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Water Reuse Vol 13 No 2, 205 doi: 10.2166/wrd.2023.082

Construction and empirical research of the evaluation index system of environmental protection enterprises' competitiveness based on the Delphi and AHP methods

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ABSTRACT

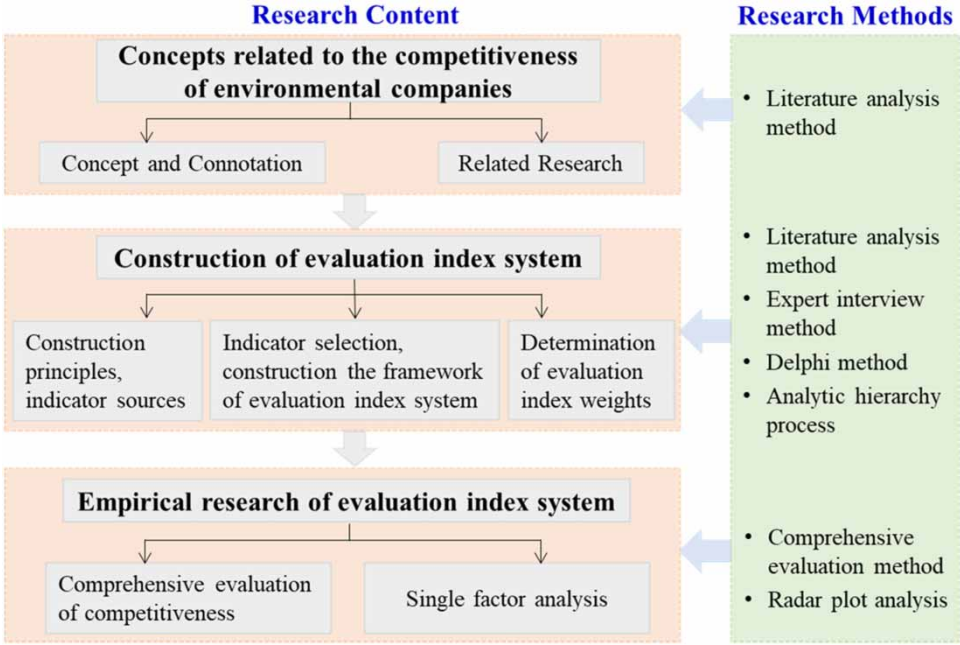
The environmental protection industry has become an important support entity for the construction of ecological civilization and economic growth in China. However, there is little research on the competitiveness of environmental protection enterprises (EPEs). The construction of a set of scientific, comprehensive, practical, qualitative, and quantitative evaluation index systems is an important prerequisite for the sustainable and healthy development of the industry. Based on the literature analysis, semi-structured interviews with experts, and the Delphi method, the evaluation indicators for the competitiveness of EPEs were determined. Qualitatively, the evaluation index system of the competitiveness of EPEs contained 5 primary indicators, 12 secondary indicators, and 39 tertiary indicators. The analytic hierarchy process was used to determine the weights of indicators at each level. The primary indicators in order of weighting were organizational management capability, business environment, financial capability, innovation capability, and social responsibility, with corresponding weights of 26.13, 24.82, 21.76, 19.60, and 7.68%, respectively. Eight A-share listed EPEs in the water sector were selected for competitive evaluation. The evaluation index system of EPEs' competitiveness, being scientific-practical, combined, and quantitative, was constructed to provide a reference for the comprehensive evaluation of enterprises and the sustainable and healthy development of the industry.

Key words: analytic hierarchy process, competitiveness, Delphi method, environmental protection enterprises, index system

HIGHLIGHTS

- The evaluation index system was constructed with five dimensions.
- Five primary indicators, 12 secondary indicators, and 39 tertiary indicators were determined in the evaluation index system.
- Eight A-share-listed EPEs in the water sector were selected for an empirical study of their competitiveness.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Through technology research and development, product production, resource utilization, engineering contracting, business circulation, information services, and other business activities, the environmental protection industry (EPI) can achieve the goals of environmental pollution prevention and control, ecological environment improvement, and restoration and natural resource protection. The EPI has been one of the seven strategic emerging industries in China (State 2010; Gao 2011). Since the 1970s, environmental protection enterprises (EPEs) have gradually flourished in China (Ma 2011), and they have been entering a critical period of transition from rapid development to high-quality development (Xu *et al.* 2014). At the same time, EPEs are the backbone of producing an ecological civilization, winning the battle against pollution, and promoting the high-quality development of the national economy (Wang *et al.* 2021). However, compared with developed countries, there is still a large gap in the level of development of China's EPEs, primarily in the low concentration of industry, the lack of core technology mastery, the lack of standardized market order, the low efficiency of financial support, and the regional differences in the efficiency of capital allocation (Zhang 2013; Huang & Wen 2017; Hao *et al.* 2018; Geng & Cui 2020). Since the '14th Five-Year Plan,' the state has introduced and implemented a series of policies and measures designed to actively promote the development of the EPI better and faster. In the 'carbon peak, carbon neutral' vision of the goal, the development of EPEs has ushered in an era of an important opportunity for deepening the main position of enterprises. Improving the competitiveness of EPEs will become an important aspect of promoting ecological and environmental quality improvement and building China into a country with a quality environment.

