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Energy Performance Contracting, Risk Factors, and Policy Implications: Identification and Analysis of Risks Based on the Best-Worst Network Method

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Abstract: The Energy Performance Contracting (EPC) industry in China faces many severe risks that hinder its development. This study aims at identifying the risk factors in China's EPC industry, developing a generic method for prioritizing these factors and identifying the key risk factors, and proposing some policy implications for China's decision-makers to draft effective measures and policies to promote the harmonious development of EPC industry in China. A total of 21 risk factors in five categories including external environmental risks, managerial and operational risks, financial and market risks, technical risks, and client risks are identified. A best-worst network (BWN) method was developed for ranking these risk factors based on the traditional Analytic Network Process (ANP) and the BW method. The results determined the BWN method were validated by ANP method, and the results determined by the BWN method were also compared with that determined by Analytic Hierarchy Process (AHP) method. According to the results, some policy implications have also been proposed for China's decision-makers.

Keywords: Energy Performance Contracting; Analytic Network Process; Best-Worst method; risk factors

1. Introduction

As the world's largest developing country, China has experienced unprecedented economic growth, which has been accompanied by increasing energy consumption. In the past decades, China's energy consumption increased from 2.61 billion tons of coal equivalent (tce) in 2005 to 4.26 billion tce in 2014 [1] with an annual growth rate of 6.6 percent [2]. With this rapid growth rate, China surpassed the US to become the largest energy consumer in the world in 2010 [3]. In addition, China has also consumed the largest share of energy globally, accounting for more than 60% [2].

The massive consumption of fossil fuels in China has also been criticized for leading to serious energy waste and environmental pollution [4]. Zhang et al. [5] pointed out that the economic growth, energy consumption, and emissions in China interact and are interdependent. About two-thirds of China's energy consumption comes from the industry sector [6]. China's industry sector consists primarily of small and inefficient factories, most of which were constructed in the 1990s, when they contributed significantly to China's energy consumption [7]. Accordingly, China implemented a variety of policies and programs for energy-saving and energy intensity improvement [8]. However, decades later, these old facilities and equipment were still in use and were highly inefficient [9]. Furthermore, due to the coal-dominated energy mix, China suffers from serious air pollution [10]. During the past several years, urban citizens in northern China have encountered a serious smog problem with an annual average concentration of PM 2.5 as high as or greater than 100 $\mu g/m^3$ [11].

In order to tackle ever-growing energy consumption and the related issues and achieve energy efficiency, scholars and policy-makers have proposed various types of solutions [12]. These solutions include energy storage technologies [13-15], carbon monitoring and management [16-18], and the utilization of renewable energy sources [19-21]. Helping the decision-makers/policy-makers to promote the development of sustainable energy is of vital importance [22]. There are various methods to improve energy efficiency as there are various factors affecting energy efficiency [23].

Among these methods, energy performance contracting (EPC) was introduced as a market mechanism to deliver energy efficiency projects to specialized energy service providers, which can help to reduce energy and monetary waste [24]. EPC was recognized as a way to achieve both energy-saving and energy efficiency improvement for the building energy efficiency retrofit project [25].

An Energy Service Company (ESCO) is the provider of EPC, which originated in North America in the late 1970s and early 1980s [26] and now has been popularized in most industrialized economies, as well as many developing countries [27]. The model of EPC was introduced to China in the late 1990s, when the Chinese government and the World Bank conducted a key international cooperation project in the field of energy conservation and management [28]. Subsequently, ESCOs and EPC have undergone tremendous and rapid development in China. Until 2012, more than 2000 ESCOs were providing energy conservation and management services in China [29]. Despite the development and progress of EPC and ESCOs that have been made in China, the ESCO industry is still quite small in size (around 400 ESCOs in China) and vulnerable to financial and market risks (loan amounts usually range from 1 million USD to 6 million USD, and it is usually difficult for Chinese banks to appraise these small-size ESCOs) [30]. The EPC business model usually involves various complex factors, e.g. energy users' status, project preferences and external influential factors [31]. In addition, contradictions in government policy discourage the development of EPC and ESCOs. Though the government has some supportive policies and incentives for ESCO development, these policies are of questionable operability and lack a mature mechanism to support ESCO development [28].

Meanwhile, there are usually various challenges and risks in China's EPC projects which lead to the low use rate of EPCs [32] . Zhang *et al*. [33] found that there are usually various risks in China's EPC projects, e.g., delay in completion, delay in payment, operational risks and uninsured loss, etc. Liu *et al*. [34] revealed that different stakeholders may have different concerns on different EPC models and the risks to different stakeholders may also be different. It is necessary to have a comprehensive investigation on the influencing factors of EPC such that the decision-makers can understand the key problems in the EPC industry and take effective action to promote the development of the EPC industry in China. In order to address, mitigate and even eliminate the risks in EPC projects, it is necessary to determine the priorities of the risk by ranking these risks for the ESCOs [35].

There are increasingly numerous studies investigating the barriers and risk factors of EPC. Garbuzova-Schlifter and Madlener [36-37] conducted a comprehensive analysis of risk analysis of EPC projects in Russia, and the Analytic Hierarchy Process (AHP) was used to rank these risk factors in terms of their roles in EPC projects. Van Heijs *et al.* [38] identified the key aspects of building design, building energy systems and occupant behavior which can effectively influence the KPIs (Key Performance Indicators) of EPC, and they used scenario analysis to construct methods for reducing financial risks in ECSOs. Yang and Chou [39] discussed the five critical challenges that exist in executing energy-saving performance contracts (ESPC), and they also proposed some lessons and implications for achieving better performance in ESPC projects. Yeatts *et al*. [40] summarized the barriers to the use of energy-efficient technologies in building, and produced a comprehensive review of strategies for overcoming these barriers. Lee *et al*. [41] identified the critical risks in EPC projects in Hong Kong and the concerns of the building owners through a questionnaire survey. Similarly, ESCOs in China encounter various kinds of risks and barriers, which hinder the development of EPC and block improvement in energy efficiency. Many studies also focused on promoting the development of EPC in China. For instance, Yuan *et al*. [42] systematically examined the evolution of policies, regulations, laws and plans for promoting the development of EPC in China. Qin *et al*. [43] employed the multi-criteria decision making method to select the best energy performance contracting business models in China among the share saving model, the guaranteed model, the energy cost-trust model and the financial lease model by considering the criteria in four dimensions including the project itself, the energy user, the ESCO, and the external environment.

This paper aims to identify barriers and risks and analyze how these risk factors and barriers discourage the adoption of EPC in China while also attempting to identify solutions to remove these barriers, promote the development of ESCOs, and improve energy efficiency in China. AHP is the most commonly used method for determining the relative weights of the barriers and risks of EPC quantitatively, but it cannot address the independence or interactions among these barriers and risks. Therefore, ANP (Analytic Network Process), which can address independence and interactions among the criteria/factors, is usually employed to calculate the relative weights of these criteria/factors. However, this approach still has a severe disadvantage. There are n(n-1)/2 times the number of comparisons when there are n criteria/factors. For instance, users need to compare 10 times the number of comparisons when there are 5 barriers and risks. The best-worst network (BWN), which can not only address the independence and interactions among the barriers and risks but also reduce the number of comparisons compared to AHP and ANP, was developed to determine the relative weights of the barriers and risks in this study.

The methodological framework of analyzing the risk factors in China's energy performance contracting industry is presented in Figure 1. The risk factors that exist in China's EPC industry were first summarized based on a literature review and focus group meeting; BWN was subsequently employed to determine the relative weights of these risk factors. An analytic network process was later employed to validate the results and compare the results determined by best-worst network method and analytic network process (ANP) with those determined by an analytic hierarchy process (AHP); finally, certain policy implications were proposed for promoting the development of China's EPC industry.

2. Barriers and risk factors for EPC

In order to investigate the barriers and risk factors in China's EPC industry, a focus group meeting was conducted on October 26th, 2016 at Chongqing University, Chongqing, China. One of our authors served as the coordinator of this focus group meeting. There were nine people invited to participate in the focus group meeting: three professors whose research focused on EPC, three experts who worked in an EPC company, and three administrators responsible for the EPC industry from the local government of China. Based on previous studies [44] and the results of the focus group meeting, a group of barriers and risk factors were identified and grouped into five categories: external environmental risks, managerial and operational risks, financial and market risks, technical risks, and client risks. These risks are presented in Table 1.

2.1 External environmental risks

External environmental risks are possible losses caused by external factors, including government policy, the economic environment and natural environmental conditions [44]. Therefore, three types of external environmental risks are considered in this article: (1) political and legal risk, (2) economic risk, and (3) natural environmental risk. The present policies and regulations about energy conservation provide few incentives to energy utility companies to implement energy saving behaviors [45]. Usually, the government policy changes over time, which may result in risks for ESCOs [46]. The performance of ESCOs can also be affected by the macroeconomic environment [47]. Energy saving effects can also be influenced by the natural conditions, e.g., weather, hydrology, landform and natural hazards [47].

