP projects in the background of China. However, there is still a gap in evaluating the relevant risks and ranking the BR PPP projects accordingly. Additionally, although the literature on PPP risk assessment is quite rich, all of those employed only one specific risk measure. The individual use of risk measures may induce different risk evaluation results due to the variation in underlying decision logic and hence is incapable of capturing the dynamics and complications of real-world situations. More importantly, the reliability of the risk evaluation is arduous to ascertain and maintain. To fill these gaps, this paper makes the first attempt to consistently utilize multiple commonly used risk methods to form a combined risk evaluation process for BR PPP projects in China, which can accomplish a comprehensive evaluation through integrating advantages of individual risk measures with high convergence and credibility.

3. Determination of Risk Evaluation Criteria and Corresponding Weights

This section presents the risk evaluation criteria system for BR PPP projects, as well as the corresponding weight of each criterion, obtained by using the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique.

3.1. Risk Factors

Risk identification is the foundation for any PPP risk management tasks, including risk evaluation, allocation, and control. Herein, we adopt the 48 risk factors (Table 1), identified in Han et al. [24], and conduct further investigations on top of them. Interested readers are referred to Han et al. [24] for a detailed procedure for generating the list.

Table 1. Risk factors of PPP brownfield remediation projects in China (adapted from [24]).

NO.	Risk Factors	NO.	Risk Factors
1	Corruption	2	Stakeholders' reliability
3	Opposition from the public/other departments	4	Immature legal system
5	Executive difference of legal provisions	6	Approval and permit
7	Availability of finance	8	Change of design proposal
9	Excessive contract change	10	Poor contract management skills
11	Supply delay	12	Delay in resolving contract, litigation or arbitration disputes
13	Technique risk	14	Force majeure
15	Cost overrun	16	Change of market demand
17	Uncompetitive tendering process	18	Private inability
19	Organization and coordination	20	Environmental and ecological risk
21	Change of the private investor	22	Insufficient financial audit
23	Different working habit	24	Unsuitable distribution of power and risk liability
25	Inadequate experience	26	High maintenance risk
27	Sanctions and penalties	28	Inadequate data and research
29	Completion delay	30	High financing cost
31	Unattractive for investors	32	Failure of expected return
33	Unqualified remediation	34	Lacking standard PPP contract template
35	Health risk	36	Reputation and image damage
37	Influence on the value of surrounding fixed assets	38	Cognitive risk and land blight
39	Litigation risk	40	Collective events
41	Inadequate supervision	42	Change of land use planning
43	Potential pollution liability	44	Unreasonable cost estimation
45	Change of remediation standard	46	Stigma
47	Influence of other urban projects	48	Debt risk

3.2. Risk Evaluation Criteria and the Weights

Han et al. [24] also showed that the 48 risk factors are not independent. That is to say, some risks are influenced by others, and some influences are higher than others. To ensure a rational evaluation of risk, the DEMATEL technique is applied here to analyze the cause and effect relationships and in order to combine related risk factors to form the evaluation criteria list.

Considering that the DEMATEL technique has been widely used, we omit the detailed procedure, which can be found in [56]. The resulting criteria and the corresponding weights are, respectively, given in Tables 2 and 3. Note that the unit of weights is "%", and the overall summation is 100%.

Table 2. The Evaluation Criteria.

NO.	Risk Evaluation Criteria	NO.	Risk Evaluation Criteria
①	Corruption	②	Opposition from the public/other departments
③	Immature legal system	④	Executive difference of legal provisions
⑤	Availability of finance	⑥	Poor contract management skills
⑦	Technique risk	⑧	Force majeure
⑨	Change of market demand	⑩	Private inability
⑪	Environmental and ecological risk	⑫	Insufficient financial audit
⑬	Unsuitable distribution of power and risk liability	⑭	Inadequate experience
⑮	Inadequate data and research	⑯	High financing cost
⑰	Lacking standard PPP contract template	⑱	Health risk
⑲	Collective events	⑳	Inadequate supervision
㉑	Potential pollution liability	㉒	Unreasonable cost estimation
㉓	Change of remediation standard	㉔	Influence of other urban projects

Table 3. The Weights of the Evaluation Criteria.

NO.	Weights	NO.	Weights
①	5.885	②	5.369
③	3.665	④	2.685
⑤	3.407	⑥	2.994
⑦	5.524	⑧	6.092
⑨	0.826	⑩	9.448
⑪	10.532	⑫	3.046
⑬	4.285	⑭	6.453
⑮	0.981	⑯	0.929
⑰	1.859	⑱	8.312
⑲	6.195	⑳	5.421
㉑	1.652	㉒	1.239
㉓	2.375	㉔	0.826

4. The Combined Evaluation Process of the Risk Level of Brownfield Remediation PPP Projects

The evaluation results by using different methods are usually different because of diverse algorithm principles. There is theoretical rationality and logic behind every approach, and it is difficult, if not impossible, to judge which method is better than others. To avoid such confusion, we propose to combine multiple evaluation methods to assess the risk level of BR PPP projects. The combined evaluation process can reduce the possibility of systematic errors and random deviations, avoid the instability of a single evaluation method, and have certain theoretical and practical significance for the improvement of the evaluation technique.

Figure 1 depicts the detailed procedures of the proposed combined risk approach. To be specific, after identifying all available BR PPP projects for the local government, the risks of projects are evaluated by utilizing individual risk methods. Then, a Kendall-W consistency check is conducted. If the consistency check is passed, these evaluation methods are used to form a portfolio; otherwise, the evaluation method that can not pass the consistency check should be removed from the portfolio. Given the portfolio, the risk evaluation result of each individual method is calculated. Next, three techniques, namely the average, Borda, and Copeland methods, are used to combine the individual results. The combination process should be repeated until all the results are consistent with each other. More detailed information is given in the following subsections.