Competitiveness refers to the comprehensive quality of subjects in the process of competing with each other, and it has a holistic and synergistic nature (Wang *et al.* 2023). From the existing published results, the research on enterprise competitiveness has focused on two aspects of evaluation determination and evaluation index selection. Currently, researchers have applied the Delphi method, the analytic hierarchy process (AHP), principal component analysis, and other methods to the construction of industry development evaluation index systems, for example, in the aviation industry and low-carbon industry (Delbari *et al.* 2016; Zhang *et al.* 2021; Su & Hu 2022). Considering the advantages of the Delphi and AHP methods in the structuration and hierarchical organizing of complex problems (Gupta & Clarke 1996) and the avoidance of the influence of answering experts by the authority of others, this study combined the Delphi and AHP methods to construct a qualitative and quantitative evaluation of EPEs' competitiveness. However, only very few researchers have evaluated the development of EPEs from the perspectives of financial capability, innovation capability, or development index (Zhang *et al.* 2018; Liang

et al. 2019; Kang 2020). These studies have limitations in reflecting the level of development and comprehensive strength of the enterprises, and they do not take into account the impact of the enterprises' social responsibility in daily operation and management or their business environment on the development of the enterprises. Thus, they fail to reflect the comprehensive development level of EPEs. The present study considered competitiveness as the evaluation objective, evaluated the level of competence demonstrated by the company in various aspects and the impact of the external environment on the development of the company, and then used these to construct a comprehensive, practical, and qualitative–quantitative evaluation index system. Such a system is essential for the benign development of enterprises themselves and the industry.

Based on the above analysis, this study determined the evaluation index pool of EPEs' competitiveness through literature analysis and expert interviews, and the Delphi and AHP methods were combined to construct an evaluation index system for EPEs' competitiveness from five dimensions, i.e., innovation capability, financial capability, social responsibility, organizational management capability, and business environment. The AHP method was used to give certain weights to indicators at all levels. Eight A-share listed EPEs in the water sector were selected for competitive evaluation. The evaluation index system of EPEs' competitiveness constructed provides theoretical guidance to promote the sustainable and healthy development of EPEs.

2. RESEARCH METHODS

2.1. Literature analysis methods

'Environmental protection enterprises,' 'enterprise competitiveness,' 'enterprise development evaluation,' 'innovation capability,' 'financial capability,' 'social responsibility,' and 'listed companies' were used as keywords and searched in CNKI, Wanfang Data Platform, Web of Science, Elsevier, and other Chinese and English databases. Based on the principles of comprehensiveness, operability, and comparability, a preliminary pool of indicators for evaluating EPEs' competitiveness was formed by collating and analyzing the literature.

2.2. Semi-structured interviews

By designing a suitable interview outline, eight experts from the fields of business and management of EPEs, corporate finance, corporate innovation, and government-enterprise relations were invited for semi-structured interviews, including one expert from government agencies, four business managers from environmental companies, and three researchers from universities in the field of economics and management. In consideration of the different fields covered by the experts, four expert interview outlines were designed, namely the theme of EPEs, innovation capability, financial capability, and government-enterprise relations. The pool of indicators for evaluating EPEs' competitiveness was further enriched through expert interviews.

2.3. Delphi method

The Delphi method, also known as the expert consultation method, uses anonymous opinions (Linstone & Turoff 2011). The experts are independent individuals who do not interact with each other but only with the researchers, and the experts' opinions gradually converge to obtain more authoritative and reliable research results after several rounds of consultation (Klenk & Hickey 2011). This method can effectively avoid changes in personal judgment by individuals influenced by other authoritative experts (Tersine & Riggs 1976; Kauko & Palmroos 2014), and the number of experts should be from 15 to 50. Based on the preliminary determination of EPEs' competitiveness evaluation index pool through preliminary literature research and expert interviews, an expert consultation questionnaire was formed.

The expert consultation questionnaire consisted of five parts. (1) *Colophon*: the background, purpose, and significance of the study were briefly introduced. (2) *Basic information of experts*: demographic items such as gender, age, highest education level, nature of the work unit, title, and length of practice were listed. (3) *Importance rating scale of EPEs' competitiveness evaluation index*: the Likert five-point scale was used to divide the rating scale into five levels of very important, important, generally important, unimportant, and very unimportant, and assigned 5, 4, 3, 2, and 1 points accordingly (Shao *et al.* 2021). Experts were invited to rate the importance of each indicator, and an expert opinion column was set up after each level of the indicator importance rating table to enable experts to fill in their opinions on the addition, deletion, or merging of indicators. (4) *The degree of authority of experts*: it included the familiarity of experts with the content of the consultation and experts based on the judgment of the content of the consultation in two parts. Among these, the experts' judgment based on consulting content was divided into four options of work experience, theoretical analysis, literature reference, and intuitive feeling.

The specific quantification table is shown in Table 1 (Shao *et al.* 2021). The quantification table of familiarity is shown in Table 2 (Ying *et al.* 2019). (5) An appendix included in the questionnaire contained explanatory notes on the preliminary formulation of the tertiary indicators.

The expert consultation questionnaires were distributed and collected through WeChat or e-mail. After the questionnaires were collected, the importance ratings of indicators and expert opinions were compiled and analyzed. Indicator screening criteria comprised a mean importance score of $\geq$3.50 and a coefficient of variation (CV) of $\leq$0.250. Those who met both conditions were retained, while those who met only one condition were selected after discussion, and those who did not meet both conditions were eliminated.

