International Journal of Natural Resources and Environmental Studies
ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 2, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijnres.v2n1.16
Journal homepage: https://wepub.org/index.php/IJNRES/index

Risk Management Strategies for Waste-to-Energy Projects Utilizing BOT Models

Xinggang Jie[1], Yinggang Jie[2, *]

[1] Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia
[2] China Mobile Information Technology Center Guangzhou, China
*Corresponding Author: JIEYINGGANG (jieyinggang@chinamobile.com)

ABSTRACT

Since the 1990s, with the implementation of the reform and opening up policy, the rapid development of China's economy, the progress of urbanization is getting faster and faster, and as one of the urban wastes, the treatment of domestic waste has also attracted more and more attention. The municipal solid waste incineration treatment, and the heat generated after combustion is used to generate electricity, referred to as "garbage incineration power generation", because this way can make the waste to reduce, harmless, and can be converted into part of the electricity, because it is widely used in the treatment of municipal solid waste by local governments. Due to the shortage of government funds, most domestic waste incineration projects are implemented in BOT mode. Waste incineration power generation projects are often a large investment, for investors, the recovery period is long, the technical requirements are high, the investment agreement signed with the government is also very complex, coupled with the imperfect supporting laws and policies in China, so that the process of waste incineration power generation projects have many problems and risks, through the operation, construction, investment and other links. Based on the theoretical content of risk management in project management and combined with practical cases, this paper puts forward countermeasures and suggestions for important risks in the project, so as to analyze and discuss the risks of garbage incineration BOT project. Firstly, this paper investigates and collates the research situation of relevant projects at home and abroad, and systematically summarizes the project research results from three aspects, namely, BOT risk management of waste incineration power generation projects, BOT model of projects and BOT project risk research. Secondly, the multi-case study method was used to analyze the risks of 3 typical waste-to-power generation BOT projects, collect risk factors, construct risk aggregation, and summarize 5 types of key risks and 14 kinds of risks. Then, according to the BOT agreement signed with the government side, the specific risk management method is proposed. The goal of this study is the LF waste incineration power generation project. The author participated in the project and identified and evaluated the project risks through risk list and hierarchical analysis, so as to find out the main risks in the project such as government risk, public opinion risk, completion risk and operational risk. In addition, in combination with the project risk, specific risk coping strategies are proposed according to the risk coping strategies proposed in the paper and the actual situation of the project, so as to reduce the degree of project risk and reduce risk losses. For other similar projects in China, there is reference and reference significance and value.

KEYWORDS

Risk identification; Risk response; BOT mode; Risk management; Waste incineration power generation.

1. INTRODUCTION

With the development of The Times and the improvement of economic level, the problem of urban solid waste disposal has become a common problem faced by all countries in the world in urban development. China, which is still in the stage of development, also needs to face this problem. How to deal with domestic waste in a timely and environmentally friendly manner is an important measure for environmental protection and urban management, and is also a necessary condition for maintaining a clean city and harmonious ecological development. There are three kinds of waste disposal methods widely used in the world today: sanitary landfill, compost disposal and incineration for power generation. It is simple and low cost to use sanitary landfill to deal with domestic waste, but it needs a lot of land for landfill, and there are still hidden dangers of environmental pollution in this way. Compost disposal is conducive to waste recycling, but depends on the composition of the waste, and will cause secondary pollution to the environment, the above two modes can not meet the government's high requirements for environmentally friendly waste disposal. Waste incineration power generation as a relatively novel way of household waste disposal, because the project use land area is not much, and can reduce and harmless waste, but also into part of the energy, for today's world, especially the lack of land resources for countries, more by green. The method of incineration power generation refers to the treatment of using urban live waste as raw materials, burning it in a specific incinerator, and then using the heat generated by incineration to generate electricity. Incineration power generation mode can not only harmlessly dispose of garbage, but also use the calorific value of garbage to generate electricity, which is welcomed by most countries in the world with insufficient land area. Compared with the other two processing aspects, incineration power generation has higher technical requirements, greater capital needs, and a longer return cycle, especially the relatively high risk, which is also the reason for this study. Waste incineration power generation technology has been implemented for a long time in developed countries such as Europe, the United States and Japan. China started relatively late, and the domestic construction of waste power generation projects is also very few. Since entering the 21st century, with the government paying more attention to environmental protection and the lack of land resources and other reasons, waste incineration power generation technology has been gradually adopted. Many cities in China have adopted the BOT(build-Operate-Transfer) project construction mode to introduce social capital investment and technical strength to Build waste incineration power generation projects. However, judging from the physical implementation of waste incineration projects across the country so far, there are many problems in the construction of waste incineration power generation projects in BOT mode, such as imperfect government regulations, large public opposition, insufficient waste supply, and incomplete related supporting facilities. Thus, the development of BOT mode of municipal waste incineration power generation has been influenced. As for the social capital side that invests in the construction of waste incineration power generation projects, it is more necessary to accurately understand the risks in such projects and take effective measures to achieve the purpose of investing in construction projects.

2. LITERATURE REVIEW

2.1. BOT model research

2.1.1. BOT Mode Introduction

PPP (Public Private Partnership), translated as "public-private partnership", means that local governments sign medium - and long-term contracts (concession agreements) with social capital parties, transferring basic public facilities and other projects that should be undertaken by the government to social entities in the form of franchise rights. It is characterized by attracting domestic and foreign social capital into the field of public facilities, and by obtaining franchise rights of social capital to design, build, and operate infrastructure projects, in order to reduce the financial pressure of local governments and transfer risks to enterprises. PPP modes include BOT, BOO, etc. [2-4]. BOT mode refers to that the government hands over the municipal infrastructure projects that should have been invested by the government to social investors for investment and construction in the form of bidding. Local governments sign concession agreements with social investors, and the social investors set up project companies to carry out investment and financing, design, construction, operation and other activities for the corresponding infrastructure during the franchise period, and transfer the relevant facilities to the government after the expiration of the concession. Social investors can obtain the corresponding investment profits of the project during the licensed period. According to the franchise agreement signed by both parties, after the project reaches the franchise period agreed by both parties, the investor shall return the operation and management rights of the project to the government. Through years of practice, the advantages of BOT mode are summarized: (1) reducing the financial burden of the government; (2) Provide opportunities for social capital to participate in urban infrastructure construction; (3) The entry of social capital improves the efficiency and reduces the cost; (4) Increase the government's financial revenue in the process of project operation [5]. According to Kohli (1995), the construction cost and time of electric power projects in the private sector is only 60% to 75% of that of the government. Private water supply projects in Argentina, Chile, and Malaysia have increased water treatment capacity by two to four times compared to government projects at a cost of only 15% to 25%[6].