2.2 Managerial and operational risks

Managerial and operational risks are usually caused by internal managerial factors and project-related factors. Managerial problems can be a lack of professional talent [48], problems with the project team [49], decision mistakes, information asymmetry [46], the ability to operate and control over project [34], and even the procurement of equipment and materials [50]. The risks from a project are mainly caused by the status of the project, i.e., the age and location of building [20]. In sum, the managerial and operational risks include the following aspects: (1) strength of the project team, (2) decision risk, (3) ability risk, (4) information management risk, (5) procurement risk, and (6) construction risk.

2.3 Financial and market risks

The financial and market risks for ESCOs are primarily derived from the supply and demand situation of the market, price changes, and the channels to raise money. The uncertainty of market demand and industry competition can lead to great market risks for ESCOs [44]. The market price for human capital, materials and equipment can increase for some unexpected reasons, which may lead to an increase in construction costs [51-52], while dropping energy prices can result in an overall cost saving effect for the project [53]. It is difficult to survive in a fierce market for small ESCOs that cannot get abundant financial support [54-55]. Since most ESCOs in China are small and medium enterprises (SMEs), and they have a very small chance to get a loan from the bank [28]. Even if they can get some financial support, they will usually face a high interest rate [51]. In this research, the following risk factors are considered to be market and financial risks: (1) risk of market competition, (2) risk of price change, (3) risk of market demand, and (4) high interest rate risk.

2.4 Technological risks

The ESCO industry in China is still in the initial stage, and these businesses have no example with well-round experience and procedures to learn from or listen to [56]. The absence of standardized procedure can be a typical technological risk for ESCOs in China. Also, the lack of advanced and competitive technologies for improving energy efficiency and the methodology to measure and verify energy saving effect hinder the adoption and effect of EPC and the ESCO industry in China [28,52]. Four technological risks are included in this paper: (1) Lack of standards for implementing EPC, (2) advanced technology and equipment risk, (3) project quality risk, and (4) energy-saving measurement and verification risk.

2.5 Client risks

The client risks usually originate due to the insufficient communication between ESCOs and their clients. Client risks can result from different reasons. For example, the client may not be satisfied with the energy saving effect, there may be something that ESCOs and their clients overlooked in their contracts, and clients may fake the energy information of the project [57]. Three kinds of client risks are considered in this study: (1) Client awareness risks: a client's negative response to ESCOs caused by fear of decreased revenues or a lack of interest. (2) Contract risks: risk caused by an incomplete contract. (3) Credit risk: risk resulting from a client refusing to implement the contract or complete the payment. (4) Business risk: non-effective energy savings and low energy efficiency caused by improper operations and mistakes in business management.

After determining these risks, it is still difficult for the stakeholders to use niche targeting measures and implications to mitigate these risks when the funding is limited. These risks in the EPC industry can be ranked from the most important to the least. After that step, we can propose corresponding measures and strategies to help mitigate the critical risks effectively. The methods for ranking these risks are presented in section 3.

3. Methods

ANP is derived from AHP, which was developed by Saaty [58], is different from AHP. AHP determines the weights of the criteria by decomposing the complex multi-criteria decision-making problem into different levels which may consist of several sub-factors in the established hierarchal structure, but usually neglects the interdependences and interrelationships among these sub-factors in each level [59]. ANP is modified from AHP to incorporate the interdependences and interrelationships among the criteria [60]. Therefore, ANP has been widely used in many fields because of this advantage [61]. There are usually two types of ANP methods for determining the weights of the criteria. One way is to determine the weights through creating an unweighted super-matrix, a weighted super-matrix [62], and a limit super-matrix, and the other way is to determine the weights of the criteria based on the matrix operations and perform a pair-wise comparison of the criteria on each criterion [59, 63]. Compared with the first method for ANP, the second approach is easier to operate. AHP is the foundation of ANP, but there are several drawbacks in AHP, i.e., difficulty in establishing a consistent matrix and too many comparisons when the number of criteria is greater than five. For instance, AHP determines the relative weights or priorities of the criteria by using the numbers from 1 to 9, and their reciprocals to establish a consistent comparison matrix. However, it is usually difficult for the decision-makers to establish a consistent comparison matrix as there are usually various types of ambiguity, vagueness, and subjectivity in human judgments. Besides these disadvantages, AHP cannot consider the independence and interactions among barriers and risks. Although ANP as an improved method of AHP can incorporate the independence and interactions among the barriers and risks when determining their weights, it still needs many more comparisons and makes it difficult for users to establish consistent comparison matrices.

The Best-Worst (BW) method as an innovative method and powerful tool for weight determination, which is different from and easier than the AHP method, was developed by Rezaei in 2016 [64-65]. The BW method only needs to determine the relative preferences of the best criterion over all the other criteria and that of all the other criteria over the worst criterion to determine the relative weights/priorities of the criteria. The BW method has been widely used recently for its advantages of easy-operation, good performance on consistency, requirement of less comparison data, and production of more reliable results [64]. In this study, the BWN method is developed by integrating the BW method developed by Rezaei [64-65] with the traditional ANP. The new BWN method has the following innovations:

(1) The interdependences and interactions among the criteria can be incorporated when determining the relative weights/priorities of the criteria;

(2) The BW method, which needs less times for comparisons and is more consistent compared with AHP, was used to substitute AHP used in ANP; and

(3) The principles of ANP were incorporated into the BWN method.

The BWN method consists of three steps:

Step 1: Determining the relative importance (weights) of the factors through the Worst-Best method by assuming that there is no dependency among the factors [64-65]. This step consists of four sub-steps based on the works of Rezaei [64-65]:

Sub-step 1: Determining the best (e.g., most desirable or most important) and the worst (e.g., least desirable or least important) factors, denoted by f_B and f_W, respectively. The decision-makers in this step determine the two extreme factors according to their judgment and rank one as the best and the other as the worst. It is worth noting that certain related technological reports, papers, and books related to these factors will be provided to these decision-makers such they can make a decision about selecting the best and the worst factors.

In order to illustrate the BW method for determining the relative weights or priorities of the factors, an illustrative case was studied. Assuming that there are four factors (f_1, f_2, f_3 and f_4), and f_2 and f_4 have been recognized as the best and the worst factor, respectively. Then, we can see that B=2, W=4.

Sub-step 2: Determining the Best-to-Others (BO) vector and the Others-to-Worst (OW) vector. The BO vector and OW vector represent the relative preferences of the best over all the other criteria and that of all the other criteria over the worst criterion by using the scales used in the Saaty method [58], as presented in Table 2. Next, the vector can be obtained, as presented in Eq.1 and Eq.2, respectively.

$$BO = [a_{B1} \quad a_{B2} \quad \cdots \quad a_{Bn}] \tag{1}$$

$$OW = [a_{1W} \quad a_{2W} \quad \cdots \quad a_{nW}] \tag{2}$$

where $a_{Bj}\,(j=1,2,\cdots,n)$ and $a_{jW}\,(j=1,2,\cdots,n)$ represent the relative preference of the best criterion over the *j*-th criterion and that of the *j*-th criterion over the worst criterion.

It is apparent that when $j = B$, then $a_{Bj} = 1$, and when $j = W$, then $a_{jW} = 1$.

As to the illustrative case, if the decision-makers held the view that the relative importance or priority of the best factor (name f_2) compared with f_1, f_3 and f_4 are 'essential importance' (corresponding to 5), 'moderate importance' (corresponding to 3), and 'absolute importance' (corresponding to 9), respectively, then, it could be obtained that

$$BO = [a_{B1} \quad a_{B2} \quad a_{B3} \quad a_{B4}] = [a_{21} \quad a_{22} \quad a_{23} \quad a_{24}] = [5 \quad 1 \quad 3 \quad 9] \tag{3}$$

In a similar way, if the decision-makers held the views that the relative importance or priorities of f_1, f_2 and f_3 compared with the worst factor (name f_4) are 'between equal importance (corresponding to 1) and moderate importance (corresponding to 3)', 'absolute importance' (corresponding to 9), and 'moderate importance'(corresponding to 3), respectively; thus, it could be obtained that

$$OW = [a_{1W} \quad a_{2W} \quad a_{3W} \quad a_{4W}] = [a_{14} \quad a_{24} \quad a_{34} \quad a_{44}] = [2 \quad 9 \quad 3 \quad 1] \tag{4}$$

Sub-step 3: Determining the weights of the criteria.

The optimal weights of the criteria should satisfy the conditions presented in Eqs.5-6.

$$\frac{\omega_B}{\omega_j} = a_{Bj}\,(j=1,2,\cdots,n) \tag{5}$$

$$\frac{\omega_j}{\omega_W} = a_{jW} \, (j = 1, 2, \cdots, n) \tag{6}$$

To satisfy all of these conditions, the solution which satisfies the condition that the maximum absolute difference is $\left|\frac{\omega_B}{\omega_j} - a_{Bj}\right|$ and $\left|\frac{\omega_j}{\omega_W} - a_{jW}\right|$ for all j is minimized. Then, the weights of the criteria can be determined by solving the following problem:

$$\begin{aligned} & \min \max_j \left\{ \left|\frac{\omega_B}{\omega_j} - a_{Bj}\right|, \left|\frac{\omega_j}{\omega_W} - a_{jW}\right| \right\} \\ & s.t. \\ & \sum_{j=1}^{n} \omega_j = 1 \\ & \omega_j \geq 0, \, j = 1, 2, \cdots, n \end{aligned} \tag{7}$$

Equation(7) can be transferred into the following problem:

$$\begin{aligned} & \min \xi \\ & s.t. \\ & \left|\frac{\omega_B}{\omega_j} - a_{Bj}\right| \leq \xi, \, j = 1, 2, \cdots, n \\ & \left|\frac{\omega_j}{\omega_W} - a_{jW}\right| \leq \xi, \, j = 1, 2, \cdots, n \\ & \sum_{j=1}^{n} \omega_j = 1 \\ & \omega_j \geq 0, \, j = 1, 2, \cdots, n \end{aligned} \tag{8}$$

where ω_B represents the weight of the best criterion, ω_W represent the weight of the worst criterion, and ω_j denotes the weight of the j-th criterion.