2.4. Analytic hierarchy process method

The AHP method is based on the idea of initial decomposition and then synthesis; this splits the structure of the target based on the interrelationships between the constituent elements and constructs a recursive hierarchical model (Thanki *et al.* 2016) using the pairwise comparison method to relate the elements of the same layer and form a judgment matrix. The methodology uses concepts from linear algebra to solve for the maximum characteristic roots and eigenvectors of the judgment matrix, then conducts a consistency test, and finally reduces the output to the weights of the relative importance of the scheme layer to the target layer, resulting in this layer being systematic, practical, and concise. The main steps are as follows.

2.4.1. Establishing a recursive hierarchy model

The relevant factors are stratified from top to bottom, converted into a hierarchically structured model, and a hierarchical structure diagram is constructed.

2.4.2. Constructing a two-comparison judgment matrix

According to the established hierarchical model, a judgment matrix was constructed by comparing two indicators of the same level based on the Saaty scale. The specific scales are shown in Table 3 (Saaty 1987).

2.4.3. Single-level ranking and consistency test

The eigenvectors of each judgment matrix were calculated by using the sum-product method, and the calculation steps were as follows.

Let the judgment matrix be

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

where a_{ij} denotes the importance of indicator i relative to indicator j, $a_{ij} > 0$, $a_{ji} = 1/a_{ij}$.

Table 1 | Quantification table of the expert's judgment basis of the consulting content

	Basis of influence on expert judgments		
Basis of judgment	**Large**	**Middle**	**Small**
Working experience	0.5	0.4	0.3
Theoretical analyses	0.3	0.2	0.1
Literature references	0.1	0.1	0.1
Intuitive sensations	0.1	0.1	0.1

Table 2 | Quantification table of the expert's familiarity with the consulting content

Very familiar	**Familiar**	**Generally familiar**	**Unfamiliar**	**Very unfamiliar**
1	0.8	0.6	0.4	0.2

Table 3 | Saaty scale and its meaning

Scales	Meanings
1	The two factors are equally important
3	Comparing the two factors, the former is slightly more important than the latter
5	Comparing the two factors, the former is significantly more important than the latter
7	Comparing the two factors, the former is strongly more important than the latter
9	Comparing the two factors, the former is extremely more important than the latter
2, 4, 6, 8	The middle value of the above two adjacent judgments
1, 1/2, …, 1/9	If the ratio of the importance of factor i and factor j is a_{ij}, then the ratio of the importance of factor j and factor i is $a_{ji} = 1/a_{ij}$

The elements in matrix A were normalized by columns:

$$\bar{a}_{ij} = a_{ij} / \sum_{k=1}^{n} a_{kj}, \quad i, j = 1, 2, \ldots, n \tag{2}$$

The columns of the same row of the normalized matrix are added:

$$\tilde{w}_i = \sum_{j=1}^{n} \bar{a}_{ij}, \quad i = 1, 2, \ldots, n \tag{3}$$

The summed vector was divided by n to obtain the weight vector:

$$w_i = \tilde{w}_i n \tag{4}$$

The maximum characteristic root is computed:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i} \tag{5}$$

where $(Aw)_i$ denotes the ith component of the vector Aw.

Consistency test on the judgment matrix A was checked.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

Referring to Table 4, the RI was obtained, and the CR was calculated as follows:

$$CR = \frac{CI}{RI} \tag{7}$$

when CR < 0.1, the judgment matrix A passed the consistency test, and the feature vector was the weight vector.

Table 4 | RI values of the random consistency index

$n \times n$ Matrix	2	3	4	5	6	7	8
RI values	0	0.52	0.89	1.12	1.26	1.36	1.41

2.4.4. Total hierarchical ordering

For the same layer of indicators, the relative weights of the indicators were obtained by averaging the weight vectors of the judgment matrices that passed the consistency test, and then the absolute weights were obtained:

$$W_2' = W_1 \times W_2 \tag{8}$$

where W_2' is the weight of the combination of secondary indicators, W_1 is the weight of primary indicators, and W_2 is the relative weight of secondary indicators.

$$W_3' = W_2' \times W_3 \tag{9}$$

where W_3' is the combined weight of the tertiary indicators, W_2' is the weight of the combination of secondary indicators, and W_3 is the relative weights of the tertiary indicators.

2.5. Statistical methods

Excel 2016, IBM SPSS Statistics 25.0, and Statistical Product and Service Software Automatically (SPSSAU) were used for data statistics and analysis. The questionnaire recovery rate ($R\%$) was used to indicate the positivity coefficient of experts:

$$R\% = \frac{n'}{n} \times 100\% \tag{10}$$

where n' is the number of valid questionnaires recovered, and n is the number of questionnaires distributed. A recovery rate of $\geq 70\%$ was considered positive.

The expert authority factor was used to indicate the degree of expert authority:

$$Cr = (Ca + Cs)/2 \tag{11}$$

where Cr is the authority coefficient of the expert, Ca is the basis of the expert's judgment of the consulting content, Cs is the expert's familiarity with the consulting content, and Cr is in the range 0–1, where a greater value of Cr indicates a higher authority of the experts, and $Cr \geq 0.70$ is considered to have high authority and reliability (Yang *et al.* 2020).

CV and Kendall's W coefficient were used to indicate the degree of concentration of experts' opinions. A smaller CV indicated a greater convergence of experts' opinions. Kendall's W coefficient ranged from 0 to 1, and values close to 1 indicated a higher level of agreement, with a test level of $P = 0.05$ (Yang *et al.* 2020).