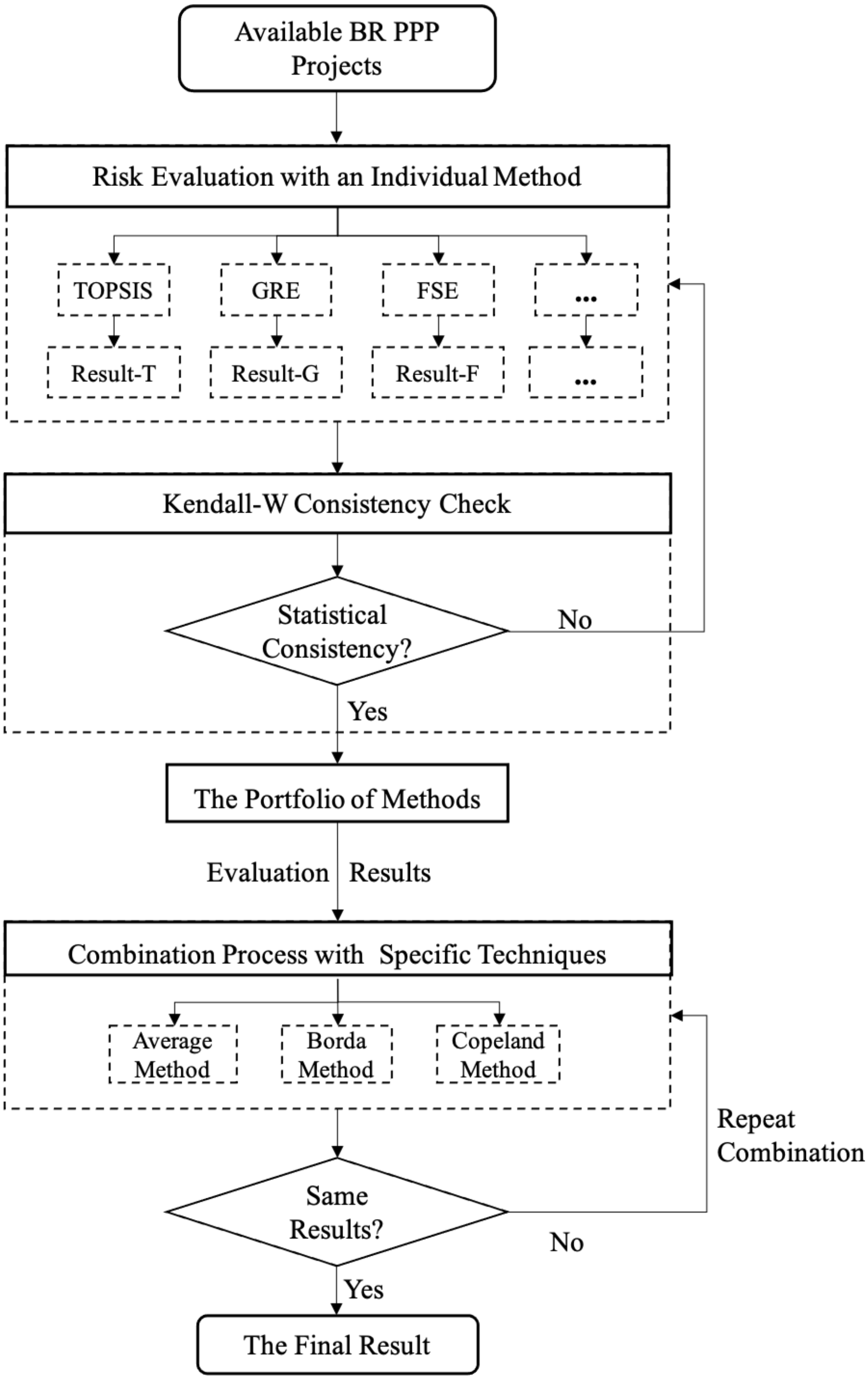

Figure 1. The Detailed Procedures to Combine Multiple Evaluation Results.

4.1. Available BR PPP Projects

In China, urban construction lands are normally owned by local governments and considered as kinds of infrastructure, to some extent. The local government announces PPP-related tender documents on their official websites. Tender announcements on BR PPP projects are still scarce in China, but the situation will be improved in the foreseeable future as more attention is given to BR projects. Thus, if interested in investing in BR projects, a private company can select from the set of announced brownfield lands in terms of the risk control ability and other preferences. The proposed method can be used by either party to evaluate the risk associated with those projects.

4.2. The Risk Evaluation of BR PPP Projects with an Individual Method

There is a large group of risk evaluation methods in the existing literature that can be applied in BR PPP risk assessment. We herein take three most commonly used ones that deal with different features of the situation.

4.2.1. Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

The TOPSIS method was proposed by Hwang and Yoon [57] to select a relatively ideal solution from multiple solutions with multiple indicators. It has been widely used in various fields for multi-objective decision analysis from a systemic insight [37,58,59]. The key step of this method is to determine the positive ideal solution and the negative ideal solution in finite schemes. The positive ideal solution consists of the optimal value of each indicator in all schemes, and accordingly, the negative ideal solution consists of the worst value of each indicator in all schemes. Among the feasible solutions, TOPSIS aims for the one that not only has the closest distance from the positive ideal solution and the farthest distance from the negative ideal solution [60]. The detailed implementation steps of the TOPSIS method used in this BR PPP project risk assessment are given as follows.

(1) Establish an initial risk index matrix R, where r_{mn} represents the value of the m^{th} project on the n^{th} index, m is the total number of available projects, and n is the total number of indexes.

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \tag{1}$$

(2) Standardize the matrix R to matrix B by using the following equation, where $i = 1, 2, \ldots, m$, and $j = 1, 2, \ldots, n$. Matrix B consists of element b_{ij}.

$$b_{ij} = \frac{r_{11}}{\sum\limits_{i=1}^{m} r_{ij}} \tag{2}$$

(3) Construct a weighted normalized matrix C, whose elements can be expressed as the following equation. In this equation, $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, and w_j is the weight of the j^{th} index, as shown in Table 2.

$$c_{ij} = w_j b_{ij} \tag{3}$$

(4) Defining the positive ideal solution S^+ and the negative ideal solution S^- as follows, where $i = 1, 2, \ldots, m$, and $j = 1, 2, \ldots, n$.

$$S^+ = \{S_j^+ = max(c_{ij})\} \tag{4}$$

$$S^- = \{S_j^- = min(c_{ij})\} \tag{5}$$

(5) Calculate the Euclidean distance of each available BR PPP project to the positive ideal solution and the negative ideal solution by using the following equations, where $i = 1, 2, \ldots, m$, and $j = 1, 2, \ldots, n$.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (c_{ij} - S_j^+)^2} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (c_{ij} - S_j^-)^2} \quad (7)$$

(6) Achieve the final evaluation result based on Equation (8), where $i = 1, 2, \ldots, m$. D_i is the relative proximity to the ideal solution. The higher the D_i is, the higher the risk of the i^{th} available BR PPP project.

$$D_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (8)$$

4.2.2. Grey Relational Evaluation (GRE)

When making decisions, there is always unknown information coexisting with known information. A grey system is defined to describe such a decision environment that contains both clear and unclear information. The grey system theory [61] takes a random process as a grey process that changes in a space–time area. As an effective method to analyze systems with incomplete information, it has been used for predicting decision-making and programming. As a core branch of the grey theory, GRE was proposed by Deng and Deng [62]. The detailed procedures to evaluate the risks of BR PPP projects based on the GRE are shown as follows.