The ξ^* is the value of the objective function in Equation (8) under the optimum conditions $\omega_1^*, \omega_2^*, \omega_3^*, \ldots,$ and ω_n^*.

Accordingly, the equation for determining the weights of the factors in the illustrative case can also be determined:

$$
\begin{aligned}
&\min \xi \\
&s.t. \\
&\left| \frac{\omega_2}{\omega_1} - 5 \right| \le \xi \\
&\left| \frac{\omega_2}{\omega_3} - 3 \right| \le \xi \\
&\left| \frac{\omega_2}{\omega_4} - 9 \right| \le \xi \\
&\left| \frac{\omega_1}{\omega_4} - 2 \right| \le \xi \\
&\left| \frac{\omega_3}{\omega_4} - 3 \right| \le \xi \\
&\sum_{j=1}^{4} \omega_j = 1 \\
&\omega_j \ge 0, j = 1, 2, \cdots, 4
\end{aligned}
\tag{9}
$$

In solving Equation (9), results can be obtained. The results are $\xi^* = 0.1270$, $\omega_1 = 0.1245$, $\omega_2 = 0.6068$, $\omega_3 = 0.2023$, $\omega_4 = 0.0665$.

Sub-step 4: Consistency check.

The comparison is fully consistent when $a_{Bj} a_{jW} = a_{BW} (j = 1, 2, \cdots, n)$. However, this ideal condition cannot always be achieved due to the ambiguity and vagueness that exists in human judgments. The consistency ratio can be calculated for a consistency check, as presented in Eq.10,

$$
CR = \frac{\xi^*}{CI} \tag{10}
$$

where CR represents the consistency ratio, and CI represents the consistency index.

The consistency index can be obtained according to Table 3, and the value of the consistency ratio belonging to the interval $[0 \quad 1]$ indicates the consistency level. The closer the value to zero, the more consistent the comparison is; contrarily, the closer the value to one, the more consistent the comparison is.

For the consistency check in the illustrative case, $a_{24} = a_{BW} = 9$, the consistency index (CI) is 3.00, thus, the consistency ratio can be calculated as $CR = \frac{0.1270}{5.23} = 0.0243$ according to Eq.10. The solution is near zero, and this implies high consistency.

Step 2: Determining the inner dependency matrix (D) of the factors with respect to each factor. The elements of the j-th column vector in matrix D represent the relative effects of all the other factors on the j-th factor, and this vector can be obtained through establishing the comparison matrix with respect to the j-th factor. Similarly, all the column vectors in matrix D can be obtained.

$$D = \begin{vmatrix} 1 & d_{12} & \cdots & d_{n1} \\ d_{21} & 1 & \cdots & d_{n2} \\ \vdots & \cdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & 1 \end{vmatrix} \tag{11}$$

It is worth noting that the i-th row vector represents the relative effect of the i-th factor on the other factors, and all of the diagonal elements in matrix D equal 1 according to Ref. [61,66], where d_{ij} represents the relative effect of the i-th factor on the j-th factor.

Step 3: Calculating the inter-dependent priorities of the n factors by Eq.12, then normalizing the inter-dependent priorities of the n factors by Eq. 13.

$$\mathrm{W}' = D \times \mathrm{W}_1 = [\omega_1, \omega_2, \cdots, \omega_n] \tag{12}$$

$$\mathrm{W} = \left[\omega_1 \Big/ \sum_{i=1}^{n} \omega_i , \omega_2 \Big/ \sum_{i=1}^{n} \omega_i , \cdots, \omega_n \Big/ \sum_{i=1}^{n} \omega_i \right] \tag{13}$$

where W' represents the weight vector of the inter-dependent priorities of the n factors, and W represents the normalized weight vector of the inter-dependent priorities of the n factors.

4. Results and discussion

The proposed BWN method has been employed to prioritize the risks of EPC under China's conditions. The BW method was first used to determine the weights of the risk of five aspects with the assumption that these five aspects are independent, the inner dependency matrix of the five aspects and, finally, the inter-dependent weights of these five aspects (**Stage 1**). Next, the local weights of the sub-risks in each aspect were also be determined by the BW method in a similar way (**Stage 2**). Finally, the global weights of each of the sub-risks was be determined by calculating the product of the local weight of the sub-risk and the inter-dependent weight of the corresponding weight which this sub-risk belongs to (**Stage 3**).

4.1 Inter-dependent weights of these five risk aspects (stage 1)

Taking the determination of the weights of the risk of five aspects with the assumption that these five aspects are independent as an example, the four sub-steps of the BW method were specified as follows:

Sub-step 1: The most important risk aspect and the least important risk aspect of EPC in China were also determined in the focus group meeting. Management and operation risk (MOR) and Technological risks (TR) were recognized as the most important and the least important aspects, respectively.

Sub-step 2: The relative preferences of the most important aspect (MOR) over all the other aspects and the relative preference of all the other aspects over the least important aspect were also determined, as presented in Eqs.14-15. Note that EER, FMR, TR, MOR, and ClR are denoted by the numbers C_1, C_2, C_3, C_4, and C_5, respectively. Accordingly, B=4, W=3, and a_{12} represents the relative importance of EER compared with FMR.

$$BO = \begin{bmatrix} a_{41} & a_{42} & a_{43} & a_{44} & a_{45} \end{bmatrix} = \begin{bmatrix} 3 & 2 & 6 & 1 & 5 \end{bmatrix} \quad (14)$$

$$OW = \begin{bmatrix} a_{13} & a_{23} & a_{33} & a_{43} & a_{53} \end{bmatrix} = \begin{bmatrix} 2 & 3 & 1 & 6 & 1 \end{bmatrix} \quad (15)$$

Sub-step 3: Finding the optimal weights of the criteria by solving equation (16)

$$\begin{aligned}
&\min \xi \\
&s.t. \\
&\left|\frac{\omega_4}{\omega_1}-3\right| \le \xi \\
&\left|\frac{\omega_4}{\omega_2}-2\right| \le \xi \\
&\left|\frac{\omega_4}{\omega_3}-6\right| \le \xi \\
&\left|\frac{\omega_4}{\omega_5}-5\right| \le \xi \\
&\left|\frac{\omega_1}{\omega_3}-2\right| \le \xi \\
&\left|\frac{\omega_2}{\omega_3}-3\right| \le \xi \\
&\left|\frac{\omega_5}{\omega_3}-1\right| \le \xi \\
&\sum_{j=1}^{4} \omega_j = 1 \\
&\omega_j \ge 0, j = 1, 2, \cdots, 4
\end{aligned} \tag{16}$$

The results are: $\xi = 0.1401$, $\omega_1 = 0.1586$, $\omega_2 = 0.2216$, $\omega_3 = 0.0775$, $\omega_4 = 0.4540$,and $\omega_5 = 0.0883$. Accordingly, the independent weights of the five aspects can be determined, as presented in Table 17.

$$W_1 = \begin{bmatrix} 0.1586 \\ 0.2216 \\ 0.0775 \\ 0.4540 \\ 0.0883 \end{bmatrix} \tag{17}$$

Sub-step 4: According to $a_{34} = a_{BW} = 6$, the consistency index (CI) is 3.00, thus, the consistency ratio can be determined $CR = \frac{0.1401}{3.00} = 0.0467$. As it is close to zero, this implies a very high consistency.

Similarly, the inner dependency matrix for describing the interdependences and interactions among these five aspects can be obtained by using the BW method five times to determine the effects of all the other four aspects (excluding the studied aspect) on each of the five aspects. Taking the effects of the other four aspects (FMR, TR, MOR, and ClR) on EER as an example, FRM and ClR have been recognized the most important and the least important aspects that affect EER, the relative weights representing the effects of these four aspects on EER can be determined after determining the BO vector and the OW vector by using the BW method, as presented in Table 4. In a similar way, the effects of the four aspects (EER, TR, MOR, and ClR) on FMR, the effects of the four aspects (EER, FMR, MOR, and ClR) on TR, the effects of the four aspects (EER, FMR, TR, and ClR) on MOR, and the effects of the four aspects (EER, FMR, TR, and MOR) on ClR can also be determined, the inner dependency matrix (matrix D) of the five aspects can be determined and is presented in Table 5.