2.1.2. Participant BOT in BOT mode

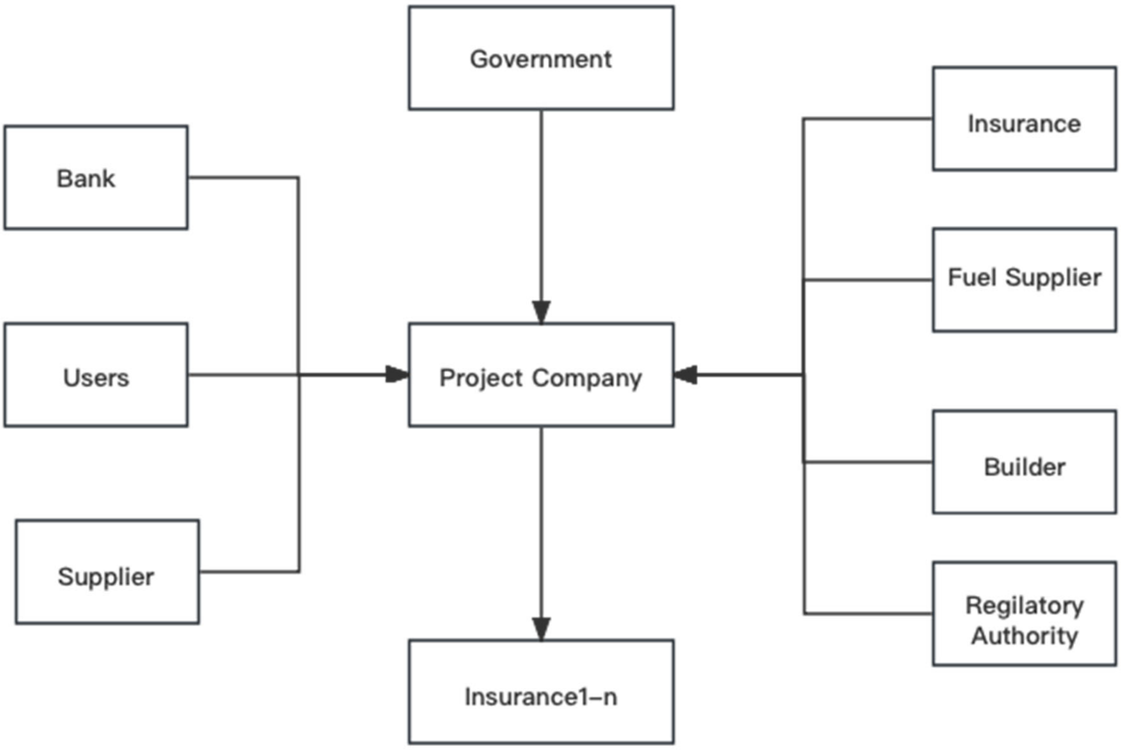

Figure 1. BOT project structure model

There are more participants in BOT mode and its organizational structure is more complex. The relevant participants mainly include local governments, social capital parties, project companies, banks, material suppliers, contractors, supervisors, operators, insurance companies, etc. Local governments determine social investors by means of public bidding. Social investors jointly establish the project company through bidding; The government then signs a franchise agreement with the newly formed project company, which allows the project company the right to invest, construct and operate the project within a certain period of time. The project company obtains investment funds through bank loans and other financing methods; Sign EPC contracts with contractors to complete project design, procurement and construction tasks; Entrust the supervisor to supervise the quality, duration and progress of the project; The risk of the project company is transferred through the signing of insurance contracts with insurance companies. After the completion of the project, the project company can entrust the operating company through the corresponding contract to be responsible for the operation of the project during the contract period. The common BOT project structure model is shown in Figure 1.

2.1.3. Phases of BOT mode

BOT mode mainly includes four stages: preliminary preparation, project construction, operation management and handover management. Shown in Figure 2

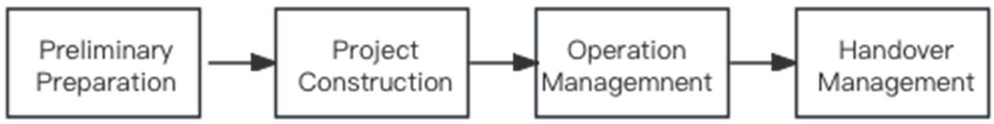

Figure 2. BOT mode phase division

1) Preliminary preparation. It is mainly related to the preparation work of the government for the bidding of infrastructure, and investors participate in the bidding. The winning company will sign a franchise agreement with the government and set up the project company. The project company inspects the project, carries out design and financing, and prepares to start construction of the project.

2) Project construction. The general contractor shall start construction under the arrangement of the project company. The supervision company shall supervise the quality, safety and progress of the project and report to the project company. The project company shall reasonably arrange the project funds to implement the project smoothly.

3) Operation management. After the completion of the project construction, the project company can choose its own operation and management according to its own situation, or it can hire a professional management team to entrust the operation. After the operation of the project, part of the income ensures the normal operation of the project, and part is used to repay the financing loan.

4) Transfer management. The government and the project company shall operate according to the franchise time stipulated in the relevant franchise agreement signed before, and after the expiration of the franchise, the project company shall transfer the right of operation and management of the infrastructure project to the government for free operation. The project company shall maintain the working equipment to ensure that the equipment is in good condition at the time of handover.