(1) Assume that there are m alternatives that need to be evaluated. Herein, the evaluation criteria including n (that is 24) indexes are shown in Table 2. Therefore, the initial indicator matrix can be established as the following equation, where g_{mn} means the value of the m^{th} alternative on the n^{th} index.

$$G = \begin{bmatrix} g_{11} & \cdots & g_{1n} \\ \vdots & \ddots & \vdots \\ g_{m1} & \cdots & g_{mn} \end{bmatrix} \quad (9)$$

(2) Standardize the matrix G to matrix Y by using the following equation, where $i = 1, 2, \ldots, m$, and $j = 1, 2, \ldots, n$. Matrix Y consists of element y_{ij}.

$$y_{ij} = \frac{g_{ij} - g_j^{min}}{g_j^{max} - g_j^{min}} \quad (10)$$

(3) Generate the optimal sequence Y_0 as the reference sequence: $Y_0 = (y_{01}, \ldots, y_{0j}, \ldots, y_{0n})$, where y_{0j} means the optimal value of the j_{th} index in all alternatives.

(4) Account for the differences between alternatives and the reference sequence. Based on the results, the difference matrix can be built as follows:

$$\Delta Y = \begin{bmatrix} \Delta y_{11} & \ldots & \Delta y_{1n} \\ \vdots & \ddots & \vdots \\ \Delta y_{m1} & \ldots & \Delta y_{mn} \end{bmatrix} \quad (11)$$

where $\Delta y_{ij} = |y_{0j} - y_{ij}|, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$.

(5) Calculate the grey relational coefficient according to the following equation, where u represents the distinguishing coefficient, usually taken as 0.5.

$$e_{ij} = \frac{\min_{i=1}^{m} \min_{j=1}^{n} \Delta Y_{ij} + \mu \max_{i=1}^{m} \max_{j=1}^{n} \Delta Y_{ij}}{\Delta Y_{ij} + \mu \max_{i=1}^{m} \max_{j=1}^{n} \Delta Y_{ij}} \tag{12}$$

(6) Getting the result of the grey relational degree r_i according to the following equation, where $i = 1, 2, \ldots, m$. The greater the value of the r_i, the higher the ranking of the i^{th} alternative.

$$r_i = \frac{1}{n} \sum_{j=1}^{n} e_{ij} \tag{13}$$

4.2.3. Fuzzy Synthetic Evaluation (FSE)

The FSE method is based on fuzzy mathematics and has been widely used in solution evaluation and decision-making in uncertain situations. This method generally quantifies some qualitative indicators with unclear boundaries according to the membership degree theory of fuzzy mathematics. The main procedures to evaluate the risk of BR PPP projects by using FSE are presented next.

(1) A panel of t experts is invited to judge the risk level of a specific criterion over a 5-degree range, where "1" indicates "very low" and "5" indicates "very high". Let the number of experts who assess criterion j as e_l be t_{jl}. For the jth criterion, the membership function can be expressed as

$$M_j = \{m_{j1}, m_{j2}, m_{j3}, m_{j4}, m_{j5}\} \tag{14}$$

where $m_{jl} = t_{jl}/t$. Note that $\sum_{l=1}^{5} m_{jl} = 1$ holds for every criterion.

(2) Computing the score of the j^{th} criterion according to

$$s_j = \sum_{l=1}^{5} m_{jl} e_l \tag{15}$$

(3) The risk level of a specific project i can be expressed as

$$r_i = \sum_{j=1}^{24} w_j s_j \tag{16}$$

where the weight of each criterion can be checked in Table 2. The risk levels of potential projects can be ranked according to their scores.

4.3. Consistency Check of Results from Individual Methods

The consistency of risk priority results from each evaluation method is checked by using the Kendall-W method. The accepted consistency means that the results are highly relevant, and all the individual methods can be included in the method portfolio. Assume that N BR PPP projects can be evaluated by M methods. The risk level of the N BR PPP projects can be prioritized for each method according to the evaluation result. The rank R_{MN} shown in Table 4 prepared data for the Kendall-W checking, and the detailed processes are as follows.

Table 4. Data Format for Kendall-W Checking.

	Project 1	**Project 2**	**...**	**Project N**
Method 1	R_{11}	R_{12}	...	R_{1N}
Method 2	R_{21}	R_{22}	...	R_{2N}
...	...	...	...	...
Method M	R_{M1}	R_{M2}	...	R_{MN}
Rank Sum	R_1	R_2	...	R_N

(1) Establish the null hypothesis and alternative hypothesis. $H0$: the results from M evaluation methods are not consistent; $H1$: the results from M evaluation methods are consistent.

(2) Develop the checking parameter: $\chi^2 = M(N-1)W$.

$$W = \sum_{a=1}^{N} \frac{(R_a - \frac{M(N+1)}{2})^2}{\frac{M^2 N(N^2-1)}{12}} \tag{17}$$

where M and N represent the count of evaluation methods and BR PPP projects, respectively; R_a means the rank sum of the a^{th} project as shown in Table 4. The parameter χ^2 approximately follows the chi-square distribution of $N-1$ degrees of freedom.

(3) Statistical Analysis. For a certain significance level α, if the χ^2 belongs to the negative threshold $\theta = \{\chi^2 | \chi^2 > \chi^2_\alpha(N-1)\}$, the null hypothesis cannot hold and the results from M methods are consistent; otherwise, the null hypothesis holds and the results from M methods are inconsistent.