Next, the inter-dependent weights of the four aspects can be determined according to Eq.12, as presented in Eq.18.

$$W' = D \times W_1 = \begin{bmatrix} 0.4229 \\ 0.3522 \\ 0.4361 \\ 0.5212 \\ 0.2671 \end{bmatrix} \tag{18}$$

Finally, the normalized inter-dependent weights of the five aspects can also be determined according to Eq.13, and the results are presented in Eq.19. Thus, the weights of the five categorie,s including external environmental risks, managerial and operational risks, financial and market risks, technical risks, and client risks, are 0.2215, 0.1761, 0.2181, 0.2607, and 0.1336, respectively.

$$W = \begin{bmatrix} 0.2115 \\ 0.1761 \\ 0.2181 \\ 0.2607 \\ 0.1336 \end{bmatrix} \tag{19}$$

4.2 Local weights of the sub-risks in each aspect (stage 2)

In this stage, the local weights of the risk factors in each of the five categories have been determined. Taking the political and legal risk (EER_1), economic risk (EER_2), and natural environmental risk (EER_3) in the category of external environmental risks as an example, EER_1 and EER_3 were recognized the most important and the least important risk factors in this category, respectively. After determining the BO and WO vectors ($BO = \begin{bmatrix}1 & 2 & 5\end{bmatrix}$ and $OW = \begin{bmatrix}5 & 3 & 1\end{bmatrix}$), the local weights of these three risk factors can be determined, as presented in Table 6. Similarly, the local weights of the risk factors in each of the other four categories can also be determined (see Table 7),.

4.3 Global weights of the sub-risks (stage 3)

In this stage, the global weights of the risk factors in each of the five categories have been determined. The global weight of each risk factor equals the product of the local weight of the risk factor and the weight of the category to which the corresponding risk factor belongs. For instance, the global weight of the political and legal risk (EER_1), which belongs to the category of external environmental risks (EER), can be determined: the local weight of the political and legal risk (EER_1)×the weight of the category of external environmental risks=0.2215×0.5746=0.1273. In a similar way, the global weights of the other risk factors can also be determined, as presented in Table 7.

4.4 Discussion

The cause-effect diagram for risk factors in China's EPC industry can be determined and is presented in Figure 2. According to the relative weights of the five categories, it is apparent that technological risks are the most severe followed by external environmental risks, financial and market risks, managerial and operational risks, and client risks. Therefore, from a macro perspective, mitigating the technological risks of energy performance contracting is the most important task for China's decision-makers. Meanwhile, the decision-makers in China should also pay more attention to external environmental risks, and financial and market risks. The corresponding measures and strategies that are developed to mitigate the risk in these two categories should also be adopted to promote the development of EPC in China.

In comparing the relative global weights of risk factors, these factors can be categorized into three groups: one is the 'significantly important group,' including political and legal risk, risk of market demand, advanced technology and equipment risk, and energy-saving measurement and verification risk, the relative weights of which are greater than 0.1. Another is the 'moderately important group,' including ability risk, economic risk, credit risk, and risk of price change, whose relative weights are between 0.05 and 0.1. The other is the 'less important group,' including decision risk, procurement risk, high interest rate risk, and the other factors whose relative weights are less than 0.05. These results can produce significant insights for China's decision-makers and may contribute to the drafting of effective measures by correctly assigning limited funds for promoting the development of EPC in China.

The BWN method is similar to ANP, as it can incorporate the interdependences and interactions among the criteria when determining their relative weights/priorities. In order to validate the BWN method, ANP was also employed to determine the relative weights of these 21 risk factors. Taking the relative weights of EER, FMR, TR, MOR, and ClR as an example, the comparison matrix can be firstly determined, as presented in Table 8. The consistency index (CI) of the comparison matrix is 0.0152, and the consistency ratio (CR) can then be determined. The CR is 0.0136, smaller than 0.10, which means that the comparison matrix can be recognized as a consistent comparison matrix. Therefore, the relative weights of EER, FMR, TR, MOR, and ClR are 0.1586, 0.2273, 0.0599, 0.4548, and 0.0994, respectively.

The inner dependencies among the five aspects can also be determined. Taking the relative effects of the four aspects (FMR, TR, MOR, and ClR) on EER as an example, the comparison matrix is presented in Table 9. The consistency ratio is 0.0015, which is smaller than 0.10, and therefore the comparison matrix for determining the relative effects of the four aspects (FMR, TR, MOR, and ClR) on EER can be recognized as a consistent matrix. Thus, the relative effects of the four aspects (FMR, TR, MOR, and ClR) on EER are 0.3936, 0.3936, 0.1375, and 0.0753, respectively.

In a similar way, the relative effects of the four aspects (EER, TR, MOR, and ClR) on FMR, the relative effects of the four aspects (EER, FMR, MOR, and ClR) on TR, the relative effects of the four aspects (EER, FMR, TR, and ClR) on MOR, and the relative effects of the four aspects (EER, FMR, TR, and MOR) on ClR can also be determined (see Table 10).

The inner dependency matrix of the five aspects used in ANP can be determined, as presented in Table 10. The normalized inter-dependent weights of the five categories including external environmental risks, managerial and operational risks, financial and market risks, technical risks, and client risks can be determined by Eq.18 and Eq.13, and they are 0.2086, 0.1792, 0.2132, 0.2604, and 0.1386, respectively.

In a similar way, the local weights of the criteria in each of the five aspects can also be determined, and the results are presented in Tables 11-15. Following that, the global weights of the 21 risk factors in China's EPC industry can be determined by ANP, and the results are presented in Table 16. The comparison of the global weights of the 21 risk factors in China's EPC industry determined by BWN, ANP and AHP is presented in Figure 3. It is apparent that the results determined by BWN and ANP are very similar, but the results determined by these two methods are highly different from those determined by AHP because both the BWN and the ANP can incorporate the interdependences and interactions among the risk factors, while AHP recognizes all of the factors as independent.

5. Policy implications

According to the results of this study, the following policy implications may be useful for China's decision-makers:

(1) China's administration should focus on mitigating technological risks, external environmental risks, and financial and market risks from a macro perspective to improve the confidence of all of the stakeholders of energy performance contracting.

I. For the technological risks, China's administration should establish thorough technological standards and regulations to manage the harmonious development of EPC in China. Meanwhile, the special funding should be set for the R&D of advanced technologies for energy-saving. For instance, the administration can launch some special funding for energy-saving in building sector for managing energy efficiency and energy retrofit of buildings. The development of science and technology for energy saving is the most important driving factor for assuring the effects of EPC and the project quality of EPC.

II. For the external environmental risks, China's administration should create complete regulations and a legal framework to guarantee that benefits will pass to all stakeholders in the value chain of EPC. Rapid economic growth is the most important signal of a good economic environment for the investors of EPC; however, the slowdown of economic growth recently may cause an investment reduction in EPC due to the decrease in opportunities for low-or-zero-interest loans. Accordingly, China's administration should set various financial support policies (i.e. subsidies, low-or-zero-interest loans) for the stakeholders in the value chain of EPC to lower the investment cost and reduce the payback time. Moreover, China should also develop special insurance for the stakeholders in the value chain of EPC to protect against risks caused by a natural or environmental disaster.

III. For the financial and market risks, China's administration should focus on establishing a free and transparent market mechanism to guarantee a steady, free and competitive EPC market.

(2) Resolving the political and legal risk, risk of market demand, advanced technology and equipment risk, and energy-saving measurement is the key for the success of the EPC industry in China. The best way to accomplish this is for China's administration to take problem-oriented measures: (i) setting up special governmental sectors for governing and managing the EPC industry in China; (ii) drafting complete regulation system to regulate the EPC industry; (iii) vigorously stimulating market demand and developing market potential; (iv) encouraging the R&D of advanced energy-saving technologies; and (v) establishing technological standards for energy-saving measurement at a national level.

(3) Mitigating ability risk, economic risk, credit risk, and risk of price change are also important for building a harmonious environment for the development of EPC in China. Ability risk can be mitigated by adopting advanced energy-saving technologies and accumulating engineering and demonstration experience in China's EPC industry. Thus, the participation of foreign and private capital with advanced technologies and plenty of engineering

experience in energy-saving is significantly important. As for the economic risk, strong governmental support in various ways (i.e. subsidies and policies) is a prerequisite. Credit risk can be addressed by signing detailed and clear contracts and setting strict regulations and laws with serious punishments for violators to safeguard the benefits of the aggrieved parties. Price change risk, such as the decrease of energy, can also be effectively lowered by signing detailed and clear contracts to state the expected effects of EPC projects with consideration towards price change.

6. Conclusions

This study aims to summarize the risk factors in China's EPC industry, develop a framework for prioritizing these factors, identify the key risk factors, and propose several policy ideas for China's decision-makers to draft effective measures and policies to promote the harmonious development of the EPC industry in China. A total of 21 risk factors in five categories, including external environmental risks, managerial and operational risks, financial and market risks, technical risks, and client risks, were identified. The BWN method was developed for ranking these risk factors and was based on the traditional ANP and the BW method.

According to the results of the BWN analysis, these five categories were prioritized according to their relative importance. The order of importance is: technological risks, followed by external environmental risks, financial and market risks, managerial and operational risks, and client risks. Then, these risk factors were categorized into three groups including a 'significantly important group' (i.e., political and legal risk, risk of market demand, advanced technology and equipment risk, and energy-saving measurement and verification risk), a ‘moderately important group’ (i.e., ability risk, economic risk, credit risk, and risk of price change), and a ‘less important group’ (i.e., decision risk, procurement risk, high interest rate risk, and the other factors). Some policy implications have also been proposed according to the results of the BWN analysis, like proposing China’s decision-makers draft effective measures and strategies to promote the harmonious development of EPC industry in China.