2.2. Research on BOT Project Risk

Many scholars have classified the risks of BOT projects from different standards and perspectives. In domestic and foreign studies, BOT project risks are classified in the following ways: Robert LK Tiong (1997) divides BOT project risks into three categories according to risk categories. The first is country risk, which is composed of political, macroeconomic, currency, transfer and sovereign risks. The second is the project risk, which mainly includes the project itself, including financing risk, technical risk and operational risk. Finally, customer risk mainly refers to whether customers are willing to pay for the products and services provided by the infrastructure [7]. Darrin Grimsey (2002) divided the risks of BOT projects into two stages according to the occurrence time of risks. The first is the whole process risk, such as environmental risk, political risk, force majeure risk and legal risk. The second is local risk, which refers to the risks occurring in a certain stage of project implementation, including construction risk (project construction stage), operational risk (operation management stage), financial risk (operation management stage), and technical risk (operation management stage) [8]. Huang Xincai (2011) divided BOT projects into controllable risks and uncontrollable risks, and believed that controllable risks could be solved by corresponding technical means, such as production risk, equipment risk, decision risk and design risk. Due to changes in policies and environment, risks that cannot be controlled by enterprises are uncontrollable risks of projects, such as environmental protection risks, credit and financial risks, legal risks and market risks [9]. Yang Ping (2013) divided the construction risk of BOT project into two categories: systemic risk and non-systemic risk. It is believed that the systematic risk of project construction is related to the natural environment, financial risk, political risk of the country and legal risk of the host country. Non-systematic risk refers to the potential market, production, completion and technology risks in the process of project construction [10]. According to different stages of BOT projects, some scholars have divided risk types from different dimensions such as risk scope, risk controllability, risk systematization and risk occurrence time. The classification of risks helps to take corresponding measures based on specific risks, so as to avoid or reduce risks. The risk classification of BOT projects is shown in Table 1.

Table 1. BOT Project Risk Classification

Classification Standard	**Category**	**Specific Types of Risk**
Scope	User Risk	Willingness of users to pay for the products and services provided by the infrastructure
	Country Risk	Financing, transfer, political, macroeconomic, and social risks
	Project Risk	Operational, technical, and currency risks
Time	Local Risk	Operational, construction, technical, and financial risks
	Overall Process Risk	Force majeure, political, legal, economic, and environmental risks
Controllability	Controllable Risk	Operational, production, design, decision-making, equipment, and design risks
	Uncontrollable Risk	Environmental, political legal, market, and financial risks
Systemicity	Systemic Risk	Legal, financial, and political risks
	Non-Systemic Risk	Operational, production, completion, and technical risks

2.2.1. Study on BOT Mode Risk

Liang Yongsheng (2014) analyzed and studied the risk of the BOT construction project of Mian-xi Expressway and believed that the project production risk was the most critical first-level index in the project. Project production risk should be paid attention to in the process of this project operation. Through the analysis of 7 first-level indicators, the biggest risk weight affecting the project is the project production risk, the smallest is the project completion risk, and the rest are social risk, financial environment risk, production and operation risk, market environment risk and irresistible factor risk in descending order. The analytic hierarchy process (AHP) and fuzzy evaluation method are applied to assess the risk of the project, and the risk level of the project is considered as moderate risk [11]. Mohamed (2002) believes that political risk is the key risk of BOT projects, followed by project construction risk, operation management risk and market environment risk [12]. M.M. Kemaraswamy (2010) studied the role of the government in BOT projects from the perspective of the government, and believed that the success of the project was related to the cooperation and support of the government [13]. Patrick (2009) studied the risk of expressway BOT project and believed that local policy risk was the main risk of the project, which should provide help for policy changes and realize risk avoidance and identification based on corresponding measures [14]. Zhu Qingyun (2015) studied the risk of financing model of Qingdao Dongjiakou Port BOT project. Natural disaster risk, technical risk, project completion delay risk and port cost overspend risk account for the overall weight of high risk and high risk. In terms of project construction process, attention must be paid to these risk factors [15]. At the beginning of 2005, scholars Jeffrey Philip Obbard and Kay Lang Ng studied the actual operation of BOT and believed that the most important thing to pay attention to was the political risk of the investment country [16]. Prior to this, scholars Ruan Nan and Huan Yanbing proposed that enterprise credit risk and bank credit investigation are the core of BOT project investment and financing [17]. In 2006, Stephen O Ogunlana et al. then carried out a study on the investment risk of BOT projects, believing that the most important factors to be considered are the interest rate change risk and exchange rate spread risk of the investor country [18]. Marten Wolfs proposed that, under the influence of the policies of developing countries, whether they can provide credit guarantee can directly affect the final success or failure of BOT projects [19]. In terms of risk sharing, in 2006, scholars Ogunlana and Abednego conducted a study on the BOT project implemented from Jakarta to Bandung Expressway, and the results showed that: The correctness of risk sharing can have a decisive impact on the efficiency of a project, and the two are directly proportional. In addition to determining who should bear the risk sharing, it is also necessary to solve the problem of when and how to share the risk sharing, and to prevent and avoid the risk through the adoption of reasonable measures [20]. Hurst (2004) proposed that the principal-agent theory could be used to solve the problem of risk sharing in BOT agreements. He believed that an optimal contract should be designed to achieve the goals of both parties under the condition of information asymmetry and emphasize the optimal allocation of risks so as to motivate the agent to achieve the goals of the principal [21]. In general, the risk research focus of BOT projects should be the identification of risk factors, the way of risk sharing and the evaluation of risk importance. Due to the differences in politics, economy, time, geography and other environment, scholars from different countries have different results on risk identification and importance judgment. Most scholars focus on risk sharing in the study of risk management, and rarely talk about how to deal with specific risks.

3. RISK IDENTIFICATION AND EVALUATION OF WASTE INCINERATION POWER GENERATION BOT PROJECT

3.1. Risk Identification of waste incineration power generation BOT project

3.1.1. Multi-case analysis of garbage incineration power generation BOT project

This paper collects the data of existing garbage incineration BOT projects in China by referring to network data, relevant literature and actual work, and analyzes and summarizes the cases and problems to achieve the establishment of the main risk factors in the project. For details,as shown in Table 2.

Table 2. Case study of waste incineration BOT project

No.	Project Name	Investing Company	Completion Year	Waste Processing Capacity	Project Investment	Issues Encountered	Risk Classification
1	Jiangsu Changzhou Wujin Waste-to-Energy Project	Everbright Environmental Energy (Changzhou) Co., Ltd.	2008	1000 tons/day	279 million RMB	1. Conflict between civil and installation works, affecting construction progress; 2. Insufficient capacity of sewage treatment station, leading to economic losses; 3. Government-supplied waste contained non-combustible materials like bricks and iron, increasing operational costs, leading to significant company losses; 4. Environmental pollution from waste incineration, strong opposition from local residents.	1. Delayed completion risk; 2. Lack of supporting facilities risk; 3. Waste supply risk; 4. Operation management risk.
2	Shenzhen Nanshan Waste Incineration Power Plant (Phase II)	Shenzhen Energy Environmental Co., Ltd.	2010	1500 tons/day	300 million RMB	1. Toxic gases from waste incineration released into the air due to the inability to use imported flue gas treatment equipment, causing air pollution; 2. Disagreements with the government on waste treatment fees and on-grid electricity tariffs, leading to delays; 3. Local residents strongly oppose the environmental impacts of the project.	1. Operation management risk; 2. Government regulatory risk; 3. Fee payment risk.
3	Chongqing Tongxing Waste Incineration Power Project	Chongqing Sanfeng Environmental Group Co., Ltd.	2005	1200 tons/day	315 million RMB	1. Discrepancy between government data and reality; 2. Disagreement on equipment procurement, delay in supporting facilities; 3. Insufficient waste amount, delayed payment of waste treatment fee; 4. The company compromised public interest in pursuit of profit.	1. Government credit risk; 2. Waste supply risk; 3. Fee payment risk; 4. Lack of supporting facilities risk; 5. Operation management risk.