By removing methods that induce an inconsistent risk priority of these projects, the left methods can make up a new portfolio. Until the statistical consistency checking is passed, the final portfolio of methods can be achieved.

4.4. The Combination of Risk Evaluation Results from Individual Method

Although the statistical consistency checking has been verified, the risk priority results of BR PPP projects from each individual method in the portfolio may not be the same because of different algorithm bases. By using certain combination techniques, inconsistent priority results can be combined. If the combined results from different techniques are the same, the result is acceptable; otherwise, the combination process needs to be repeated. Three combination techniques are introduced in detail.

4.4.1. Average Method

The rank sum of each project is transferred to a score according to the following principles. The smallest and largest rank sums of a project are respectively scored N and 1. Based on the score results, the risk priority of BR PPP projects can be determined. In the case where the rank sums of more than one project are the same, their rank variances of different methods should be considered in addition. The rule is that the smaller the variance, the higher the new rank priority.

4.4.2. Borda Method

The Borda method, one of the most well-known combination techniques, was introduced by Borda in the late 1700s [63]. It follows the principle that the minority is subordinate to the majority. If more methods support the evaluation in which the risk value of project A is higher than that of project B, it can be expressed as $A \succ B$. The score of $S_{A \succ B}$ can be defined with Equation (18). The total score of Project A can be expressed as

$(\sum_{B=1}^{N} S_{A \succ B})$. After getting the total scores of all projects, the risk level of available BR PPP projects can be ranked accordingly.

$$S_{A \succ B} = \begin{cases} 1, A \succ B \\ 0, otherwise \end{cases} \tag{18}$$

4.4.3. Copeland Method

The Copeland Method is developed on the basis of the Borda method [64] , while the score of $S_{A \succ B}$ is defined by Equation (19). The total score of Project A can also be expressed as $(\sum_{B=1}^{N} S_{A \succ B})$. After getting the total scores of all projects, the risk level of available BR PPP projects can be ranked.

$$S_{A \succ B} = \begin{cases} 1, A \succ B \\ 0, A = B \\ -1, A \prec B \end{cases} \tag{19}$$

4.5. Determination of the Final Result

For each combination technique, a risk rank sum of available BR PPP projects can be obtained, and the rank sum of each project can be prioritized. If the priority results from all three combination techniques are the same, the final priority result is obtained; otherwise, this combination process repeats for inconsistent rankings until the uniform is achieved.

5. Case Study

In this case study, we assume seven BR PPP projects. Each is evaluated by experts with average scores from 1 to 5 in terms of the aforementioned 24 risk evaluation criteria (Table 5). Take the evaluation of Project 1 with regard to the first criterion, for example. The average score of 10 experts for this criterion is 3.1.

Table 5. Average Score from Experts.

Criteria	Project							Criteria	Project						
	1	2	3	4	5	6	7		1	2	3	4	5	6	7
①	3.1	3.1	3.1	3.3	3.9	2.9	1.6	②	3	3.2	2.3	3	3.7	3.3	2.7
③	3.8	3	2.9	3.2	2.5	3.1	3.9	④	2.9	3.3	2.9	3	2.9	3.3	3.1
⑤	2.6	3.2	2.9	3.1	2.2	2.6	2.9	⑥	2.3	3.2	3.4	3.7	2.4	3.4	2.9
⑦	3.2	3.8	2.1	2.9	2.6	3.1	3	⑧	3.1	3.4	3	2.4	3.4	3.3	3.6
⑨	2.6	3.3	4	2.8	3.1	3.3	2.8	⑩	3	3.7	3.1	2.5	2.4	3.3	2.4
⑪	2.7	2.9	3.4	3.8	3.7	2.5	3.3	⑫	3.3	2.8	2.8	3.3	2.5	2.6	3.1
⑬	2.5	3.3	2.9	2.9	3.2	3.5	2.9	⑭	3.1	3.2	2.5	2.8	2.5	3.1	3.6
⑮	2.7	3.1	2.4	3.1	3.4	2.7	2.6	⑯	3.4	2.9	3.1	2.4	3	3	3.5
⑰	2.7	3.6	2.3	2.6	2.7	3	3.2	⑱	2.8	3.3	3.5	3.8	3.2	2.4	3.8
⑲	3	2.2	2.8	3.4	3.1	3.8	2.6	⑳	2.6	3.2	3.2	3.8	2.7	2.7	2.2
㉑	3.7	3.1	2.9	3.1	2.4	2.7	3.2	㉒	2.6	4	3.1	2.7	3.1	3	2.9
㉓	3.1	2.9	3.6	3.6	3.2	2.5	2.6	㉔	2.5	3.5	2.3	2.4	2.6	2.4	3.4

5.1. Model Application

Step 1: Evaluate these projects with individual methods

Three commonly used risk evaluation methods (TOPSIS, GRE, and FSE) are introduced in Section 4.2. Herein, the risk of the seven BR PPP projects are evaluated with them, and the results are shown in Table 6. According to evaluation results, the risk priority of these projects by using each evaluation method can be determined and shown in the "Rank" column, where 1 and 7, respectively, represent the lowest and highest risk levels. As can be observed, all evaluation methods support that Project 1 obtains the smallest risk value and the first rank. However, the risk priority results are not completely the same for other projects. For instance, the risk priority results of Project 7 are 3th, 5th, and 2th with FSE, GRE, and TOPSIS, respectively.

Table 6. Evaluation results with the individual method.

	FSE	Rank	GRE	Rank	TOPSIS	Rank	Rank Sum
Project 1	2.9361	1	0.0261	1	0.3913	1	3
Project 2	3.197	7	0.031	7	0.6674	6	20
Project 3	2.9681	2	0.0268	2	0.5078	4	8
Project 4	3.1644	6	0.0309	6	0.6892	7	19
Project 5	3.0032	5	0.0281	4	0.5751	5	14
Project 6	2.9966	4	0.0277	3	0.4461	3	10
Project 7	2.9767	3	0.0287	5	0.4109	2	10

Step 2: Check the consistency of evaluation results with different methods

According to Section 4.3, the data used here are summarized in Table 7. In this case, $M = 3$ and $N = 7$. Applying Equation (17), the value of W is approximately 0.881. Therefore, the value of the checking parameter χ^2 can be determined according to $\chi^2 = M(N-1)W = 3 * 6 * 0.881 = 15.858$. Under the condition of the significance level $\alpha = 0.05$, the $\chi^2_\alpha(N-1)$ is 12.592. The null hypothesis is rejected because $\chi^2 > \chi^2_{0.05}(6)$, and the evaluation results with different methods are deemed to be consistent under the condition of significance level $\alpha = 0.05$. Hence, we can directly proceed to the next step.