The mitigation of the risk factors in China’s EPC industry is complicated, and the identification of the critical factors and the investigation of the cause-effect relationships among these factors usually involves multiple groups of decision-makers/stakeholders who may have different preferences and opinions. Therefore, the authors’ future work is to develop a methodology which can incorporate the preferences and opinions of different decision-makers/stakeholders and achieve group decision-making when determining the relative weights of the risk factors in China’s EPC industry.

Acknowledgement

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NOMENCLATURE

Abbreviations

Analytic Hierarchy Process: AHP

Analytic Network Process: ANP

Best-to-Others: BO

Best-Worst: BW

Best-Worst Network: BWN

Consistency Index: CI

Consistency Ratio: CR

Client risks: ClR

External Environmental Risks: EER

Energy Performance Contracting: EPC

Energy Service Company: ESCO

Energy-Saving Performance Contracts: ESPC

Financial and Market Risks: FMR

Inner Dependency Matrix: D

Managerial and Operational Risks: MOR

Others-to- Worst: OW

Particular Matter: PM

Research, Development and Demonstration: RD&D

Technological Risks: TR

Superscripts

$*$: the optimum value

Subscripts

B: best

Bj: the best criterion over the j-th criterion

BW: the best criterion over the worst criterion

jW: of the j-th criterion over the worst criterion

$j=(1,2,\cdots,n)$: the j.th

W: worst

Symbols

a: the relative preference

f: the factor

ω: the weight

W': the weight vector of the inter-dependent priorities of the n factors

W: the normalized weight vector of the inter-dependent priorities of the n factors.

ξ: the objective function of programming (8)

References

[1] China National Bureau of Statistics. China Statistical Yearbook 2014. China Statistics Press, Beijing: 2015.

[2] British Petroleum. BP Statistical Review of World Energy 2015, London: 2015. Available at: <http://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2015/bp-statistical-review-of-world-energy-2015-full-report.pdf> accessed May 2, 2016.

[3] British Petroleum. BP Statistical Review of World Energy 2011, London: 2011. Available at: < http://www.bp.com/content/dam/bp-country/de_de/PDFs/brochures/statistical_review_of_world_energy_full_report_2011.pdf> accessed May 2, 2016.

[4] Zhang XH, Wu LQ, Zhang R, Deng SH, Zhang YZ, Wu J, Li YW, Lin LL, Li L, Wang YJ, Wang LL. Evaluating the relationships among economic growth, energy consumption, air emissions and air environmental protection investment in China. Renew Sust Energ Rev 2013; 18: 259-70.

[5] Zhang XH, Zhang R, Wu LQ, Deng SH, Lin LL, Yu XY. The interactions among China's economic growth and its energy consumption and emissions during 1978–2007. Ecol Indic 2013; 24: 83-95.

[6] Shen B, Price L, Lu H. Energy audit practices in China: National and local experiences and issues. Energy Policy 2012; 46: 346-58.

[7] Li L, Tan Z, Wang J, Xu J, Cai C, Hou Y. Energy conservation and emission reduction policies for the electric power industry in China. Energy Policy 2011; 39(6): 3669-79.

[8] Price L, Levine MD, Zhou N, Fridley D, Aden N, Lu HY, McNeil M, Zheng NN, Qin Y, Yowargana P. Assessment of China's energy-saving and emission-reduction accomplishments and opportunities during the 11th Five Year Plan. Energy Policy 2011; 39(4): 2165-78.

[9] Lo K. A critical review of China's rapidly developing renewable energy and energy efficiency policies. Renew Sust Energ Rev 2014; 29: 508-16.

[10] Zhang R, Jing J, Tao J, Hsu SC, Wang G, Cao J, Lee CSL, Zhu L, Chen Z, Zhao Y, Shen Z. Chemical characterization and source apportionment of PM 2.5 in Beijing: seasonal perspective. Atmos. Chem. Phys. 2013; 13(14): 7053-74.

[11] Li H, Yang S, Zhang J, Qian Y. Coal-based synthetic natural gas (SNG) for municipal heating in China: analysis of haze pollutants and greenhouse gases (GHGs) emissions. J Clean Prod. 2016; 112: 1350-59.

[12] Dixon RK, McGowan E, Onysko G, Scheer RM. US energy conservation and efficiency policies: Challenges and opportunities. Energy Policy 2010; 38(11): 6398-408.

[13] Li, G., Zheng, X. Thermal energy storage system integration forms for a sustainable future. Renewable and Sustainable Energy Reviews, 2016; 62: 736-757.

[14] Li, G. Energy and exergy performance assessments for latent heat thermal energy storage systems. Renewable and Sustainable Energy Reviews, 2015; 51: 926-954.

[15] Li, G. Organic Rankine cycle performance evaluation and thermoeconomic assessment with various applications part II: economic assessment aspect. Renewable and Sustainable Energy Reviews, 2016; 64, 490-505.

[16] Li, G. Comprehensive investigations of life cycle climate performance of packaged air source heat pumps for residential application. Renewable and Sustainable Energy Reviews, 2015; 43, 702-710.

[17] Li, G. Comprehensive investigation of transport refrigeration life cycle climate performance. Sustainable Energy Technologies and Assessments, 2017; 21, 33-49.

[18] Li, G. Investigations of life cycle climate performance and material life cycle assessment of packaged air conditioners for residential application. Sustainable Energy Technologies and Assessments, 2015; 11, 114-125.

[19] Dogan E, Seker F. Determinants of CO2 emissions in the European Union: the role of

renewable and non-renewable energy. Renewable Energy, 2016; 94: 429-439.

[20] Li, G. Sensible heat thermal storage energy and exergy performance evaluations. Renewable and Sustainable Energy Reviews, 2016; 53, 897-923.

[21] Li, G. Organic Rankine cycle performance evaluation and thermoeconomic assessment with various applications part I: Energy and exergy performance evaluation. Renewable and Sustainable Energy Reviews,2016; 53, 477-499.

[22] Huge J, Waas T, Eggermont G, Verbruggen A. Impact assessment for a sustainable energy future—Reflections and practical experiences. Energy Policy 2011; 39(10): 6243-53.

[23] Patterson, M. G. What is energy efficiency?: Concepts, indicators and methodological issues. Energy policy 1996; 24(5): 377-390.

[24] Davies HA, Chan EK. Experience of energy performance contracting in Hong Kong. Facilities 2001; 19(7/8), 261-68.

[25] Xu P, Chan EHW, Qian QK. Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China. Energy Policy 2011; 39(11): 7389-98.

[26] Okay N, Akman U. Analysis of ESCO activities using country indicators. Renew. Sustain. Energ. Rev. 2010; 14 (9): 2760-71.

[27] Ürge-Vorsatz D, Köppel S, Liang C, et al. An Assessment of on Energy Service Companies (ESCOs) Worldwide. World Energy Council; London: 2007.

[28] Gan DL. Energy service companies to improve energy efficiency in China: barriers and removal measures. Procedia Earth and Planetary Science, 2009; 1(1): 1695-1704.

[29] EMCA. ESCO map in China. 2012. Available at: <http://e-mag.emca.cn/n/20120410053118.html> accessed May 3, 2016.

[30] Wong JL. Energy Service Companies in China. Oct.28.2009. Available at:

<http://greenleapforward.com/2009/10/28/energy-service-companies-in-china/> accessed May 4, 2016.

[31] Qin, Q., Liang, F., Li, L., Wei, Y. M. Selection of energy performance contracting business models: A behavioral decision-making approach. Renewable and Sustainable Energy Reviews, 2017; 72, 422-433.

[32] Zhou, Y., Pan, M., Zhou, D. K., Xue, L. Stakeholder risk and trust perceptions in the diffusion of Green Manufacturing Technologies: Evidence from China. The Journal of Environment & Development, 2018; 27(1), 46-73.

[33] Zhang, M., Wang, M., Jin, W., Xia-Bauer, C. Managing energy efficiency of buildings in China: A survey of energy performance contracting (EPC) in building sector. Energy Policy, 2018; 114, 13-21.

[34] Liu, P., Zhou, Y., Zhou, D. K., Xue, L. Energy Performance Contract models for the diffusion of green-manufacturing technologies in China: A stakeholder analysis from SMEs' perspective. Energy Policy, 2017; 106, 59-67.

[35] Wang, L., Peng, J. J., Wang, J. Q. A multi-criteria decision-making framework for risk ranking of energy performance contracting project under picture fuzzy environment. Journal of Cleaner Production, 2018; 191, 105-118.

[36] Garbuzova-Schlifter M, Madlener R. Risk analysis of energy performance contracting projects in Russia: an analytic hierarchy process approach. In Operations Research Proceedings 2015 (pp. 683-690). Springer, Cham.

[37] Garbuzova-Schlifter, M., & Madlener, R. (2016). AHP-based risk analysis of energy performance contracting projects in Russia. Energy Policy, 97, 559-581.