3.1.2. Identified risk aggregation

By analyzing the above three cases of waste incineration power generation projects, we can conclude the common risk factors in the cases.

The main ones are as follows:

1. Plan site selection risks

2. Risk of delay in completion

3. Garbage supply risk

4. Technical risks
5. Risk of lack of supporting facilities
6. Operational management risks
7. Public opinion risk
8. Policy and regulatory risks
9. Fee payment risk
10. Change risk
11. Risk of government decision-making
12. Environmental pollution risk
13. Government credit risk
14. Risk of income cost change

Through the analysis of multiple cases, the risk factors of 14 garbage incineration BOT projects are summarized. Through comparison, it is found that some of these risk factors have a common convergence point.

3.2. Risk Assessment Methods of This Study

The primary methods of this research are the fuzzy evaluation method, analytic hierarchy process (AHP), and multiple case analysis. The first step is to use the analysis of specific cases of past waste-to-energy BOT projects to identify key risk factors within these cases. Then, using the analytic hierarchy process to determine the weight of each risk factor present in the cases, and finally, determine the risk level of this project through fuzzy comprehensive evaluation. The specific methods are as follows:

3.2.1. Determination of Risk Factor Index Weight Coefficients

The advantage of the analytic hierarchy process is that it effectively combines qualitative with quantitative analysis. It can incorporate expert subjective judgment into a well-designed processing model, quantitatively measure qualitative indicators, and determine the weight coefficients of each risk indicator of the project. Through quantitative processing, a relative value is produced, which can reduce the impact of experts' subjectivity in determining the risks of various project indicators. This study adopts an improved analytic hierarchy process, which can further reduce subjective judgment.

(1) Compiling a Hierarchical Structural Model

Establishing a hierarchical structural model means first determining the overall evaluation indicators of the scheme, then analyzing the risk factors affecting the overall project goal layer by layer according to the hierarchical principle. The structural model can be divided into the objective layer—criteria layer—indicator layer. The upper structure in the three-layer structure dominates the lower structure, and the influencing factors at the same layer do not affect each other.

(2) Using an Improved Exponential Scale to Construct Judgment Matrices

In the analytic hierarchy process model, the first step is to quantitatively process expert subjective judgments through judgment scales to conduct analysis work. Generally, the judgment scales implemented by experts are signs of the scale of importance between elements, represented by numerical values to indicate their relative importance.

Suppose we are comparing N factors B={B1, B2...Bn} to ascertain their impact on a certain factor C. How should we compare to ensure the reliability of the data? Scholars such as Saaty believe that a comparison matrix can be constructed by comparing factors, selecting two factors at a time, and using aij to represent the ratio of the impact that Bi and Bj have on C. As for the entire set of comparison results, V represents the judgment matrix between C and B, with the result being A=(aij)nxm [38].

Table 3. Judgment Matrix A

C	B_1	B_2	……	B_n
B_1	a_{11}	a_{12}	……	a_{1n}
B_2	a_{21}	a_{22}	……	a_{2n}
……	……	……	……	……
B_n	a_{n1}	a_{n2}	……	a_{nn}

Previous applications of the Analytic Hierarchy Process (AHP) typically derive scales from the aij values, which range from 1 to 9 and their reciprocals. This approach has the advantages of being practical and straightforward; however, it can lead to inaccuracies in results and a lack of rationality, with the potential for errors in consistency checks.

This paper, acknowledging the shortcomings of the traditional AHP, has reconstructed a new scale for the indices. The re-established AHP judgment criteria consist of five levels of division: equally important, slightly more important, markedly more important, strongly more important, and extremely more important. Based on the principle of logical judgment transitivity, if there are comparative levels between A to B and B to C, then there is a transitive characteristic in the comparative level from A to C. In other words: A:C = (A:B)/(B:C). Suppose A to B is markedly important, and B to C is slightly more important, then A to C would be strongly important, as specified in the following table 4 [39].

Table 4. A-B-C Logical Transitivity

B/C **A/C** **A/B**	**Equally**	**Slightly**	**Markedly**	**Strongly**	**Extremely**
Equally	Equally	Slightly	Markedly	Strongly	Extremely
Slightly	Slightly	Markedly	Strongly	Extremely	Extremely
Markedly	Markedly	Strongly	Extremely	Extremely	Extremely
Strongly	Strongly	Extremely	Extremely	Extremely	Extremely
Extremely	Extremely	Extremely	Extremely	Extremely	Extremely

Assume that the scores for Equally Important, Slightly Important, Markedly Important, Strongly Important, and Extremely Important are respectively 1, a2, a4, a6, a8. The pairwise comparison level score is equivalent to a^(m-n), where m > n, and with 9 as the judgment limit. Given that a8=9, then a=1.3161. With these settings, the improved exponential scale table can be derived as follows in table 5.