Table 7. Data for Consistency Checking.

	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7
FSE	1	7	2	6	5	4	3
GRE	1	7	2	6	4	3	5
TOPSIS	1	6	4	7	5	3	2
Rank Sum	3	20	8	19	14	10	10

Step 3: Combine the evaluation results with different methods

Herein, the aforementioned Average method, Borda method, and Copeland method are used to combine the individual evaluation results.

(1) Average method
The rank sums of Project 1 to Project 7 are 3, 20, 8, 19, 14, 10, and 10. As can be observed, the rank sums of Project 6 and Project 7 are both 10. Hence, their variances should be considered. For Project 6, its variance is $\frac{1}{3}[(4-\frac{10}{3})^2 + (3-\frac{10}{3})^2 + (3-\frac{10}{3})^2] = \frac{2}{9}$. For Project 7, its variance is $\frac{1}{3}[(3-\frac{10}{3})^2 + (5-\frac{10}{3})^2 + (2-\frac{10}{3})^2] = \frac{14}{9}$. It is obvious that the variance of Project 6 is smaller than that of Project 7, and hence Project 6 has a relatively higher risk priority. As a result, the ranking shows: 1, 7, 2, 6, 5, 3, and 4.

(2) Borda method
Taking Project 3 as an example, all methods support that the risk of Project 1 is higher than that of Project 3, so $S_{3\succ 1} = 0$ according to Equation (18). In the same way, $S_{3\succ 2} = 1$, $S_{3\succ 3} = 0$, $S_{3\succ 4} = 1$, $S_{3\succ 5} = 1$, $S_{3\succ 6} = 1$, $S_{3\succ 7} = 1$. Therefore, the total score of Project 3 is $S_3 = \sum_{B=1}^{N} S_{3\succ B} = 5$. Based on the Borda method, the total scores of Project 1 to Project 7 are 6, 0, 5, 1, 2, 3, and 4, and hence their combined rank result is 1, 7, 2, 6, 5, 4, and 3.

(3) Copeland method
Also taking Project 3 as an example, all methods support the fact that the risk of Project 1 is higher than that of Project 3, so $S_{3\succ 1} = -1$ according to Equation (19). In the same way, $S_{3\succ 2} = 1$, $S_{3\succ 3} = 0$, $S_{3\succ 4} = 1$, $S_{3\succ 5} = 1$, $S_{3\succ 6} = 1$, $S_{3\succ 7} = 1$. Therefore, The total score of Project 4 is $S_3 = \sum_{B=1}^{N} S_{3\succ B} = 4$. Based on the Copeland method, the total scores of Project 1 to Project 7 are 6, −6, 4, −4, −2, 0, 2 and hence their combined rank result is 1, 7, 2, 6, 5, 4, and 3.

The combined results are summarized in Table 8. As can be observed, the combined ranks of seven projects by using these combination methods are still not completely the same, and the combination process should be repeated based on the first round of combination results. By conducting the average method, Borda method, and Copeland method again on those projects with different rankings, the second round of combination results are summarized in Table 9. As can be observed, the combined ranks of seven projects using these combination methods are completely the same in the second round. Hence, this is the final risk priority result.

Table 8. The First Round Combination Result.

Combined Results	Average Method		Borda Method		Copeland Method	
	Score	**Rank**	**Score**	**Rank**	**Score**	**Rank**
Project 1	21	1	6	1	6	1
Project 2	4	7	0	7	−6	7
Project 3	16	2	5	2	4	2
Project 4	5	6	1	6	−4	6
Project 5	10	5	2	5	−2	5
Project 6	14	3	3	4	0	4
Project 7	14	4	4	3	2	3

Table 9. The Second Round Combination Result.

Combined Results	Average Method		Borda Method		Copeland Method	
	Score	**Rank**	**Score**	**Rank**	**Score**	**Rank**
Project 1	21	1	6	1	6	1
Project 2	3	7	0	7	−6	7
Project 3	18	2	5	2	4	2
Project 4	6	6	1	6	−4	6
Project 5	9	5	2	5	−2	5
Project 6	13	4	3	4	0	4
Project 7	14	3	4	3	2	3

5.2. Results' Interpretation

After two rounds of combinations, the priority results from different methods became the same. As shown in Table 9, the risk level priorities of Project 1 to Project 7 are 1, 7, 2, 6, 5, 4, and 3, respectively. For a specific project, the smaller the rank value, the lower the risk. Thus, the priority ranking indicates that Project 1 and Project 2 have the lowest and the highest risk, respectively. From the perspective of the local government (the public party) that initiates a BR PPP project, they need to match appropriate private parties for each project, considering their risk tolerance. From the view of the private party, they need to choose BR PPP projects given their risk preference and tolerance. The selection of projects follows a well-known principle: high risk and high return. At the same time, only pursuing high returns and ignoring the risk controllability is likely to lead to project failure, which may lead to enormous losses. The proposed risk evaluation model with combined methods is more accurate because it integrates different evaluation algorithms and makes the results variances reach convergence quickly. Therefore, it can support both the public and the private parties to choose appropriate cooperation partners from a risk perspective.

6. Conclusions

Considering the large number of brownfield sites, funding shortage has been a main obstacle for this industry. In China, the government is trying to use the PPP mode to overcome the financing dilemma. Due to the high-risk features of both BR and PPP, stakeholders are very cautious about implementing PPP in BR projects. To support the decision-making process of the public and private parties, this paper aims to evaluate the risk of BR PPP projects in China by combining multiple risk measures. More specifically, 24 risk evaluation criteria and their weights are first determined. To overcome the challenge that different evaluation methods can lead to different risk priority results of BR PPP projects, a combined evaluation model was developed, which includes a combination process and considers the information from consistent individual evaluation methods. A case study including seven BR PPP projects is employed to show the applicability and effectiveness of the proposed combined evaluation model. It can be shown from our study that a consistent risk assessment result can be efficiently achieved within two iterations.