2.6. Comprehensive evaluation method

According to the constructed index system for evaluating EPEs' competitiveness, the original datum of each indicator was forwarded, converted to dimensionless form, and normalized; the processing methods detailed in Equations (12)–(15) were applied; and then the comprehensive evaluation was conducted.

Positive indicators:

$$x_{ij}' = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{12}$$

Negative indicators:

$$x_{ij}' = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \tag{13}$$

Moderate-type indicators:

$$x_{ij}' = 1 - \frac{|x_{ij} - x_{j-best}|}{\max\{|x_{ij} - x_{j-best}|\}} \tag{14}$$

Interval-type indicators:

$$x'_{ij} = \begin{cases} 1 - \dfrac{p - x_{ij}}{\max(p - \min x_{ij},\ \max x_{ij} - q)}, & x_{ij} < p \\ 1, & p \le x_{ij} \le q \\ 1 - \dfrac{x_{ij} - q}{\max(p - \min x_{ij},\ \max x_{ij} - q)}, & x_{ij} > q \end{cases} \tag{15}$$

$$E_i = 100 \sum_{j=1}^{n} x'_{ij} \times W_j \tag{16}$$

Here, x_{ij} denotes the original value of the jth indicator of the ith enterprise, x'_{ij} denotes the standardized indicator value of the jth indicator of the ith enterprise, x_{j-best} denotes the optimal solution of the jth index, p denotes the left boundary value of the optimal interval for the jth indicator, q denotes the right boundary value of the optimal interval for the jth indicator, E_i denotes the competitiveness score of the ith enterprise, and W_j denotes the combined weight of the jth indicator.

3. RESULTS AND DISCUSSION

3.1. Determination of the indicator pool

The establishment of a comprehensive and wide-ranging evaluation index system for EPEs' competitiveness is an inevitable requirement for promoting deeper reform and sustainable development of enterprises. Research has shown that internal and external factors such as profit and loss status, development strategy, organization size, social responsibility, market environment, and macro policies all played significant roles in enterprises' competitiveness (Ang *et al.* 2022). Based on the current shortcomings in the evaluation of enterprise competitiveness in China and the existing research results, the views of domestic experts in related fields were integrated to construct a competitiveness evaluation index system for EPEs comprising five dimensions: innovation capability, financial capability, social responsibility, organizational management capability, and business environment.

Innovative R&D is the basis of enterprise reform, and upgrading is the key driving force for enhancing enterprise competitiveness (Li *et al.* 2019). Innovation activities include two processes: the input of innovation factors and the output of innovation results (Liang *et al.* 2019). The input of innovation refers to the enterprises' investment in human and financial resources in the innovation process, which can reflect the degree of importance the company attaches to innovation R&D (Xiao & Liu 2021). At the same time, universities had a significant advantage in scientific research personnel, and the cooperation between enterprises and universities and scientific research institutes in production, learning, and research helped to realize resource sharing, so that scientific research knowledge could be applied to actual production, thereby achieving a win-win situation for both schools and enterprises. The quality of employees, the proportion of the number of R&D personnel, the amount of R&D investment, and the state of integration of industry–academia–research were selected to evaluate the level of enterprises' input of innovation (Ma & Cao 2020; Cai *et al.* 2021). Meanwhile, the number of results achieved by a firm was an important expression of innovation output capacity. The number of granted patents, the number of papers published, the number of standards participated in, and the number of honorary awards were selected (Ma *et al.* 2018).

As a for-profit organization, financial capability was one of the important indicators used to evaluate the competitiveness of a company. By summarizing the literature (Fenyves *et al.* 2015; Malichová & Ďurišová 2015; He *et al.* 2021a), the financial competitiveness of enterprises was evaluated in four aspects: solvency, operating capacity, profitability, and growth capacity. Solvency indicated the ability of an enterprise to repay its debts and was an important symbol reflecting the financial condition and operating ability of an enterprise as well as the key to its survival and development. The current ratio, quick ratio, and gearing ratio were selected for measurement (Lv & Pan 2017). Operating capacity reflected the level of business management and the ability to apply capital. Inventory turnover, accounts receivable turnover, current assets turnover, and total assets turnover were selected (Du & Cui 2017; Liu 2020). Profitability reflected an enterprise's capacity to obtain profits through business activities; the stronger the profitability was, the stronger the capital strength of the enterprise was, and the more secure the enterprise was in its operation and development. The net operating margin, cost margin, return on net assets, and earnings per share were selected (Dai & Wang 2011; Zhang & Du 2018). Growth capability referred to the potential for sustainable development embodied by business activities, as this could reflect the direction and speed of future

development of the enterprise. The growth rate of total assets, the growth rate of net profit, and the growth rate of operating income were selected (Dai & Wang 2011; Lv & Pan 2017).

Active corporate social responsibility can help enterprises improve their competitiveness (Nyuur *et al.* 2019; Le 2022). From the stakeholder perspective, the responsibilities of the enterprise to its employees and partners and the legal responsibilities that need to be fulfilled were classified as internal social responsibility, and the responsibilities to society at large were classified as external social responsibility. Among these, the tertiary indicators under internal social responsibility specifically included employee profitability level, employee training, tax credit rating, and penalty expenditures (Xu & Dong 2019). The tertiary indicators under external responsibility included the donation-to-income ratio, employment growth rate, and social responsibility report disclosure (Xu & Dong 2019).