Table 5. A-B-C Logical Transitivity

Meaning	A and B Equally Important	A and B Slightly Important	A and B Markedly Important	A and B Strongly Important	A and B Extremely Important	Intermediate Judgment Value
Level Score	1	a2	a4	a6	a8	a^(m-n), m > n
Scale	1	1.7321	3	5.1966	9	1.3161^(m-n), m > n

In 2006, scholars Wu Zheming and Liang Haixia proposed that due to the influence of subjectivity, the comparison results in practical applications might not satisfy the consistency check. If the consistency check is not satisfied, it is necessary to adjust the judgment matrix. To reduce the computational burden, scaling is applied to the judgment values of only one factor at a time, and the data for the remaining positions in the judgment matrix are obtained based on the following recursion method.

$$a_{ij} = 1, i, j = 1,2,\cdots, n$$
$$a_{ji} = \frac{1}{a_{ij}}, i, j = 1,2,\cdots, n \tag{1}$$

For the lower triangular scale, after obtaining the first column of judgment values, the recursion formula is as follows:

$$a_{ij} = \frac{a_{i,j-1}}{a_{i-1,j-1}} j = 2,3,\cdots, n; j = i+1,\cdots, n \tag{2}$$

If scale the upper triangle, after obtaining the first row of scales, there is a recurrence formula:

$$a_{ij} = \frac{a_{i-1,j}}{a_{i-1,j-1}} j = 2,3,\cdots, n; 1 = j+1,\cdots, n \tag{3}$$

For the traditional AHP method, n(n-1)/2 judgments need to be carried out in pairs. Through the above method, only (n-1) factors need to be marked, so the computational load can be reduced and the goal of maintaining the consistency of the judgment matrix can be achieved.

(3) Test the relative importance and consistency of elements.

In order to clearly compare the importance of the risk factors located at the same layer, the maximum feature root of the judgment matrix should be calculated first. The method is as follows: First, calculate the arithmetic average value of each element in each row of the judgment matrix, that is：

$\overline{W_i^{\bullet}}$

$$\overline{W_i^{\bullet}} = \frac{1}{n}\sum_{i=1}^{n} a_{ij}, i = 1,2,\cdots, n \tag{4}$$

Second: normalized $\overline{W_i^{\bullet}}$ to get $\overline{W_i}$

$$\overline{W}_i=\frac{\overline{w_i^{\bullet}}}{\sum_{i=1}^{n}\overline{w_i^{\bullet}}},i=1,2,\cdots,\ n \tag{5}$$

Furthermore, the maximum eigenroot $\lambda_{\max}$ of the judgment matrix is calculated

$$\lambda_{\max}=\sum_{\mathrm{i}=1}^{n}\frac{(AW)_i}{(n\overline{W}_i)} \tag{6}$$

Finally: check the consistency of CI.

$$CI=\frac{\lambda_{\max}-n}{n-1} \tag{7}$$

In this company, the divisor of the judgment matrix is n. In terms of the random consistency index RI, the details are as follows [41], and the ratio operation is also realized:

$$CR=\frac{CI}{RI} \tag{8}$$

Table 3-8. Consistency indicators RI

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

If CR is less than 0.10, it means that the judgment matrix consistency test is qualified, and the weight vector W can be accepted

(4) Calculate the composite weights and perform the consistency check

Considering the acquisition of the relative weights of each criterion within the judgment hierarchy, it is necessary to conduct a comprehensive calculation of the risk factors at each criterion layer. Then, sort the related weights of each criterion and perform a consistency check. This involves layer-by-layer verification from the criterion layer to the objective layer, calculating the composite importance.

For the composite importance of element Bj in layer B, the specific calculation formula is as follows:

$$b_j=\sum_{i=1}^{n}a_i b_j^{\,i},j=1,2,\cdots,\ n \tag{9}$$

It can be seen from this that the sum of relative importance weights based on the comprehensive importance weights of the upper factors is the comprehensive importance of the lower j factors.

3.2.2. Establishing a Multi-Level Fuzzy Comprehensive Evaluation Model

When evaluating objectives, various indicators and factors are often involved. The specific method is as follows: Represent the set of factors of the target object with the letter U, then rate each factor separately, using V to represent the obtained judgment set. Upon determining the degree of factor membership, combined with its proportion in the evaluation system and calculation rules, the final evaluation result can be obtained.

From the perspective of the waste-to-energy BOT project process, risks vary and are diverse. These risk factors influence each other. The method of fuzzy evaluation can quantify experts' subjective opinions, and the quantified data can more directly address actual problems. A first-level fuzzy evaluation model can be used to evaluate general, simpler systems. However, waste-to-energy projects are comprehensive, requiring multi-level evaluation from different angles. Each angle may involve various risk factors; therefore, a first-level fuzzy evaluation model cannot meet the project risk evaluation needs. It is necessary to establish a multi-level fuzzy evaluation model, evaluating each subset separately to calculate the comprehensive membership degree. In the next chapter, this paper will apply the multi-level fuzzy comprehensive evaluation model to assess risks for the LF waste-to-energy project soon to be implemented by the author's company. The specific steps are as follows:

1: Creation of risk factor set: U equals {U1, U2, ⋯, Un};

2: To judge the establishment, V equals {V1, V2, ⋯, Vm};

3: Evaluate individual factors

$$f: U \to \Phi(V)$$

$$u_i \big| \to f(u_i) = (r_{i1}, r_{i2}, \cdots, r_{im}) \in \Phi(V) \tag{10}$$

Fuzzy mapping f represents fuzzy relation $R_f \in \Phi(U \times V)$, that is $R_f(u_i, v_i) = f(u_i, v_i) = r_{ij}$, so Rf can be identified according to fuzzy matrix $R \in u_{n \times m}$:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{bmatrix} \tag{11}$$

In the above formula, R represents the single factor evaluation matrix, and we can see that the fuzzy transformation from U to V is Rf. , U (U1, U2,... Un) can realize the construction of fuzzy comprehensive evaluation model, and U1 and other elements belong to the model.

3.2.3. Definition of Model weights This paper calculates the weights among various risk factors in the hierarchy through the improved analytic hierarchy process, and obtains the weight index $\Omega = (w_1, w_2, \cdots, w_n)$

3.2.4. Comprehensive evaluation.

The weight index is $\Omega = (w_1, w_2, \cdots, w_n)$ applied to the formula of fuzzy mathematical evaluation model $\Omega \times R = B$, in the calculation process of gratitude fuzzy comprehensive evaluation ($B = (b_1, b_2, \cdots, b_m)$) , reflecting the overall evaluation result.

4. RISK RESPONSES FOR WASTE-TO-ENERGY BOT PROJECTS

In the face of many cities grappling with the encroachment of waste, most local governments strongly encourage the development of waste-to-energy projects, enacting numerous related policies. Under conditions that ensure a certain return on investment, for social capital parties who have reached an intention agreement with the government or have signed a concession agreement for waste-to-energy projects, opting for risk avoidance means giving up on the project, inevitably resulting in significant losses. Such an approach rarely occurs in reality. Therefore, this paper focuses on studying and analyzing methods of responding to several types of risks, among which risk sharing is the most important response measure and the focus of this discussion.