The strength of the combined evaluation process lies in the fact that it can adequately integrate the benefits of various risk measures and in the meantime overcome the potentially inconsistent results from individual methods. As a result, the credibility of the risk prioritization results is increased, and hence provides support to both governments and privates in making more informed decisions. Although only three risk measures and three combination techniques are applied in the work, our combined decision framework can be enhanced by introducing additional measures and techniques. On the other hand, due to the confidentiality requirement and lack of public brownfield information in China, our analyses are conducted based on a hypothetical case. In the future, we plan to obtain more real-world BR data so to reveal more practical indications. In addition, the allocation and control of risk are also of great significance for PPP projects, and therefore will be examined in our future works. Last but not least, it would be interesting, yet challenging to extend our risk assessment to a larger conceptual framework, integrating regeneration and urban resilience into our consideration.

Author Contributions: Conceptualization, Q.H. and Y.Q.; methodology, Q.H. and H.Z.; software, H.Z.; validation, Q.H. and H.Z.; formal analysis, Q.H. and Y.Q.; investigation, Q.H., Y.Q.; resources, Q.H. and G.Y.K.; data curation, Q.H. and Y.Q.; writing—original draft preparation, Q.H.; writing—review and editing, G.Y.K.; visualization, Y.Q. and H.Z.; supervision, G.Y.K.; project administration, Y.Q.; funding acquisition, Q.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China (Award Number: 72104040), Chongqing Social Science Planning Fund (Award Number: 2020QNGL27), Central University Basic Research Fund of China (Award Number: 2021CDJSKJC21), Postdoctoral Research Foundation of China (Award Number: 2020M683253) and Natural Science Foundation Project of Chongqing, Chongqing Science and Technology Commission (Award Number: cstc2020jcyj-bshX0038). The fourth author also appreciates the support from Discovery Grants from the Natural Sciences and Engineering Research Council of Canada (RGPIN-2015-04013, RGPIN-2022-03514).

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The research received powerful support from Chongqing Municipal Housing and Urban-Rural Development Commission, Chongqing Municipal Bureau of Planning and Natural Resources.

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

References

1. Alker, S.; Joy, V.; Roberts, P.; Smith, N. The Definition of Brownfield. *J. Environ. Plan. Manag.* **2000**, *43*, 49–69. [CrossRef]
2. USEPA. United States Environmental Protection Agency Grants and Fellowship Information. 2018. Available online: https://www.epa.gov/grants/united-states-environmental-protection-agency-grants-and-fellowship-information (accessed on 25 October 2018).
3. Green, T. Evaluating predictors for brownfield redevelopment. *Land Use Policy* **2018**, *73*, 299–319. [CrossRef]
4. Sessa, M.R.; Russo, A.; Sica, F. Opinion paper on green deal for the urban regeneration of industrial brownfield land in Europe. *Land Use Policy* **2022**, *119*, 106198. [CrossRef]
5. Han, Q.; Zhu, Y.; Ke, G.Y.; Lin, H. A two-Stage Decision Framework for Resolving Brownfield Conflicts. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1039. [CrossRef] [PubMed]
6. Jiang, Y.; Tang, Y.T.; Long, H.; Deng, W. Land consolidation: A comparative research between Europe and China. *Land Use Policy* **2022**, *112*, 105790. [CrossRef]
7. Han, Q.; Zhu, Y.; Ke, G.Y. Analyzing the financing dilemma of brownfield remediation in China by using GMCR. In Proceedings of the 2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Budapest, Hungary, 9–12 October 2016; pp. 002431–002435. [CrossRef]
8. Alexander, R. Network Structures and the Performance of Brownfield Redevelopment PPPs. *Public Perform. Manag. Rev.* **2012**, *35*, 753–768. [CrossRef]
9. Rasheed, N.; Shahzad, W.; Khalfan, M.; Rotimi, J.O.B. Risk Identification, Assessment, and Allocation in PPP Projects: A Systematic Review. *Buildings* **2022**, *12*, 1109. [CrossRef]
10. Whitman, I. Brownfield redevelopment by the private sector: Market driven decision making. In *Brownfield Sites III: Prevention, Assessment, Rehabilitation and Development of Brownfield Sites*; WIT Press: Southampton, UK, 2006; Volume 94, p. 11121. [CrossRef]
11. Glumac, B.; Han, Q.; Smeets, J.J.; Schaefer, W. Optimal PPP Agreement for a Brownfield Redevelopment Project. In Proceedings of the 18th Annual European Real Estate Society Conference, Eindhoven, The Netherlands, 15–18 June 2011; Technical report; European Real Estate Society (ERES): Amsterdam, The Netherlands, 2011. [CrossRef]
12. Li, X.; Yang, H.; Li, W.; Chen, Z. Public-private Partnership in Residential Brownfield Redevelopment: Case Studies of Pittsburgh. *Procedia Eng.* **2016**, *145*, 1534–1540. [CrossRef]
13. Glumac, B.; Han, Q.; Schaefer, W. A negotiation decision model for public-private partnerships in brownfield redevelopment. *Environ. Plan. B Urban Anal. City Sci.* **2018**, *45*, 145–160. [CrossRef]
14. Yang, M.; Zhu, Y.; Lin, H.; Ahmad, N. Recognition of Barriers in Brownfield Redevelopment PPP Project. In Proceedings of the 2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Macao, China, 15–18 December 2019; pp. 805–809. [CrossRef]
15. van den Hurk, M.; Williams, D.; dos Santos Pereira, A.L.; Tallon, A. Brownfield regeneration and the shifting of financial risk: Between plans and reality in public-private partnerships. *Urban Res. Pract.* **2022**, *published online*. [CrossRef]
16. Minolfi, G.; Albanese, S.; Lima, A.; Tarvainen, T.; Fortelli, A.; Vivo, B.D. A regional approach to the environmental risk assessment-Human health risk assessment case study in the Campania region. *J. Geochem. Explor.* **2018**, *184*, 400–416. [CrossRef]
17. Minolfi, G.; Albanese, S.; Lima, A.; Tarvainen, T.; Rezza, C.; Vivo, B.D. Human health risk assessment in Avellino-Salerno metropolitan areas, Campania Region, Italy. *J. Geochem. Explor.* **2018**, *195*, 97–109. [CrossRef]
18. Zhao, W.; Liao, Y.; Zhou, S.; Zhou, B. Ecological remediation strategy for urban brownfield renewal in Sichuan Province, China: A health risk evaluation perspective. *Sci. Rep.* **2022**, *12*, 4300. [CrossRef] [PubMed]
19. Luo, C.; Ju, Y.; Dong, P.; Gonzalez, E.D.R.S.; Wang, A. Risk assessment for PPP waste-to-energy incineration plant projects in china based on hybrid weight methods and weighted multigranulation fuzzy rough sets. *Sustain. Cities Soc.* **2021**, *74*, 103120. [CrossRef]
20. Li, H.; Liang, M.; Zhang, C.; Cao, Y. Risk Evaluation of Water Environmental Treatment PPP Projects Based on the Intuitionistic Fuzzy MULTIMOORA Improved FMEA Method. *Systems* **2022**, *10*, 163. [CrossRef]
21. Gupta, S.; Khanna, R.; Kohli, P.; Agnihotri, S.; Soni, U.; Asjad, M. Risk evaluation of electric vehicle charging infrastructure using Fuzzy AHP—A case study in India. *Oper. Manag. Res.* **2022**, *16*, 245–258. [CrossRef]
22. Yu, Y.; Darko, A.; Chan, A.P.C.; Chen, C.; Bao, F. Evaluation and Ranking of Risk Factors in Transnational Public Private Partnerships Projects: Case Study Based on the Intuitionistic Fuzzy Analytic Hierarchy Process. *J. Infrastruct. Syst.* **2018**, *24*, 04018028. [CrossRef]
23. Shrestha, A.; Chan, T.K.; Aibinu, A.A.; Chen, C.; Martek, I. Risk Allocation Inefficiencies in Chinese PPP Water Projects. *J. Constr. Eng. Manag.* **2018**, *144*, 04018013. [CrossRef]
24. Han, Q.; Zhu, Y.; Ke, G.Y.; Hipel, K.W. Public private partnership in brownfield remediation projects in China: Identification and structure analysis of risks. *Land Use Policy* **2019**, *84*, 87–104. [CrossRef]
25. Guo, P.; Li, H.; Zhang, G.; Tian, W. Contaminated site–induced health risk using Monte Carlo simulation: evaluation from the brownfield in Beijing, China. *Environ. Sci. Pollut. Res.* **2021**, *28*, 25166–25178. [CrossRef]
26. Ludvigsen, P.; Green, S.; Heltzer, J.; Lee, J. A visualization approach to prioritizing insurance claims from complex, multi-PRP Superfund sites. *Environ. Claims J.* **2019**, *31*, 239–251. [CrossRef]
27. Zhang, H.; Liu, G.; Han, Q.; Chen, G. Mapping the Barriers of Utilizing Public Private Partnership into Brownfield Remediation Projects in the Public Land Ownership. *Land* **2023**, *12*, 73. [CrossRef]