The business scale referred to the number of one or more elements or the collection of resources owned by the enterprise. The total assets, operating income, net profit, and the number of employees were selected as evaluation indicators. Management capability was an important manifestation of the 'soft power' of an enterprise. Usually, the management level of an enterprise is influenced by its scale, and the larger the scale, the higher the requirement for the management capability of the enterprise. The nature of the enterprise, the education level of the manager, and the management cost rate were selected as the evaluation indicators (He *et al.* 2021b).

The business environment was the sum of the environment and conditions in which the enterprise was located, and it contained many elements such as political, economic, legal, and social factors that could be used to determine the impact of the external environment on the operational development of the enterprise. This study included two secondary indicators, market environment, and policy environment, to evaluate the business environment. The market share and the top list were selected to evaluate the competitiveness of the enterprise in the market environment. The literature (Duan *et al.* 2022; Fang *et al.* 2022; Zuo & Lin 2022) showed that fiscal and tax policies were important ways to promote enterprise development, and government subsidies and tax breaks were selected to evaluate the impact of policy environment on enterprise competitiveness.

Through reviewing the relevant literature and conducting expert interviews, a preliminary pool of indicators for evaluating the competitiveness of EPEs was formed, comprising 5 primary indicators, 12 secondary indicators, and 40 tertiary indicators. The secondary indicators refined the scope covered by the primary indicators, and the tertiary indicators were the quantitative measures of the secondary indicators to which they belonged, facilitating data statistics and evaluation analysis.

3.2. Construction of the indicator system

3.2.1. Basic information of experts

The study employed one round of expert consultation based on the Delphi method, inviting 34 experts from EPEs, universities, research institutes, and government agencies to participate in the response (Table 5). The survey was distributed in 17 provinces or autonomous regions, namely Beijing, Tianjin, Shanghai, Chongqing, Heilongjiang, Jilin, Hebei, Shandong, Jiangsu, Fujian, Shaanxi, Henan, Zhejiang, Hubei, Sichuan, Xinjiang Uygur Autonomous Region, and Yunnan. Among these, 67.65% of the experts had doctorate degrees; 70.59% had senior titles; and 58.83% had more than 10 years of experience in the field of environmental protection.

3.2.2. The degree of expert activeness

The survey was conducted by e-mail or WeChat distribution, and Questionnaire Star or Microsoft Word was used to help experts complete this round of questionnaire responses. Thirty-four questionnaires were distributed, and 34 questionnaires were returned, of which 30 were valid, so that the positive coefficient of experts was 88.24%. The results showed that the experts participated in the consultation with a high degree of positivity.

3.2.3. The degree of expert authority

According to the self-assessment scores of experts' judgment basis and familiarity with the consultation content, the average authority coefficient of experts in this round of consultation was calculated to be $0.77 > 0.70$, indicating that the 30 experts who responded effectively had a high degree of authority and that the questionnaire results were credible.

3.2.4. The degree of expert coordination

The Kendall's W values for primary, secondary, and tertiary indicators in this round were 0.161, 0.215, and 0.201 (Table 6), respectively, all of which were statistically significant ($P < 0.001$).

Table 5 | Basic information of experts ($n = 34$)

Items	Classification	Number/person	Constituent ratio (%)
Gender	Male	20	58.82
	Female	14	41.18
Age	< 40	18	52.94
	40–49	13	38.24
	≥ 50	3	8.82
Highest academic degree obtained	Ph.D. degree	23	67.65
	Master's degree	10	29.41
	Bachelor's degree	1	2.94
Nature of work unit	Government agencies	2	5.88
	Universities or research institutes	19	55.88
	State-owned enterprises	6	17.65
	Private enterprises	7	20.59
Title	Positive senior	9	26.47
	Associate senior	15	44.12
	Intermediate	7	20.59
	Junior	0	0.00
	Others	3	8.82
Length of employment	<5 years	10	29.41
	6–10 years	4	11.76
	11–15 years	13	38.24
	≥ 16 years	7	20.59

Table 6 | Concentration of expert opinion

Indicators	Kendall's *W*	χ^2	*P*
Primary indicators	0.161	19.376	<0.001
Secondary indicators	0.215	70.922	<0.001
Tertiary indicators	0.201	235.740	<0.001

3.2.5. Selection and determination of evaluation indicators

According to the index screening principle, the indexes with a mean importance score of <3.50 and CV > 0.250 were deleted. The mean importance scores of the primary indicators were 4.11–4.71, with CVs of 0.131–0.191, all of which were retained. The mean importance scores of the secondary indicators ranged from 3.57 to 4.47, with CVs of 0.126–0.229, all of which were retained. The mean importance score of the tertiary indicator 'the number of papers published' with an average value of $3.10 < 3.50$ and the CV of $0.255 > 0.250$ were excluded. The average importance score of 'penalty expenditures' was $3.73 > 3.50$, and the CV was $0.267 > 0.250$. This indicator was negative and played an important role in restraining and regulating the business behavior of enterprises, and thus it was retained. The mean importance score of 'donation-to-income ratio' was $3.43 < 3.50$, with a CV of $0.246 < 0.250$. As one of the highest manifestations of corporate social responsibility (Liang *et al.* 2010), actively contributing to the society would bring a series of positive effects to the development of the company (Lys *et al.* 2015), and thus it was retained. The mean value of the importance score of 'employment growth rate' was $3.63 > 3.50$, and the CV was $0.280 > 0.250$. Enterprises were one of the carriers of labor absorption (Fan *et al.* 2019), and it was their social responsibility to provide jobs and solve employment problems. The inclusion of this index in the evaluation system was conducive to promoting enterprises to better share the worries of society, alleviate the employment pressure, and thus improve the social image of enterprises, so it was retained. The mean importance score of 'nature of the enterprise' was

3.77 > 3.50, and the CV was 0.263 > 0.250. Compared with private enterprises, state-owned enterprises were more oriented by policies; had advantages in obtaining loans from financial institutions, financial support, and government subsidies (Zhang 2016); and were more competitive in the reform and development of enterprises, and thus they were retained. The mean importance scores of the remaining tertiary indicators were 3.57–4.47, with CVs of 0.112–0.249, and they were all retained.