4.1. Sharing of Risk

Risk sharing refers to identifying possible risk bearers according to the attributes of risks during the project implementation process, and then allowing different participants to bear the appropriate risks according to their risk-bearing capacity and suitability, thereby reducing the overall project risk. In practical operations of the project, social capital can share project risks with insurance companies, material and equipment suppliers, and local governments, among other institutions.

4.1.1. Sharing Risks with the Government

From the perspective of waste-to-energy BOT projects, the project owner and the grantor of the concession rights are both the government, which grants the social capital party the exclusive right to handle domestic waste within a certain area for the concession period. From the perspective of social capital, the government is the largest risk bearer, and the BOT agreement is an important means for the project company to share risks with the government.

The Concession Agreement (BOT Agreement) is an agreement signed between the local government or its authorized government department and the social investor. It is the most core legal document in a BOT project. The BOT agreement typically stipulates the duration of the concession period, the unit price for waste treatment, methods and modes of price adjustment and payment, the scope and quality of waste supply, etc. The BOT agreement specifies the rights and obligations of the local government and the social capital party respectively, with corresponding unit prices for different risks. Assuming all external conditions are consistent, the waste disposal unit price can most directly reflect the risk-sharing ratio between the government and the investor.

4.1.2. Sharing Risks with the General Contractor

After signing the BOT agreement, the project company prepares to mobilize resources for project construction. As the project is about to commence construction, the project company can transfer risks by signing an EPC contract with the general contractor, who will then be fully responsible for the project construction phase.

Through the EPC contract, the project company can transfer risks such as project completion, including delays, cost overruns, and engineering quality, to the EPC contractor, thereby achieving risk sharing.

The total project price stipulated in the EPC contract can specifically reflect the relationship between the investor and the construction contractor, including profit and risk relations. From the perspective of project implementation, a fixed-price EPC contract can stabilize the project company's profits and risks, seemingly reducing the risks faced by the investor. However, the EPC contract is a long-term agreement, and many unforeseeable issues will arise during its actual implementation. For the EPC contractor, who undertakes preliminary design, geological surveys, and construction design, if the contract stipulates a fixed total price but risks encountered during the actual implementation exceed expectations, choices that affect the overall quality of the project may be made, leading to greater losses for the investor. Therefore, including open clauses in the EPC contract or provisions for appropriate adjustments based on actual project conditions has become a common practice in actual applications, also more effectively avoiding risks.

4.1.3. Sharing Risks with Insurance Companies

Transferring project risks through insurance is another important method. For example, the project company obtains insurance services from insurance companies by paying premiums. Insurance coverage usually includes project property safety, project asset loss, project equipment insurance, construction personnel casualty insurance, etc. Project insurance can enhance the project's risk resistance capability, hence it's an effective method for project risk transfer in practical operations.

4.2. Risk Response

4.2.1. Response to Operational Management Risk

4.2.1.1 Response to Operational Risk

Operational management risk, if not handled properly, will affect the related interests of the government, concessionaires, and operators. Therefore, responding to the project's operational risks is crucial. Common measures for responding to project operational risks include: (1) choosing an experienced operator. Waste-to-energy BOT projects belong to complex, capital-intensive industries with significant project financial risks, so the project's operator must have extensive experience in waste-to-energy operations. (2) After selecting the operator, sign a long-term operation contract. This contract binds the operator to reduce risks during project operation. (3) Strengthen equipment checks during operation. Regular supervision should be enforced to urge the operator to reserve sufficient special funds for equipment maintenance.

4.2.1.2 Response to Waste Supply Risk

For most waste-to-energy plants, there may be a risk related to waste supply, such as substandard quality of waste or insufficient supply quantities, during the initial operation phase. These situations not only affect the operating efficiency of the plant but also result in lower waste treatment volumes and actual power generation than projected, directly impacting the project's profitability. The primary reasons include: the design scale in the project feasibility report, considering the performance and efficiency of incineration equipment, usually takes the waste volume of the median year of the concession period; and inaccurate waste supply data provided by local governments and overly ambitious planning are significant causes.

To address waste supply risk, there are three main approaches: firstly, risk retention, where the project company during the feasibility study increases on-site investigation efforts, focusing on detailed research on local population, economic development, local waste collection and transportation, and conducting on-site sampling analysis of the waste to be treated. This ensures the design data and actual data are as consistent as possible to ensure the feasibility report's design parameters and scale match reality. Secondly, risk transfer to the government by setting a minimum guaranteed waste supply volume in the BOT agreement, thus ensuring the project company achieves expected profits. Thirdly, risk transfer by finding new sources of domestic waste to increase the waste supply volume or change the waste quality, such as aged waste from landfills, wooden waste from woodworking factories, and other high calorific value industrial wastes, can serve as new sources for incineration.

4.2.1.3 Response to Cost Payment Risk

Cost payment risk refers to the risk of the power company failing to pay the feed-in tariff on time or the government failing to pay the waste disposal fee in a timely and full manner as agreed in the BOT contract. Investigations show that many local governments in China's waste-to-energy projects, affected by fiscal revenue, have delayed waste disposal fee payments, preventing project companies from achieving expected returns. In contrast, the State Grid Corporation, facing no financial difficulties, rarely encounters such issues. The main method to respond to cost payment risk is to avoid its occurrence as much as possible. First, set the payment deadlines and forms of the waste disposal fee in the BOT contract, and regulate the government's corresponding liability for breach of contract. If delayed payments occur, appropriate fees should be charged in addition to bank interest for the same period. Moreover, the project company should actively communicate with the local government and the responsible departments for fiscal appropriations to ensure timely and full receipt of the waste disposal fee.

4.2.1.4 Response to Cost and Revenue Change Risk

The risk of cost and revenue changes refers to the risk of increased operating expenses or reduced profits due to the rise in prices of fuel, labor, etc., after the project has been built and put into operation. Reasons for the increase in operating costs can be categorized into two: first, during the construction process, various reasons cause the total construction cost to rise, leading to an increase in asset amortization expenses during the operation period, including the rise in prices for civil construction, incineration equipment, materials, machinery, and land costs. Second, after the project has entered the actual operation phase, management experience deficiencies of the operating unit, the rise in auxiliary fuel prices, and labor costs contribute to the cost increase. The response to the increase in asset amortization expenses will be detailed in section 4.2.3. After the project has been put into operation, the risk of increased operating costs due to the rise in auxiliary fuel prices and labor costs can be transferred to the government. In other words, it's predetermined in the BOT agreement that when corresponding boundary conditions change, the waste disposal unit price can be adjusted according to a formula to minimize the project company's losses. The cost increase due to the operating unit's lack of management experience, often because of frequent failures in waste incineration equipment, leading to increased equipment maintenance costs, can be addressed by the project company through risk transfer and mitigation methods. This includes regular maintenance of waste incineration equipment to reduce equipment failure rates and outsourcing the maintenance work of waste incineration equipment to a professional maintenance company. At the same time, the maintenance company's responsibilities should be stipulated in the outsourcing contract to transfer the risk.