[38] van Heijst AA, Hensen JJ, Hoogervorst ICC. Analyzing the performance gap by identifying its causal factors and quantifying their individual impacts for Energy Performance Contracts.

2017. This file is available at: http://www.janhensen.nl/team/past/master/Heijst_2017.pdf (access on 23rd November, 2017).

[39] Yang JB., Chou HY. Key challenges in executing energy-savings performance contracts in public buildings: Taiwan experience. Journal of the Chinese Institute of Engineers, 2017; 40(6): 482-491.

[40] Yeatts DE, Auden D, Cooksey C, Chen CF. A systematic review of strategies for overcoming the barriers to energy-efficient technologies in buildings. Energy Research & Social Science, 2017; 32: 76-85.

[41] Lee P, Lam PTI, Lee WL. Risks in energy performance contracting (EPC) projects. Energy and Buildings, 2015; 92: 116-127.

[42] Yuan, X., Ma, R., Zuo, J., Mu, R. Towards a sustainable society: the status and future of energy performance contracting in China. Journal of Cleaner Production 2016; 112: 1608-1618.

[43] Qin Q, Liang F, Li L, Wei YM. Selection of energy performance contracting business models: A behavioral decision-making approach. Renewable and Sustainable Energy Reviews, 2017; 72: 422-433.

[44] Zhang Y, Han QM, Liu CB, Sun JY. Analysis for critical success factors of energy performance contracting (EPC) projects in China. In Industrial Engineering and Engineering Management, 2008. IEEM 2008. IEEE International Conference on (675-679). IEEE.

[45] Zhang XH, Li X, Chen SL. Problem and countermeasure of energy performance contracting in China. Energy Procedia, 2011; 5: 1377-81.

[46] Hu. JR, Zhou EY. Engineering risk management planning in energy performance contracting in China. Systems Engineering Procedia 2011; 1: 195-205.

[47] Xu P, Chan EH. ANP model for sustainable Building Energy Efficiency Retrofit (BEER) using Energy Performance Contracting (EPC) for hotel buildings in China. Habitat

International, 2013;37: 104-112.

[48] Huang ZY, Zhuang YS, Han Y. Risk Identification and Comprehensive Evaluation in Energy Performance Contracting Projects in China. Journal of Engineering Management, 2013; 1: 012. (in Chinese)

[49] Davies HA., Chan EK. Experience of energy performance contracting in Hong Kong. Facilities, 2001; 19(7/8): 261-268.

[50] Hui SC. Opportunities and challenges of energy performance contracting to improve existing buildings in Hong Kong. In Proceedings of the Joint Symposium 2002: Achieving Sustainable Performance in Built Environment 2002:1-10.

[51] Duan XP. Research on financial risk evaluation of energy performance contract project in China. Journal of Xiangtan University (Philosophy and Social Sciences) 2013; 37(5): 62-66. (in Chinese)

[52] Ren H, Zhao D, Cai WG.Study on the Risks of Energy Performance Contracting Projects. Construction Economy 2015;36(7):7: 100-103.(in Chinese)

[53] Jackson J. Promoting energy efficiency investments with risk management decision tools. Energy Policy 2010; 38(8): 3865-73.

[54] Charles AG, Nicole CH, Julie GO. Review of US ESCO industry market trends: an empirical analysis of project data, Energy Policy 2005; 33: 387–405.

[55] Nicole H, Charles G, Donald G, Terry ES, Dave B. A Survey of the U.S. ESCO Industry: Market Growth and Development from 2000 to 2006, Ernest Orlando Lawrence Berkeley National Laboratory, 2007.

[56] Martinot E. World bank energy projects in China: influences on environmental protection. Energy Policy 2001;29(8): 581-594.

[57] Vine E. An international survey of the energy service company (ESCO) industry. Energy

Policy 2005; 33(5): 691-704.

[58] Saaty, T. L. Analytic network process. In Encyclopedia of Operations Research and Management Science (pp. 28-35). 2001. Springer US.

[59] Shahabi, R. S., Basiri, M. H., Kahag, M. R., Zonouzi, S. A. An ANP–SWOT approach for interdependency analysis and prioritizing the Iran′ s steel scrap industry strategies. Resources Policy 2014; 42, 18-26.

[60] Saaty, T. L. Decision making—the analytic hierarchy and network processes (AHP/ANP). Journal of systems science and systems engineering 2004; 13(1), 1-35.

[61] Saaty, T. L. Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks. 2005. RWS publications.

[62] Aragonés-Beltrán, P., García-Melón, M., & Montesinos-Valera, J. How to assess stakeholders' influence in project management? A proposal based on the Analytic Network Process. International Journal of Project Management 2017; 35(3), 451-462.

[63] Gwo-Hshiung, T., Tzeng, G.H., Huang, J.J. Multiple Attribute Decision Making: Methods and Applications. CRC Press, Taylor & Francis Group, Boca Raton, FL,2011, ISBN: 978-1-4398-6157-8.

[64] Rezaei, J. Best-worst multi-criteria decision-making method. Omega 2015; 53, 49-57.

[65] Rezaei, J. Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega 2016; 64: 126-130.

[66] Zamani, M., Rabbani, A., Yazdani-Chamzini, A., & Turskis, Z. An integrated model for extending brand based on fuzzy ARAS and ANP methods. Journal of Business Economics and Management 2014; 15(3), 403-423.

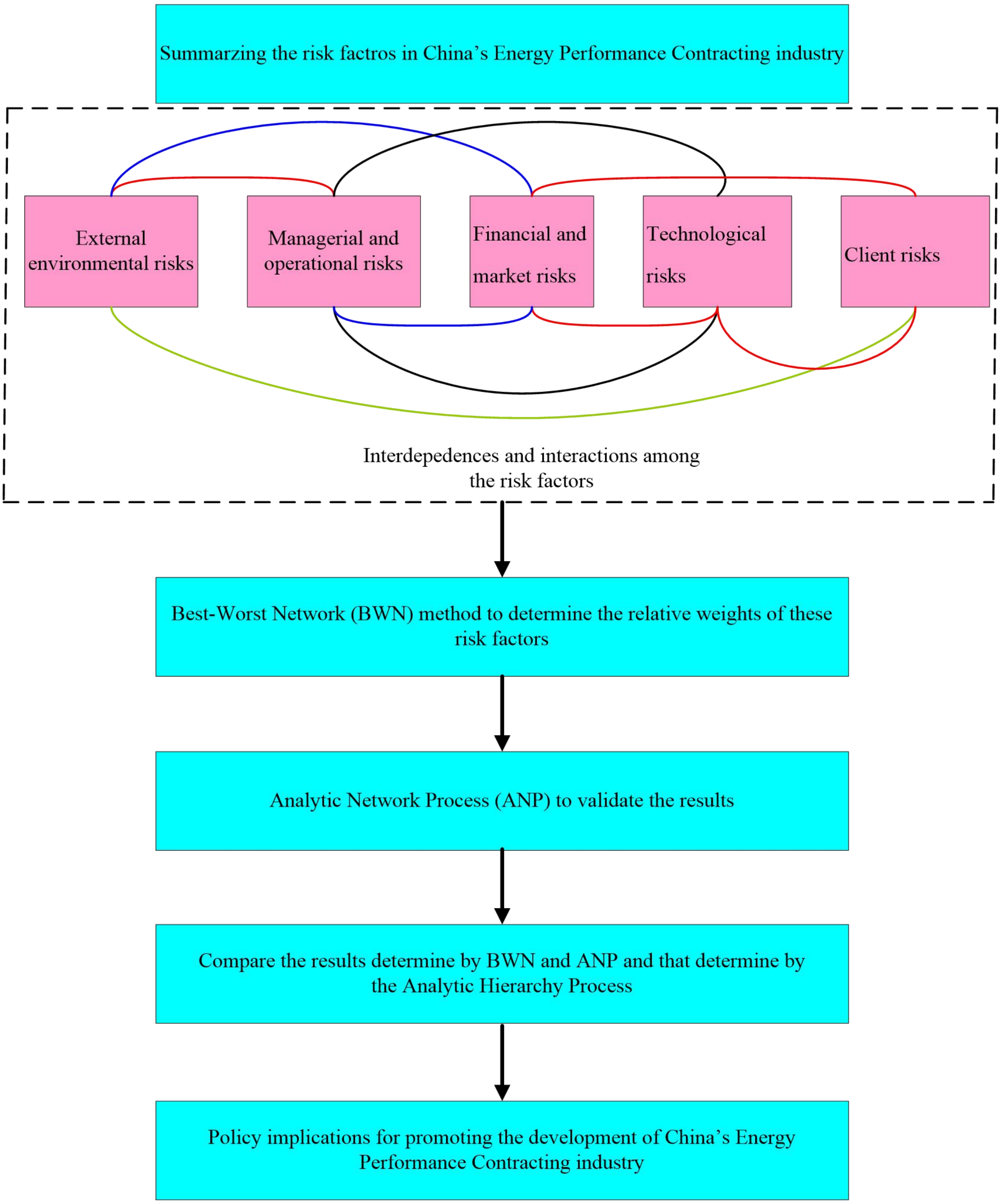
Figure Captions

Figure 1: The methodological framework of analyzing the risk factors in China's energy

performance contracting industry

Figure 2: The cause-effect diagram for risks in China's EPC industry

Figure 3: The comparison of the global weights of the 21 risk factors in China's EPC industry determined by BWN, ANP and AHP