After expert consulting, 5 primary indicators, 12 secondary indicators, and 39 tertiary indicators were finally determined. The index system contained five dimensions of EPEs: innovation capability, financial capability, social responsibility, organizational management capability, and business environment, as detailed in Figure 1.

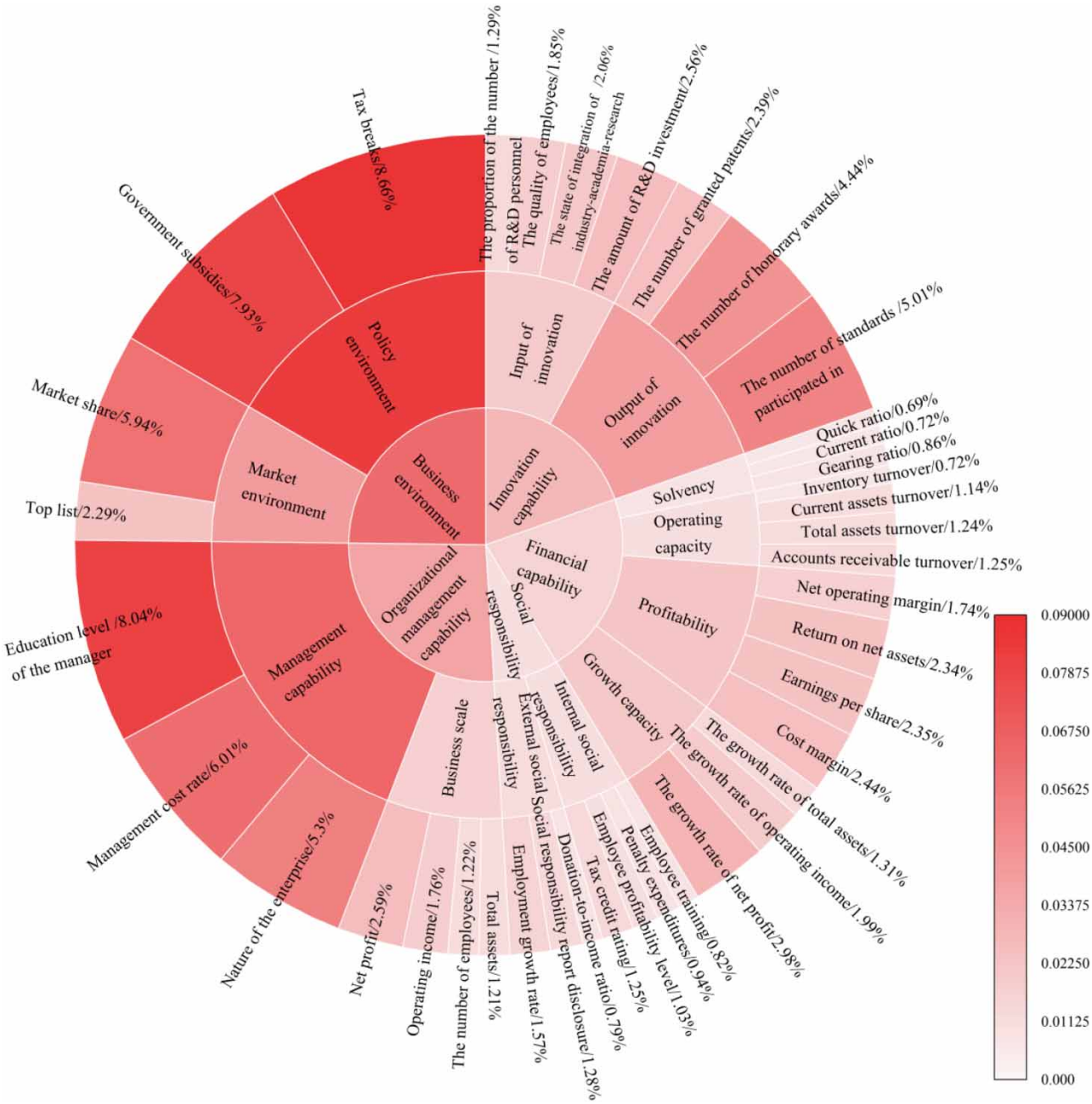


Figure 1 | Evaluation index system and index weights of the competitiveness of EPEs. *Note*: Penalty expenditure was a negative indicator. The current ratio and the quick ratio were moderate indicators, which means that the value is close to a certain value, the better the indicator is. The gearing ratio was an interval indicator, which means that the index value is the best within a certain interval range, and there is no good or bad value in the interval. And the others were positive indicators.

3.3. Determination of indicator weights

Twenty-two experts were invited to answer the questionnaire on the evaluation index weight of EPEs' competitiveness, among which 19 questionnaires were valid. The indicator weights were determined according to their answers. Based on the principle of the AHP method, SPPAU was used to calculate the relative weights of indicators at each level; using Equations (8) and (9), the combined weights of indicators at each level were obtained, as detailed in Figure 1.