28. Liu, G.; Li, Z.; Han, Q.; Zhang, H. The redevelopment mode seletion framework for Third Front Brownfields in China. *Environ. Sci. Pollut. Res.* **2023**, *30*, 33061–33074. [CrossRef] [PubMed]
29. Fan, X.; Qiu, S.; Sun, Y. Land finance dependence and urban land marketization in China: The perspective of strategic choice of local governments on land transfer. *Land Use Policy* **2020**, *99*, 105023. [CrossRef]
30. Guo, S.; Shi, Y. Infrastructure investment in China: A model of local government choice under land financing. *J. Asian Econ.* **2018**, *56*, 24–35. [CrossRef]
31. Howland, M. Private Initiative and Public Responsibility for the Redevelopment of Industrial Brownfields: Three Baltimore Case Studies. *Econ. Dev. Q.* **2003**, *17*, 367–381. [CrossRef]
32. Fan, L.; Dai, Y.; Zhao, Q. Research on a PIPP Model For Urban Brownfield Governance. *Environ. Sci. Tech.* **2015**, *7*, 177–181.
33. Glumac, B.; Han, Q.; Schaefer, W.; van der Krabben, E. Negotiation issues in forming public-private partnerships for brownfield redevelopment: Applying a game theoretical experiment. *Land Use Policy* **2015**, *47*, 66–77. [CrossRef]
34. Ameyaw, E.E.; Chan, A.P. Evaluation and ranking of risk factors in public–private partnership water supply projects in developing countries using fuzzy synthetic evaluation approach. *Expert Syst. Appl.* **2015**, *42*, 5102–5116. [CrossRef]
35. Wu, Y.; Li, L.; Xu, R.; Chen, K.; Hu, Y.; Lin, X. Risk assessment in straw-based power generation public-private partnership projects in China: A fuzzy synthetic evaluation analysis. *J. Clean. Prod.* **2017**, *161*, 977–990. [CrossRef]
36. Nguyen, A.; Mollik, A.; Chih, Y.Y. Managing Critical Risks Affecting the Financial Viability of Public Private Partnership Projects: Case Study of Toll Road Projects in Vietnam. *J. Constr. Eng. Manag.* **2018**, *144*, 05018014. [CrossRef]
37. Liu, J.; Wei, Q. Risk evaluation of electric vehicle charging infrastructure public-private partnership projects in China using fuzzy TOPSIS. *J. Clean. Prod.* **2018**, *189*, 211–222. [CrossRef]
38. Rezaeenour, J.; Mousavi-Saleh, M.; Kolahkaj, A.R. Analyzing the risk factors of private public partnerships for water supply projects using fuzzy synthetic evaluation: A case study of Iranian water supply projects. *Water Sci. Technol.-Water Supply* **2018**, *18*, 1005–1019. [CrossRef]
39. Ahmadabadi, A.A.; Heravi, G. Risk assessment framework of PPP megaprojects focusing on risk interaction and project success. *Transp. Res. Part A Policy Pract.* **2019**, *124*, 169–188. [CrossRef]
40. Li, Y.; Wang, X. Using fuzzy analytic network process and ISM methods for risk assessment of public-private partnership: A China perspective. *J. Civ. Eng. Manag.* **2019**, *25*, 168–183. [CrossRef]
41. Xu, Y.; Yeung, J.F.; Chan, A.P.; Chan, D.W.; Wang, S.; Ke, Y. Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach. *Autom. Constr.* **2010**, *19*, 929–943. [CrossRef]
42. Li, J.; Zou, P.X.W. Fuzzy AHP-Based Risk Assessment Methodology for PPP Projects. *J. Constr. Eng. Manag.* **2011**, *137*, 1205–1209. [CrossRef]
43. Han, Z.; Porras-Alvarado, J.D.; Sun, J.; Zhang, Z. Monte Carlo Simulation-Based Assessment of Risks Associated with Public Private Partnership Investments in Toll Highway Infrastructure. *Transp. Res. Rec.* **2017**, *2670*, 59–67. [CrossRef]
44. Mao, Y.; Zhang, Y. Risk Evaluation System of Utility Tunnel PPP Project Research Based on Fuzzy Comprehensive Evaluation Method. In Proceedings of the 2017 International Conference on Innovations in Economic Management and Social Science (IEMSS 2017), Hangzhou, China, 15–16 April 2017; Atlantis Press: Amsterdam, The Netherlands, 2017; pp. 550–555. [CrossRef]
45. Bai, L.; Li, Y.; Du, Q.; Xu, Y. A Fuzzy Comprehensive Evaluation Model for Sustainability Risk Evaluation of PPP Projects. *Sustainability* **2017**, *9*, 1890. [CrossRef]
46. Wu, Y.; Xu, C.; Li, L.; Wang, Y.; Chen, K.; Xu, R. A risk assessment framework of PPP waste-to-energy incineration projects in China under 2-dimension linguistic environment. *J. Clean. Prod.* **2018**, *183*, 602–617. [CrossRef]
47. Song, W.; Zhu, Y.; Zhou, J.; Chen, Z.; Zhou, J. A new rough cloud AHP method for risk evaluation of public–private partnership projects. *Soft Comput.* **2022**, *26*, 2045–2062. [CrossRef]
48. Ofungwu, J.; Eget, S. Brownfields and health risks—air dispersion modeling and health risk assessment at landfill redevelopment sites. *Integr. Environ. Assess. Manag. Int. J.* **2006**, *2*, 253–261. [CrossRef]
49. James, K.; Farrell, R.E.; Siciliano, S.D. Comparison of human exposure pathways in an urban brownfield: Reduced risk from paving roads. *Environ. Toxicol. Chem.* **2012**, *31*, 2423–2430. [CrossRef] [PubMed]
50. Wu, Q.; Zhang, X.; Liu, C.; Chen, Z. The de-industrialization, re-suburbanization and health risks of brownfield land reuse: Case study of a toxic soil event in Changzhou, China. *Land Use Policy* **2018**, *74*, 187–194. [CrossRef]
51. Sun, H.; Li, J.; Lin, J.J.; Zhao, J. Research on comprehensive environment risk assessment of brownfield reuse in Xishan District, Wuxi City. In *Advanced Materials Research*; Trans Tech Publications, Ltd.: Stafa-Zurich, Switzerland, 2012; Volume 356, pp. 3047–3050. [CrossRef]
52. Liu, S.; Wang, L.; Guo, C. Heavy metal pollution and ecological risk assessment in brownfield soil from Xi'an, China: An integrated analysis of man-land interrelations. *PLoS ONE* **2020**, *15*, e0241398. [CrossRef] [PubMed]
53. Chen, I.c.; Ma, H.w. Using risk maps to link land value damage and risk as basis of flexible risk management for brownfield redevelopment. *Chemosphere* **2013**, *90*, 2101–2108. [CrossRef] [PubMed]
54. Enell, A.; Andersson-Sköld, Y.; Vestin, J.; Wagelmans, M. Risk management and regeneration of brownfields using bioenergy crops. *J. Soils Sediments* **2016**, *16*, 987–1000. [CrossRef]
55. Mahammedi, C.; Mahdjoubi, L.; Booth, C.; Butt, T.E. Framework for preliminary risk assessment of brownfield sites. *Sci. Total Environ.* **2022**, *807*, 151069. [CrossRef]