4.2.1.5 Response to Environmental Pollution Risk

As an environmental protection project, waste-to-energy plant projects may cause pollution to the surrounding environment, which is of great concern to local residents and the government. In the early stages of the project, public opposition might prevent the project from being implemented; if environmental pollution accidents occur after the project is operational, it could lead to fines from government departments up to closure. Therefore, responding to environmental pollution risk can have a decisive impact on the success or failure of waste-to-energy projects and is a focus of work and links. The causes of environmental pollution mainly include leachate, flue gas, odor, fly ash, noise, etc., generated during the waste incineration process.

There are two main methods to address environmental pollution risk: risk mitigation and retention. During the early stages of the project, it involves selecting a qualified design institute to prepare an environmental impact assessment report and subsequently ensuring that the design and construction strictly adhere to the requirements specified in the environmental assessment approval. Also, hiring professional environmental supervisors to ensure that various environmental protection measures are implemented during the construction process is crucial. After the project commences operation, it is essential to strictly follow the content related to the environmental assessment approval and conduct online monitoring of various emissions such as water and air to promptly respond to emergencies.

The second method is risk transfer, which primarily involves contracting the treatment of waste incineration byproducts such as fly ash or leachate to contractors with the necessary qualifications, or outsourcing the project's operational work. It's important to clearly define the obligations and responsibilities of the contractor in the outsourcing contract so that all liabilities in the event of a pollution incident or risk are borne by the contractor.

4.2.2. Responding to Government Risks

Government risks refer to government credit risk, the risk of missing ancillary facilities, policy and regulation risks, and government decision-making risks. From the company's perspective, responding to government risks is crucial because changes in policies and other factors can significantly impact the success of the project.

4.2.2.1 Responding to Government Credit Risk

Many local governments in China still exhibit a mentality of officialdom and bureaucratic style. As a result, cooperation between the project concession company and the government must be well-prepared for potential government credit risks. As investors, to effectively respond to the government's credit risk, specific clauses can be included in the BOT agreement to specify that if the government acts in bad faith when the project enters the implementation phase, it will bear certain liabilities for breach of contract.

4.2.2.2 Responding to the Risk of Missing Ancillary Facilities

Waste-to-energy projects require corresponding ancillary facilities, such as power supply lines, water, gas, and road infrastructure. Typically, government departments are responsible for coordinating the construction of these facilities, and their insufficiency can affect the project's progress. To address this risk, provisions can be included in the concession agreement stipulating that if ancillary facilities are not completed as scheduled, the construction period and concession period can be appropriately extended.

4.2.2.3 Responding to Policy and Regulation Risk

Policy and regulation risk refers to changes in government policies and regulations related to the project during its implementation or after it becomes operational, leading to increased production and operational costs. For example, changes in tax relief policies or stricter standards for wastewater and waste discharge can lead to higher operational costs, a decrease in electricity prices due to electricity policy changes, or the need to upgrade original equipment due to new technical policies.

Current domestic laws and regulations related to waste-to-energy projects include notices on tax incentives for environmental protection, energy-saving, and water-saving projects, notices on adjusting and improving VAT policies for products and services of resource recycling, the Renewable Energy Law of the People's Republic of China (Amendment), and notices from the National Development and Reform Commission on improving the pricing policy for waste-to-energy electricity.

To address project risks arising from changes in relevant government policies and regulations, two approaches can be taken: sharing risks with the government and risk retention. Sharing risks with the government means listing in the BOT agreement all currently implemented laws and regulations related to the project. If these policies and regulations change, causing the project company's operational costs to rise or profits to decrease, the project company can be compensated in an appropriate manner. Risk retention means that the project company itself tries to resolve the cost increase caused by the aforementioned reasons through improving operational management levels, reducing production costs, and undertaking technological transformations.

4.2.2.4 Responding to Government Decision-Making Risk

Government decision-making risk refers to risks arising from a lack of management experience or objective difficulties in the government's risk forecasting for waste-to-energy projects, such as overly ambitious project scales or irrational project siting.

While project investors cannot influence the government's decisions, risks can be transferred to the government through specific clauses in the BOT agreement. Thus, it can be stipulated in the BOT agreement that if the project's construction period is extended or investment increases due to government reasons, the concession period will be accordingly extended, and the government will bear the corresponding losses. Additionally, during the early stages of the project, investors should actively cooperate with government departments to ensure that decisions are scientifically sound and reasonable, thereby reducing the likelihood of such risks occurring or minimizing losses.

4.2.3. Responding to Completion Risks

From the perspective of project investors, whether a waste-to-energy project can be completed on time under quality and quantity conditions directly affects the potential profits for investors. Therefore, effectively identifying and reasonably responding to such risks can ensure the project is completed and operational on schedule. Completion risks mainly include planning and siting risks waste incineration process.

To address environmental pollution risk, there are two main methods: mitigation and retention, and risk transfer. In the project's early stages, a qualified design institute should be selected to compile an Environmental Impact Assessment (EIA) report, and subsequent design and construction work should strictly follow the requirements of the EIA approval. At the same time, professional environmental supervision should be employed to ensure the implementation of environmental protection measures during the project's construction. After the project is operational, it should also strictly adhere to the EIA approval's stipulations and implement online monitoring of various emissions such as water and air to respond promptly to emergencies.

Another method is risk transfer, primarily through contracts to outsource the treatment work of fly ash or leachate generated by waste incineration to contractors with the relevant qualifications, or outsourcing the project's operational work. It's important to specify in the outsourcing contract the contractor's obligations and responsibilities, with all liabilities for factory pollution incidents and risks borne by the contractor.

4.2.4. Response to Government Risks

Government risks refer to government credit risk, the risk of missing ancillary facilities, policy and regulation risk, and government decision-making risk. From the company's perspective, responding to government risks is crucial because changes in policies and other factors can significantly impact the project's success.