As can be seen from the indicator weights in Figure 1, the primary indicators were ranked in descending order of importance: organizational management capability, business environment, financial capability, innovation capability, and social responsibility. Overall, it seemed that the weights of the first four primary indicators were relatively close, ranging from 19.60 to 26.13%, and the weight of social responsibility was 7.68%. The weight of social responsibility is not as high as the other four first-level indicators, but its importance to the development of the enterprises is still taken into account. Social responsibility is not only an intangible asset of an enterprise but also an important opportunity for its development. It is gradually developing into an important way to improve corporate image, economic benefits, and competitiveness. Enterprises actively fulfill their social responsibilities to stakeholders, which help to establish a good corporate image, improve corporate visibility, increase the belongingness and loyalty of employees and consumers, and attract more outstanding talents and partners, so that enterprises can grasp the competitive advantages and development opportunities in the fierce market competition and maintain their core competitiveness.

3.4. Evaluation study on the competitiveness of EPEs in the water sector

The listed EPEs are the leading enterprises in the EPI. According to the industry classification of listed enterprises of the China Securities Regulatory Commission and the results of the industry classification of 41 listed enterprises in the financial sector such as EASTMONEY and Changjiang Securities, eight A-share listed EPEs in the water sector were selected as sample companies to conduct an empirical study of their competitiveness in 2021. All data were obtained from China Stock Market and Accounting Research Database (CSMAR), annual reports of enterprises, the official website of the State Taxation Administration, the Juchao Information Network, and the official website of Enterprise Search.

The empirical study found that the competitiveness scores of the sample EPEs ranged from 22.12 to 57.54 (Figure 2), and the competitiveness levels of the companies were distributed in three development echelons. The competitiveness scores of BOW and Capital ECO-Pro Group were in the first echelon; the competitiveness scores of XREC, TCEPC, CPEP, and

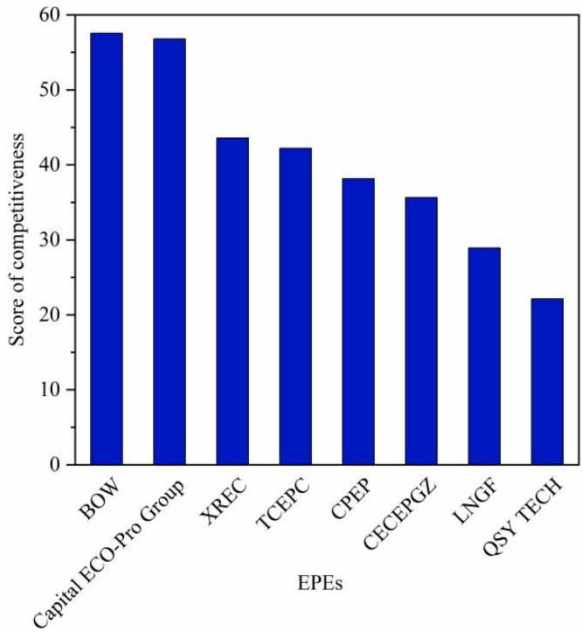


Figure 2 | The scores of EPEs' competitiveness.

CECEPGZ were in the second echelon, ranging from 35.65 to 43.58. LNGF and QSY TECH were located in the third echelon, with a significant gap compared to the first- and second-tier EPEs.

Regarding the five dimensions, the innovation capability competitiveness scores of the sample EPEs ranged from 2.88 to 11.69, with LNGF and BOW being more prominent in their innovation capabilities (Figure 3). From the secondary indicators, the output of innovation scores of BOW and LNGF was at the top, and the output of innovation scores of BOW, LNGF, CECEPGZ, and TCEPC was higher than their input of innovation scores. The innovation input–output benefits were greater than 1, while the innovation input–output benefits of the other four sample EPEs were less than 1 (Figure 4). This may be because innovation output exhibits a certain lag compared to innovation input.

The financial capability competitiveness scores of the sample EPEs ranged from 4.71 to 13.84 (Figure 3). CPEP, XREC, and TCEPC had an advantage in financial capability, with their solvency, operating capability, profitability, and growth capability