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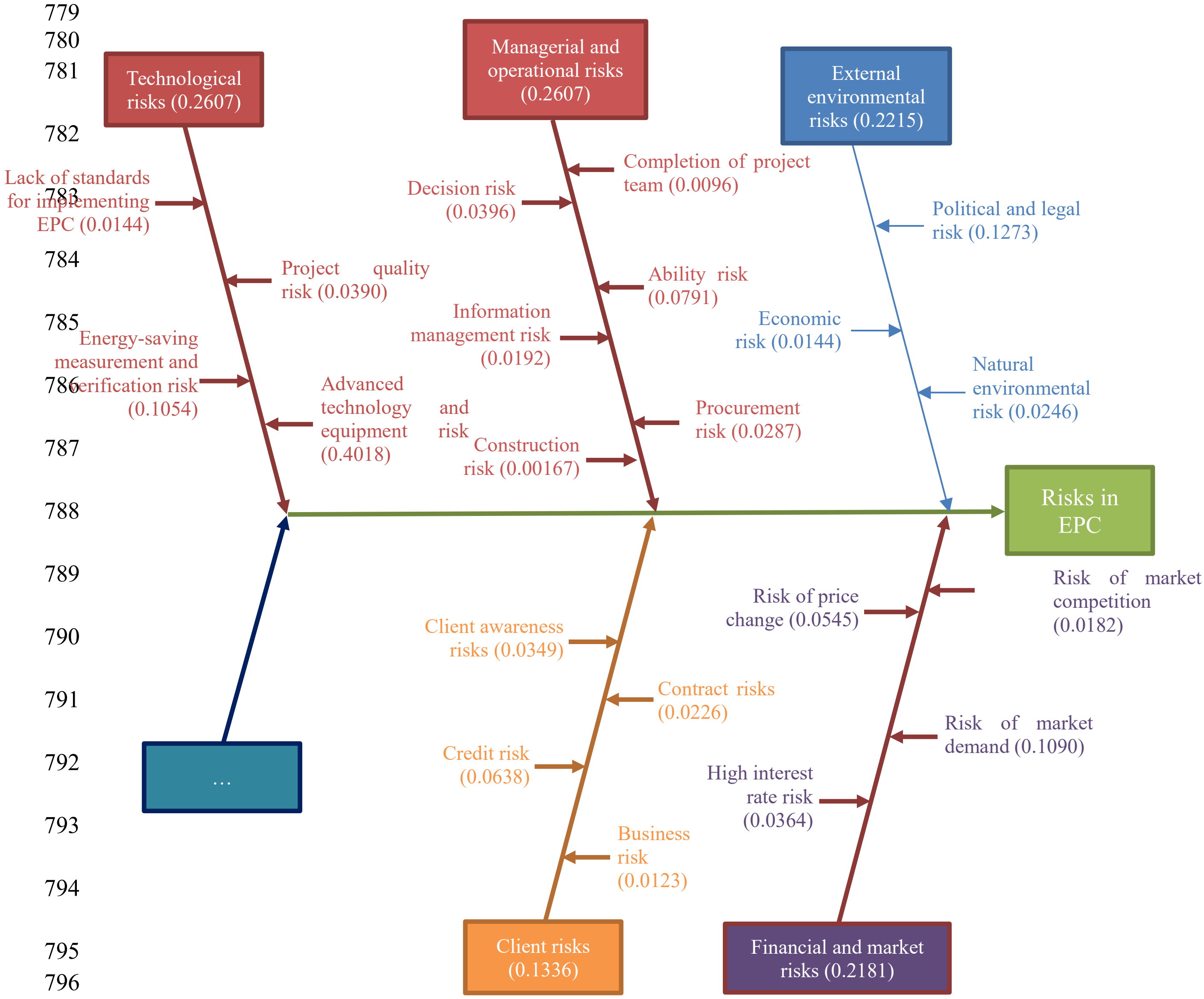

Figure 2: The cause-effect diagram for risk factors in China's EPC industry

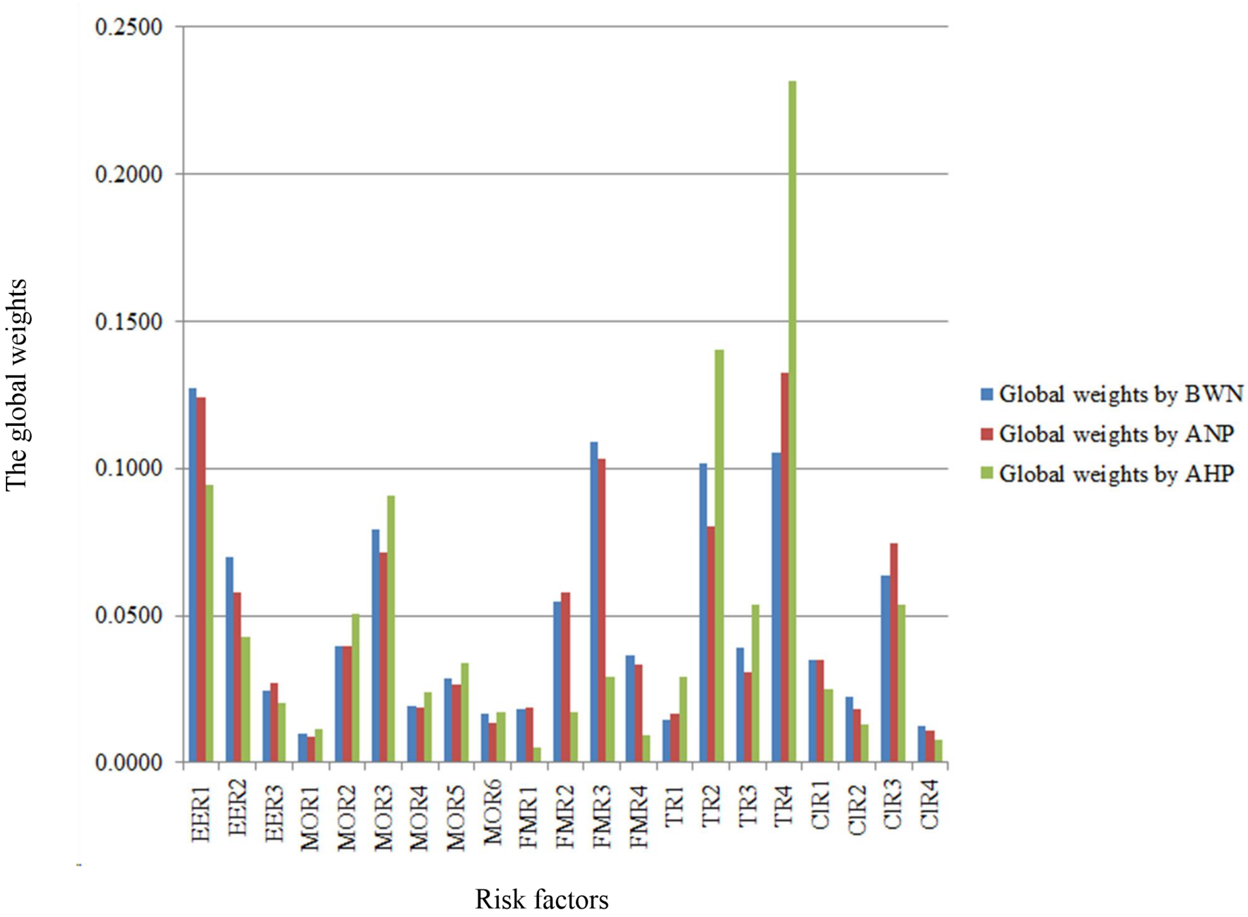

Figure 3: The comparison of the global weights of the 21 risk factors in China's EPC industry determined by BWN, ANP and AHP

Table 1: Categories and risks for Energy Performance Contracting

Categories	Risks	References
EER: External environmental risks	EER_1: Political and legal risk	[19, 27, 28, 30, 36, 37, 38, 39, 40]
	EER_2: Economic risk	[19, 30, 36]
	EER_3: Natural environmental risk	[19, 27]
MOR: Managerial and operational risks	MOR_1: Completion of project team	[19, 30, 36, 37]
	MOR_2: Decision risk	[29, 36]
	MOR_3: Ability risk	[27, 29]
	MOR_4: Information management risk	[29, 36, 40]
	MOR_5: Procurement risk	[29, 37, 38]
	MOR_6: Construction risk	[29]
FMR: Financial and market risks	FMR_1: Risk of market competition	[29, 36, 40]
	FMR_2: Risk of price change	[27, 28, 29, 36, 39, 40, 41]
	FMR_3: Risk of market demand	[19, 27, 29, 30, 36, 37, 39, 45]
	FMR_4: High interest rate risk	[29, 39, 45]
TR: Technological risks	TR_1: Lack of standards for implementing EPC	[29, 37]
	TR_2: Advanced technology and equipment risk	[27, 29, 36, 39, 40]
	TR_3: Project quality risk	[36, 40]
	TR_4: Energy-saving measurement and verification risk	[29, 38, 39]
ClR: Client risks	ClR_1: Client awareness risks	[19, 30, 45]
	ClR_2: Contract risks	[19, 27, 25, 36, 39, 40]
	ClR_3: Credit risk	[29, 30, 36, 40]
	ClR_4: Business risk	[29, 39, 40]