4.2.2.1 Responding to Government Credit Risk

Given the presence of officialism and bureaucratic styles in many local governments in China, as the project's concessionaire cooperating with the government, it is essential to be fully prepared for potential government credit risks. As project investors, to effectively respond to government credit risk, specific clauses can be included in the BOT agreement, stipulating that if the government acts in bad faith when the project moves into implementation, it will bear certain liabilities for breach of contract.

4.2.2.2 Responding to the Risk of Missing Ancillary Facilities

Waste-to-energy projects require corresponding ancillary facilities, such as supporting power lines, water, gas, and road infrastructure. Generally, government departments are responsible for coordinating the construction of these ancillary facilities. Insufficient ancillary facilities can affect the project's progress. To address this risk, it can be stipulated in the concession agreement that if the ancillary facilities are not completed as scheduled, the construction period and concession period can be extended accordingly.

4.2.2.3 Responding to Policy and Regulation Risk

Policy and regulation risk refers to changes in government policies and regulations related to the project during its implementation or after it becomes operational, leading to increased production and operation costs. For example, changes in tax relief policies or stricter standards for wastewater and waste discharge could lead to higher operational costs, electricity policy changes causing electricity prices to drop, or new technical policies requiring equipment upgrades.

Currently, the main legal and regulatory documents related to waste-to-energy projects in China include "Notice on the Publication of the Catalogue of Environmental Protection, Energy Saving, and Water Saving Projects Eligible for Corporate Income Tax Preferences," "Notice on Adjusting and Improving the Value-Added Tax Policy for Products and Services of Comprehensive Resource Utilization," "Renewable Energy Law of the People's Republic of China" (Amendment), and "Notice of the National Development and Reform Commission on Improving the Pricing Policy for Waste Incineration Power Generation," among others.

To respond to project risks caused by changes in related government policies and regulations, two approaches can be taken: sharing risks with the government and retaining risks. Sharing risks with the government means listing in the BOT agreement the current laws and regulations related to the project. If these policies and regulations change, leading to increased operational costs or reduced profits for the project company, the government could compensate the project company for part of the income. Risk retention means the project company itself addresses the cost increase caused by the aforementioned reasons through improving operational management, saving production costs, and undertaking technical renovations.

5. SUMMARY

This paper, based on 3 waste-to-energy BOT projects that have been initiated or are operational in China, analyzes and identifies 14 common risk factors in such projects through analysis and induction. These 14 risk factors are then categorized and merged into 5 major categories with 14 key risks; finally, from the perspective of project investment owners, the paper discusses the response measures for these key risks one by one. The main conclusions of this paper are summarized as follows:

(1) According to the case studies of waste-to-energy BOT projects that are under construction or operational in China, risks caused by governmental reasons (including government decision-making risk, policy and regulation risk, government credit risk, cost payment risk, waste supply risk, etc.) are key risks affecting whether the project can be implemented and operated smoothly. The response method can be: to transfer the risks to the government through specific clauses in the project concession agreement. When signing the concession agreement, if many boundary conditions of the project cannot be determined, leading to an inability to accurately predict the project construction investment and operational costs, a provisional waste disposal unit price can be agreed upon, which can be adjusted later based on actual settlement data after the project has been operational for some time. This approach can reduce the impact of such risks on social capital, thus ensuring that the project company can achieve the expected profits.

(2) During the construction process of the project, the project company can transfer some of the completion risks (including engineering quality risk, engineering safety risk, cost overrun risk, and completion risk) to the general contractor through the EPC general contracting method. In the EPC general contracting agreement, the responsibilities and rights of the general contractor should be clearly stipulated, with the general contractor responsible for all quality, safety, progress, and schedule issues during the project construction period. After the project officially becomes operational, the project company can also transfer operational risks by entrusting the entire plant to other operators for management. However, it must be stipulated in the operation contract that the operator should bear the obligations, such as bearing all responsibilities if environmental pollution incidents occur during operation.

(3) In today's society, where public environmental awareness is increasingly strong, how to accurately face public opinion risk and avoid its occurrence will directly affect whether the waste-to-energy project can be implemented and operated smoothly. For public opinion risks caused by improper government decisions, it can be agreed in the concession agreement that the government is

responsible for resolving them. At the same time, the project company should strictly comply with environmental protection requirements for project construction and operation and actively communicate with the local community to gain the understanding of the surrounding residents, thus avoiding the occurrence of public opinion risk.

Due to the diversity of subjective and objective conditions where the project is located, the characteristics of specific waste-to-energy projects also vary, as do the key risk factors they face. In practical application, it is more appropriate to analyze specific risks and response measures in conjunction with the specific characteristics of the project.

CONFLICTS OF INTEREST

Have no conflict of interest.

ACKNOWLEDGEMENTS

None

REFERENCES

[1] Kayal Lakshmanan, Fabrizio Tessicini, Antonio J. Gil, Ferdinando Auricchio. “A fault prognosis strategy for an external gear pump using Machine Learning algorithms and synthetic data generation methods”, Applied Mathematical Modelling, Vol. 123, pp. 348-372, 2023. https://doi.org/10.1016/j.apm.2023.07.001

[2] Ministry of Ecology and Environment. (2016, October 22). Opinions on Further Strengthening the Incineration Treatment of Urban Domestic Waste (Document No. 227 of 2016). Retrieved from https://www.mee.gov.cn/gkml/hbb/gwy/201611/t20161124_368164.htm

[3] National Development and Reform Commission, Ministry of Housing and Urban-Rural Development. (2021, May 6). Notice on Issuing the "14th Five-Year Plan for the Development of Urban Domestic Waste Classification and Treatment Facilities" (Document No. 642 of 2021). Retrieved from https://www.ndrc.gov.cn/xxgk/zcfb/tz/202105/t20210513_1279763.html?code=&state=123

[4] Gong, S. T., Xu, Y. L., & Yao, Z. F. (2017). Research on Key Risks of PPP Waste Incineration Power Generation Projects Based on Multiple Cases. Management and Administration, 2017(11), 145-150. https:// 10.16517/j.cnki.cn12-1034/f.2017.11.040.

[5] Zhang, J. Q. (2019). Application Research of Fuzzy Comprehensive Evaluation Method in Enterprise Safety Management (Master's thesis). Liaoning University of Science and Technology. https://10.26923/d.cnki.gasgc.2019.000111.