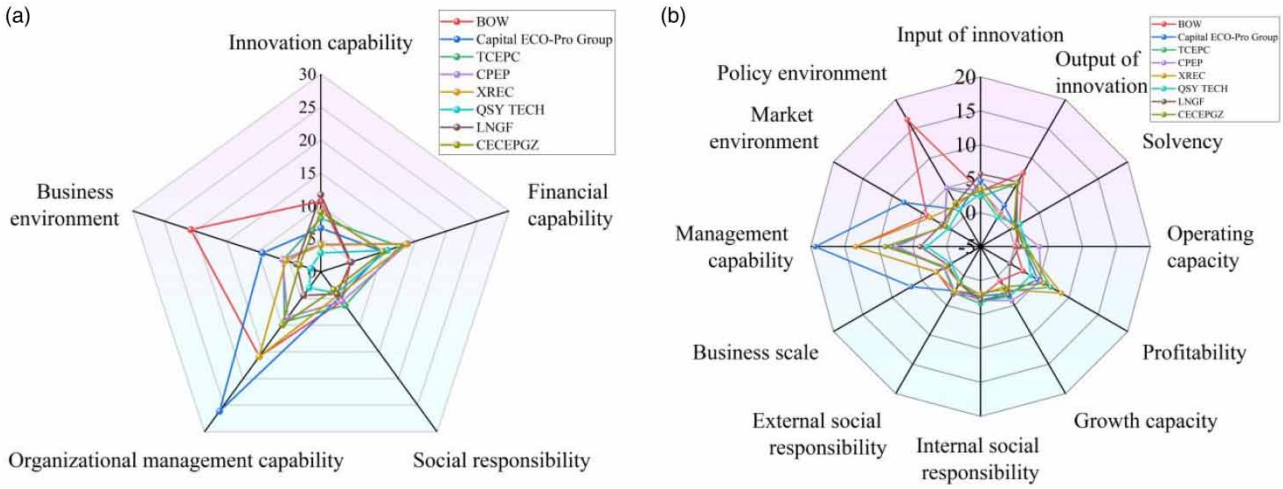


Figure 3 | Results of (a) the first indicator scores and (b) the secondary indicator scores for EPEs' competitiveness.

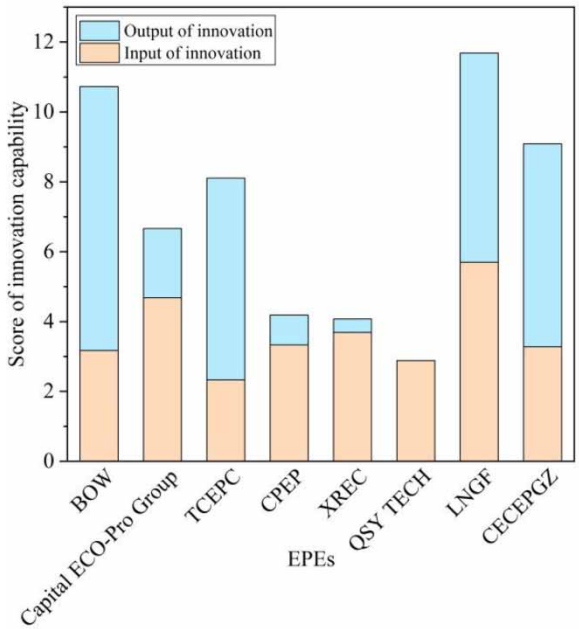


Figure 4 | The scores of EPEs' innovation capability.

scores exceeding the average or being close to the average of the sample EPEs. The profitability scores of XREC and TCEPC were 87.78 and 49.34% above average, respectively, and the operating capability and growth capability of CPEP were 133.51 and 55.96% above average, respectively, giving the companies a leading edge in the evaluation of financial capability competitiveness.

The social responsibility competitiveness scores of the sample EPEs ranged from 3.32 to 6.25, and the overall difference was not significant (Figure 3). The competitiveness scores of the sample EPEs' organizational management capabilities ranged from 2.96 to 26.13 (Figure 3). The top three companies were Capital ECO-Pro Group, XREC, and BOW, which had clear leading advantages. The Capital ECO-Pro Group had a 64.33% higher organizational management capability competitiveness score than XREC in second place. In terms of the secondary indicators, the Capital ECO-Pro Group ranked first in the sample EPEs in terms of business scale competitiveness and management capability competitiveness. Reasonably expanding the scale of operation, improving the education level of managers, and increasing the investment in management costs are among the important ways for enterprises to improve their organizational management capabilities.

The business environment competitiveness scores of the sample EPEs ranged from 1.65 to 20.73 (Figure 3). BOW was firmly in the top position, followed by the Capital ECO-Pro Group, but with a difference of 11.47 in the business environment competitiveness score. From the secondary indicators, the market environment competitiveness score of the Capital ECO-Pro Group was 8.02, which was 3.08 times the average competitiveness score of the market environment of the sample EPEs. In addition, the policy environment competitiveness score of BOW was 16.59, 3.71 times the average competitiveness score of the policy environment of the sample EPEs, prompting the enterprises to maintain their leading position in the evaluation of business environment competitiveness.

4. CONCLUSIONS

A pool of evaluation indexes of EPEs' competitiveness was selected and determined by literature analysis and expert interviews, and an evaluation index system for the competitiveness of EPEs was constructed by the Delphi method. The system comprised five dimensions: innovation capability, financial capability, social responsibility, organizational management capability, and business environment, 12 secondary indicators, and 39 tertiary indicators, and the weights of indicators at each level were determined by the AHP method. Among the primary indicators, organizational management capability, business environment, financial capability, and innovation capability were the main factors influencing the competitiveness of EPEs. Among the secondary indicators, management capability, policy environment, the output of innovation, and profitability had more significant impacts on the competitiveness of enterprises. Among the tertiary indicators, the weight of tax breaks, education level of the manager, government subsidies, management cost rate, market share, nature of the enterprise, the number of standards participated in, and the number of honorary awards in setting standards had larger weights and were the main influencing factors on the competitiveness of EPEs. The empirical study showed that the ranking of the competitiveness scores of the sample EPEs was as follows: BOW, Capital ECO-Pro Group, XREC, TCEPC, CPEP, CECEPGZ, LNGF, and QSY TECH.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (42207297), the Shandong Provincial Department of Ecology and Environment A series of research projects to promote the modernization of the environmental governance system and governance capacity (SDGP370000000202102007025), the Natural Science Foundation of Shandong Province (ZR2021QD063), and the Jinan Water Science and Technology Project of China (JNSWKJ202204). The authors are grateful to co-author, Dr Chenguang Li, for his great contribution to the conceptualization, writing-review and editing, and for his funding acquisition for this work.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 29 November 2022; accepted in revised form 7 February 2023. Available online 10 March 2023