56. Falatoonitoosi, E.; Leman, Z.; Sorooshian, S.; Salimi, M. Decision-Making Trial and Evaluation Laboratory. *Res. J. Appl. Sci. Eng. Technol.* **2013**, *5*, 3476–3480. [CrossRef]
57. Hwang, B.G.; Zhao, X.; Gay, M.J.S. Public private partnership projects in Singapore: Factors, critical risks and preferred risk allocation from the perspective of contractors. *Int. J. Proj. Manag.* **2013**, *31*, 424–433. [CrossRef]
58. Yang, T.; Zhang, Q.; Wan, X.; Li, X.; Wang, Y.; Wang, W. Comprehensive ecological risk assessment for semi-arid basin based on conceptual model of risk response and improved TOPSIS model-A case study of Wei River Basin, China. *Sci. Total Environ.* **2020**, *719*, 137502. [CrossRef] [PubMed]
59. Zhao, J.; Duan, Y.; Liu, X. Study on the policy of replacing coal-fired boilers with gas-fired boilers for central heating based on the 3E system and the TOPSIS method: A case in Tianjin, China. *Energy* **2019**, *189*, 116206. [CrossRef]
60. Deng, H.; Yeh, C.H.; Willis, R.J. Inter-company comparison using modified TOPSIS with objective weights. *Comput. Oper. Res.* **2000**, *27*, 963–973. [CrossRef]
61. Deng, J. Introduction to grey system theory. *J. Grey Syst.* **1989**, *1*, 1–24.
62. Deng, J.; Deng, Q. Grey and fuzzy decisions for irrigation canal lining. *Agric. Syst. Sci. Integr. Res.* **1985**, *2*, 26–31.
63. Borda, L.C. Mémoire sur les élections au scrutin. In *Histoire de l'Académie Royale des Sciences Pour*; l'Imprimerie Royale: Paris, France, 1784.
64. Dortaj, A.; Maghsoudy, S.; Ardejani, F.D.; Eskandari, Z. A hybrid multi-criteria decision making method for site selection of subsurface dams in semi-arid region of Iran. *Groundw. Sustain. Dev.* **2020**, *10*, 100284. [CrossRef]