Table 2: Comparison scale in Saaty method [58]

Scales	Definition	Note
1	Equal importance	i is equally important to j
3	Moderate importance	i is moderately important to j
5	Essential importance	i is essentially important to j
7	Very strong importance	i is very strongly important to j
9	Absolute importance	i is very absolutely important to j
2,4,6,8	Intermediate value	The relative importance of i to j is between to adjacent judgment
Reciprocal	Reciprocals of above	The value had been assigned to i when compared to j, then j has the reciprocal value compared to i

Table 3: Consistency Index (CI) table [64-65]

a_{BW}	1	2	3	4	5	6	7	8	9
Consistency index (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Table 4: Relative effects of the four aspects (FMR, TR, MOR, and ClR) on EER

	Most important:**FMR**-C_1		Least important:**CR**-C_4	
BO(a_{1j})	1	1	3	5
OW(a_{j4})	5	5	2	1
Weights	ω_1	ω_2	ω_3	ω_4
	0.3926	0.3926	0.1388	0.0759
Results	$\xi^* = 0.1716$, CI=2.30, CR=0.0746			

Note: FMR, TR, MOR, and CR denotes by C_1, C_2, C_3, and C_4 , respectively in this table

Table 5: The inner dependency matrix of the five aspects

Matrix D	EER	FMR	TR	MOR	ClR
EER	1	0.5000	0.5195	0.1565	0.4776
FMR	0.3926	1	0.1643	0.0717	0.2612
TR	0.3926	0.2500	1	0.4979	0.1689
MOR	0.1388	0.0833	0.2403	1	0.0923
CR	0.0759	0.1667	0.0706	0.2739	1

Table 6: Local weights of the political and legal risk (EER_1), economic risk (EER_2), and natural environmental risk (EER_3) in the category of external environmental risks

Most important: EER_1		Least important: EER_3	
BO(a_{1j})	1	2	5
OW(a_{j3})	5	3	1
Weights	ω_1	ω_2	ω_3
	0.5746	0.3143	0.1111
Results	$\xi^* = 0.1716$, CI=2.30, CR=0.0746		

Note: EER_1, EER_2 and EER_3 denotes by C_1, C_2, and C_3, respectively in this table

Table 7: the global weights of the risk factors in each of the five categories

Categories	Risks	Global weights
EER: External environmental risks (0.2215)	EER_1: Political and legal risk (0.5746)	0.1273
	EER_2: Economic risk (0.3143)	0.0696
	EER_3: Natural environmental risk (0.1111)	0.0246
MOR: Managerial and operational risks (0.1761)	MOR_1: Completion of project team (0.0544)	0.0096
	MOR_2: Decision risk (0.2246)	0.0396
	MOR_3: Ability risk (0.4491)	0.0791
	MOR_4: Information management risk (0.1088)	0.0192
	MOR_5: Procurement risk (0.1632)	0.0287
	MOR_6: Construction risk (0.0947)	0.0167
FMR: Financial and market risks (0.2181)	FMR_1: Risk of market competition (0.0833)	0.0182
	FMR_2: Risk of price change (0.2500)	0.0545
	FMR_3: Risk of market demand (0.5000)	0.1090
	FMR_4: High interest rate risk (0.1667)	0.0364
TR: Technological risks (0.2607)	TR_1: Lack of standards for implementing EPC (0.0554)	0.0144
	TR_2: Advanced technology and equipment risk (0.3905)	0.1018
	TR_3: Project quality risk (0.1497)	0.0390
	TR_4: Energy-saving measurement and verification risk (0.4044)	0.1054
ClR: Client risks (0.1336)	ClR_1: Client awareness risks (0.2612)	0.0349
	ClR_2: Contract risks (0.1689)	0.0226
	ClR_3: Credit risk (0.4776)	0.0638
	ClR_4: Business risk (0.0923)	0.0123

Table 8: The relative weights of EER, FMR, TR, MOR, and ClR

	EER	FMR	TR	MOR	ClR
EER	1	1/2	3	1/3	2
FMR	2	1	3	1/2	2
TR	1/3	1/3	1	1/7	1/2
MOR	3	2	7	1	5
ClR	1/2	1/2	2	1/5	1
CI=0.0152, CR=0.0136					
Weights	0.1586	0.2273	0.0599	0.4548	0.0994

Table 9: The relative effects of the four aspects (FMR, TR, MOR, and ClR) on EER by AHP

EER	FMR	TR	MOR	ClR
FMR	1	1	3	5
TR	1	1	3	5
MOR	1/3	1/3	1	2
ClR	1/5	1/5	1/2	1
CI=0.0014, CR=0.0015				
Weights	0.3936	0.3936	0.1375	0.0753

Table 10: The inner dependency matrix of the five aspects used in ANP

Matrix D	EER	FMR	TR	MOR	ClR

EER	1	0.4959	0.5008	0.1494	0.4829
FMR	0.3936	1	0.1494	0.0717	0.2720
TR	0.3936	0.2672	1	0.5008	0.1570
MOR	0.1375	0.0827	0.2780	1	0.0882
ClR	0.0753	0.1542	0.0717	0.2780	1

Table 11: Local weights of the political and legal risk (EER_1), economic risk (EER_2), and natural environmental risk (EER_3) in the category of external environmental risks by AHP

	EER_1	EER_2	EER_3
EER_1	1	2	5
EER_2	1/2	1	2
EER_3	1/5	1/2	1

CI=0.0028, CR=0.0048			
Weights	0.5954	0.2764	0.1283

Table 12: Local weights of the seven risk factors in the category of managerial and operational risks (MOR) used by AHP

	MOR_1	MOR_2	MOR_3	MOR_4	MOR_5	MOR_6
MOR_1	1	1/4	1/7	1/2	1/3	1/2
MOR_2	4	1	1/2	2	2	3
MOR_3	7	2	1	4	3	5

MOR_4	2	1/2	1/4	1	1/2	2
MOR_5	3	1/2	1/3	2	1	2
MOR_6	2	1/3	1/5	1/2	1/2	1
CI=0.0161, CR=0.0130						
Weights	0.0496	0.2223	0.3998	0.1051	0.1483	0.0748

Table 13: Local weights of the four risk factors in the category of financial and market risks (FMR) by AHP

	FMR_1	FMR_2	FMR_3	FMR_4
FMR_1	1	1/3	1/5	1/2
FMR_2	3	1	1/2	2
FMR_3	5	2	1	3

FMR_4	2	1/2	1/3	1
CI=0.0048, CR=0.0054				
Weights	0.0882	0.2720	0.4829	0.1570

Table 14: Local weights of the four risk factors in the category of technological risks (TR) by AHP

	TR_1	TR_2	TR_3	TR_4
TR_1	1	1/5	1/2	1/7
TR_2	5	1	3	1/2
TR_3	2	1/3	1	1/4
TR_4	7	2	4	1

CI=0.0072, CR=0.0080				
Weights	0.0641	0.3080	0.1185	0.5093

Table 15: Local weights of the four risk factors in the category of client risks (ClR) by AHP

	ClR_1	ClR_2	ClR_3	ClR_4
ClR_1	1	2	1/2	3
ClR_2	1/2	1	1/5	2
ClR_3	2	5	1	6
ClR_4	1/3	1/2	1/6	1

CI=0.0082, CR=0.0091				
Weights	0.2531	0.1297	0.5383	0.0790

Table 16: The global weights of the 21 risk factors determined by ANP and AHP

Categories	Inter-dependent weights	Independent weights	Risk factors	Local weights	Global weights by ANP	Global weights by AHP
EER	0.2086	0.1586	EER_1	0.5954	0.1242	0.0944
			EER_2	0.2764	0.0577	0.0428
			EER_3	0.1283	0.0268	0.0203
MOR	0.1792	0.2273	MOR_1	0.0496	0.0089	0.0113
			MOR_2	0.2223	0.0398	0.0505
			MOR_3	0.3998	0.0716	0.0909
			MOR_4	0.1051	0.0188	0.0239
			MOR_5	0.1483	0.0266	0.0337
			MOR_6	0.0748	0.0134	0.0170
FMR	0.2132	0.0599	FMR_1	0.0882	0.0188	0.0053
			FMR_2	0.2720	0.0580	0.0173
			FMR_3	0.4829	0.1030	0.0289

			FMR_4	0.1570	0.0335	0.0094
TR	0.2604	0.4548	TR_1	0.0641	0.0167	0.0292
			TR_2	0.3080	0.0802	0.1401
			TR_3	0.1185	0.0309	0.0539
			TR_4	0.5093	0.1326	0.2316
ClR	0.1386	0.0994	ClR_1	0.2531	0.0351	0.0252
			ClR_2	0.1297	0.0180	0.0129
			ClR_3	0.5383	0.0746	0.0536
			ClR_4	0.0790	0.0109	0.0079